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Perceptual and Adaptational Basis for the Management of Indoor Climate : A Study in Warm Australian Environments

A dissertation submitted in support of an application for the degree of Doctor of Philosophy

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by

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August 1985

The work as presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material either in whole or in part, for a degree at this or any other institution.



Richard J. de Dear

ABSTRACT

The study examines thermal perception in office buildings and the potential for energy conservation in the practice of air conditioning. The specific objective of the study was to assess the degree of control that the body-environment heat balance exerts on thermal sensation, comfort, acceptability and preference. The setting also provided the opportunity to explore affective, cognitive and behavioural aspects of indoor-climate-related attitudes and their relationships with processes of thermal perception.

Six separate field studies were conducted in a total of 23 air-conditioned and 8 non-air-conditioned buildings, involving 1163 respondents and 3290 complete sets of data. Two surveys in air-conditioned buildings were conducted in tropical Darwin; one in the "Dry" season, the other in the build-up to the "Wet" season. There were two surveys in sub-tropical Brisbane's summer; one in air-conditioned, the other in non-air-conditioned buildings, while there were also air-conditioned and non-air-conditioned building surveys conducted in mid-latitude Melbourne's summer. Subjective thermal assessments were recorded from each respondent on three separate occasions, and these were accompanied by full sets of microclimatological data necessary to define the body-environment heat balance. These measurements were used in two mathematical models of thermal comfort; 1) Predicted Mean Vote (PMV), and 2) Standard Effective Temperature (SET), which were used to standardise thermal environments for between-group comparisons.

Each respondent on their first interview was also questioned on various aspects of their thermal history. Attitudes and beliefs were assessed by means of free-answer questions, checklists, rating scales and successive interval attitude scales.

Mean levels of standardised warmth were generally similar in all four air-conditioned surveys, whereas the mean thermal sensations, comfort and temperature preference assessments elicited by those environments were significantly different between these surveys. Furthermore, the standard effective temperatures associated with optimal comfort and 20% warmth dissatisfaction were both found to vary significantly between the six surveys; the highest values being recorded in the Darwin "Dry" air-conditioned and Brisbane non-air-conditioned surveys, while the lowest values were observed in Melbourne. These data are broadly consistent with the notion of thermal experience, comprising both indoor and outdoor components, exerting an influence on thermal perceptual set points, as predicted by adaptation level theory. Further support for this interpretation was obtained from the between-survey comparisons of thermal sensitivity, with the highest values being observed in the surveys where microclimatological parameters were most homogeneous. Also, respondents who had recently arrived in Darwin from cooler locations had significantly cooler comfort set points than did long-term residents of the tropics, and exposure to home air conditioning in Darwin lowered comfort set points further.

The attitudinal data indicated that indoor climatic factors were ranked by occupants among the most important determinants of built-environmental quality. All air-conditioned buildings surveyed had extensive concern among their occupants that mechanical air cooling had

adverse health effects. The "sick building" syndrome possibly represents an exagerated form of this background malaise. Belief in adverse health effects was closely associated with disaffection for air conditioning, and a preference for passive designs. A majority of non-air-conditioned building occupants preferred such buildings, while the reverse was true of the air-conditioned building occupants. Preference for mechanical cooling was highest in the build-up to Darwin's "Wet" season, but for six months of the year, a majority preferred non-air-conditioned buildings in that city. Overall thermal impressions of indoor seasonal conditions, and the general level of thermal satisfaction with the survey buildings were both dissociated from prevailing mean microclimatological conditions.

The notion of a universally optimal climate, advanced originally by climatic determinists, and subsequently promulgated by the HVAC industry, ignores both the physiological and psychological adaptability of building occupants. Recognition of this perceptual plasticity facilitates energy conservation in HVAC sytem operation by reductions of outdoor/indoor thermal gradients, temperature drifts and ramps, and broadened set temperature control deadbands. Furthermore, a greater reliance on human adaptation instead of mechanical adjustment, combined with widespread concern about the side-effects of air conditioning, enhance the viability of passive architectural solutions.

PREFACE

This study of thermal perception very clearly falls into the multidisciplinary category, drawing on the ideas and data of climatology, architectural science, environmental psychology and psychophysics, thermal physiology and HVAC engineering. The author's formal training is, however, in geography. While the number of contemporary geographers contributing to the research in this area is small, Chapter 1 points out the rich and colourful history of geographers earlier in the current century, working on this problem of man-climate interaction. Furthermore, of the various disciplines mentioned above, geography is perhaps the best placed to synthesise the detailed output from the specialists into a broader view of the topic.

In anticipation of a readership with a diversity of academic backgrounds, a small GLOSSARY of unavoidable "jargon" has been included in the front of the thesis. The thesis is loosely structured on the Harvard model, with the first three chapters giving a broad overview of the main themes in the literature. Out of these reviews come a series of research questions and hypotheses in Chapter 4, and these form the basis of a subsequent methods chapter, two results chapters and a concluding chapter. SI units have been used throughout except in the equations and programs associated with Fanger's (1970) models, where kilo calorie units have been retained in the computational expressions at least. All temperatures have been expressed in Celsius, but the convention of expressing temperature ranges of differences in Kelvin is followed. Statistical significance is expressed throughout as the better of either the 0.05 or 0.01 levels. The several flowchart diagrams in the thesis have adhered to the International Organisation for Standardisation's

standard for information processing flowcharts symbols (1980). In particular, the square symbol is used to denote basic processes, the parallelogram denotes any input/output function, the diamond symbol stands for any decision or switching-type operation, the triangle is used to show two or more sets of data merging into one output, while the oval denotes a terminal point in the flowchart (start/stop). Apart from the flowcharts, Chapter 2 also contains some block diagrams depicting physiological systems. While the style is different in these, their legends clarify the meaning of the symbols used.

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TABLE OF CONTENTS

	Page
Abstract	i
Preface	iv
Acknowledgements	vi
Table of Contents	vii
List of Figures	xi
List of Tables	xiii
Glossary	xvi
Notation	xxi
CHAPTER 1: DETERMINISM, ADAPTATION AND ADJUSTMENT	1
1.1 Climatic Determinism	1
1.2 Adaptation in Modern Man-Environment Systems	10
1.3 Human Factors and Air Conditioning	14
1.3.1 Definitions of air conditioning	15
1.3.2 The arguments for air conditioning	16
1.3.3 Indoor climate standards	26
1.3.4 User reactions to air conditioning and the "sick building" syndrome	32
1.3.5 The energy shortage and air conditioning	40
CHAPTER 2: PHYSIOLOGICAL CONTROLS	47
2.1 Autonomic Thermoregulation	48
2.1.1 Homeothermy	48
2.1.2 Thermoreception and integration	49
2.1.3 Effector systems	52
2.2 Physiological Correlates of Sensation, Comfort and Behavioural Thermoregulation	59
2.2.1 Thermal sensation and comfort	61
2.2.2 Overt behavioural responses	65
2.3 Processes of Long-Term Adaptation to the Thermal Environment	67
2.3.1 Acclimatisation	68
2.3.2 Habituation	75
CHAPTER 3: METHODOLOGIES AND MODELS IN APPLIED RESEARCH	78
3.1 Climate Chamber Studies of Thermal Comfort	79
3.1.1 Chamber studies using rating scales	81
3.1.2 Chamber studies using the preferred temperature method	87
3.2 Mathematical Models of Human Thermal Response	91
3.2.1 Fanger's heat-balance models	92
3.2.2 The Standard Effective Temperature index	97
3.3 Field Studies of Thermal Comfort	100
3.4 Reconciliation of Chamber and Field Studies	106
CHAPTER 4: RESEARCH QUESTIONS AND HYPOTHESES	112
4.1 Thermal Comfort Surveys	114
4.2 Thermal Constancy Versus the Adaptation Hypothesis	116
4.3 Attitudes on Indoor Climate Issues	117
4.4 Interactions Between Instantaneous Thermal Assessments and Non-Thermal Factors	119

CHAPTER 5: THESIS METHODS 120

5.1 Research Design and Samples 121
5.1.1 Selection of cities: The outdoor climatic variable 121
5.1.2 Selection of buildings: The climate-control variable 123
5.1.3 Samples of respondents 130
5.2 Measurement of Heat-Balance Variables 132
5.2.1 Air temperature and humidity 132
5.2.2 Relative air velocity 134
5.2.3 Mean radiant temperature 136
5.2.4 Metabolic heat production 137
5.2.5 Clothing factors 138
5.3 Derivation of Heat-Balance Comfort Index Values 142
5.4 The Outdoor Meteorological Environment 145
5.5 The Questionnaires 147
5.5.1 Thermal questionnaire 147
5.5.2 Attitudinal, cognitive and behavioural questionnaire 150
5.6 Summary of Methods and Procedures 156

CHAPTER 6: RESULTS AND DISCUSSION I - THERMAL QUESTIONNAIRE 160

6.1 Climatic Data 160
6.1.1 Outdoor meteorological variables 160
6.1.2 Indoor microclimatic variables 162
6.1.3 Other heat-balance data: Metabolism and clothing 167
6.1.4 Rational indices of warmth 171
6.2 Seven-Point Scales of Subjective Warmth 173
6.2.1 Descriptive statistics 173
6.2.2 Correlation and regression of subjective warmth on microclimatic variables 177
6.2.3 Probit analysis of subjective warmth on microclimatic variables 190
6.3 Thermal Constancy Versus the Adaptation Hypothesis 204

CHAPTER 7: RESULTS AND DISCUSSION II - ATTITUDE QUESTIONNAIRE 210

7.1 Free-Answer Beliefs About Air Conditioning in the Workplace 211
7.1.1 Disadvantages 211
7.1.2 Advantages 216
7.2 Air Conditioning and Health Issues 219
7.2.1 Belief in the adverse health effects of air conditioning 219
7.2.2 Identification of "sick buildings" 220
7.2.3 Ailments attributed to summer air conditioning 222
7.3 Passive Smoking in the Workplace 225
7.4 Attitudes Toward Air Conditioning in the Workplace 228
7.4.1 Salience of attitudes on indoor climatic issues 228
7.4.2 Thurstone successive-interval scale of affect toward air conditioning 230
7.4.3 Stated preferences for air-conditioned or free-running buildings 236

7.5 Perceived Control of Microclimatic Conditions 243
7.6 Overall Impressions of Indoor Warmth and Satisfaction 249
7.7 Interactions Between Subjective Response to Microclimate and Non-Thermal Factors 258

CHAPTER 8: SUMMARY, APPLICATION AND CONCLUSIONS 266

8.1 Thermal Comfort Surveys 267
8.2 Thermal Constancy Versus the Adaptation Hypothesis 273
8.3 Attitudes on Indoor Climate Issues 279
8.4 Interactions Between Instantaneous Thermal Assessments and Non-Thermal Factors 287
8.5 General Conclusions 289

APPENDICES 293

Appendix A: The Contribution of Psychologists to Thermal Comfort Research 293
Appendix B: Ping-Pong Globe Thermometers for Mean Radiant Temperature 302
Appendix C: Fortran IV and BASIC Programs for PMV, PPD and SET Indices 310
Appendix D: The Thermal Questionnaire 324
Appendix E: Analysis of Seven-Point Scales of Warmth 329
Appendix F: The Six Surveys' Attitudinal, Cognitive and Behavioural Questionnaires 337
Appendix G: Thurstone and Successive-Interval Attitude Scales 377
Appendix H: Probit Neutrality Models and Scattergrams for the Three Scales of Subjective Warmth on Air Temperature and SET 393

BIBLIOGRAPHY 401

LIST OF FIGURES

FIGURE		PAGE
1.1	Huntington's hypothesis on the control of human performance by temperature	4
1.2	Conceptual scheme for the man-environment system	13
2.1	Simplified diagram of autonomic thermoregulation	50
2.2	Conceptual representation of the autonomic thermoregulatory system with proportional controller and adjustable functional set points	58
2.3	The parallel model of thermoregulation	63
2.4	Thermal sensations and comfort with multiple inputs	65
3.1	The concept of thermal load in PMV model	96
3.2	The Pierce 2 node model of thermoregulation used in calculation of SET	99
3.3	Neutral temperatures in field studies related to outdoor temperature	105
4.1	Flow chart of the various relationships in the man-climate system	113
5.1	Location map showing climatic zones of the three cities surveyed	122
5.2	Air-conditioned buildings in Darwin surveys	127
5.3	Air-conditioned buildings in Brisbane surveys	128
5.4	Non-air-conditioned buildings in Brisbane surveys	128
5.5	Air-conditioned buildings in Melbourne surveys	129
5.6	Non-air-conditioned buildings in Melbourne surveys	129
5.7	Assman aspirated psychrometer	133
5.8	Hot-wire anemometer	135
5.9	Ping-pong globe thermometer compared with traditional 150mm version	137
6.1	Path analyses for clothing insulation with indoor and outdoor temperatures	170
6.2	Neutralities and transition temperatures on the ASHRAE scale	193

6.3	Neutralities and transition temperatures on the Bedford scale	194
6.4	Neutralities and transition temperatures on the PREFV scale	195
7.1	Perceived disadvantages of air conditioning in the workplace	212
7.2	Perceived advantages of air conditioning in the workplace	217
7.3	Frequency distribution of the Thurstone successive-interval scale of affect toward air conditioning	233
7.4	Monthly breakdown of Darwin respondents' preferences for air-conditioning in the workplace	242
7.5	Mean overall thermal assessments of each building for the season of survey plotted against their mean instantaneous ASHRAE scale votes	252
7.6	Plot of mean satisfaction with summer thermal conditions in Brisbane and Melbourne buildings against mean overall thermal assessments of those buildings	254
B.1	Response curves for 40mm and 150mm diameter globe thermometers	309
E.1	The hypothetical relationship between ED20 and transition temperature ED50	334
G.1	Common psychological continuum upon which scale values of all attitude statements were measured	387
H.1	Probit neutrality models in the Darwin "Dry" survey (AC)	395
H.2	Probit neutrality models for the Darwin "Build-up" survey (AC)	396
H.3	Probit neutrality models for the Brisbane air-conditioned survey	397
H.4	Probit neutrality models for the Brisbane non-air-conditioned survey	398
H.5	Probit neutrality models in the Melbourne air-conditioned survey	399
H.6	Probit neutrality models in the Melbourne non-air-conditioned survey	400

LIST OF TABLES

TABLE		PAGE
1.1	Griffith Taylor's wet-bulb temperature comfort scale	4
1.2	Typical "sick building" symptoms	35
3.1	Rating scales and associated numerical coding commonly used in comfort research	82
3.2	Summary of preferred temperatures from Danish Technical University studies	90
5.1	Long-term averages of weather variables in the survey cities	122
5.2	Air-conditioned buildings selected for study in Darwin, Brisbane and Melbourne	125
5.3	Non-air-conditioned buildings in Brisbane and Melbourne	126
5.4	Biographical characteristics of the six building occupant samples	131
5.5	Metabolic rates of typical office tasks and related activities	138
5.6	Individual clothing garment insulation values	140
6.1	Outdoor meteorological conditions during the six surveys	161
6.2	Summary statistics for the indoor microclimatic variables	163
6.3	Human variables involved in microclimatic heat balance	168
6.4	Mean clothing insulation in Darwin disaggregated by sex	168
6.5	Mean clothing insulation in Brisbane disaggregated by sex	168
6.6	Mean clothing insulation in Melbourne disaggregated by sex	168
6.7	Summary statistics for rational indices of warmth	172
6.8	Summary statistics for rating scale responses to microclimatic conditions	174
6.9	Correlation and regression coefficients for the bivariate relationship between seven-point scales of subjective warmth and four indices of microclimatic warmth	178
6.10	Stepwise regression of subjective warmth on indoor operative temperature, partial vapour pressure, air velocity, metabolic rate and clothing insulation	185 186
6.11	Partial regression coefficients for operative temperature in models of subjective warmth that have five independent variables	189

6.12	Neutralities observed on seven-point scales of warmth using either air temperature or standard effective temperature as independent variable	191
6.13	Standard deviations of the probit regression neutrality models	197
6.14	Acceptable temperatures as derived by probit analysis of the 20% warmth dissatisfaction criterion	203
6.15	Comparison of six methods of assessment for the six surveys' neutralities	206
7.1	Belief in the adverse health effects of summer air conditioning	219
7.2	Belief in the adverse health effects of summer air conditioning in Brisbane's AC survey buildings	221
7.3	Belief in the adverse health effects of summer air conditioning in Melbourne's AC survey buildings	221
7.4	Ailments attributed to summer air conditioning	223
7.5	Self-assessments of general health status at time of interview	224
7.6	Non-smokers' sensory irritation resulting from exposure to cigarette smoke in the workplace	226
7.7	Attitudes of non-smokers to the segregation of smokers in the workplace	227
7.8	Relative importance of indoor climatic issues in overall built environmental quality	229
7.9	Preferences for air-conditioned or free-running buildings in Brisbane and Melbourne	237
7.10	Percentages of respondents claiming to have no control over microclimatic conditions in the workplace	244
7.11	Summary statistics for overall indoor warmth assessments on the ASHRAE scale	250
7.12	Zero-order correlation matrix of thermal dissatisfaction with other microclimatic and perceptual variables	256
7.13	Stepwise multiple correlation analysis of thermal satisfaction building means as the dependent variable.	257
7.14	t tests between the mean DISCR scores of various sub-samples	259
7.15	Bivariate correlation and regression of the DISPO variable with length of residence	264
B.1	Comparison of T_{mrt} derived from 150mm and 40mm globe thermometers	307

E.1	Goodness of fit using transformed and untransformed temperatures	333
G.1	The original 49 item attitude statement pool	381 382
G.2	Cumulative proportions for judgements of 49 attitude statements in 11 successive categories	383
G.3	Normal deviates for the upper limits of successive intervals	385
G.4	Successive interval widths	386
G.5	Scale values of attitude statements	389
G.6	Derivation of the scale values for items 13 and 25	391
G.7	Derivation of the scale values for items 8 and 12	391

GLOSSARY

AC : Anagram for air conditioning

Acclimatisation (acclimation) : A physiological change within the lifetime of the person that reduces thermal strain.

Adaptation : Used in the current thesis to denote a physiological or psychological change within the lifetime of the person that reduces strain caused by stressful environments.

Adaptation Level : The optimal or neutral level of stimulation for a group or an individual.

Adjustment : Environmental modification that reduces the strain resulting from some environmental stressor.

Alliesthesia : The dependence of thermal comfort on both internal and external signals.

ASHRAE : American Society of Heating, Refrigerating, and Air Conditioning Engineers.

ASHRAE scale : A seven-point scale of thermal sensation.

ASHVE : American Society of Heating and Ventilating Engineers (now ASHRAE).

Bedford scale : A seven-point scale of thermal comfort.

Beta coefficients : Regression coefficient that have been standardised by expressing data in terms of standard deviations.

Bradykinin : Cholinergic vasodilator released from sweat glands.

Climate chamber : Research laboratory for thermal comfort and physiology research in which ambient, radiant, and wet bulb temperatures are controlled along with air circulation patterns and velocities.

Climatic Determinism : An extension of the general theory of determinism, in which every event in the world is subject to causal law. Climate determinism emphasises the control of climate over human affairs.

Clo : The unit of measurement for clothing insulation. One clo unit is the amount of insulation necessary to maintain comfort and a mean skin temperature of 33degC in ambient temperature of 21degC, air velocity less than 0.1m/s, relative humidity at 50% and metabolic heat production at sedentary levels.

Deadband : The range of temperatures within which HVAC systems regulate indoor conditions (cf. set point). Used as a conservation strategy.

DISCR : Calculated for a comfort survey respondent by subtracting their ASHRAE scale vote from the PMV prediction at the time of interview.

DISPO : Calculated for a comfort survey respondent by averaging DISCR scores from three separate interviews.

ED50 and ED20 : That level of environmental warmth that induces 50% or 20% of building occupants to cast comfort votes warmer than some specified value on the seven-point scales.

Effective temperature : The old effective temperature index combined in a single value the effects of temperature, humidity and air movement on thermal sensation. The numerical value on the index was that of "still" air, saturated with vapour, that would induce the same sensation as the actual environment did.

Effectors (thermoeffectors) : The primary physiological systems of thermogenesis, sweating and vasomotor activity that actually change the rates of heat loss-gain between the body and the environment.

External mechanical efficiency : Parameter relating the quantity of work achieved from the metabolic process. Assumed to be zero for most indoor activities.

Epidemiology : Study of the factors influencing the frequency and spread of diseases (esp. environmental causes in the current thesis).

Fenestration : Arrangement of windows in buildings.

Free-running : Buildings with no centralised climate controlling systems (analogous to passive).

Gain constant : The slope of the equation that relates the load error signal to the magnitude of thermoeffector response.

Habituation : Reduction of perception of repeated stimulation, excluding receptor adaptation and effector fatigue.

Homeostasis : Tendency of a system to remain constant.

Homeothermy : Maintenance of a deep body temperature constantly within the narrow range between 36.4 and 37.5degC.

Human Biometeorology : The study of the influence of weather and climate on healthy man and diseased subjects.

HVAC : Heating, ventilating and air conditioning.

Hyperacclimatisation : Advanced form of acclimatisation induced artificially in controlled laboratory setting, or an exhaustive regimen of work in heat.

Integrator : Physiological process involving the comparison of incoming thermosensory data with the system set points, and the generation of an actuating signal.

Load error : The actuating signal that results from a comparison of sensory data with effector set points. Load error magnitude is proportional to the error between input and set point.

NAC : Anagram for non-air-conditioned.

Naturalistic research : In environmental psychology, the field study approach, ensuring that the people under investigation are unaware of the researchers, and their environment is left undisturbed by the research.

Neutrality : That level of temperature or some warmth index that induces maximum voting in the central category of a seven-point of warmth.

Passive Smoking : Inhalation of tobacco smoke by sharing space with smokers.

Path analysis : Analytical method that quantifies the strength of causation between two or more variables.

Performance : Human productivity or output in the workplace.

Predicted Mean Vote (PMV) : The mean thermal sensation of a large group of people predicted on the basis heat balance calculations (Fanger, 1970).

Predicted Percent Dissatisfied (PPD) : The percentage of a large group of people who would vote outside the central three categories of a seven-point scale of warmth. Based on the heat-balance PMV function.

Preferred temperature : Derived by the method of direct determination in climate chambers, where the subject selects their ideal level of warmth. Alternatively, that temperature resulting from the solution of Fanger's (1970) comfort equation.

PREFV : A new seven-point scale of warmth on which respondents indicate whether they would prefer temperatures higher or lower than those prevailing at the time of interview.

Probit analysis : Statistical method of regressing a quantal variable on one or more variables that are at the interval level of measurement.

Proportional control : Magnitude of response in the effector system is proportional to the error between sensory input and set point.

Psychophysics : The study of the way the magnitude of subjective sensation varies with changes in physical stimulation.

Psychrometry : Determination of the properties of gas-vapour mixtures (esp. the air-water vapour system).

Receptor (thermoreceptor) : Neuronal structure differentially sensitive to temperature and which responds to a maintained temperature with a characteristic sustained impulse frequency.

Reference temperature : The value of the controlled variable around which homeostasis is maintained.

Semantic set : Argument against the use of rating scales in psychophysics that claims the central categories of such scales may not be the preferred level of stimulation.

Set point : In control systems, that level of the controlled variable at which an effector system is activated.

Sick building syndrome : High frequency of non-specific health complaints that appear to be related to some aspect of the built environment.

Sidestream smoke : Tobacco smoke emanating from the side of a cigarette rather than that which is drawn through the filter by the smoker.

Specific dynamic action : Metabolic heat generated by the absorption of food.

Standard clothing ensemble : Cotton twill shirt and trousers with a known thermal insulation of 0.6clo. Used in chamber studies of thermal comfort.

Temperature drifts : Passive temperature changes in an occupied space.

Temperature ramps : Actively controlled temperature changes in an occupied space.

Temperature "set backs" : Lowering of thermostat set points so as to conserve energy in the heating season.

Temperature "set forwards" : Opposite of "set backs". Energy conservation in air cooling.

Thermal acceptability : The percentage of a group of building respondents who evaluate their thermal environment as being within the central three categories of a seven-point scale of warmth.

Thermal Adaptation Hypothesis : Subjective neutrality shifts toward some average value of the person's thermal history. An extension of the Adaptation Level Theory in environmental psychology.

Thermal Constancy Hypothesis : Thermal neutrality is the same regardless of thermal experiences or acclimatisation, once the effects of thermal radiation, evaporation, convection, metabolism and clothing insulation on the body-environment heat balance have been accounted for.

Thermal sensitivity : The rate of change in subjective warmth per unit change in environmental warmth.

Thermobile : Adjusting set points of HVAC according to some running averages of both indoor and outdoor temperatures, c.f. thermostat (Auliciems, 1984).

Thermogenesis : Metabolic heat production, including shivering and non-shivering forms.

Transmitter substance : Chemical that conveys impulse from neuron to neuron, neurone to gland, or neuron to muscle.

Tropical neurasthenia : A syndrome of predominantly psychological symptoms afflicting exclusively sojourners and residents of tropical regions. Early hypotheses linked the syndrome to climatic causes, but these have largely been supplanted by social and psychological explanations.

Variable Air Volume (VAV) : HVAC system design in which conditioned air is supplied at a constant temperature but in varying volumes to the occupied space.

Vasomotor action : Control of peripheral blood flow by muscular coating on arterioles.

Zoning : In HVAC systems, different parts of the occupied space receive different thermal loads that necessitate separate supplies conditioned air. Zoning is the partitioning of the occupied space to match the HVAC system's design.

Zoo-keeper approach : Strict and centralised control of a building's environmental systems.

NOTATION

A_{Du}	Body surface area from Du Bois formula (m^2)
C	Convective heat loss per unit surface area (W/m^2)
d	Diameter of globe thermometer (m)
E	Evaporative heat loss per unit surface area (W/m^2)
ET*	The new ASHRAE effective temperature (degC)
F_{cl}	Clothing area factor (ND) (non dimensional)
F_{pcl}	Clothing permeation efficiency factor (ND)
g	Radiant response ratio for globe thermometer (ND)
h_c	Convective transfer coefficient (ND)
h_r	Radiant transfer coefficient (ND)
I_{clo}	Intrinsic clothing insulation (clo)
I_{cle}	Effective clothing insulation (clo)
K	Body heat lost/gained by conduction per unit surface area (W/m^2)
L	Local temperature effect (ND)
M/A_{Du}	Metabolic free energy production per unit body surface area (W/m^2)
P_a	Partial vapour pressure (mmHg)
PMV	Predicted mean vote (7 point sensation scale)
PPD	Predicted percentage dissatisfied (%)
R	Body heat lost/gained by radiation per unit surface area (W/m^2)
RH	Relative humidity (%)
$\bar{S}/A_{Du}$	Evaporative heat loss by sweating per unit surface area ($Kcal/m^2.hr$)
SET	Standard effective temperature (degC)
SVP	Saturation vapour pressure (mmHg)
T_a	Indoor ambient dry bulb temperature (degC)
T_{cl}	Clothing surface temperature (degC)
T_g	Globe temperature (degC)
T_{hy}	Hypothalamic temperature (degC)

T_i	Mean indoor temperature (ambient or globe) recorded during a comfort survey (degC)
$T_{\bar{m}}$	Mean monthly outdoor air temperature (degC)
T_{mrt}	Mean radiant temperature (degC)
T_o	Operative temperature (degC)
T_{sc}	Spinal cord temperature (degC)
$T_{set(\ )}$	Functional set point for effector system in brackets (degC)
T_{sk}	Skin temperature (degC)
$\bar{T}_{sk}$	Mean skin temperature (degC)
T_{wet}	Wet bulb temperature (degC)
T_ψ	Neutrality (degC)
$T_{\psi 0}$	Neutrality observed in field studies (degC)
$T_{\psi i}$	Neutrality predicted on basis of mean indoor temperature (Humphreys, 1975) (degC)
$T_{\psi ii}$	Neutrality predicted from outdoor mean monthly temperature for free-running buildings (Humphreys, 1976) (degC)
$T_{\psi iii}$	Neutrality predicted from outdoor mean monthly temperature for climate-controlled buildings (Humphreys, 1976) (degC)
$T_{\psi iv}$	Neutrality predicted from mean indoor and outdoor temperatures for all buildings (Auliciems, 1983) (degC)
$T_{\psi v}$	Neutrality predicted by Fanger's (1970) PMV model (degC)
v	Indoor air velocity (m/s)
w	Skin wettedness (%)
α	Gain constant for thermoeffector afferent signal (ND)
ε	Emissivity factor for black globe thermometer (ND)
η	Efficiency factor (ND)
σ	Steffan Boltzmann constant
Σclo	Sum of individual garments' insulation values (clo)

CHAPTER ONE

DETERMINISM, ADAPTATION AND ADJUSTMENT

1.1 Climatic Determinism

Interest in the relationship between man and the atmospheric environment goes back as far as the Hippocratic writings on "Airs, Waters and Places" (circa 400 BC) in which the effects of weather and climate on human health and temperament were systematically examined (Tromp, 1980, p.4). It wasn't until the current century that the notion of atmospheric influences received its most comprehensive and forceful expression in the doctrine that is now referred to as climatic determinism. The nineteenth century German Geographer, Friedrich Ratzel, summarised the general

thesis in the following statement (1901, p.64, cited by Sprout and Sprout, 1965, p.50):

> "The course of history in America, just as in the corresponding periods of time in northern Asia, in Africa, and in Australia, only confirms the belief that lands, no matter how distant from one another they may be, whenever their climates are similar, are destined to be scenes of analogous historical development."

Perhaps the best known protagonists in the present century are Ellsworth Huntington and Griffith Taylor, whose writings represent landmarks in twentieth century geography. Their hypothesis came under heavy fire from those who preferred to emphasise the human free-will and other causal factors in the Universe. These philosophical bones of contention have since come to be seen as unfair criticism insofar as they imply that climate was held to be the single causative factor in the world; a position far removed from that espoused by Huntington and Taylor (Chappell, 1975). Another reason for the strong criticism of the determinists, and perhaps a more justified grievance, was that the dependent variables employed in their model were often too vague and qualitative to be subjected to the sweeping generalisations characteristic of the determinists. Variables such as human comfort, human health indices such as morbidity, mortality and fertility statistics (Huntington, 1924; Taylor, 1949) seem quite amenable to having quantitative interpretations imposed upon them, but the use of ill-defined or at best ethnocentric concepts such as "level of civilisation" (Huntington, 1924; Markham, 1947) and "national energy" (Markham, 1947) inevitably provoked sustained criticism to such an extent that the term "determinism" still carries with it perjorative overtones in the social sciences (see Platt, 1948, p.126-132 for a detailed

critique).

Controversy notwithstanding, the central idea in climatic determinism, that of climatic optima, has made a lasting impact on the modern science of biometeorology. On the basis of ingenious studies into seasonal variations in factory operatives' piece-work productivity, Huntington suggested 16degC to be the optimum outdoor temperature for physical work. Further, analysis of seasonal effects on the academic performance of large samples of students formed the basis of Huntington's suggestion that 3degC was the best outdoor temperature for mental work under the conditions of housing and diet that prevailed in Connecticut at that time. Reasoning that human progress demanded both physical and mental effort, Huntington concluded that the ideal climate would have a mean annual temperature midway between the above two figures; about 10degC (Huntington, 1924, Ch.4 and 5). The relations are depicted in Figure 1.1. However, having an optimal annual average temperature was a necessary but insufficient basis for the ideal climate. Huntington also laid stress on the stimulating effect of variable weather. Day-to-day temperature fluctuations of about 2K were considered important as were pronounced seasonal differences (Huntington, 1924, Ch.10).

Griffith Taylor, who made use of the human comfort factor in his hypothesis of climatic influences on human life, put forward wet bulb temperature as a climatic index, as summarised in Table 1.1. Taylor used this scale to construct climographs, which indicated monthly averages for the climatic parameter. Using characteristic a posteriori logic, Taylor worked from the leading northern hemisphere centres of white population to construct a "type white climograph" that illustrated the geographical "...limits of comfortable settlement for the Anglo-Saxon branch of the

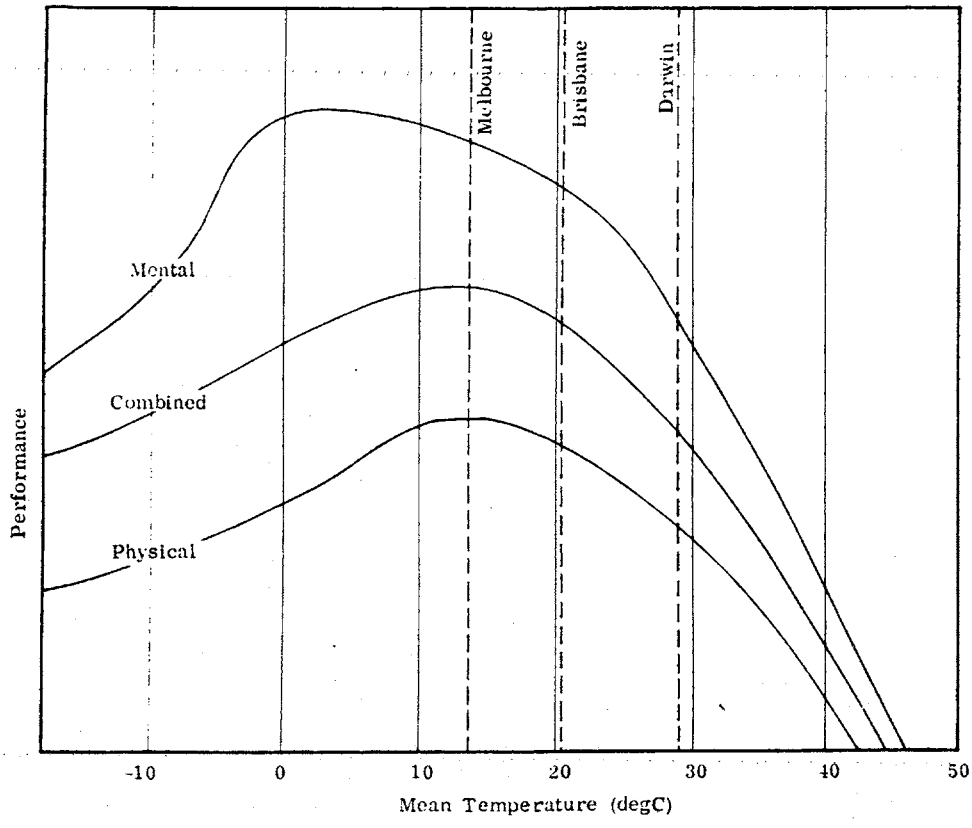


FIGURE 1.1 : Huntington's hypothesis on the control of human performance by temperature (After Griffith Taylor, 1949, p.418)

TABLE 1.1 : Griffith Taylor's wet-bulb temperature comfort scale (1916)

Wet-bulb temperature	Comfort level
< 4.4	= raw or keen
4.4 - 7.2	= very rarely uncomfortable
7.2 - 12.8	= ideal
12.8 - 15.6	= very rarely uncomfortable
15.6 - 18.3	= sometimes uncomfortable
18.3 - 21.1	= often uncomfortable
21.1 - 23.9	= usually uncomfortable

white race" (Taylor, 1916, cited by Grenfell Price, 1939, p.197).

Publishing some time after these early determinists, Markham's (1947) formulation of the "ideal climate" had the benefit of a substantial amount of carefully conducted laboratory research by the emerging heating and ventilation industry. He concluded that ideal indoor conditions ranged from 15.6 to 24.4degC, with relative humidity being maintained between 40 and 70%. Translating these figures to the outdoor environment of earlier civilisations in which it was generally believed that lighter clothing ensembles were worn, Markham concluded that the annual isotherm of 21degC delineated the ideal outdoor climate on a world map (1947, pp.31-37).

The implications of the climatic determinists' hypothesis for Australian settlement policy earlier this century were quite controversial. Griffith Taylor endeavoured for twenty years to inform the Australian public and its decision makers that it was "...useless to try and fill up the arid and more northern tropic lands as long as there was better land not fully utilized in the south and east" (1949, p.412). This was not to say that "white man" could not settle in the more climatically stressed regions, but rather, that there would have to be compelling economic or perhaps strategic advantages to overcome the climatic disability. This has proven to be a particularly contentious point of view whenever the "White Australia" and "Populate the North" policies enjoy wide political support.

Historical evidence supporting the contention that tropical Australia was unsuitable for white settlement was very easy for the climatic determinists to marshal. From 1500 onwards, the Portuguese, Spaniards, Dutch, English, French and other Europeans poured into tropical Asia, Africa and America. Initially these invasions were

spectacularly successful but "...quickly and irresistably, however, the tropical climates...began to take their toll" (Grenfell Price, 1939, p.13). In the case of British settlement of Barbados in the Carribbean, their population of 37 thousand in 1640 was reduced to 16 thousand by 1786 (Grenfell Price, 1939, pp.21-29).

The cause of this profound decline has been attributed to a variety of factors ranging from poor diet and barbaric treatment of servants, through to poor administration and unfavourable economic circumstances, but the tropical climate received most of the blame for the failure of Britain's Caribbean experiment. Belief that the English "moral constitution" broke down under a tropical sun and that the capacity for work was eroded by climatic stress were prominent among English interpretations of the Caribbean experiment. Huntington (1924) drew a similar conclusion not only for the West Indies but other incursions of whites into the tropics which ended in failure, such as the Americans in Panama, as well as the British in the Bahamas, India and Africa. Huntington (1924) and numerous other writers on the topic (see Sargent, 1963, for reviews) attributed these manifold problems to the influence of tropical climates on human will, and the term "tropical neurasthenia" was coined to denote the syndrome (Woodruff, 1900). A weakness of will manifested itself in a general lack of industry or "tropical inertia", which afflicted both the mind and the body. The weakness of will was also held responsible for low sexual morality, irrascible temper and fits of anger, drunkeness bordering on alcoholism, proneness to gambling and a profound disregard for the truth! (Huntington, 1924, pp.68-74). Tropical neurasthenia was also held responsible for causing the "poor white" syndrome in South Africa and Rhodesia (Zimbabwe).

Historically, there seemed to be nothing but support for this hypothesis about the effects of tropical climate on white settlers. There was however, one contemporary case which confounded it; that of Queensland Australia, which was widely hailed as "...one of the most successful white penetrations in the tropical world" (Grenfell Price, 1939, p.52). Sir Raphael Cilento, Director of the Australian Institute of Tropical Medicine in Townsville in the twenties became a leading spokesman for the potential of white settlement in the tropics. His 1925 monograph was the first attempt to systematically disentangle the conjecture, polemics and opinions from more objective pieces of information about so-called tropical neurasthenia. The "success" of the Queensland experiment was gauged by the census returns for the state in which vital statistics such as death, infant mortality rates and life expectancy between 1906 and 1917 compared more than favourably with those for the Commonwealth as a whole (Cilento, 1925, pp.50-55).

In explaining this success against the backdrop of dire prognoses of the climatic determinists, Cilento pointed out several unique features of the Queensland situation. First and foremost, the white settlers there were not in contact with a numerous and disease-ridden native population; hookworm and malaria were claimed to be a key cause of the failure of white tropical settlement. Stemming from this basic difference in the "Queensland experiment" was the shortage of a native population for the white settlers to exploit. Servants and coloured labourers were expensive, hence the white settlers in Queensland were forced to engage in all types of work from the heaviest manual labour to the most intellectually demanding occupations. The need for manual labour thus greatly facilitated the body's natural and metabolic adjustments (see

Section 2.3.1).

Further, Cilento was keenly aware of the need for behavioural adaptations in the tropics and successfully urged that appropriate clothing and architecture be adopted. Also, adjustments in the types and quantities of food were suggested along with a plea for moderate alcoholic intake. Another behavioural adjustment recommended was the rescheduling of the working day between the hours of 6 a.m. and 2 p.m., after which the worker would be free for recreation. Coupled with these behavioural adjustments were several suggestions for what one might call psychological adaptation. Foremost among these was the need for tropical immigrants to think of themselves as settlers rather than adopting the "sojourner mentality". Grenfell Price (1939, pp.3-4) also emphasised this factor and in his definition of tropical settlers he excluded officials, soldiers, traders, missionaries and drifters who, because of the short duration of their visit, were prepared to put up with makeshift dwellings and appliances and transitory social arrangements. Cilento (1925) suggested that true settlers such as Queensland's had a civic pride and community interests that motivated them to create more comfortable and lasting physical and social environments.

Another psychological factor that Cilento felt was involved in the failures of previous white attempts to settle the tropics was that of indolence and self-indulgence which were characteristic of any country where Europeans acted as a small superstratum controlling and exploiting a sizeable native population. This factor was missing from the Queensland situation because of the small indigenous population. As well as removing these psychological dangers, such a situation enhanced the immigrant's level of physiological acclimatisation, as mentioned above.

These ideas were echoed more recently by Sargent (1963, p.296) who concluded that psycho-social mechanisms were implicated in the aetiology of tropical neurasthenia:

> "Isolation from accustomed social and cultural surroundings is trying because most people are conservative about altering their customary mode of living, eating, dressing, working and playing. Failure to compromise traditional habits with those more suitable to local conditions may be deleterious."

Cilento's use of Queensland as an illustration of the potential for successful adaptation and acclimatisation in the tropics inevitably provoked vitriolic rebuttals from the determinists whose hypothesis was premised on the fixity of human response (at least under conditions of constant "level of civilisation"). Huntington (1924, p.380) based his refutation on the concept of natural selection; only the fittest and boldest members of a community would assume the role of pioneer in a region that had a reputation for considerable discomfort. This conjecture can of course just as easily be turned around to support the opposite conclusion about the quality of tropical settlers in Queensland; that they were desperados not so much selected by the challenge of the frontier but repelled from the centres of their culture. Markham also felt the necessity to explain why the seeming success of a white population in tropical Queensland did not contradict the climatic determinists' hypothesis (1947, p.213). Accordingly;

> "...the emigrants that have built...[Queensland]...up came from more favoured lands; they brought their energy with them, and for a time these areas are bound to reflect their energy. But sooner or later climate will tell. We have seen in South Africa that the 'poor white' problem has developed relentlessly over two centuries, but Queensland...[has] not yet been settled extensively for two generations."

Although only 40 years have passed since Markham's writings, the rapid

development of Queensland so far doesn't support his dire prognosis. However, he did qualify his comments by writing that if Queensland could acquire climate controls against heat and humidity (air conditioning), it would progress as fast as any sub-tropical area in the world (Markham, 1947, p.213).

1.2 Adaptation in Modern Man-Environment Systems

The debate about adaptability versus fixity of human response to environmental stress was not laid to rest with the environmental determinists earlier this century. If anything, the issues have come under closer scrutiny with the emergence of new academic disciplines, or more correctly, interdisciplines, addressing the complex relationships between man and the natural or built environment. One such sub-discipline is environmental psychology, which had its origins in the 1960's with the recognition by architects, human geographers and town planners of the valuable contribution that psychologists could make to their endeavours.

There are several models that have been used by environmental psychologists to interpret their empirical data (Bell et al., 1978; Poiner, 1979), but of these perspectives, Adaptation Level (AL) theory is particularly germane to the topic at hand. The original concepts of adaptation level were put forward by Michels and Helson (1949) in the context of experimental psychophysics (see Appendix A), but have since been applied to a broad spectrum of topics such as "hedonic relativism" and welfare economics (Appley, 1971; Brickman and Campbell, 1971). In terms of being a general scheme for understanding man-environment

interactions, AL theory was first employed by Wohlwill (1966; 1974). He interpreted the concept of adaptation as being applicable to all levels of the man-environment relationship; from physiological through to cognitive and behavioural levels.

The central hypothesis of Wohlwill's (1974) model is that there is an optimal level of environmental stimulation for each individual and that deviation from the optimum acts as a powerful determinant of affective, cognitive and behavioural evaluations of environments. The optimal level or neutral zone of stimulation is called the adaptation level and its role in determining affective responses according to stimulus discrepancy, has long been recognised in psychological theory (McClelland et al., 1953), tested in laboratory experiments (Haber, 1958), and consistent with an important neurological model (Hebb, 1949).

The adaptation level of an individual for a particular stimulus is established as a function of past exposures, and the concept of adaptation in Wohlwill's model is simply defined as "...a quantitative shift in the distribution of judgemental or affective responses along a stimulus continuum, as a function of continued exposure to a stimulus" (1974, p.134). The introduction of relativity into the man-environment relationship starkly contrasts with the structuralist tradition of absolute relationships in much of the perceptual psychology that preceded AL theory.

Following the terminology of Sonnenfeld (1966), the above definition of adaptation can be clearly distinguished from environmental adjustment, which is a behavioural change effected on the environment so as to modify the level of a set of stimuli. Adjustments can be considered as a means

of reducing the necessity for the individuals to endure levels of stimulation that widely deviate from already established neutral zones. On the other hand, if adjustments such as microclimatic control by air conditioning were not resorted to, AL theory predicts that the subjective evaluations of the "natural" indoor climate would tend towards neutral with prolonged exposure.

Several interesting questions have been raised by Sonnenfeld (1966) and Dubos (1961; 1965) about the interaction between adaptation and adjustment as depicted in Figure 1.2. These authors consider that modern technological civilisation places too great an emphasis on the adjustments of, and escape from, environmental stimuli that depart from prevailing adaptation levels. In the words of Dubos (1961, p.49);

> "By changing the physical world to fit his requirements, or wishes, he [man] has almost done away with the need for biological adaptations on his part. He has thus established a biological precedent and is tempting fate for biological fitness achieved through evolutionary adaptation has been so far the most dependable touchstone of permanent success in the living world."

Furthermore, the interaction between adaptation and adjustment raises the possibility of environmental adjustment being simply a treadmill of attempting to satisfy ever-increasing expectations of comfort.

Stokes (1975) hypothesised that in the world of marketing, the rapidly increasing volume of consumer complaints results from a rate of increase in consumer expectations being greater that the perceived improvement in product performance or quality. One could envisage the same conclusions about the effects of environmental adjustment; that the discrepancy between levels of environmental stimulation and adaptation levels which are considered acceptable are diminishing, or expectations

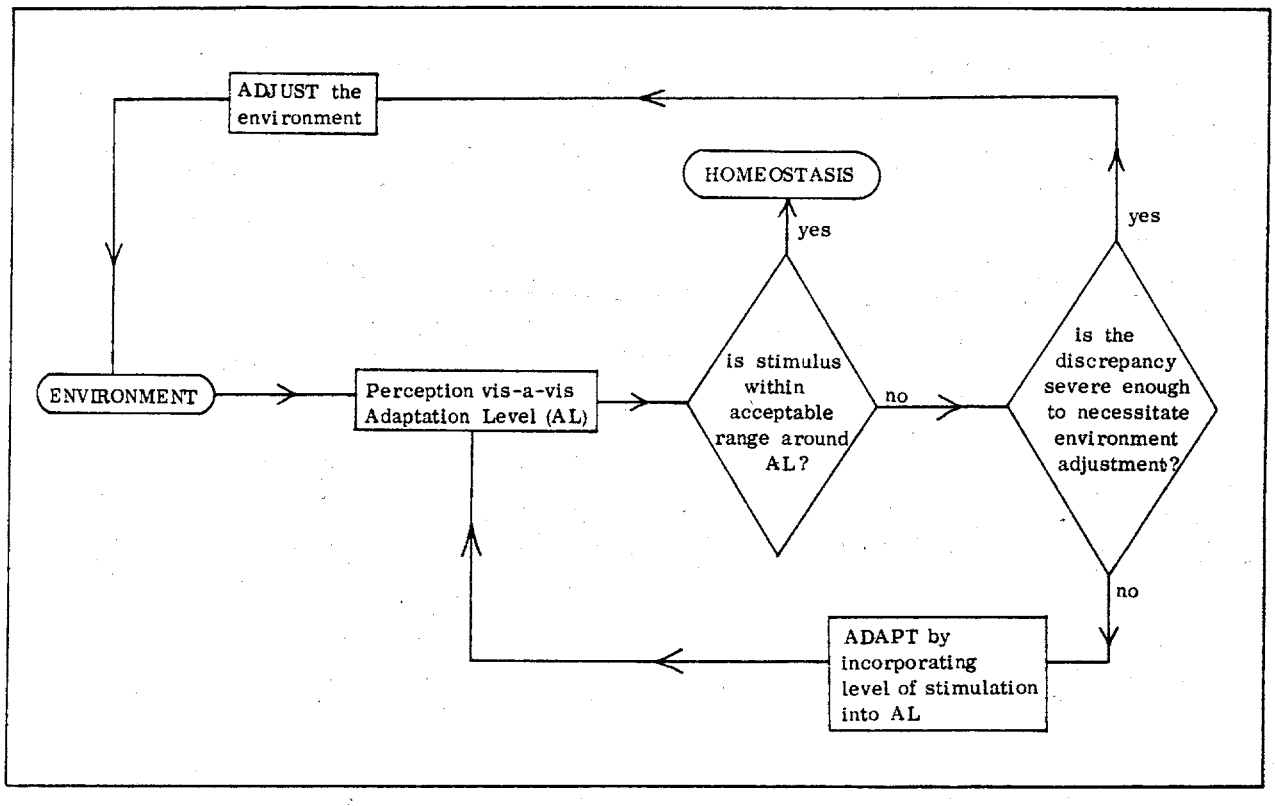


FIGURE 1.2 : Conceptual scheme for the man-environment system

are increasing as a result of technological civilisation's failure to make adequate recognition of adaptation as a mode of response. Thus, even though the degree of control that building services engineers are capable of bringing to indoor climates is increasing (adjustment), the benefits are probably obeying the law of diminishing returns. Environmental quality will therefore be lagging behind the environmental expectations of building occupants, giving rise to demands for ever increasing sophistication of controls which can never be met despite vast inputs of engineering technology and energy.

As a theoretical perspective for interpreting man-environment relations, the AL model has been criticised by Bell et al., (1978, p.81) on the grounds that it allows too much individual variability in adaptation levels. That is, because each individual has a unique history of exposure to various environmental stimuli, their neutral zones for those stimuli will vary accordingly, and the ability of the AL model to predict their affective responses will be marginal. Whilst this criticism may be valid for a psychologist who has principally been concerned with individual differences, the theory still has considerable utility for a research design in which group differences are the focus, as is the case in the current thesis.

1.3 Human Factors and Air Conditioning

The later climatic determinists such as Markham (1947) and Griffith Taylor (1949) were prophetic in their emphasis on air conditioning in the development of tropical Australia. It would seem that the architects and engineers responsible for the built environments of all Australian cities have placed greater stock in technical adjustment to heat and humidity rather than relying on human adaptation. The current section gives a brief overview of air conditioning and the human factors relating to it. After defining the term "air conditioning", the chapter reviews the arguments that have been used to justify the installation of these expensive climate controls. Some of these arguments have stressed the ability to liberate architecture from the constraints of local climate, but more important to the current thesis are the purported human benefits; principally comfort and performance. This discussion is

followed by a review of some of the more important indoor thermal climate standards currently in existence.

Although indoor air quality issues are not the focus of this thesis, it is recognised that they become inseparable from thermal considerations in discussions of human reactions. Finally, the technology of Heating, Ventilating and Air Conditioning (HVAC) systems, and the various standards that guide its implementation, have evolved in an era of abundant fossil fuels and are therefore extremely dependent on massive energy inputs. The single most important event in the HVAC industry's recent history was the energy shortfall of the mid 1970's. Consequently, it is appropriate to conclude the current chapter with a discussion of the implications of this energy shortage on the practice of air conditioning and also the implications for comfort, health and occupant acceptance of air-conditioned indoor climates. A recurring theme throughout the remainder of the chapter is the role played by psychological variables such as expectation and perceived microclimatic control in determining human reactions.

1.3.1 Definitions of air conditioning

The McGraw-Hill Encyclopedia of Science and Technology (1971, p.163) defines air conditioning as "...the control of certain aspects of the environment within a defined space to facilitate the intended function of that space". This definition can be subdivided into process and comfort air conditioning. The former is concerned with facilitating production, manufacturing or operational activities and is of little importance to the current thesis. Comfort air conditioning refers to spaces occupied by people and is achieved by control of the following environmental

variables; air temperature, air motion, humidity and concentrations of various pollutants including dust, germs, odors, and gases. These controlled variables can be classified into thermal and air quality factors.

The current thesis is focused on thermal issues of indoor air, particularly air cooling, but mention is made of the air quality dimensions of indoor climate. It should be pointed out that the above definition of air conditioning excludes so-called evaporative air conditioners as these devices have the desired control over only dry bulb temperature and that control is closely determined by the level of humidity in the atmosphere. Therefore, the term evaporative cooler seems more appropriate for these systems. The reader who is interested in the engineering aspects of air conditioning hardware is directed to the following references; Szokolay, 1980, pp.355-405; McQuiston and Parker, 1977; Harris and Conde, 1974; Jones, 1969; Haines, 1971; Sheridan et al., 1963; Faber et al., 1979; Juler, 1963.

1.3.2 The arguments for air conditioning

The essential function of a building envelope is to act as a filter between the external and built environments (Martin, 1974). Fluctuations in the external climate have to be dampened or filtered; external noise may require attenuation and external illumination has to be brought to the interior in the right quantity and quality. The technology of air conditioning represents a closely controlled, mechanical substitute for the building envelope's climatic-filter role.

Like most costly technological developments, air conditioning has penetrated its market only after vigorous campaigning on its benefits while de-emphasising the costs. The costs include installation and running expenses as well as various human penalties that will be discussed later in the current section. The benefits of air conditioning can be classified as either human or architectural.

The human justification for air conditioning has been very thoroughly marketed to the point where the building client, and usually their architect as well, believe unquestionably that the perfect indoor climate can and must be obtained (Metcalfe, 1969). The "sales pitch" usually makes mention of the following advantages (Black and Milroy, 1966; Pepler and Fabrizio, 1970; Metcalfe, 1969; Angus, 1968; Martin, 1974; Billington, 1969; Quinn, 1966):

Thermal comfort: This most obvious advantage figures prominently in the common perception of air conditioning. When Pepler and Fabrizio (1970) surveyed the attitudes of teachers in Oregon towards air conditioning schools, they noted that comfort was the most frequently stated benefit. The respondents were actually teachers in non-air-conditioned schools. Black and Milroy (1966) questionnaired attitudes of occupants in air-conditioned and non-air-conditioned office buildings in London. Contrary to Pepler and Fabrizio, they found in the summer time in general, that the non-air-conditioned building was rated on a five-point scale most frequently as "comfortable" whereas the three air-conditioned buildings of that study were somewhere between "comfortable" and "passable". Only on extremely hot days did the air-conditioned building comfort ratings improve above those of the non-air-conditioned building.

Cleanliness: By sealing indoors off from the pollution of central business district atmospheres, air conditioning is said to provide a much cleaner environment than is available with natural ventilation. Also, depending on the type and efficiency of filter systems in use, air conditioning can remove dust, pollen and other particulates from the intake air stream. Black and Milroy (1966) found three quarters of their London air-conditioned respondents answered that they found their offices clean when directly asked. A further 17% said that the building was not dirty although there was not as much improvement in comparison to non-air-conditioned offices as they had expected. However, the enjoyment of this benefit of air conditioning is very directly related to the quality of plant maintenance of the filtration units, which, according to one commentator, is more often than not substandard (Metcalfe, 1969).

Noise: The sealing of windows that is standard practice in the design of air-conditioned buildings enables a lot of the external street noise to be excluded from the internal environment. Most of Black and Milroy's (1966) non-air-conditioned clerical workers mentioned the outside noise of their building as a source of annoyance. Indeed, 80% said that the problem was so great in their London office that it limited the number of, and duration that, windows could be opened. Langdon (1965) found that as many as two thirds of the occupants of non-air-conditioned buildings situated on main thoroughfares were "really bothered" by traffic noise. However, in the same study it was found that, in air-conditioned buildings, annoyance from internally generated noise was much more prominent. This no doubt reflects the change in floor plan from small offices to large open-plan designs as much as the presence or absence of air conditioning. Apart from indirectly

increasing annoyance from internal noise, air conditioning directly contributes to acoustic disturbance with fan, motor, bearing and other mechanical noise, not to mention the noises generated by air flow in ducts (Croome, 1969). Like open-plan office noise, the disturbance from these HVAC system noises increases as the external acoustic environment is further supressed.

Health: It has been suggested by some vigorous advocates of air conditioning that health can benefit from the reduced transmission of germs and disease (Metcalfe, 1969). British Army personnel managers commissioned a study into the potential health benefits of air conditioning in Middle East and Far East garrisons (Quinn, 1966). A pilot study of morbidity of NCOs and airmen in both air-conditioned and non-air-conditioned work places and sleeping quarters in Aden was completed. It was found that the incidence of sickness as measured by first attendance at sick-bay was more than twice as high for those without air conditioning in their work place and sleeping quarters than was the case for air-conditioned personnel. However, the causal nexus in these data is tenuous to say the least. The survey did not control for differing trades and physical fitness of subjects. The heavier jobs which are more prone to industrial accidents would have been concentrated in the non-air-conditioned group, therefore the validity of Quinn's (1966) conclusion is questionable. Another survey, which looked at workers of the Metropolitan Life Insurance Company in New York, showed no significant difference in the incidence of respiratory or non-respiratory diseases between personnel in buildings with or without air conditioning (McConnell et al., 1937, cited by Tromp, 1980, p.207).

Personnel productivity: By far the most vigorously argued case for air conditioning has been based on the assertions that employee efficiency is enhanced, absenteeism is reduced and staff turnover is minimised (Weiss, 1959; Tweddell, 1964; Pepler and Fabrizio, 1970; Sheridan et al., 1963; Billington, 1969). The latter two claims aren't taken very seriously but the first of these assertions has been elevated to the status of an axiom and therefore warrants closer discussion. The connection of employee productivity to thermal conditions represents a restatement of the central contention of the climatic determinists such as Huntington (1924) and Markham (1947), which was discussed more fully in Section 1.1. In its modern form, the argument asserts that if the cost per employee of providing an optimally comfortable indoor climate amounts to $X, and that the performance decrement of not providing such an optimal environment amounts to $Y in lost productivity, then economic rationality demands that the employer installs the necessary climate controlling equipment if and only if $X is less than $Y. Expressing this proposition mathematically, Weiss (1959, p.72) claims the economic justification of air conditioning is established when:

$$\int_{t_1}^{t_2} (\eta AC - \eta)\, dt \;.\; S > C_{AC} - C \quad (1.1) \qquad (1.1)$$

where η is employee efficiency/productivity

S is annual salary bill

C is total annual charges (interest, depreciation, operation and maintenance)

t is time

AC is air conditioning

It would seem a fairly straightforward task to establish the costs of air conditioning. Much more difficult has been the business of estimating the temperature-efficiency relationship. Starting with the most basic attempts, Weiss (1963, p.106) observed officers of a government department in Queensland "droop" at an effective temperature (old scale) of 26degC and he estimated, on the advice of several statisticians (whose authority in the subject was never explained), that such "drooping" amounted to a 10-20% efficiency decrement. A more rigorous study of the temperature-performance relationship by Mackworth (1946) has become a classic in the topic. Male wireless telegraph operators were studied under various heat loads and the number of mistakes made in their transmitted messages were recorded. Converting Mackworth's temperatures, metabolic rates, clothing and air velocities into the new ASHRAE effective temperatures, a slight performance decrement was observed at 32degET*. Pepler (1956) and Watkins (1956) employed experimental procedures similar to Mackworth's (1946) and also observed performance decrements at 32degET* (see Auliciems, 1973, for a detailed review of thermal effects on performance research).

It would be a mistake however to conclude on the basis of these studies that heat exerted a uniform or simple effect on performance (Pepler, 1962). More recent studies by Wyon and Holmberg (1973) and Wyon et al. (1981) have emphasised the complexity of the heat effect. Performance tests and behavioural observations made of school children under varying levels of moderate heat stress indicated that attention, reading speed and comprehension were all worse at 27degC than they were at either 30degC or 20degC (Wyon and Holmberg, 1972). These data supported the hypothesis that arousal decreased at intermediate levels of

heat stress (Provins, 1966), due to the behavioural adjustments of adopting a relaxed posture and maximising the body's effective radiation area while reducing metabolic heat production until the onset of sweating at slightly higher temperatures.

Further grounds for circumspection in interpreting the above mentioned heat-performance studies were provided by Woods et al. (1981). Using the standard effective temperature as their index of environmental warmth in an actual hospital laundry, Woods et al., (1981) found no statistical relationship between moderate heat stress and productivity (piece-work and machine-paced tasks). In a state-of-the-art review of thermal environment, learning, and task performance studies, McNall (1979) concluded that scientific support of this generally accepted hypothesis was scarce and would remain so. This was due to the tendency for inter- and intra-individual differences in motivation to confound any thermal effects.

By administering 14 separate academic performance tests, in air-conditioned and non-air-conditioned schools, McNall and Nevins (1967) could find no statistical support for the air conditioning of schools (Pinellas County, Florida, U.S.A.). Pepler (1971) found statistical correlations between performance decrements and outdoor temperature variations for students in non-air-conditioned classrooms in Oregon, U.S.A. However, the same relationship was established for students in air-conditioned classrooms even though the indoor climate was held constant. Therefore the study failed to support the case for air conditioning Oregon schools. Damm and Fenelon (1956) administered a battery of mental performance tests to school children in Toowoomba and Townsville, Queensland Australia, during summer and winter months. It

was found that the tropical summer in Townsville was the season of best performance, whereas the relatively mild summer of Toowoomba coincided with performance decrements. One possible interpretation of these data was that the children of Toowoomba had been sensitised to thermal variations by the pronounced seasonal and diurnal changes in that city, in contrast to the more uniformly hot climate of Townsville. Regardless of the interpretation, Damm and Fenelons' (1956) results do not support the case for air conditioning schools in the tropics. Finally, Langkilde (1979) found little or no effect of temperature variations between 18 and 30degC on the six office-simulation tasks performed by 15 laboratory subjects.

Therefore, the literature on the effects of heat on performance is at best ambivalent. Even if it was accepted that heat stress produced performance effects, it is only evident at fairly extreme conditions above 32degET* (except for Wyon and Holmberg, 1973). Further, it is an over zealous interpretation of the observed performance decrements to attempt putting monetary values on a temperature-productivity curve as suggested by some advocates of air conditioning (Weiss, 1963). Similar scepticism has been expressed by McIntyre (1984) and Fisk (1981) who consider that the direct influence of building temperature on productivity under normal working conditions is considerably smaller than most environmental engineers would wish to admit. Indeed, according to Herzberg et al. (1959, cited by Fisk, 1981, p.29), management scientists rate work environment as low as 14th in their lists of factors influencing productivity. In all but stress conditions, other motivational factors swamp any direct effects of heat on work output.

From the discussion of the preceding five human advantages of air conditioning it can be concluded that in all but the most severe climates, there is ambivalent scientific evidence justifying HVAC climate controls. It is logical therefore to address the architectural reasons for installing air conditioning. In discussing trends in British buildings, Martin (1974) commented that modern architecture and technology had broken with a tradition of understanding climate. The same conclusion can be drawn by a casual observer of modern architecture in the Australian context. In an age of abundant fossil fuels, there seemed no sound reason not to buy liberation from the demands of climate with massive energy inputs (Burberry, 1978). The benefits of architecture unrestrained by climatic considerations with the advent of HVAC climate controls can be enumerated (Martin, 1974; Billington, 1969; McIntyre, 1984; Sheridan et al., 1963; Metcalfe, 1969; Lloyd, 1974; Sherratt, 1974; Hill et al., 1974):

1. air conditioning has removed the requirement for the building envelope to have thermal mass, as its role as climatic filter has been withdrawn.

2. The logical extension of the preceding principle is the glass-curtain external finish prevalent in most modern high-rise buildings. Fenestration has changed from being a primarily functional consideration in design to become a largely aesthetic factor with the introduction of air conditioning. Deprived of their functional role, windows are invariably of the unopenable type in air-conditioned buildings.

3. Orientation of buildings on their site before air conditioning was often determined in warm climates by the need to minimise building surface areas presented to morning and afternoon sun. An air-conditioned building copes with different heating or cooling loads being placed on different parts of the structure by zoning the control system.

4. Perhaps the most important architectural benefit of air conditioning is the possibility of deep-space planning. The basic research on lighting and ventilation conducted before World War II indicated that without air-conditioning, the distance that a work station could be from the building perimeter was constrained by the amount of natural light available and also the requirement for ventilation (McIntyre, 1984). Both of these are directly a function of fenestration; the larger the windows, the deeper the space (Hill et al., 1974). However, in the mid-latitude climates at least, increasing window size induced thermally uncontrollable buildings. Therefore the pre-air conditioning building had a large perimeter to floor-area ratio, and office design consisted of small, naturally lit cells in which the relatively small number of occupants could exercise considerable control over their immediate luminous, acoustic and thermal environments. Air conditioning, combined with a reappraisal of artificial lighting methods, in short, enabled the move toward the open office plan in which proximity to windows was not a

consideration (Lloyd, 1974).

1.3.3 Indoor Climate Standards

Accompanying the above design effects of air conditioning were several changes in the functioning of modern buildings. As mentioned earlier, the trend towards open-plan office carried implications for the control of indoor environments. With the aggregation of building occupants into large open areas, and the substitution of mechanical environmental systems for passive ones, there has been a profound shift in environmental control away from small groups of individuals to a central building services manager. Several commentators have described this trend as the "zoo-keeper" approach to indoor environmental management. In the words of Cooper (1982a, p.245):

> "...responsibility, production and control of comfort has become divorced from those who occupy the internal environments which buildings afford. Instead, comfort has been transformed into a commodity produced for occupants : it is no longer viewed as an objective towards which they may strive, if they so choose, by employing means placed at their disposal by designers in order to enable them to do so."

In this light, the architects, engineers and other members of the design team have been described as benevolent dictators operating under the principle of Utilitarianism; the greatest happiness of the greatest number. Obviously they impose their own concept of happiness onto their design (Cooper, 1982a). This concept is embodied in various indoor climate standards and the experimental procedures employed in their development (see Sections 3.1 and 3.2 for details).

Briefly looking at the historical development of indoor climatic standards, it is often pointed out that during this century there has been a trend toward higher indoor temperatures in developed northern hemisphere countries (McIntyre, 1980, p.202; Rohles, 1980, p.545; Auliciems, 1981c, p.119; Hanes, 1974, p.30), and the indoor climate standards have followed, or perhaps even led this trend. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, formerly ASHVE) recommended standard for winter comfort was 17.8degC in 1924, 18.9degC in 1925, 20degC in 1941 and 25degC in 1960 (Rohles, 1980, p.545; 1970, p.309). Whether this trend can be explained solely in terms of people wearing lighter clothing indoors during winter, or instead, people expecting and getting higher standards of comfort indoors, is not as clear as the impermanence of these standards. Although they have been derived from scientific experiments, they are not the immutable "scientific facts" that the practising HVAC engineer tends to regard them as. Rohles (1980, p.546) seems to be something of a dissenting voice among the comfort specialists publishing in ASHRAE's Transactions because he contends that comfort standards can take advantage of, and actively encourage the ability of people to adapt within a range of conditions much wider than any design criteria practised to date. Hence he suggests that exposure to temperatures below the U.S. winter standards as is the case in Great Britain, could lower the temperature people prefer for comfort.

It seems as if Americans practised air conditioning enthusiastically very early in the history of the technology; Leopold (1947) found in his field studies across the U.S.A. that large buildings' thermostats were being maintained at the same setting for both winter and summer

conditions. Britons on the other hand were much more tolerant of elevated temperatures in their air-conditioned buildings during warm weather and objected to the same temperatures being artificially maintained in the heating season (Harrison, 1958; Thornley, 1969).

Leopold's observations (1947) indicate that the practice of air conditioning slightly led the ASHVE (subsequently ASHRAE) standard at that time which still differentiated seasonal design conditions. Subsequent revisions of ASHRAE Standard 55 on "Thermal Environment Conditions for Human Occupancy" in 1966 and 1974 ceased this seasonal specification. The Carrier Handbook of Air Conditioning System Design (1965, p.20) also deleted seasonal standards, opting for a flat 23.3 to 24.4degC (45-50%R.H.) design condition in both summer and winter for the U.S. In an undated System Design Manual for the entire Australian market, the Carrier Corporation recommended some seasonal differences with 24degC (50%R.H.) in summer and 21degC (30%R.H.) in winter. In a review of practices in air-conditioned multi-storey office buildings in Australia, Gorman (1965) concluded that Australians had a preference for nothing over 23.9degC. Although no details were given about how this figure was arrived at, it does lend support to the aforementioned Carrier recommendations.

By far the most technically sophisticated and generalised comfort standards have been those based on climate chamber research. The two state-of-the-art examples are the 1984 International Organisation for Standardisation's (ISO) "Moderate Thermal Environment" document 7730 (1984) and the ASHRAE Standard 55 on the "Thermal Environmental Conditions for Human Occupancy" (ASHRAE, 1981b). The experimental methods employed in developing both of these standards are described in

detail in Chapter 3.

The ISO 7730 standard is based on the comfort models of Fanger (1967; 1970). It uses the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices to measure and evaluate moderate thermal environments. The PMV model is discussed in considerable detail in Section (3.2.1). Basically it predicts the mean response of a large group of adults on the standard ASHRAE seven-point scale of warmth (see Table 3.1) on the basis of the following six variables affecting the body-environment heat balance; ambient air temperature, humidity, radiant temperature, relative air velocity, level of clothing insulation being worn and the level of metabolic heat being produced by the occupants.

In discussing the philosophy behind the ISO standard 7730, Fanger (1984) emphasised the impossibility of satisfying everyone with any combination of thermal factors. All that is technically possible when more than one person share a thermal environment is that 95% of them will rate the environment as, "slightly cool, neutral, or slightly warm"; Fanger's definition of acceptable on the ASHRAE sensation scale (see Table 3.1). The PPD index is a function that calculates the percentage of occupants who would vote outside the central three categories on the ASHRAE scale. The optimal PPD of 5% occurs when the PMV score for an environment is zero (neutral). The "utilitarian" principle of "the greatest amount of happiness" as discussed above, translates into a PPD score of 5%. The ISO standard 7730 recognises that some variability around the optimal solution is inevitable so it recommends that the following criteria for PMV be met (Fanger, 1984, p.92):

$$-0.5 < PMV < +0.5$$

This means in PPD terms that dissatisfaction should be less than 10%.

While recognising the existence of individual differences in subjective response to thermal stimuli, Fanger has consistently and vigorously denied the existence of systematic group differences in thermal neutrality (1970; 1984). Like most other biological phenomena, subjective thermal sensations in a large, randomly selected group of people are claimed to be normally distributed, and entirely explicable in terms of the six heat balance variables mentioned above. This "thermal constancy" hypothesis denies the influence of age, sex, race, acclimatisation and the general thermal experiences of groups of people over their preference for particular bodily states and sensations. By incorporating the PPD index into the standard, ISO has clearly extended the thermal constancy hypothesis to non-neutral thermal assessments on the ASHRAE scale as well. That is, there is an assumption that people the world over have not only the same preferred thermal state, but they also change their thermal assessments from acceptable to unacceptable at the same level of environmental stress, regardless of their differing thermal histories.

The universality of International Standard ISO 7730 is seemingly supported by the fact that it was approved by the member bodies of the following countries :

Australia	Germany, F.R.
Belgium	Hungary
China	Netherlands
Czechoslovakia	New Zealand
Denmark	South Africa
Egypt, Arab Rep.	Sweden
France	Switzerland

The only country whose member body expressed disapproval of the document

on technical grounds was the United Kingdom. It would seem from these data as if the notion of an international comfort standard has a widespread appeal notwithstanding the methodological weaknesses underpinning the "thermal constancy hypothesis".

The ASHRAE comfort standard 55-74 is probably the most widely cited authority by indoor climate practitioners. It is based on the exhaustive climate chamber research projects at Kansas State University (see Section 3.1) that sought to determine subjective sensations elicited by various combinations of the four key microclimatic variables of air and radiant temperatures, humidity and air velocity while holding clothing and activity levels constant. Just as the ISO 7730 standard is based on a mathematical model of comfort, so too is the ASHRAE modal comfort zone; namely the new Effective Temperature (ET*) and the associated Pierce 2 node model of thermoregulation. Since the ET* and its more generalised version, the Standard Effective Temperature (SET) are discussed in detail in Section 3.2.2, it is sufficient to describe it here as an index of the dry bulb temperature of a uniform enclosure at 50% RH in which humans would have the same net heat exchange by radiation, convection, and evaporation (that is, lie on loci of constant physiological strain) as they would in the varying conditions of the actual environment (ASHRAE, 1981a, p.8.18).

The ASHRAE comfort standard, like the ISO 7730 standard, reflects the underlying "constancy hypothesis" insofar as no seasonal or geographic differences in comfort response are recognised. The ability for people to adapt to climate is ignored by these standards and they are therefore faintly reminiscent of the climatic determinists who earlier this century first promulgated the idea of immutable climatic optima.

Unlike the original determinists, their latter day counterparts in the HVAC industry believe that no climate is uninhabitable or incapable of sustaining a "high level of civilisation", providing that sufficient energy is available for the production of artificial climates according to the specifications contained in the comfort standards.

1.3.4 User reactions to air conditioning and the "sick building" syndrome

Despite the efforts of the HVAC industry and other members of the design team to create the best possible indoor environment, very few of their buildings meet with complete approval from occupants. Indeed, concern about the ill-effects of air conditioning goes back to the very early stages of the industry , with the paper by Newton et al. (1938) on shock experiences of 275 workers after entering and leaving cooled and air-conditioned offices being an example. More recently, disquiet about the side-effects of the "perfect climate" has been demonstrated by the announcement from the National Secretary of Australia's largest white-collar union, the Administrative and Clerical Officers' Association (Munro, 1984, p.4) that:

> "One of the most common complaints voiced by office workers concerns inadequate ventilation and air conditioning systems. Many officers are too hot or too cold and draughty...An increasing number of complaints and enquiries from members about air conditioning led ACOA to commission the Queensland and New South Wales' Workers Health Centres to jointly prepare a comprehensive report on air conditioning."

Given the prevalence of air conditioning in modern architecture on the one hand, and the strong indications of discontent among its consumers on the other, it is surprising that so little systematic field research into occupant reactions has been conducted (Tromp, 1980, p.207).

One such study by Thorne and Purcell (1976) provided support for the climate monotony hypothesis (Gerlach, 1975) in air conditioning. In an earlier study, Black and Milroy (1966) investigated the factors which contributed to building occupant dissatisfaction in London during summer. By questionnairing the occupants of three types of air-conditioned office buildings and a fourth, non-air-conditioned building, the unexpected result that thermal comfort was greatest in the non-air-conditioned building was obtained. Even when respondents were asked for comfort assessments in very hot weather, the mean vote was no worse in the non-air-conditioned building than in two of the three air-conditioned buildings. Many of the air conditioning complaints in Black and Milroys' (1966) study related to the perceived inefficiency and variability in temperature control in the HVAC systems, even though the range of temperatures recorded was less than that in the non-air-conditioned building, suggesting that people were having an expectation of what air conditioning was supposed to be like and then evaluating the quality of an air-conditioned environment according to those expectations, rather than what pre-air conditioning buildings were like.

In an Australian study similar to Black and Milroys' (1966) London survey of air conditioning related attitudes, Wong (1967) noted that a majority of the air-conditioned building respondents in Sydney preferred working in such buildings while the opposite was the case for occupants of non-air-conditioned buildings, indicating the environmental expectations and preferences are closely related to the range of recent experiences (Wong, 1967).

The air-conditioned buildings produced by the integrated environment design approach since the 1970's often produced occupant complaints. These grievances, if not ignored, were usually dealt with by getting the services engineer to test the HVAC system for compliance with the relevant indoor climatic standards (McIntyre, 1984) such as ASHRAE Standard 62-73 (Standards for Natural and Mechanical Ventilation), the Nordic standard (Nordic Committee on Building Regulations, 1980) and the Standards Association of Australia's AS 1668 (Rules for the Use of Mechanical Ventilation and Air Conditioning in Buildings, Part 2 - Ventilation Requirements, 1980). More often than not, these tests indicated that the HVAC systems were supplying the required volume of ventilation air. According to Cain (1979a), air conditioning practice to date has been more than generous with the delivery of fresh air to occupants in America at least. Failing these obvious ventilation rate tests, the complaints in buildings are usually written off as vexatious trouble-making by occupants; in short, the work of malingerers. Nevertheless, widepread dissatisfaction in air-conditioned buildings usually persisted and the term "sick building syndrome" was coined (Stolwijk, 1984). At other times the set of unspecific symptoms and ill-defined malaise had been referred to as "tight" or "stuffy" building syndrome. The symptoms comprising the syndrome generally include those listed in Table 1.2.

Some cases of the "sick building" syndrome have been taken seriously and according to Stolwijk (1984), there has been as many as 500 epidemiological investigations of afflicted buildings in the U.S.A. and Western Europe. Traditional approaches of occupation hygiene have focused on specific air quality and indoor air pollution issues

TABLE 1.2 : Typical "sick building" symptoms

Mucous membrane irritation	Sore throat
Eye irritation	Shortness of breath
Headaches	Wheeze
Odour irritations	Lethargy/fatigue
Skin irritations	Abnormal taste
Cough	Dizziness
Sinus congestion	

(Compiled from Stolwijk, 1984; Waller, 1984; Pickering et al., 1984; Breysse, 1984)

associated with air conditioning such as those listed below (for more detail see Turiel, 1985):

1. Formaldehyde: This toxic gas is known to cause irritation to eyes, upper airways and sometimes skin (Andersen, 1979) and is an indoor pollution problem due to its extensive use in modern building materials (Cohn et al., 1984). Lower ventilation rates induce increased levels of formaldehyde.

2. Airborne allergens : These biological compounds provoke immunological hypersensitive reactions including an overproduction of antibodies which in turn can trigger the release of histamines in the blood (Lowenstein et al., 1979). The major allergic symptoms include a runny nose and itchy or watery eyes as experienced in hayfever and allergic rhinitis (Lowell, 1979; Mullarkey, 1979). The key sources of airborne allergens are pollen (infiltrating from outdoors), animal hair and dander, and complex house dust containing mites and other allergens, chilled water

mist (humidifier fever in HVAC buildings), fungi and moulds (Korsgaard, 1979; Lowenstein et al., 1979; Reed and Swanson, 1984).

3. Humidity: Atmospheric water vapour affects health insofar as moisture and mucous in the upper airways serves the function of removing dust and bacteria from inhaled air. Field studies and epidemiological research indicate that increasing humidity from the very low indoor levels common during the heating season can decrease the incidence of common colds and absenteeism (Green, 1974; 1979a; 1979b; 1984).

4. Tobacco smoke: Despite the growing concern in the last five years about the potential of passive smoking to cause lung cancer, the statistical evidence for this connection is ambivalent (White et al., 1980; Lebowitz, 1984). There is however ample evidence for the deleterious effects of passive smoking on the respiratory function of asthmatics (Dahms, et al., 1981). Also allergic and non-smoking subjects, when exposed to sidestream smoke, report greater incidence of eye irritation, nasal symptoms, cough, wheezing and sore throats (Speer,1968). Lundqvist (1979) has highlighted the need for enormous increases in ventilation rates if the difficulties of passive smoking are to be mitigated.

5. Air ionisation: The hypothesis that air conditioning depletes indoor air of negative ions has been popular since the 1950's. The positive ions are often claimed to foster bacteria growth and also to trigger the release of the neurohormone serotonin. The latter is thought to be related to fatigue, poor concentration, irritability and tension (Krueger, 1972). While there is a large volume of research supporting the ionisation hypothesis, much of it has been performed by manufacturers of negative ion generators, and therefore the weight of evidence is considered insufficient to justify the use of ionisers as a routine in air-conditioned buildings (McIntyre, 1980). Hawkins and Morris (1984) examined the possibility of negative ion generators in air-conditioned offices reducing the incidence of "sick building" complaints. Analysis of variance failed to reveal any statistically significant differences in either personal comfort or well-being ratings between the control and experimental field samples of building occupants.

6. Airborne infectious particles : The hypothesis that air conditioning can facilitate the transfer of infectious particles has gained acceptance in the last 30 years (La Force, 1984). The microorganism can come from the outside air via ventilation air intakes or, from human sources within the building. According to Lidwell (1979), the species of most medical significance are from human sources and are transferred as droplet nuclei in the range of 0.5

to 5 microns which enables them to remain airborne for long periods of time and also to penetrate deep into the respiratory system and thus increase probability of infection (Swift, 1979). It has been recognised that certain features of the air conditioning process are conducive to the proliferation of such infectious microorganisms and perhaps the most controversial example is Legionella pneumophilia (Legionnaire's Disease) which is ideally suited to the conditions found in humidifiers, water cooling towers and other wet processes in air conditioning. Perhaps more important in terms of numbers affected, are the diseases of influenza and the common cold. The rate of these cross-infections have been related to known exposures of office workers to known cases at work and the immunological status of the population (Lidwell et al., 1965), but is also presumably related to the fresh air ventilation rate per building occupant.

Despite the large number of studies into the aetiology of the "sick building" syndrome, reports of clear causes being identified (such as the six points listed above) are very rare in the literature. Consequently, reported cases of effective correction are even more rare (Stolwijk, 1984). Waller's (1984) case study in the U.K. is typical of most in that the traditional occupational hygiene approach of examining only physical and air quality factors was notably unsuccessful; "...It was found that pollutants, bacteria, a lack of fresh air or anything fundamentally wrong with the HVAC systems were unlikely to be a cause of

the complaints" (Waller, 1984, p.351). Nevertheless, the problem seems to be definitely related to air conditioning. For example, Pickering et al., (1984) found in their random samples of work forces in an air-conditioned building and a naturally ventilated building, large and statistically significant excesses of nasal symptoms, irritation of the eyes, dry throat, headache, lethargy and dry skin in the air-conditioned building.

If the role of specific physical factors in the aetiology of "sick building" syndrome seems only minor, attention must be turned to psychological aspects of air conditioning. Waller (1984) suggested that staff need the feeling that they can influence, if not control, their indoor environment. With the centralisation of this control in the hands of the building engineer in modern air-conditioned office blocks, it was suggested that a frustration manifests itself in unspecific complaints about indoor climate. Waller (1984) went on to report that many occupants of air-conditioned premises had unrealistically high expectations of the HVAC system (largely as a result of the HVAC industry's own marketing strategy), which, when not met, became a source of dissatisfaction. Also, the "zoo-keeper" approach discussed above rendered the indoor climate unpredictable for the occupants and this arbitrariness became a source of frustration rather than the physical characteristics of the indoor climate per se (Waller, 1984, p.351).

Other authors have also condemned the alienation of occupants from the control of their immediate environment (Hawkes, 1982; Cooper, 1982a; Baird et al., 1981; Carlton-Foss, 1982) and their concerns are illustrated by the way that any semblance of user-control over environmental systems such as a light switch usable in the "off" position

or better still, an openable window, have quickly become very sought after status symbols in the modern office building (Baird et al., 1981; Martin, 1974, p.7). Obviously the centralised control of indoor environments carries with it a necessity to control building occupants' behaviour also, in order to "...prevent stability and uniformity being disrupted by people seeking to alter environmental conditions to suit their own aspirations and expectations" (Cooper, 1982a, p.278). These psychological hypotheses about the "sick building" syndrome were echoed in Stolwijk's commentary on the topic (1984, p.26):

> "An important element in the occupant's perception of a building is the degree of control they feel they have. If the occupants do not have effective access to the actual controls for their space, then the only method open to them is to express dissatisfaction with the conditions to people they feel are or should have access to these controls...Almost universally, investigators who seriously analyze the conditions in a building find that the fact of a serious evaluation taking place is seen by the occupants as evidence of their having regained some measure of control over their space. Even if the investigation does not produce clear recommendations or objective improvements, there is a clear improvement in the subjective perception."

1.3.5 The energy shortage and air conditioning

The energy shortage of the mid 1970's brought with it some serious implications for the practice of air conditioning. Since most of the indoor climate research reviewed in preceding sections evolved in a period of abundant fossil fuels, the standards and HVAC practice that emerged in that period reflected an overriding concern with ideal or optimal indoor conditions. However, with the energy shortfall in 1974 came a shift in emphasis towards sub-optimal conditions that cost less energy to maintain. The indoor climate journals were flooded with articles about energy conservation and thermal comfort research started

using new focal terms such as "acceptability", "tolerance" and "dissatisfaction" as opposed to "comfortable" or "neutral" in the earlier research (Klassen, 1979). Much of the energy conservation-comfort literature is based on the mainstream "thermal constancy" hypothesis, but towards the end of the current section, mention will be made of a new direction in comfort research which emphasises the roles of attitudes, expectations and other intervening psychological variables in determining how energy conserving indoor climates are subjectively experienced.

In an air-conditioned building, each litre of outdoor air that is brought into the occupied space has to be conditioned by the HVAC system first. On the other hand, air that is recirculated from the occupied space has thermal and humidity characteristics closer to the system's design conditions, and therefore requires less conditioning than outdoor air. Consequently, it is obvious why so much attention has been given by the HVAC industry to the reduction of ventilation rates since the energy shortage of the mid 1970's. Cain (1979a) has emphasised the importance of the olfactory sense in detecting ventilation rates and this point has represented one of the major impediments to the successful implementation of energy conserving ventilation standards such as ASHRAE Standard 90-75 (Energy Conservation in New Building Design) and the Nordic Standard (1980). Apart from exacerbating the air quality problems enumerated above, reduced ventilation rates and the increased odour levels resulting would possibly increase the incidence of the "sick building" syndrome (Stolwijk, 1984; Fanger, 1981).

A useful comparison of the relative value of various onservation strategies for HVAC systems was provided by Fleming (1979). Using a building simulation program called the "ASHRAE Fundamental Office

Building" and exposing the model to a full year's climate simulation for Vallejo, California (Latitude 38N and Longitude 121), Fleming held constant all design and energy consumption characteristics with the following exceptions; ventilation rates, inside design temperature and allowance of an increased deadband temperature range in the HVAC thermostat. The annual savings of these conservation strategies suggested that the thermal comfort option of widening the deadband in the thermostat held most promise.

Various thermal models have been developed to predict or assess the degree of occupant acceptance of sub-optimal indoor climates (Rohles et al., 1975; Berglund and Gonzalez, 1978a; Fanger, 1970) with the Predicted Percent Dissatisfied (PPD) by Fanger being the most widely known technique. The latter model was an extension of the comfort equation and Predicted Mean Vote (PMV) models. Being based on steady-state exposures, the PPD model is perhaps most suited to predicting thermostat set-backs (in heating season) and set-forwards (in cooling season). According to the Fanger model, a shift in PMV from zero to ± 0.8 will increase the PPD from its minimum of 5% to 20%. Eighty percent occupant satisfaction seems to have become regarded as the outer limit in comfort recommendations (Berglund, 1979; Fanger, 1981; ASHRAE. 1981b).

Perhaps the most important thermal comfort option in energy conservation is the use of transient indoor climates. Allowing inside temperatures to drift passively with outside conditions and fluctuations in internal loads cannot only reduce energy consumption but also allows the conditioning load to be shifted into off-peak tariff periods (Berglund and Gonzalez, 1978a). In summer, a building could be

pre-cooled during the night with outside and refrigerated air, and then the indoor climate could be allowed to drift passively or, at least run with lowered refrigeration inputs during the day when the occupants were in the building. The suggestion of passive control during the period of occupancy indicates that the energy shortage may eventually re-emphasise the use of the building envelope's thermal mass and other architectural features to filter the external climate (Szokolay, 1980; Arnold, 1978).

Griffiths and McIntyres' (1974) laboratory study into occupant acceptance of controlled temperature ramps found a deadband of $\pm$2.25K either side of the optimum temperature to be satisfactory. This finding was well supported by Berglund (1978b; 1979; Berglund and Gonzalez, 1978b) who also found a deviation of $\pm$2.25K away from optimum to be acceptable to 80% of subjects. These findings tend to contradict the published standards on thermal comfort. The modal comfort envelope of ASHRAE 55-74 (Thermal Environmental Conditions for Human Occupancy) is only 3.5K wide for sedentary people at 50% humidity, 0.6 clo, air velocity at 0.13 m/s and Tmrt equal to Ta. Only in the most recent revision of ASHRAE's comfort standard (ASHRAE 55-81) is there a concession to energy conservation (Berglund, 1980). The new standard has two comfort envelopes; one for summer and one for winter. This seasonal differentiation is based on the belated recognition of the seasonal variations in clothing behaviour (Rohles, Konz and Munson, 1982). As usual, the 1981 revised standard denies the existence of acclimatisation, seasonal (other than clothing), sex, race or age differences in the recommended design conditions. The new standard permits temperature drifts and ramps but the permissable summer range of the comfort envelope at 50% RH is 22.8-26.1degC, which falls short of the 5K dead-band found

acceptable by Berglund (1978b; 1979; Berglund and Gonzalez, 1978b) under their experimentally induced transients.

The interest of ASHRAE in conserving energy by speci ication of summer and winter comfort envelopes was no doubt partly stimulated by the United States Federal Energy Administration's (FEA) guidelines of 1974, which sought to raise and lower desired working conditions by 3.3K in summer and winter respectively (Gagge, Nishi and Nevins, 1976). Using the Pierce 2 node model of thermoregulation, Gagge and Nevins (1975) predicted that optimal thermal comfort could still be maintained by following the FEA summer guidelines, but only if clothing insulation was reduced to 0.2 clo (according to Gagge, Burton and Bazett (1941), one unit of clo represents the amount of thermal insulation required to maintain a sedentary man indefinitely comfortable in an environment of 21degC and air motion at 0.1 m/s).

In a field study of a New York office building that had implemented FEA guidelines, only 50% of respondents had clo levels as low as 0.4, therefore the outer limit of the FEA summer guidelines (26.7degC) was responsible for considerable dissatisfaction among building occupants. Another major conclusion of the Gagge and Nevins field study of energy conservation practice was that an overwhelming majority (85%) of respondents stated their performance would be impaired by any change in temperature towards the outer limits of the FEA guidelines (1975, p.II-15). Elder and Tibbott (1981) also found a low degree of user-acceptance in their field study of an energy efficient office building. Reaction to the thermal environment was extremel negative, with levels of dissatisfaction at about 80% of surveyed occupants. Unfortunately, Elders and Tibbott didn't report any microclimatic

measurements, but they intimated that the FEA guidelines were implemented (1981, p.10).

In all of the thermal comfort-conservation research reviewed so far in the current section, the objective of thermal comfort is viewed as being contrary to that of energy conservation. This conflict strongly reflects the "thermal constancy" hypothesis which emphasises the body-environment heat-balance and minimising physiological effort in the maintenance of that balance. Recently there has been a small band of dissenting voices on this mechanistic view of thermal perception and energy conservation. For example, Cooper (1982b) asserted that there was nothing intrinsically problematical about combining the provision of acceptable indoor conditions with a minimised and regulated consumption of energy. Instead, the need for reconciliation between comfort and energy conservation arose from the narrow definitions employed for these two goals and also the methods employed by the HVAC industry to achieve them. Accordingly, much of the resistance shown by building occupants to energy conservation stems from the previous emphasis on "optimal" and constant indoor climates. These artificial conditions have come to be expected if not demanded as a basic right by modern building occupants. This is the old problem of unrealistically elevated expectations discussed in Section 1.3.3 in relation to the historical development of indoor climatic standards (see also Auliciems, 1981c).

Apart from expectations, Cooper (1982b, p.86) suggested other psychological dimensions to the comfort-conservation problem. In particular, most energy conserving HVAC systems centralise even more than their earlier counterparts the management of energy consumption. Building occupants lose all of their local control over thermal

conditions and as a result, become hostile to the "technical-fix" conservation strategy imposed upon them by the building services engineer. This psychological hypothesis of thermal acceptability provides support for the devolution of current environmental control practices from "exhaustive mode" (the zoo-keeper approach) to the "selective strategy" (Hawkes, 1982). In the latter scheme, more emphasis is placed on passive architectural control of the environment until weather conditions become so severe that mechanical controls are temporarily activated. Of course, in the less severe climates the selective control strategy of energy conservation merges smoothly into the completely passive design approach (Szokolay, 1980).

Carlton-Foss (1982) reiterated some of the elements of the above psychological hypothesis in his assertion that the trend towards centralised energy management and conservation strategies created a self-fulfilling prophecy; people are treated like a handicap to conservation and therefore are obliged to live up to the engineers' expectations of them. That author recommended that human and organisational factors in energy engineering become treated as essential components in conservation instead of "barriers to implementation" or nuisances. This approach translates into occupant participation and negotiation during the design and analysis of an energy program..."working with people's resistance can offer enormous benefits...the organisation that reduces ventilation and sets back thermostats need not run into a confrontation with its unions..." (Carlton-Foss, 1982, p.39). In short, if energy conservation is to meet broad acceptance, the old "zoo-keeper" approach to indoor climate control has to be abandoned.

CHAPTER TWO

PHYSIOLOGICAL CONTROLS

In human biometeorology, it is convenient to use the concepts of systems theory in organising responses to moderate levels of thermal stress (Wyon, 1970; Auliciems, 1981c). In a simplistic stimulus-response system, the environment presents varying doses of stress that elicit physiological strain. However, more sophisticated systems depict an hierarchy of responses that interact with each other and also integrate the human and environmental sub-systems into a self-regulating unit. The various levels in such an hierarchy consist of, in ascending order of complexity; 1) physiological (autonomic), 2)

psychological (perceptual), 3) behavioural and 4) cultural. Such a scheme provides a logical framework on which to base the literature review for the current chapter. The only deviation from this outline will be the omission of "cultural" adjustments as this has already been dealt with in the preceding chapter (particularly in relation to air conditioning). The chapter finishes with a discussion of two processes of long-term adaptation to the thermal environment; acclimatisation and habituation.

2.1 Autonomic Thermoregulation

The current section begins with an explanation of the body's thermal balance with its environment. Then, the body's physiological, or more accurately, autonomic thermoregulatory systems are described. In particular, the transducers or receptors, the system's integrator and finally, effector mechanisms are examined with an emphasis throughout on the control of the system. This approach highlights the concepts of "proportion control" and "adjustable set-point" which reappear later in the thesis when discussing behavioural and cultural dimensions of thermoregulation, as well as processes of adaptation.

2.1.1 Homeothermy

Homeothermic man has to maintain a constant internal body temperature of about 37degC, although a circadian rhythm has been confirmed between the temperatures of 36 and 38degC (Edholm, 1978). The maintenance of this relatively constant internal temperature is achieved by balancing bodily heat production with heat dissipation. Gagge (1936) first expressed this

concept in the widely known heat-balance equation:

$$M = -E \pm C \pm K \pm R$$

that indicates that heat produced by metabolism (M) is equal to heat loss by evaporation of sweat (E), convection (C), conduction (K) and radiation (R). In addition there has to be a term for bodily heat storage, negative or positive according to the heat gain or loss from peripheral body tissue without changing the core temperature. The maintenance of this heat-balance is accomplished by autonomic and behavioural thermoregulation.

Perhaps the most useful starting point for an explanation of the autonomic thermoregulatory system is the simple block diagram put forward by Stolwijk (1970) that depicts the controlling and controlled systems. The components of Figure 2.1 form the outline of the remainder of the current section.

2.1.2 Thermoreception and integration

Bligh and Johnson (1973, p.956) defined thermoreceptors as neuronal structures that were differentially sensitive to temperature and which responded to a maintained temperature with a characteristic, sustained impulse frequency. Research indicates that thermoreceptors are concentrated in three main sites (Hensel, 1970); 1) the skin, where they are known to be anatomically as well as physiologically separate structures for cold and warmth reception, 2) the pre-optic anterior hypothalamus in the brain where there is also a separation of warmth and cool sensing units, and 3) the spinal cord.

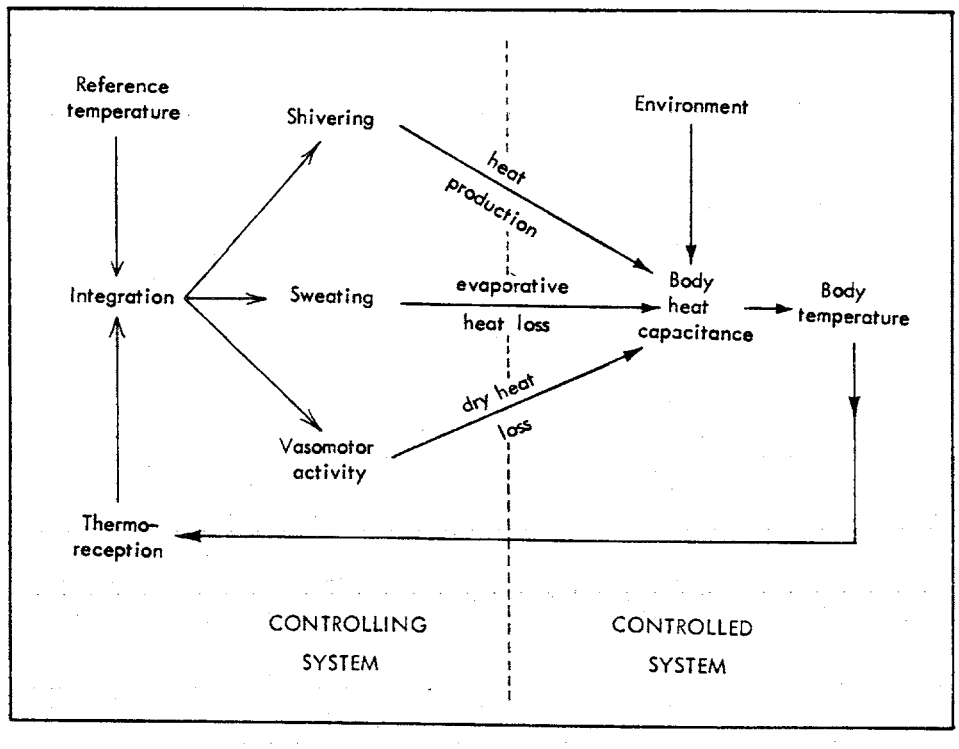


FIGURE 2.1 : Simplified diagram of autonomic thermoregulation. (Adapted from Stolwijk, 1970).
(—→) open arrowheads = information flows
(—→) filled arrowheads = heat flows.

Referring to the simple block diagram of thermoregulation in Figure 2.1, the thermal data transduced by the thermoreceptors are transmitted neurally to an integrator located in the hypothalamus, where they are compared with a reference temperature of the system. Hammel's (1968) comprehensive literature review of thermoregulation concluded that the temperature of the hypothalamus was the controlled or reference variable in the system. If the incoming thermoreceptor data are below the reference temperature, the magnitude of the negative error is encoded into efferent signals destined for the thermoeffector mechanisms such as shivering, which in turn raise the temperature, and reduce the negative error. Similarly, if the sensory inputs to the hypothalamic integrator are above the reference temperature, a positive error is transduced into

signals that activate the heat-loss effectors. It is in this sense that the hypothalamus has been likened to a thermostat (e.g. von Euler, 1962).

While the concept of a bodily "thermostat" has been useful in discussing thermoregulation, it would be more accurate to refer to the hypothalamus as a proportional controller of the type commonly discussed in control theory texts (Milhorn, 1966). However, an important difference is that the autonomic thermoregulator has adjustable set temperatures. It is necessary to differentiate at this stage the concept of the reference level at which the dependent variable is controlled, from the functional set temperatures, at which the various autonomic responses are initiated (Hammel, 1970).

The process by which the functional set temperatures are adjusted was clearly outlined by Hammel et al. (1963, p.1146). The set point for temperature regulation is; 1) decreased by a rising or elevated skin and extrahypothalamic core temperature (e.g. spinal), and 2) increased by a falling or lowered skin and extrahypothalamic core temperature. By these means, thermoregulation can be activated either by displacement of the hypothalamic temperature itself, as is the case under extreme thermal stress when the core temperature deviates from the norm, or by the displacement of the functional set temperatures resulting from cutaneous and extrahypothalamic core thermosensory data.

Apart from the authors already cited in the above description of the "proportional controller with adjustable set temperatures model, the concept also has support from Corbit (1970) and Hensel (1973). Recognition of the two inputs to the load error signal is also made in

the Pierce 2 node mathematical model of thermoregulation in which the driving function is a 1-to-9 weighted mean of skin and core temperatures (Nishi and Gagge, 1977).

2.1.3 Effector systems

The view of thermoregulatory control described above, has been largely derived from the application of control systems theory to the autonomic effector systems of sweating, vasomotion and shivering. The essence of this approach is the opening of feedback loops. In the thermophysiological context this means thermally stimulating the various receptor sites while monitoring the effector system's response magnitude (Brown and Brengelmann, 1970). The following review of the three main effector systems; sweating, vasomotion and shivering, will outline the "majority views" about their control. The main emphasis will be on the sweating system as it is the most relevant to subsequent discussions of heat acclimatisation (Section 2.3). However, the vasomotor and shivering effectors (subsuming all thermogenesis forms) are discussed as they further illustrate the application of modern control theory to physiological systems.

Sweat glands, which are innervated by the sudomotor nerves, have ducts from their location in the deep layers of the skin (dermis) to the skin surface. Sweat that is evaporated draws its latent heat of vaporisation, under most environmental conditions, from the body's peripheral tissue. Sweating is one of the most important avenues of bodily heat loss and constitutes the major part of the term "E" in Gagge's (1936) heat-balance equation, referred to earlier in the current section (Equation 2.1).

Benzinger (1970) has argued that the actuating signal for sweating was the temperature of blood flowing through the cranium, as transduced at the pre-optic anterior hypothalamus. At about 37.2degC in the cranium, Benzinger observed a sharp initiation of sweating and concluded that this temperature was the reference value of the human thermostat. Concomitant with this role of central thermosensors was Benzinger's (1979) denial of a long standing belief that sweating was elicited by warm reception at the skin. The only role of peripheral thermosensors in sweating was cold sensor inhibition of the response. Skin temperature input was simply to prevent the wasteful accumulation of unevaporated sweat on the skin (Benzinger, 1969).

A conflicting hypothesis concerning the role of skin temperature in the sweating response has been advanced by Bullard et al. (1970). One of their experiments consisted of maintaining the subject in ambient temperatures sufficient to induce sweating, and then applying more intense heat to a small area of the subject's left thigh whilst measuring the sweat rates of the locally heated area and also a control area on the subject's right thigh. The results showed that local heating of the skin increased the sweat rate, but the effect was extremely confined to the area being heated; the control right thigh showed no appreciable increase in sweat rate. Another similar experiment consisted of maintaining subjects in ambient temperatures of 25degC with no sweating and then applying localised heating to a small area of the left thigh whilst measuring sweat rates of the heated skin area and also a control area on the right thigh. The results showed that local skin heating produced no sweat under these conditions. Both these experiments' results suggested to Bullard et al. (1970) that the amount of

transmitter substance released at the neuro-glandular interface per unit of central neural drive for sweating, was a function of local skin temperature. The evidence presented, also suggested that the local skin temperature's influence on sweating rates was multiplicative with the central drive because when the centrally derived neural drive was zero, local heating of the skin failed to elicit a sweat response.

The same authors went further in contradicting the Benzinger hypothesis of central control of sweating by asserting that cutaneous thermoreceptors integrated their signals into the functional set temperature. One of the experiments used as evidence for this view of the sweat response consisted of occluding the subject's right arm with a sphygmamometer cuff while being seated in ambient temperatures between 36 and 40degC. Greater heat stress was applied to the arms, distal to the occlusion, whilst measuring sweat rates of the subject's thighs. Results showed an increased sweat response even though the only communication between the heated and measurement sites was neural (due to the occlusion). Bullard et al. (1970) concluded that the functional set point for sweating had changed rather than the gain constant or sensitivity of the thermoregulatory centres. Combining the local skin temperature effect and the neural influence of mean skin temperature on the functional set temperature, the following model of the sweat response was put forward (Bullard et al., 1970, p.606):

$$\text{sweat rate} = \alpha \{ T_{hy} - T_{set(sw)}[N] \} L \qquad (2.2)$$

where $T_{set(sw)}[N]$ is the intrinsic reference input as modified by the neural loop of mean skin temp.

T_{hy} is hypothalamic temperature
L is local skin temperature effect
α is gain sensitivity constant

The second effector mechanism by which the body removes or conserves heat is referred to as vasomotor action. The amount of blood flowing near the skin affects the amount of heat that is transported from the body core to the surface, where it is available for the evaporation of sweat, radiant conduction and convective heat transfers to the environment. The volume of peripheral blood is controlled by a thick muscular coating around arterioles. These muscles are innervated by sympathetic vasomotor nerves; an increase in sympathetic tone causes vasoconstriction and a reduction of skin blood flow, while a decrease in sympathetic tone causes vasodilation and an increase in skin blood flow. An indication of the power of this effector system is that radiant and convective heat losses by the body can be increased five to six times by vasomotor action (Edholm, 1978).

Less seems to known about the question of peripheral versus central control of the vasomotor system than the sweat response, but is seems likely that the spinal cord and hypothalamic thermosensors are involved (Simon, 1971). Like the sweating response, there is a local effect of temperature in vasomotor activity, with isolated and denervated limb areas still capable of eliciting the response (Hensel, 1973). One hypothesis accounting for this local effect is that the transmitter substances released into the neuro-muscular junction have and increasing constrictive effect on the vascular muscles with decreasing temperatures in the extremities (Keatinge, 1970). Another local temperature effect in the control of vasomotor response involves the release of cholinergic

bradykinin from the sweat glands. This active vasodilation occurs mainly in trunk and proximal limb areas which are also the areas of pronounced thermal sweating (Hensel, 1973).

The final thermoregulatory effector is thermogenesis or, as it is more commonly known, shivering (used here to subsume preliminary muscular tension). The basic feature of the response is the conversion of chemical energy very efficiently into heat by means of muscular contractions without much external work being done (Burton and Edholm, 1955). Shivering can increase body metabolism five times the basal rate (Edholm, 1978). The effector is represented in the bodily heat-balance (Equation 2.1) by "M".

As with the other thermoregulatory effector systems, there are conflicting hypotheses concerning the control of shivering. Benzinger's (1979) general argument for central warmth reception and peripheral cold reception depicts the cutaneous thermosensors as the critical stimulus for shivering. The central receptors' role in the system is described simply as warmth inhibition. That is, when the core temperature has risen above the set temperature, the neural drive for shivering is abolished by hypothalamic warmth receptors.

However, Benzinger's (1979) model seems to be contradicted by several items of experimental evidence. It has been observed that local cooling of the pre-optic anterior hypothalamus can activate cold sensitive structures which in turn elicit shivering, and also that destruction of those central cold sensors by lesions correlates with lower rates of oxygen consumption and therefore thermogenesis, between ambient temperatures of 19 and 27degC (Squires and Jacobson, 1968).

Furthermore, spinal cord thermoreceptors have also been demonstrated to increase shivering under conditions of local cooling (Thauer, 1970). Hammel (1968) interpreted the action of these thermosensors as affecting the functional set temperature of the shivering response in the hypothalamic integrator in the same way as cutaneous thermoreceptors were involved in the sweating system described earlier.

Evidence has also been presented for a local temperature effect (at the spinal cord level) on the shivering response (Pierau and Klussman, 1971). This local effect involves thermosensitive motor neurons increasing their excitability under local cooling. Therefore, the spinal cord is not only a site of thermosensitive structures that transmit to the posterior hypothalamus via ascending pathways but it also contains thermosensitive motor neurons that can reinforce the load-error drive for thermoregulation against cold.

It would be safe to say that no two reviewers of temperature regulation would draw the same schematic diagram to summarise their conclusions. The problem centres around the fact that the system in question is characterised by a multiplicity of inputs, outputs and feedbacks. Consequently, it is impossible to open one of the control loops without affecting one of the many others (Brown and Brengelmann, 1970). Nevertheless, the proportional control model, borrowed from engineering control theory and enhanced with the notion of adjustable functional set temperatures, does a reasonable job of accounting for the diverse experimental data. Figure 2.2 schematically presents the thermal and information flows discussed above. To summarise the diagram, both the core and peripheral temperatures are neurally transformed by warm and cold receptors in the spinal cord, hypothalamus and skin (T_{sc}, T_{hy} and

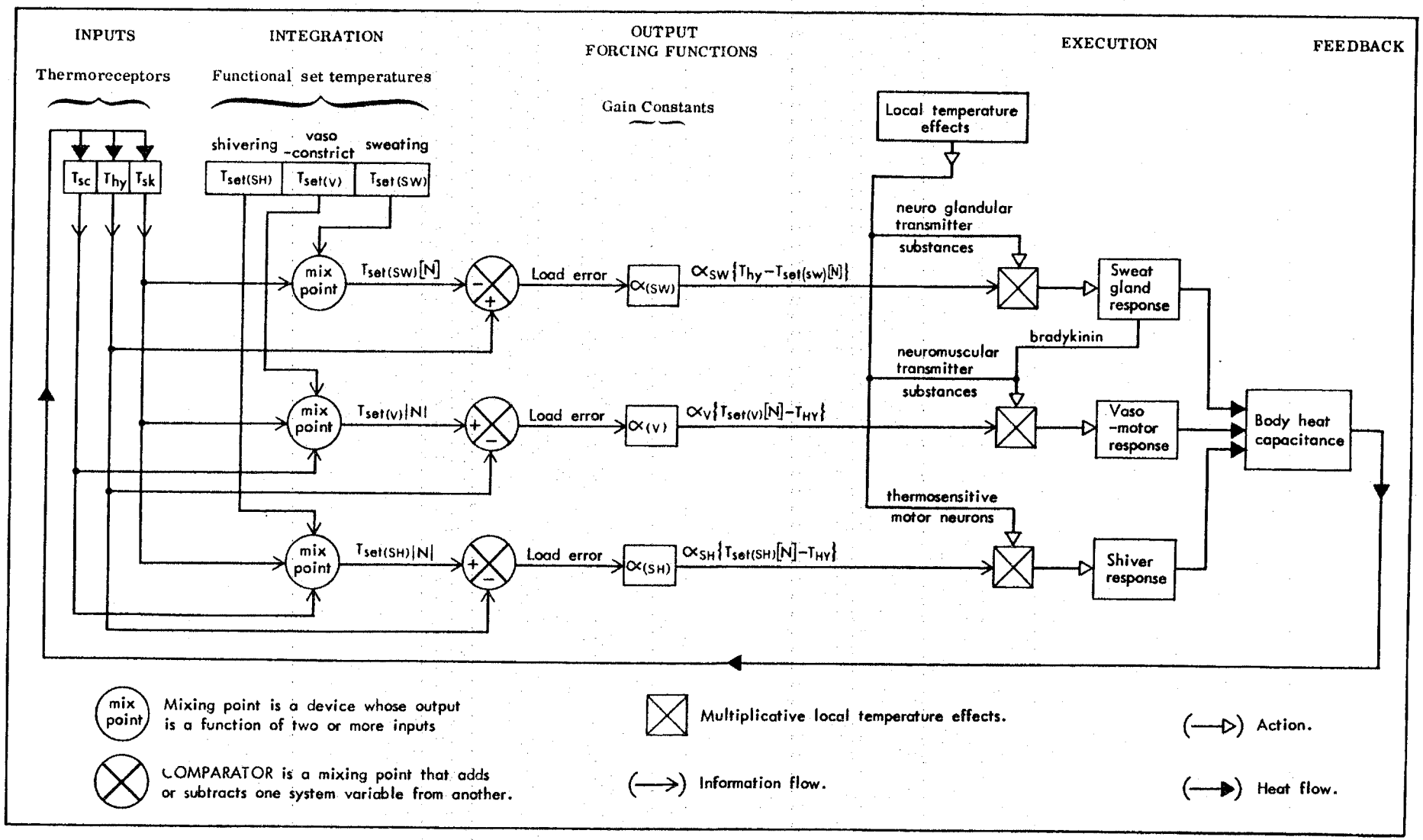


FIGURE 2.2: Conceptual representation of the autonomic thermoregulatory system with proportional controller and adjustable functional set points

T_{sk}). These data adjust the functional set temperatures in the first column of mixing points. The outputs of this interaction, $T_{set()}$ [N], are then compared with the value of the regulated variable, hypothalamic temperature. The load error or actuating signal resulting from this comparison is then attenuated or amplified by the gain sensitivity constant (α) for each effector system. The results are further modified by the various local temperature effects before the effector systems are activated. These effectors in turn exert their corrections on the heat content of the body, causing temperature feedback information for the thermoreceptors at the left-hand end of the system.

2.2 Physiological Correlates of Sensation, Comfort and Behavioural Thermoregulation

In most conceptual systems that have been used to hierarchically structure human thermal responses (e.g. Wyon, 1970; Auliciems, 1981c), psychological and behavioural processes have represented the next highest levels of integration after physiological response. In the psychological category, concepts such as acceptability and tolerance have recently been receiving attention (see Section 1.3), but by far the most important focal terms have been "thermal sensation" and "thermal comfort".

Despite the misgivings of some psychologists about the scientific utility of vague terms like "sensation" (Bevan, 1958, cited by Auliciems, 1981c, p.109), the term can best be defined as direct psychological response to simple physical stimulus (Schiffman, 1976; Helson, 1964; Rohles, 1974). The term "thermal comfort" has been much more contentious (McIntyre, 1978c; Auliciems, 1981c) but one definition enjoying wide

currency in the literature since the 1960's is "...that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 1981b, p.2). Clearly the latter definition falls into the category of "perception" rather than "sensation", insofar as meaning, experience, affect and judgement seem to be implicated (Schiff, 1971; Schiffman, 1976).

Putting these conscious psychological events into a broader biological context, it is generally agreed that they constitute the punitive drives or motivation for thermoregulatory behaviour (Hensel, 1973; McIlvaine Parsons, 1979; Cabanac, 1981; Benzinger, 1979; Gagge, Stolwijk and Hardy, 1967). While the autonomic thermoregulatory system can change the heat gains and losses of the body by making internal changes, thermoregulatory behaviour achieves the same goal by changing the environment itself or the posture of the body being presented to the environment. Thus, terms like "environmental selection" have been used in this context (Hammel, 1968). Other common classes of behavioural regulation include clothing adjustment, environmental adjustments such as climatically appropriate architecture and environmental controls such as heating, ventilation and air conditioning. The salient characteristic of these responses to the thermal environment is that the subject is consciously involved (with the possible exception of postural adjustment), whereas in the autonomic regulatory system, processes run automatically. The current section focuses on the literature dealing with the interactions between physiological, psychological and behavioural responses to the thermal environment.

2.2.1 Thermal sensation and comfort

The experiences of thermal sensation and thermal discomfort have for a long time been considered as two distinct phenomena (Winslow et al., 1937b; Hensel, 1979a; Cabanac, 1971). One can intuitively differentiate the two concepts because simple temperature sensations are verbally reported with statements such as, "It is hot", which are directed towards describing the external, objective environment. On the other hand, verbal reports of thermal comfort like, "I am hot" refer more to the subjective, emotional state of the observer.

The experimentally elicited thermal sensation reports of subjects exposed to various steady-state thermal environments have been shown to vary much more closely with environmental warmth than thermal comfort reports under the same steady-state exposures (Gagge et al., 1967). Stolwijk (1979) reported some experiments using transient instead of steady-state exposure of subjects and also found that temperature sensations were the most sensitive to environmental variation. This suggested that they were closely associated with cutaneous thermoreceptors. In contrast, the comfort experiences were much slower in response to transient exposures, suggesting a dependence on total body heat.

Of the various hypotheses justifying the existence of two discrete classes of thermal experience (Cabanac, 1971; 1981; Hensel, 1973), perhaps the most convincing was Hensel's (1973). Sensation, being more directly determined by environment than is the case for discomfort, is therefore a more reliable data source upon which people can make predictions about exposure to thermal environments. Discomfort is inappropriate for prediction because it depends on the lagged response of

internal body temperature.

The question of which physiological variables control the magnitude of conscious discomfort has been the subject of considerable research effort with often conflicting results. The reason for the focus on control relates to its direct application in mathematical models of comfort (see Section 3.2) which have become widely used by the heating, ventilating and air conditioning industries. The starting point was the work of Houghten and Yaglou (1923a) who studied the effect of combinations of ambient temperatures (dry-bulb) and relative humidity (wet-bulb) producing feelings of "equal warmth" which they equated with feelings of "equal comfort" (or discomfort). By correlating various physiological strains such as pulse-rate, sweat loss and body temperature fluctuations with their "effective temperature" index, they concluded that lines of equal comfort on the psychrometric chart were also lines of equal physiological change. By extension, Houghton and Yaglou (1923a) claimed that the line of maximum comfort was associated with minimum physiological strain within the central range.

Similar to the conclusions of Houghton and Yaglou were those of Winslow, Herrington and Gagge (1937b) who found that almost any level of involuntary autonomic thermoregulation led to reports of thermal discomfort. The implication here was that physiological strain caused the discomfort. More recently, Benzinger (1970; 1979) has taken a different line by saying that, while psychological phenomena such as discomfort are correlated with the physiological responses, this relationship exists because both are stimulated by the same neural drive. For example, the long recognised relationship between sweating and the experience of heat discomfort is not a direct causal one as suggested by

Winslow et al. (1937b), but both are caused by a rising internal temperature as received by the hypothalamic thermosensors (Benzinger, 1979). In relation to cold discomfort, Benzinger attributed causation to falling skin temperature which was also the cause of the thermoregulatory physiological responses to cold, such as shivering (Benzinger, 1970; 1979). The relationships between autonomic and behavioural thermoregulation as outlined by Benzinger could be summarised as a dual system operating in parallel with the same inputs, as depicted in Figure 2.3.

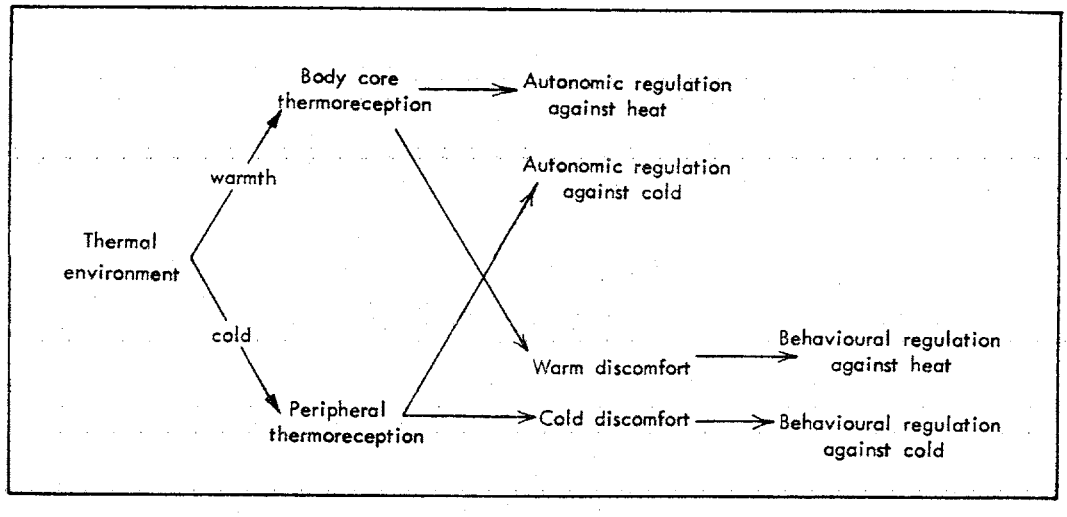


FIGURE 2.3 : The parallel model of thermoregulation.
(⟶) open arrowheads = information flows
(⟶) filled arrowheads = heat flows.

In summarising the findings of the Pierce Laboratory researchers in discomfort, Stolwijk (1979) put forward a different interpretation of the issue of control to that advanced by Benzinger (1979). For warmth discomfort, their hypothesis is closer to the older Winslow et al. (1937b) scheme insofar as the effector action of sweating, or at least the skin wettedness resulting from that action, is considered causal. However, for cold discomfort the Pierce two-node model comes closer to

Benzinger by claiming that it is the drop in skin temperature rather than the physiological act of vasoconstriction that causes discomfort (see Section 3.2.2 for a detailed discussion of the Pierce model).

Considering this diversity of opinion, the statement by Hammel (1968, p.653) that "...it is not clear whether comfort is to be attributed directly to an integration of body temperatures or to activation of physiological thermoregulatory responses and thereby indirectly to an integration of body temperatures," still holds true. Hardy et al. (1971; Hardy, 1970) adopted an eclectic solution to the problem of control by suggesting that the physiological correlate of thermal discomfort was a composite of:

1. The signals evoking temperature sensations,

2. The signals for thermoregulation (autonomic load error signals), and

3. The sensations arising from the autonomic thermoregulatory activities of vasomotor control of peripheral blood flow, sweating and shivering. This last group of signals are considered as being largely evoked from various mechanoreceptors and pain fibres.

These multiple inputs to the thermal sense are depicted in Figure 2.4 which bears a close similarity to the model put forward by Hensel (1979b, p.3).

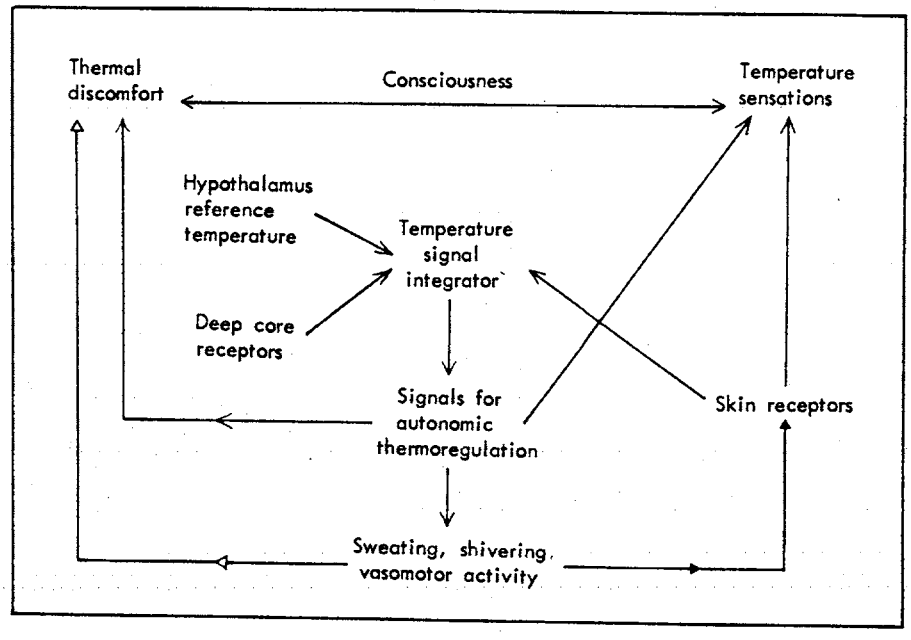


FIGURE 2.4 : Thermal sensations and comfort with multiple inputs. Arrowheads indicate the nature of interactions;
(—>) open = information flow
(—▷) closed = action
(—▶) filled = heat flow
(Adapted from Hardy et al., 1971).

2.2.2 Overt behavioural reponses

Corbit (1970) has cogently argued the need to distinguish verbal reports from bodily behaviour in the thermal comfort context. If conscious experiences of sensation and discomfort are indeed mediating variables between thermal environment and bodily behaviour, there should exist close correlation between these last two. Corbit (1970) advocated the use of operant or instrumental conditioning methodology to discern the relationship between thermal environment and behaviour. The suggestion has been adopted in studies of rats, mice, sheep, monkeys, dogs and cats, but as pointed out by McIlvaine Parsons (1979), very little work has been done with human subjects, with the exception of a study by Paul et al. (1962).

What has emerged from the animal studies is that a proportional control model, as discussed in autonomic regulation (Section 2.1), can be applied to the behavioural aspect of the topic as well (Corbit, 1970). That is, the amplitude or frequency of behavioural responses to thermal stimuli are a function of the error between various thermosensory inputs and a functional set point, in accordance with the concept of "alliesthesia" referred to by Cabanac (1971; 1981). The implication of this hypothesis is that the load error signal for behavioural regulation is mediated by a proportional magnitude or intensity of conscious discomfort.

Another parallel between the autonomic and behavioural proportional control hypotheses is that the latter also includes adjustable set temperatures, which are inversely related to skin temperature (Carlisle, 1968a), thus enabling behavioural regulation to be triggered by a quickly responding skin temperature displacement or the lagged response of internal temperature to thermal environmental perturbations. Relating these observations to the earlier discussion of the two distinct psychological responses to thermal stress; temperature sensations and thermal discomfort; thermal sensation can provide objective data about the environment very quickly by virtue of its association with peripheral thermosensors. These data can then be used as an early warning of the biological significance of a particular environment and a behavioural response can be elicited by rapid adjustment of the set point. However, thermal discomfort appears to be more related to slower responding internal heat content, or the complex signals both causing and resulting from autonomic regulation.

2.3 Processes of Long-Term Adaptation to the Thermal Environment

The various topics reviewed in the current and preceding chapters indicate the plethora of homeostatic processes involved in the relationship between human beings and their thermal environment. In the short-term range of adaptations there are complex physiological responses to changing body temperatures. Beyond these are the behavioural adaptations as mediated by psychological processes of sensation, comfort and preference. These are, in the longer time scale, conditioned by tradition and resource factors, giving rise to the "techno-cultural adjustments" discussed by Auliciems (1981c). However, at the level of the individual, there are several long-term adaptations to climate that have not yet been discussed. The current section will focus the literature on two of these; habituation and acclimatisation.

The two terms have been used in a variety of contexts (Burton and Edholm, 1955, Ch.10), and some definitions are therefore required before proceeding. Referring to the International Union of Physiological Sciences' glossary of terms for thermal physiology (Bligh and Johnson, 1973), habituation is defined as the reduction in the perception of repeated stimulation. This closely coincides with Goldsmith's (1974) use of the term to denote the altered perception of and reaction to sensory information. Hereafter the term will be confined to the altered perception of bodily states such as the level of sweating, skin or deep body temperatures. Acclimatisation on the other hand is defined as the physiological changes, occurring within the lifetime of an individual, which reduce the strain caused by stressful changes in the thermal environment (Bligh and Johnson, 1973, p.942). Some writers have used the term to refer to changes induced by the natural climate (outdoors) thus

necessitating another term, acclimation, to denote changes resulting from experimentally induced climatic stress. However, because it is unclear whether indoor climates can be classed as "natural" and also that there appears to be widespread consensus on the lack of any physiological difference between acclimation and acclimatisation, the current thesis will use only the latter term.

2.3.1 Acclimatisation

By far the most thoroughly researched long-term adaptation to the thermal environment is acclimatisation. The bulk of research focuses on the physiological changes that characterise the process and these will be briefly reviewed within the framework laid down in Section 2.1. on the autonomic thermoregulatory system. Much less attention has been given to the concomitant amelioration of thermal discomfort perceptions, but what has been published in this area will also be reviewed.

Physiological acclimatisation to heat can be seen as facilitating homeothermy under conditions that place a greater than usual load on the thermoregulatory system. The usual research strategy has been to mimic naturally occurring hot climates in the laboratory and then study the course of key physiological parameters such as heart rate, skin blood flow, various body and skin temperatures and sweat rates of a group of subjects who are confronted with a regimen of work loads in heat. The studies are conducted on a number of consecutive days and the differences observed between the physiological responses on the first and last exposure are attributed to the process of acclimatisation (e.g. Bean and Eichna, 1943; Eichna et al., 1950; Wyndham, 1965; Nadel et al., 1974; Hellon et al., 1956). The main findings of these "work-in-heat" studies

are; 1) that an acclimatised person works in heat with a lower heart rate than the unacclimatised counterpart, 2) blood pressure is more stable, 3) peripheral and body core temperatures are reduced, and finally, 4) there is a quicker onset and greater production of sweat.

It has been reported that experimentally induced heat acclimatisation produces a small decrease in the level at which internal body temperature is regulated, when the measurements are made on subjects who are sedentary and living in a thermally comfortable environment (Fox et al., 1965; Fox, 1974). This observation taken alone is counterintuitive in that it implies there is a greater amount of thermoregulatory effort involved in maintaining homeothermy after acclimatisation than before. However, one likely explanation is the lowered basal metabolic rate (BMR) reported by MacGregor and Loh (1941), who found that Europeans living in the tropics had BMR reduced by up to six percent. Another feature of heat acclimatisation is a blood volume expansion (Fox, 1965), which would ameliorate the cardiovascular strain of maintaining high volumes of peripheral blood flow in heat.

The aquisition of these adaptations to heat begins on the first day of exposure and progresses rapidly to full development by the third or fourth day in the work-in-heat studies according to Bean and Eichna (1943), with the best results being achieved by graded, progressively increasing work in the heat. However, the same authors reported that resting subjects who were exposed to a temperature of 49degC and about 15% relative humidity for three to four days also showed definite, but only partial acclimatisation. Wyndham (1970) reported that subjects naturally acquired partial acclimatisation during the normal course of seasons in South Africa, but the work-in-heat regimen described above

greatly enhanced the physiological adaptation. Ladell (1957) arrived at the same conclusion about naturally occurring and experimentally induced acclimatisation, and referred to the latter as "hyperacclimatisation". Therefore, it would seem reasonable to expect residents of hot climates who worked or recreated vigorously and regularly in the heat would show physiological responses approaching the state of hyperacclimatisation.

Fox (1974) and his associates devised an alternative to the work-in-heat method of inducing acclimatisation. Known as "passive" or "controlled" hyperthermia, the technique is based on carefully elevating the core temperature of sedentary subjects. Being passive, the research technique didn't have the confounding locomotor and cardiovascular effects of muscular stress as in traditional studies. The classical post-acclimatisation changes were observed after a couple of days, including lower body temperatures and heart rate, along with higher sweat production. However, the reduction in heart rate was less pronounced than in the work-in-heat studies and this led Fox (1965) to conclude that physical training in those studies was more important to cardiovascular efficiency than was acclimatisation. Henane and Bittel (1975) have also used the controlled hyperthermia method to induce the classical characteristics of heat acclimatisation.

The influence of race on the acclimatisation process has been extensively researched (Baker, 1958). Wyndham (1965, 1970) has investigated the tolerance of different ethnic groups for high levels of heat stress encountered in South African underground gold mines. The responses to a work-in-heat regimen of white Johannesburg caucasians, Bantu tribesmen and Kalahari Bushmen were reported both before and after laboratory acclimatisation. Wyndham found that men of African origin had

an advantage over Johannesburg caucasians during work in the heat. However, these differences disappeared after laboratory acclimatisation, leading him to conclude that the climatic experience of people was a more important factor than any morphological or genetic difference in explaining variations in tolerance of heat stress (Wyndham, 1970). Discussing these results in the wider context of the difficulties encountered by whites in the tropics, Wyndham indirectly supports Cilento (1925) and Sargent (1963), who claimed that the real danger came from a failure to fully acclimatise as well as various social problems rather than the climate per se (see Section 1.1).

Most of the traditional acclimatisation research has focused on adaptation to dry heat stress of the kind encountered in desert climates. However, hot-humid acclimatisation has also been investigated (Fox, 1965; Gonzalez et al., 1974) and the results suggest that homeothermy is facilitated by physiological adaptations different to those involved in hot-dry acclimatisation. In particular, the increased sweating capacity observed in the hot-dry situation seems to be less important in the humid condition due to the reduced evaporative potential of the environment. Thus, while sweat secretion in the humid acclimatised subject is initiated at a core temperature lower than that for the unacclimatised subjects (Gonzalez et al., 1974), the short fall in body heat dissipation in the humid condition appears to be taken up by an increased peripheral blood supply (Fox et al., 1963). This in turn increases skin temperatures and therefore dry heat losses to the environment. This finding is contrary to the reduced skin temperatures reported in the dry-heat acclimatisation studies (e.g. Hellon et al., 1956).

To more completely interpret the complex picture emerging in the preceding paragraphs it is necessary to place acclimatisation in the context of the body heat-balance equation and also the autonomic controller of that balanced system as discussed in Section 2.1. In dry-heat acclimatisation, the key change appears to be the enhanced sweating response. This enhancement is effected at both the central controller level where the onset of sweating occurs at a lower internal temperature, thus suggesting a reduction in the functional set point for the sweat response (Nadel et al., 1974; Henane and Velatx, 1973). Further, at the peripheral level of the system, there appears to be an increased sensitivity of the sweat glands to the central neural drive (Fox, 1965), indicating an increased gain constant in the system. The changes in mean skin temperature and peripheral blood supply, as controlled by the vasomotor thermoeffector, also undergo set point reductions during humid-heat acclimatisation (Fox et al., 1963).

However, the concept of thermal balance has two aspects when discussing core-periphery blood distributions and environmental heat exchanges. On the initial exposure to heat there is an increase in peripheral tissue heat content and temperature, thus decreasing the body-environment temperature gradient which in turn reduces dry heat gains from the environment. A negative effect is that the thermal gradient between body core and periphery is also reduced, therefore a greater demand is placed on the volume of peripheral blood flow to transport heat to the skin for evaporative loss. This reduces the volume of blood available for the other functions of the body and the classical symptoms of hyperthermia become manifest; namely high body temperatures and cardiovascular dysfunction. The enhanced sweat rates that accompany

acclimatisation have the effect of dissipating peripheral heat content and reducing skin temperature which in turn increases the body-environment temperature gradient and therefore dry-heat gains by the body also. This is compensated for by the increased core-periphery temperature gradient which allows a smaller volume of peripheral blood to dissipate the same amount of heat as in the unacclimatised state, thus reducing cardiovascular strain. The peripheral tissue temperature is set by acclimatisation at a level that permits thermal equilibrium between the environment and the body on the one hand, while still allowing sufficient heat transfer from core to periphery on the other. This double balance is accomplished without overtaxing blood circulation and the principle adaptation that allows these changes is an increase in sweat production (Eichna et al., 1950).

Very little research has been done on the effects of heat acclimatisation on thermal comfort responses. Avoidance of the extreme symptoms of heat exhaustion obviously means a lessening of discomfort after acclimatisation in the work-in-heat studies. However, little is known about the implications for thermal discomfort in moderate heat stress situations. Intuitively, one would expect acclimatisation to bring with it an increased subjective tolerance of thermal stress and this hypothesis has some support from the five-point summary of the physiological correlates of thermal comfort in Section 2.2. Accepting that there are three key inputs to the thermal discomfort subsystem; 1) data from peripheral thermoreceptors (skin temperature), 2) the integrated load error signals driving the autonomic effectors, and 3) the perception of those effector systems in action, then the effects of acclimatisation to heat on the first two of these suggests a diminution

of post-acclimatisation discomfort. However, the third input to the comfort subsystem, conscious awareness of effector mechanism action, would probably make the subjective discomfort of heat stress after acclimatisation actually worse than before it. The reason being that a lowered set point and increased gain constant in the sweat effector system means that after acclimatisation, sweating begins earlier and is produced in greater quantities in response to a given thermal load. Whether this third factor outweighs the first two subjective benefits of heat acclimatisation is uncertain on the basis of the currently available research.

McIntyre and Gonzalez (1976; Gonzalez, 1979) were given the opportunity to study the role of natural acclimatisation in determining the acceptability of moderate heat stress by a fortuitous five day heat wave in New Haven, Connecticut. The study was conducted on 20 young males in early June and then replicated in August, after the heat wave brought maximum temperatures between 32 and 37degC and relative humidities between 88 and 90%. The actual experimental procedure was not designed to induce acclimatisation through work or environmentally imposed heat loads, therefore any differences observed in the subjective responses between the two test periods could be attributed to the hypothesised natural heat acclimatisation. Along with various subjective data on temperature preferences, thermal discomfort and sensation, the experimenters collected physiological data on mean skin, oesophagal and oral temperatures as well as skin wettedness resulting from regulatory sweating.

In general, for the resting subjects, there were no statistically significant differences in the affective responses recorded before and after the heat wave. However, in the light exercise condition (116 W/m^2), there was an increase in preferred temperature (as measured by a rating scale) after the heat wave. The physiological data showed some features of the acclimatisation pattern, with lower body temperatures and increased skin wettedness caused by a lowering of the functional set point for sweating onset. These findings led Gonzalez (1979) into a discussion of the potential to use the body's power of acclimatisation to conserve energy in the built environment by letting indoor temperatures rise during the summer months. Although not specifically pointed out, the degree of heat acclimatisation induced by the five day heat wave in New Haven may have only been partial. A more intensive and extended exposure to heat, as encountered passively in tropical climates or induced actively through a work-in-heat regimen, could have ameliorated the subjective responses of sedentary subjects as well as the light exercisers'.

2.3.2 Habituation

The underlying concept of habituation, if not the term itself, has been around for quite some time. Indeed, Hippocrates in his 50th aphorism stated; "Those things which one has been accustomed to for a long time, although worse than things which one is not accustomed to, usually give less disturbance" (cited in Glaser, 1966, p.2). MacFarlane (1962) reviewed some early writers on the subject, beginning with Charles Darwin's anecdote about a Tierra del Fuego Indian who stood unconcerned in driving sleet which fell and thawed on her bare skin. Australian aborigines were noted to be able to sleep quite undisturbed by a night

heat which European sojourners found intolerable (MacFarlane, 1962). Eskimoes and Arctic fishermen are apparently indifferent to the cold sensations arising from manipulating their nets without gloves at zero temperatures, and naked aborigines were reported to be able to sleep through extremely cold nights or even frost temperatures oblivious of the violent shivering that was necessary to maintain homeothermy (Scholander et al., 1958; Goldsmith, 1974). Whether there was an actual diminution of discomfort in these cases is debatable, but habituation is one reasonable hypothesis.

Much of the laboratory research into habituation seems to have been done by Glaser and associates (Glaser and Newling, 1957; Glaser et al., 1959; Glaser, 1966). The key conclusion that has emerged is that habituation necessitates the storage of information because it is essentially a latent effect of stimulation that is capable of persisting even after the stimulation has ceased (Glaser, 1966). Much of the experimental evidence to support this conclusion was derived from thermoregulatory studies. Glaser (1966, p.34) described the typical study as being based on immersion of the subjects hand in 4degC water whilst monitoring subjective reports of discomfort and various physiological responses. The stimulus is administered 6 to 10 times, for every second minute period. The subject used their other hand as a control. The general finding was that subjective discomfort during immersions diminished in the hand that was repeatedly immersed, but not in the hand which was only immersed once at the beginning and once at the end of the experiment. The experimental design usually followed this sequence of immersions with a rest period of up to one hour in which both hands are kept in 33.5degC water. Then the same procedure of cold water

immersions was repeated and the degree of discomfort was still less in the hand that had been habituated over an hour before. Glaser (1966) reported similar results from habituation studies using hot water as the stimulus.

Habituation to localised heating and cooling is interesting in the laboratory setting, but to be relevant to a discussion of indoor climate, the process would have to apply to the whole body. One piece of laboratory evidence at this level was furnished by Gonzalez (1979). The study was discussed in the preceding section in the context of natural acclimatisation after a heat wave. Despite the observed increase in sweat production, the subjects, using a rating scale, reported that they were sweating less after the heat-wave than before. Although Gonzalez (1979) didn't discuss this finding in terms of habituation, it seems reasonable to hypothesise that repeated exposure to high levels of sweating during the heat wave induced naturally an habituation to the stimulation from that physiological response. As the sense of sweating constituted one of the three classes of input to the discomfort subsystem discussed in Section 2.2.1, this form of habituation becomes very significant in discussing acceptability of moderate heat stress.

Finally, to put the phenomenon of habituation into the broader context of thermoregulatory cybernetics, it seems to be a mechanism by which the set points of the thermal discomfort and behavioural response subsystems could be adjusted. Although there is a conflict in the literature over the possibility of thermal experience affecting the level of subjective response to a given physiological state, the concept of adjustable set points provides a new interpretation of thermal comfort data that have been generated in field studies (Section 3.2).

CHAPTER THREE

METHODOLOGIES AND MODELS IN APPLIED RESEARCH

This chapter briefly reviews the vast literature dealing with practical aspects of indoor thermal climate. The first section on climate chamber studies of comfort dichotomises the research into; 1) studies using rating scales for subjective assessments, and 2) studies using the more direct method of letting climate chamber occupants select their own preferred temperature. The aim of both approaches has been to fit mathematical models that describe the transformation of environmental stress into psychological strains. These indices or models are reviewed in the second section of the chapter, with particular attention being

given to Fanger's (1970) models and the Standard Effective Temperature index (SET), as these are both used later in the current investigation. Chamber studies and the models derived from them qualify for the title "applied" insofar as they have been used extensively in the formulation of indoor climatic standards for the HVAC industry (of the type already discussed in Section 1.3.3).

The main alternative research approach to the climate chamber is that of the field study. Many of the methodological characteristics of these studies are shared with environmental psychology, with the most important being the use of large and representative samples of people in "real-world" environments. What is lost in terms of internal validity by venturing outside the laboratory is compensated by enhanced external validity. Taken collectively, the large number of field studies that have been conducted in the last 50 or so years constitute a compelling argument for the influence of various adaptational processes (as discussed in Section 2.3) in thermal perception.

The final section of the chapter notes the inconsistencies between the data resulting from these two approaches and the various attempts that have been made at reconciling them are reviewed.

3.1 Climate Chamber Studies of Thermal Comfort

Both of the experimental approaches to thermal comfort share in common the fundamental perspective of psychophysics (see Appendix A). Essentially, this consists of isolating a group of people in a laboratory setting and excluding all potential influences on the dependent variable

except the stimulus under investigation. By randomly presenting various intensities of physical stimulation, statistical relationships between stimulus and response can be established. This reductionist perspective (McIntyre, 1982) has the main advantage of a high level of internal validity; confidence that variations in the presumed effect were caused by the variations in stimulus intensity (Campbell and Stanley, 1966; Cook and Campbell, 1979).

As a means of investigating the quantitative relationships between thermal stimuli and psychological responses, the climate chamber has been an invaluable tool. The major methodological departure from psychophysics laboratories is that the thermal sense reacts to a very complex interaction between whole-body and environment (as discussed in Chapter 2), instead of a convenient unidimensional stimulus as typically employed in psychophysics. As a result of this inherent complexity, climate chambers such as ASHRAE's at Kansas State University (KSU), the ASHRAE chamber at Cleveland, the Laboratory of Heating and Air Conditioning at the Technical University of Denmark, the Electricity Council Research Centre, Capenhurst-Chester U.K. and the J.B.Pierce Laboratory at Yale University in Connecticut, all have the capability of accurately maintaining constant air temperatures, humidities, mean radiant temperatures and air velocities. The more sophisticated units have the capacity for studying human responses to rapidly changing conditions of temperature and humidity so they are able to simulate temperature ramps or drifts as practised in energy conserving building management. Thermal asymmetries can also be simulated in the more sophisticated laboratories and can be used in the study of radiant or convective drafts, heated flooring and various other non-uniform

environments (Kjerulf-Jensen et al., 1975).

The academic backgrounds of the researchers undertaking climate chamber studies would range from psychology, through physiology to engineering with the latter group probably constituting the major share. The reasons for this interest by environmental engineers were succinctly articulated by Fanger (1973d, p.3):

> "Wherever artificial climates are for human occupation, the main purpose of the heating and air conditioning system is to create thermal comfort for man. Thermal comfort is the commodity being produced and the product being sold by the heating and air conditioning industry."

Little wonder that this industry has for a long time been interested in research and the identification of the "commodity" it desires to produce. Consequently, it has been organisations like the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) that have dominated the climate chamber research.

3.1.1 Chamber studies using rating scales

The major rating scales employed in these studies are included in Table 3.1. Scale A was used extensively in the earlier chamber work (e.g. Koch et al., 1960a, p.271; Nevins et al., 1966, p.286) but following the frequent criticism of the word "comfortable" as the central adjective (see for example, Marks, 1968, p.IV 1.4), the scale was slightly modified to become B in Table 3.1. This change was found by McNall et al. (1967, p.I.3.11) to have an insignificant effect on the way subjects distributed their votes when exposed to a given set of thermal conditions. Because it became the most widely used scale in the laboratory work of ASHRAE, the scale has long since been named after that organisation. Despite the

TABLE 3.1 : Rating scales and associated numerical coding commonly used in comfort research

A	B "ASHRAE"	C	D	E "Bedford"
+3 Hot	+3 Hot	+4 Very Hot	1 Comfortable	+3 Much Too Warm
+2 Warm	+2 Warm	+3 Hot	2 Slightly Uncomfortable	+2 Too Warm
+1 Slightly Warm	+1 Slightly Warm	+2 Warm	3 Uncomfortable	+1 Comfortably Warm
0 Comfortable	0 Neutral	+1 Slightly Warm	4 Very Uncomfortable	0 Comfortable
-1 Slightly Cool	-1 Slightly Cool	0 Neutral		-1 Comfortably Cool
-2 Cool	-2 Cool	-1 Slightly Cool		-2 Too Cool
-3 Cold	-3 Cold	-2 Cool		-3 Much Too Cool
		-3 Cold		
		-4 Very Cold		

plea from Rohles (1970, p.105) to expand the seven-point ASHRAE scale to nine points so as to counteract the tendency for subjects to avoid the use of the end categories of such scales (scale C in Table 3.1), the ASHRAE scale of thermal sensation still has wide acceptance among researchers who often supplement it in their questionnaires with a separate four-point scale of thermal affect (comfort) as depicted in column D of Table 3.1 (e.g. Rohles et al., 1977, p.78).

The typical research design of these chamber studies consists of paying a group of college students to participate by wearing a standard clothing ensemble and being exposed to a set of carefully measured environmental parameters for a duration of usually three hours (Rohles, 1974). Subjects are required to be seated quietly or engaged in sedentary activities unless the effects of metabolic rate are being directly investigated (e.g. McNall et al., 1967). Even though some of these studies have involved as many as 1600 subjects, exposed in groups of ten to 160 different combinations of air temperature and humidity (Rohles and Nevins, 1971), it has been pointed out by several critics that the major flaw in the research design of chamber studies is their

restricted external validity (Auliciems, 1981c; McIntyre, 1982; Cooper, 1982a). This practical difficulty was highlighted by Billington (1973, p.1):

> "The practising engineer is often worried by the necessarily artifical conditions of many laboratory trials. He finds it difficult...[to relate them] ..to the behaviour and opinions of an ordinary worker doing his every-day job in normal surroundings."

Accepting the methodological reassurances from Rohles (1974; 1978) for the time being, the main findings of the climate chamber studies based on rating scales can be summarised in seven points:

1. There are six key variables that influence the relationship between the thermal environment and the thermal sensations and comfort of people; air temperature, humidity, mean radiant temperature, air velocity, clothing insulation and metabolic heat production.

2. In sedentary conditions (about 64 W/m^2), still air (less than 0.15 m/s), 50% relative humidity, intrinsic clothing insulation at 0.6 clo and mean radiant temperature equal to air temperature, 25.6degC is the temperature that induces most votes of "neutral" on the ASHRAE scale after 3 hours of exposure (e.g. Nevins et al., 1966; Rohles and Nevins, 1971). This temperature will subsequently be referred to as chamber study neutrality.

3. There appears to be very little influence of humidity over subjective thermal ratings in the low to middle range of temperatures (e.g. Koch et al., 1960b; McIntyre and Griffiths, 1975).

4. The duration of exposure to a given thermal environment appears to negatively affect the thermal sensations of males more than it does females (Rohles and Nevins, 1968). Whether this is the result of sensory receptor fatigue or some other adaptive process as suggested by the above researchers, or more simply the effects of stored metabolic heat dissipating more slowly from men than women is unclear. The duration of exposure effect seems to amount to about a half a category on the ASHRAE scale in the course of a three hour study.

5. The sensitivity of ASHRAE votes to chamber temperature is about one of the seven-point rating scale units every 3K (Nevins et al., 1966; McIntyre and Gonzalez, 1976, p.226) as established when the mean votes of separate groups of subjects, each exposed for 3 hours to a constant thermal environment, are regressed against the temperatures of those environments.

6. The age of subjects seems to have only a minor effect in sensation votes of subjects, despite the well recognised metabolic decline that accompanies old age. Rohles and Johnson (1972) tested the age hypothesis and found elderly women to only have slightly elevated neutralities than their young college age counterparts during the first two hours of exposure in the climate chamber. In discussion time after that paper, Fanger offered an explanation in terms of a reduced evaporative heat loss through elderly skin tissue offsetting the effect that a reduced metabolic

rate would have on neutrality (Fanger's comments after Rohles and Johnson, 1972, p.136).

7. Chamber studies employing seven-point scales of warmth have generally failed to demonstrate any relationship between seasons, climate and neutrality. As this finding relates specifically to the research questions of the current thesis, the key articles will be reviewed in detail. One of the earlier studies to test this hypothesis was that of Glickman et al. (1948), in which four students were exposed to the same chamber climate in winter and summer. The mean comfort vote upon entrance to the chamber was 4.3 in winter and 4.0 in summer which was a statistically significant difference in the direction that an acclimatisation hypothesis would predict. However, this particular study was done before the use of standardised clothing ensembles in chamber studies and any differences observed could easily be attributed to the normal adjustments in clothing habits between seasons.

In a more rigorous experiment by McNall, Ryan and Jaax (1968), thermal sensation votes were collected under identical experimental conditions to those in a winter study by Nevins et al. (1966). Using analysis of variance the researchers failed to find any statistically significant differences in the thermal sensation votes between summer and winter studies. This finding suggested to the researchers that "...acclimatization does not affect the subject's preferred thermal conditions for comfort..."

(McNall, Ryan and Jaax, 1968, p.IV.2.7). A similar study combined the seasonal difference hypothesis with a geographical location hypothesis (Rohhles et al., 1977). The research design entailed two separate studies in Houghton, Michigan, 47N latitude in February and July. Seventy two college-age subjects were used in each season. The second location was San Antonio, Texas, 29N latitude and again separate winter and summer studies were conducted, with 72 subjects in each. Two subjective rating scales were employed for sensation and comfort; scales C and D from Table 3.1. In the comfort envelope of thermal conditions there were no substantial differences in the subjective assessments either between seasons or locations, hence the findings of McNall, Ryan and Jaax (1968) were corroborated. An unexpected and more substantial difference was observed towards the more extreme thermal conditions. Michigans were more comfortable at 31.7ET* during summer than they were in winter suggesting some form of seasonal adaptation had taken place. However, the opposite result was obtained for Texans who found 31.7ET* more comfortable in winter than in summer. These conflicting results led Rohles et al. (1977, p.82) to conclude that:

> "It appears that possibly the populus of the southern climates have come to <u>expect</u> [author's emphasis] air conditioning in the summer within their buildings, and are therefore more intolerant of a warmer inside environment than their northern counterpart. In contrast, the thermal conditions maintained in the winter northern climates may cause the inhabitants to be uncomfortable at higher temperatures than they would be in the summer under the same elevated temperature."

> The effects of a heat wave on the sensitivity of sensation and comfort votes in a climate chamber were investigated by McIntyre and Gonzalez (1976). For sedentary subjects there were no significant seasonal differences in subjective responses to 6K transient temperatures. However, whilst the subjects were exercising, there were significant differences between the pre- and post-heat wave studies. Exercising subjects after the heat wave wanted warmer temperatures and felt cooler (scales D and B in Table 3.1 respectively). These results combined with some physiological observations suggested to the researchers that seasonal acclimatisation reduced discomfort and in fact led to positive thermal affect for subjects performing exercise but not so for sedentary individuals (McIntyre and Gonzalez, 1976).

In concluding this seven-point summary of climate chamber studies employing rating scales, there has been no evidence to support the hypothesis that seasonal or climatic factors affect neutralities of sedentary subjects. However, under conditions of positive heat load whether induced metabolically or environmentally, the weight of climate chamber evidence supports the hypothesis that processes of adaptation alleviate subjective discomfort.

3.1.2 Chamber studies using the preferred temperature method

In the preceding section the term "neutrality" was introduced to refer to that temperature that induced the greatest proportion of subjects to cast

"neutral" or "comfortable" votes in a climate chamber experiment. Following the suggestion of McIntyre (1978a, p.102), the term "preferred temperature" will be used to denote the temperature at which a climate chamber subject requests no change in temperature. The experimental approach employed to ascertain preferred temperature consists of only one subject at a time being placed in a climate chamber while being asked at regular intervals by the experimenter whether or not they would like the chamber's temperature altered. The rapid-response climate control equipment is activated in accordance with the subject's requests and the preferred temperature is taken as the average ambient temperature (with $T_{mrt}=T_a$) during the last two hours of the exposure. The method of direct determination is usually associated with the research of Fanger and colleagues at the Technical University of Denmark, although the method has also been used in the U.K. by McIntyre (1975), who modified it slightly by replacing the experimenter's frequent questions with a climate control switch that the subject could use whenever they pleased.

If the rating scale method of chamber study can be criticised for the unrepresentative nature of its experimental samples, then the method of direct determination must be even more severely flawed because it allows only one subject to be tested for every three hours of the chamber's operation. Consequently the number of subjects involved in each study rarely exceeds 16 (e.g. McIntyre, 1978a; Fanger, 1972; Fanger et al., 1974b).

The key findings of this experimental approach to thermal comfort can be summarised into four points:

1. When subjects are confined to sedentary activity, 0.6 clo of clothing insulation, T_a=T_{mrt}, relative humidity is 50% and air velocity is less than 0.1 m/s, the average preferred temperature is between 25.0 and 25.6degC (Fanger and Langkilde, 1975, p.145), which is reasonably close to the neutrality obtained in the larger rating scale chamber studies discussed in the preceding section.

2. There appears to be little, if any, effect of age on preferred temperature (Fanger, 1973d, p.8). The explanation for this was established as a reduced evaporative loss from the skin of 84 year-olds (12.4 g/m^2 h evaporation weight loss) than 24 year-olds (19.2 g/m^2 h) offsetting the reduced metabolic rate that accompanies ageing.

3. There appears to be no relationship between the body's temperature circadian rhythm and preferred temperature nor is there any significant difference between the temperatures preferred by "morning" and "evening" types of people. The latter classification was established by a questionnaire directed towards habits and preferences concerning activities and times of day (Fanger et al., 1974b). These results are incorporated into Table 3.2.

4. The finding of particular relevance to the current thesis is that concerning seasonal and climatic effects on preferred temperatures. "The general thermal experience of the subjects does not affect the preferred temperature"

TABLE 3.2 : Summary of preferred temperatures from Danish Technical University studies

Experimental Group		Mean Preferred Temp.	Stdev Preferred Temp.	Number of Subjects
Winter swimmers	Female	24.3	1.3	8
	Male	25.7	1.1	8
Meat packers	Female	24.5	1.0	8
	Male	24.9	0.6	8
College-age controls	Female	25.1	1.2	32
	Male	25.0	1.2	32
People from tropics		26.2	NR	16
"Morning types"		24.6	1.5	8
"Evening types"		24.8	1.0	8

NR indicates data Not Reported

(McIntyre, 1978a, p.103). One study investigated the temperatures preferred by 16 Danish winter swimmers who had been exposed daily to ocean temperatures in the region of 0-6degC for at least two winters. The results of that study were compared with similar data obtained from 16 Danish meat-packers who were used to working in cold-room temperatures, and also a control group consisting of 64 Danish college-age subjects (Fanger et al., 1977). All three groups were under exactly the same environmental conditions described in Item 1 above. These three groups' preferred temperatures are contained in Table 3.2. In describing these data Fanger (1973d) asserted that if there

were any real differences at all in preferred temperatures, they were only slight and of no engineering significance. In a further study by Fanger into the effects of thermal experience on preferred temperatures, 16 long-term residents from the tropics were taken into the climate chamber soon after their arrival in Copenhagen (Fanger, 1972). This group recorded a preferred temperature slightly higher than any of the other groups but again this was claimed to be insignificant in the air-conditioning engineers' context. These data are also contained in Table 3.2.

These insignificant differences between experimental groups examined by the preferred temperature method prompted a restatement of the thermal constancy hypothesis (Fanger, 1972, p.35):

> "Our experiments indicate that man cannot be adapted to prefer a higher temperature, and our comfort conditions established in the temperate climates can, therefore, be used without corrections throughout the world, including the tropics."

3.2 Mathematical Models of Human Thermal Response

Because of the complexity of the interactions between man and the thermal environment, there have been many attempts to devise a unitary index of warmth (for reviews see Bruce, 1960; MacPherson, 1962a; 1963; Yaglou, 1949; McIntyre, 1980; Gagge, 1981). MacPherson (1962a) classified the indices into three broad categories:

1. Indices based on the measurement of physical factors, such as dry- and wet-bulb temperatures, globe temperature and equivalent temperature.

2. Indices scaled according to thermophysiological strain, such as the old effective temperature and its derivatives, corrected effective temperature, predicted four hour sweat rate, relative strain index and wet bulb globe temperature.

3. Rational indices based on calculations of heat exchange such as operative temperature, predicted mean vote and standard effective temperature. These last two represent the state-of-the-art in that they successfully integrate air- and radiant temperatures, humidity, air velocity, clothing insulation and metabolic heat production into a unitary index. They are also the basis of modern indoor climatic standards such as ISO 7730 and ASHRAE 55-81 (see Section 1.3.3).

3.2.1 Fanger's heat-balance models

The model proposed by Fanger (1967; 1970) approaches the problem of comfort in the same way that engineers have dealt with the thermal performance of buildings. All heat gains of the system are quantified and the heat losses through various avenues are accounted for. The amount of energy that needs to be spent in order to balance the outputs with the inputs represents the space heating or cooling load to the HVAC engineer, but to Fanger, it is interpreted as the amount of thermophysiological effort required for steady-state conditions. Thermal balance of the body with its environment is the first of three necessary

conditions of comfort in Fanger's hypothesis, effectively reiterating the principle laid down in Gagge's (1938) steady-state equation (2.1).

The second key assumption is that for any given level of metabolic activity, there is a corresponding mean skin temperature that most people would find comfortable. If the exigencies of thermal balance require the thermoregulatory system to raise or lower the mean skin temperature away from the comfort bench mark at that metabolic rate, thermal discomfort will be experienced. As indicated in Section 2.2.1, the nexus between comfort and skin temperature has a long history in physiological research (e.g. Winslow et al., 1937b; Benzinger, 1979; Gagge, Stolwijk and Nishi, 1971). Using college-age Americans, Fanger (1967) established an empirical relationship between mean skin temperature and metabolic rate whilst maintaining thermal comfort:

$$\bar{T}_{sk} = 35.7 - 0.032(M/A_{Du}) \qquad (degC) \qquad (3.1)$$

where $\bar{T}_{sk}$ is mean skin temperature

M/A_{Du} is metabolic rate per unit body surface area
(note: Fanger's 1970 units of Kcal/m².hr were retained in the computer programs in Appendix C)

There was a negative correlation coefficient of -0.83 for the relationship, indicating that as the metabolic rate goes up, the mean skin temperature required for thermal comfort comes down.

The third necessary pre-condition for thermal comfort in Fanger's model concerns the volume of sweat being secreted by the body. Like skin temperature, this variable was also related to the level of metabolic heat production, this time for 183 college-age Americans in thermal comfort.

$$\bar{S}/A_{Du} = 0.42\ (M/A_{Du} - 50) \qquad (Kcal/m^2.hr) \qquad (3.2)$$

where $\bar{S}/A_{Du}$ is the evaporative heat from sweating per unit body surface area

M/A_{Du} is metabolic rate per unit body surface area

The correlation coefficient for the regression equation (3.2) was +0.73 indicating that the comfortable or preferred rate of sweating increases as metabolic heat production increases.

Together the above three requirements of heat balance, skin temperature and sweat evaporation constitute the essence of the model. By combining the last two equations with the results of an exhaustive review of the physiological literature on heat loss and gain coefficients, Fanger (1967) developed his much publicised comfort equation. It can be used to calculate all combinations of air temperature, air humidity, mean radiant temperature and air velocity that will create thermal comfort for the highest possible percentage of college-age Americans wearing any level of clothing insulation and performing any type of activity. As discussed in the preceding section, the Danish Technical University has undertaken an extensive research programme into systematic group differences in preferred temperatures. The failure to find these has encouraged Fanger (1970) and indeed, the HVAC industry that uses the comfort equation, to regard it as having universal applicability.

The comfort equation purportedly gives the engineer practical information on what combination of design conditions will give the most comfortable indoor climate, but it is not very useful for assessing already existing thermal environments. Fanger took the concepts underlying his comfort equation a little further to develop the Predicted

Mean Vote (PMV) index that;

> "...makes it possible to predict the mean thermal sensation vote on a standard scale for a large group of persons for any combination of the four thermal environmental variables, the activity level and the clo-value of clothing worn by the occupants" (Fanger, 1970, p.107).

The basic idea of PMV is simply that satisfaction of the three necessary conditions of thermal comfort (as in the comfort equation) will give rise to a mean thermal sensation of a large group of people equal to zero or neutral on the standard ASHRAE seven-point subjective scale (Table 3.1). Therefore, the basic assumption is that thermal discomfort will increase in proportion to the amount of load being placed on the physiological effector mechanisms, particularly vasomotor activity (mean skin temperature) and sweat gland productivity (evaporative heat loss by sweating).

Load in this context is directly comparable to the heating and cooling loads talked about by HVAC engineers when they are calculating the size of plant required for a particular building. The PMV concept can be clarified with a simple illustration (Figure 3.1). An hypothetical person is placed in a set of non-neutral thermal conditions. By holding their mean skin temperature and evaporative heat losses due to sweating at the comfort benchmark levels prescribed by Equations (3.1) and (3.2) respectively, an imbalance would exist between metabolic heat production and the heat lost to the environment. This discrepancy is the thermal load on the body and subjective thermal sensation is claimed by Fanger (1970, p.111) to be some function of this load.

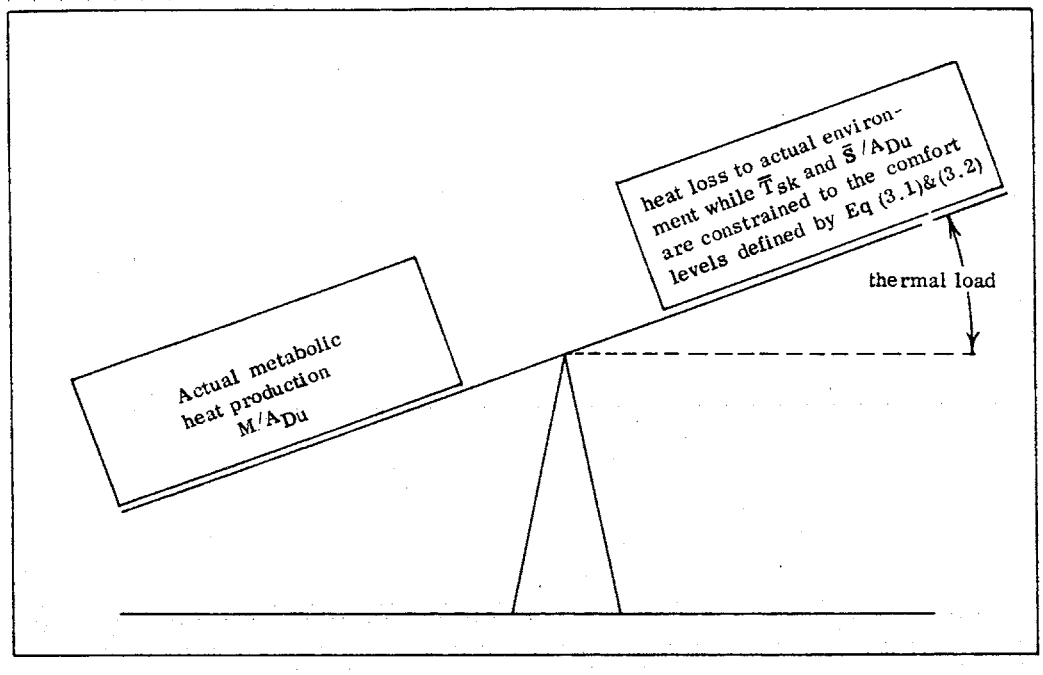


FIGURE 3.1 : The concept of thermal load in PMV model

The PMV index uses the comfort equation's derived expressions of heat loss and gain and the empirically fitted relationships of comfort benchmark skin temperature and evaporative heat loss. The job of relating subjective sensations to thermal load was done statistically by using the experimental data of Nevins et al. (1966) and McNall et al. (1968). These two data sets combined with Fanger's (1970) own data from Danish college-age subjects gave a total sample size of 1396 across a range of four different metabolic rates between 50 and 135 kcal/m^2hr (58 and 156 W/m^2). A straight line was fitted and its equation, when combined with the relation between thermal load and thermal environments (based on the comfort equation), yielded the final expression for PMV:

$$\begin{aligned} PMV = {} & [0.352\ \exp(-0.042\ M/A_{Du}) + 0.032]\ \{M/A_{Du}\ (1-\eta) \\ & - 0.35[43-0.061M/A_{Du}\ (1-\eta)-P_a] - 0.42[M/A_{Du}\ (1-\eta)-50] \\ & - 0.0023M/A_{Du}\ (44-P_a) - 0.0014M/A_{Du}\ (34-T_a) \\ & - 3.4 * 10^{-8}\ F_{cl}\ [(T_{cl}+273)^4 - (T_{mrt}+273)^4] \\ & - F_{cl}\ h_c\ (T_{cl}-T_a)\} \end{aligned} \qquad (3.3)$$

where T_{cl} is the solution of the equation:

$$T_{cl} = 35.7 - 0.032\ M/A_{Du}\ (1-\eta) - 0.18\ I_{clo}\ \{3.4 * 10^{-8}\ F_{cl}\ [(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] + F_{cl}\ h_c\ (T_{cl} - T_a)\} \quad (3.4)$$

and

$$h_c = \begin{cases} 2.05(T_{cl} - T_a)^{\frac{1}{4}} & (3.5) \\ \text{or} \quad \text{whichever is larger} & \\ 10.4\sqrt{v} & (3.6) \end{cases}$$

3.2.2 The Standard Effective Temperature index (SET)

The old effective temperature index of Houghton the Yaglou (1923a; 1923b) has probably become the most widely used index of warmth (not counting air temperature) in the last 60 years. More recently there has been intensive work at the Pierce Foundation Laboratory of Yale University to come up with a more generalised rational index, culminating in 1971 with the publication of the standard effective temperature scale (Gagge, et al., 1971). It has since been modified to be applicable to hypo- and hyper-baric atmospheres (Nishi and Gagge, 1977), so it probably represents the most comprehensive thermal index yet devised.

The standard effective temperature (SET) resembles the old effective temperature insofar as it predicts loci of constant human response to various combinations of thermal environmental parameters. The newer

index uses two thermophysiological variables; mean skin temperature ($\bar{T}_{sk}$) and skin wettedness (w), as its basis for comparing environments. The first, $\bar{T}_{sk}$, has long been known to closely correlate with thermal sensation (see Section 2.2.1) and comfort in environments that are cooler than neutral (Gagge et al., 1967; Nishi and Ibamoto, 1969; Winslow et al., 1939; Gagge, Stolwijk and Saltin, 1969). The second physiological strain, skin wettedness (w), is a measure of the average wettedness of the body surface, and is defined as the ratio between the actual amount of evaporative heat loss taking place at the skin surface and the maximum evaporative loss that could occur in the same environment. This ratio closely behaves like a scale of perceived sweating or "stickiness", which was also pointed out in Section 2.2.1 as a primary input to the sense of warmth discomfort (Winslow et al., 1939; Gagge, Stolwijk and Nishi, 1969; Gagge, Stolwijk and Saltin, 1969; Gagge, 1937). It performs better in warmer environments than skin temperature simply because when evaporation of regulatory sweat occurs, mean skin temperature is confined in a narrow 2K band until the heat load on the body causes the body surface to approach 100% wettedness.

The SET index compares diverse thermal situations by first of all predicting the levels of w and $\bar{T}_{sk}$ they would induce in a human body under steady-state thermal conditions, wearing the actual clothing ensemble, by using a simple 2 node mathematical model of the body's thermoregulatory system. Having estimated these two variables, the method calculates the temperature of a standard reference environment that would induce the same values of w and $\bar{T}_{sk}$ as occurred in the actual environment. The standard environment has the following characteristics; air temperature is equal to mean radiant temperature, relative humidity

is 50%, relative air velocity is 0.13m/s, clothing insulation being worn by the reference person is 0.6clo and they are sedentary with a metabolic rate of 64W/m^2.

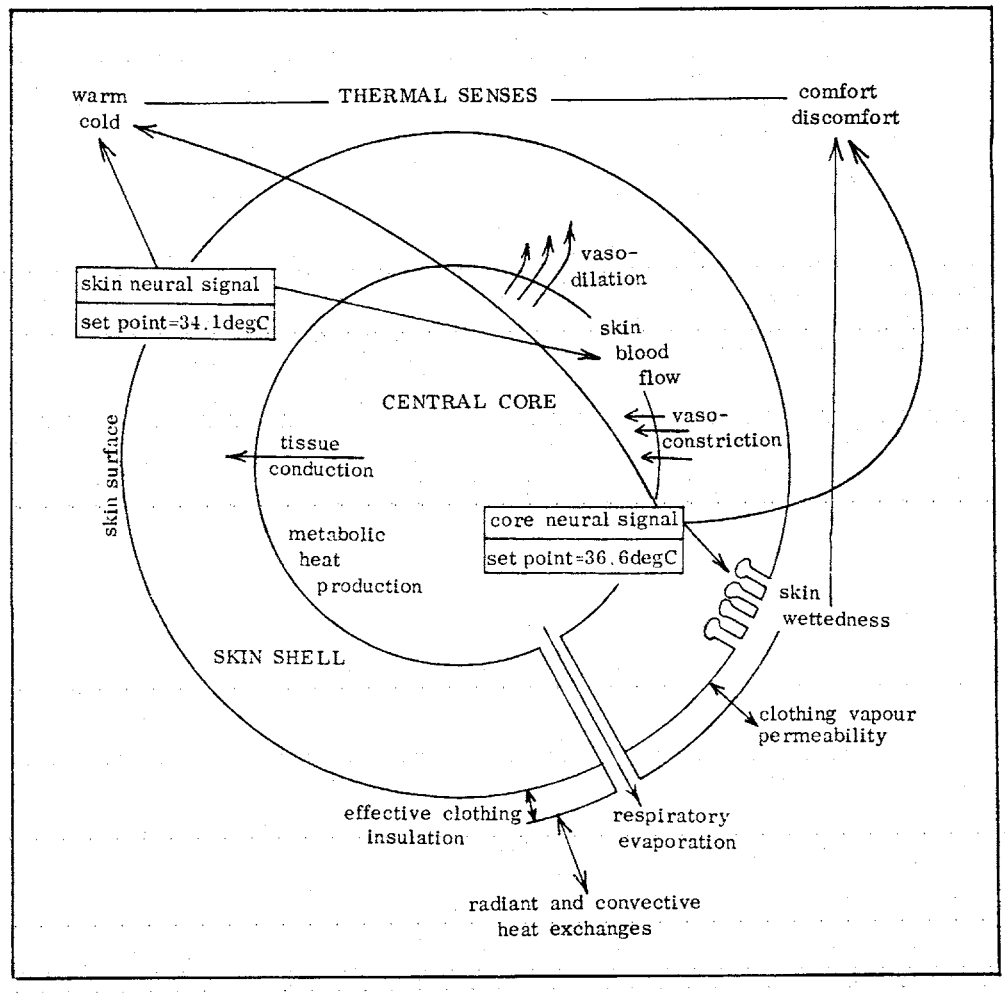


FIGURE 3.2 : The Pierce 2 node model of thermoregulation used in calculation of SET (After Gagge et al., 1971, p.249)

The Pierce two-node model used for estimating values of $\bar{T}_{sk}$ and w in SET is just one of the many analogous representations of thermoregulation that have been proposed over the years (Houdas, 1981). The body is considered to be a single cylinder consisting of two concentric shells; a central core and an outer layer that represents the skin. Heat is

generated in the core and flows to the outer shell by blood circulation and tissue conduction, therefore the degree of vasoconstriction can control much of this transfer. The thermal state of the skin and its degree of wettedness then control the sensible and insensible heat transfers through the clothing layer and to or from the thermal environment. In simulating the thermoregulatory system, the model generates estimates of the principle neural drives for the various autonomic effector mechanisms as discussed in Section 2.1. These include core temperature, skin temperature and mean body temperature. Based on physiological studies, the gain constants relating effector responses to neural drive were incorporated into the model. These, combined with the known heat transfers that each of the mechanisms is capable of effecting, allow the model to simulate the status of the system at the end of a specified time period. The general concepts of the two-node model have been summarised in Figure 3.2.

3.3 Field Studies of Thermal Comfort

As pointed out in the preceding section, there are several methodological parellels between various branches of psychology and the study of thermal comfort. In the case of chamber studies, the connection is with psychophysics' study of stimulus-response relationships in carefully controlled environments. As for field studies of thermal comfort, there is a clear methodological similarity to environmental psychology (see Appendix A). By taking the study of comfort into natural settings, there is a recognition of the complexity of environmental perception as opposed to object perception (Ittelson, 1973). The current

section briefly reviews the field studies that have been performed in the last 50 years, outlining the salient methodological issues and various theoretical interpretations that are relevant to the present discussion. For detailed reviews, the reader is directed to Nicol and Humphreys (1973), Humphreys (1975; 1976; 1981) and Auliciems (1983).

Although the work of Grivel and Fraise (1979), Humphreys (1973; 1979), Brundrett (1978) and de Freitas (1979) has complied with the unobtrusive measurement requirement of naturalistic research methodology (Brandt, 1972), most field studies have employed questionnaires to obtrusively record their dependent variables. The detail and range of these instruments' enquiries into subjective perceptions of indoor climates have varied greatly between researchers. However, the most universally used questionnaire item has been a rating scale on which respondents have been asked to indicate their subjective estimates of warmth. The number of grades on such scales has varied between researchers but the two most frequently used are known as the Bedford and ASHRAE scales, as listed in Table 3.1. Various doubts have been expressed about the degree of congruity between the psychological referents of these two scales (Auliciems, 1981d, p.28; McIntyre, 1978c, p.215), with the ASHRAE version considered to be a purely sensory scale while the Bedford is a combination of sensation and affect or comfort (Humphreys, 1975, p.3). Notwithstanding these semantic differences, the central category of each scale seems to perform in exactly the same manner in practice (McIntyre, 1978c; Humphreys, 1975), and so for the purposes of this discussion they will be treated as synonymous.

The respondents who have provided these subjective estimates in field studies have been school children, teachers, naval ratings, university students, hospital staff and workers in light industry, but most respondents have been office workers (Humphreys, 1975). In general, they have been in sedentary or at least light activities, and the researchers have usually attempted to make as few as possible interruptions to these daily activities.

Accompanying the respondents' subjective assessments of thermal conditions in field studies have been measures of the objective indoor microclimate. Again there have been considerable variations in the detail and accuracy employed in the various field studies, but the lowest common denominator between them has been ambient air temperature. Perhaps one of the most comprehensive indoor climatic records was also one of the earliest; Bedford's (1936) seminal study included measurements of dry- and wet-bulb temperatures, air velocities and also globe temperatures. From these four basic variables can be derived all of the thermal indices in the first two of the three category classification given at the beginning of Section 3.2. However, for a field study to use one of the rational heat-balance indices as its independent variable, it is necessary to record estimates of clothing insulation and metabolic rates. To date, very few field studies have complied with these requirements (Fishman and Pimbert, 1979; Howell and Kennedy, 1979).

The outdoor climates in which these comfort surveys have been conducted have ranged from a mean monthly outdoor air temperature of -24degC in the north USSR winter, up to 34degC in Baghdad (Humphreys, 1981, p.236). The buildings in which the field studies were conducted

were also varied, including 28 free-running buildings (those without any energy consuming heating or cooling plant) and 36 actively climate-controlled buildings. The distribution of these two categories of building surveys between the hot and cold climates was noted by Humphrey's (1976; 1981) to be uneven. There is a paucity of information from air-conditioned buildings in outdoor climates warmer than 23degC mean monthly temperature.

In comparing the findings of more than thirty such field studies, Humphreys (1975) regressed each survey's mean rating scale vote against its respective mean air or globe temperature. A major finding was a gradient of one scale vote (on a seven-point scale) per 20K, suggesting that people in natural settings were extraordinarily adaptable to various thermal environments. This interpretation was corroborated by an analysis of the temperatures at which the respondents in the various studies were subjectively neutral or comfortable (T_{ψ}). By regressing neutralities against their corresponding mean survey air- or globe-temperature (T_i), the following equation was derived:

$$T_{\psi i} = 2.56 + 0.83\ T_i \qquad (3.7)$$

which had a correlation coefficient of 0.96 and a standard error of the estimate at 1.1K.

Noting that there was a range of 13K in neutralities between the various field studies, Humphreys concluded that various adaptational processes were operating in the relationship between building occupants and their thermal environment. Contrary to the findings of climate chamber studies;

> "...the range of recent experience is better regarded as one of the factors which will contribute to the acceptibility of the environment to which the respondent is exposed" (Humphreys, 1975, p.13).

Following through a suggestion made by both Auliciems and MacPherson in personal communications, Humphreys (1976) hypothesised that peoples' thermal experiences would incorporate outdoor exposures as well as an indoor component. Therefore the indoor neutralities observed in field studies should bear some relationship with the outside weather or climate prevailing at the time of the surveys. After breaking down the data set into free-running and climate-controlled building studies, Humphreys related the T_{Ψ} observed in both classes of study to their respective mean monthly outdoor temperatures ($T_{\overline{m}}$). For the free-running building studies a remarkably high correlation coefficient of 0.97 was obtained, while the climate-controlled building studies had a more moderate but still highly significant correlation coefficient of 0.56. The free-running building data set yielded the following linear relationship with a standard error of the estimate equal to 1K:

$$T_{\Psi ii} = 11.9 + 0.534\ T_{\overline{m}} \qquad (3.8)$$

while the climate controlled data set produced the following equation:

$$T_{\Psi iii} = 23.9 + 0.295(T_{\overline{m}} - 22)\ \exp\{-[(T_{\overline{m}} - 22)/(24\sqrt{2})]^2\} \qquad (3.9)$$

where $T_{\Psi ii}$ is Humphreys' (1976) free-running bldg neutrality

$T_{\Psi iii}$ is Humphreys'(1976) climate controlled building neutrality

$T_{\overline{m}}$ is mean monthly outdoor temperature (midway between mean month max and in)

The scatter-plot and lines of best fit resulting from Humphreys' (1976) analysis of field study neutralities in relation to outdoor mean monthly temperatures are depicted in Figure 3.3.

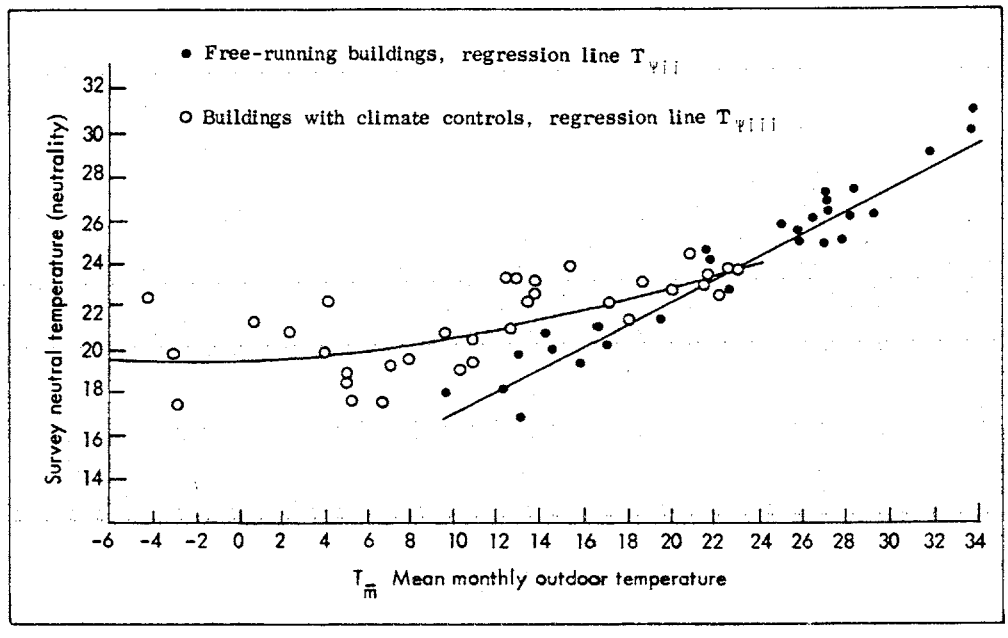


FIGURE 3.3 : Neutral temperatures in field studies related to outdoor temperature (After Humphreys, 1976)

Seven years after the initial publication of these models, Auliciems (1983) re-analysed the regression data of Humphreys. However, neutralities from field studies based on school children were deleted as were those derived from asymmetric scales of subjective warmth. These deletions were replaced with more recent data from Australasia, and by collapsing the climate-controlled and free-running buildings' results together, the revised data set consisted of neutralities based on quarter-of-a-million individual comfort assessments. Using a stepwise regression procedure, Auliciems (1983) was able to explain ~0% of the variance in survey neutrality temperatures on the basis of mean indoor air or globe temperature and mean monthly outdoor temperature, and the

standard error of the estimate was 1.1K:

$$T_{\psi iv} = 9.22 + 0.48\ T_i + 0.14\ T_m \qquad (3.10)$$

where $T_{\psi iv}$ is Auliciems' (1983) all-building neutrality
T_m is mean monthly outdoor temperature
T_i is mean indoor air or globe temperature

Collectively, the array of field studies that have been reported in the last 50 or so years constitute evidence for the adaptability of human responses to prevailing levels of environmental warmth. By way of contrast with the climate chamber studies and their associated thermal constancy hypothesis, the various equations that show the statistical dependence of field study neutralities on prevailing levels of warmth (Equations 3.7-3.10) will subsequently be referred to as the adaptation hypothesis of comfort research.

3.4 Reconciliation of Chamber and Field Studies

Methodologically, the "thermal constancy" and "adaptation" hypotheses almost represent a polar opposite pair. For example, in the context of Figure 1.2 that depicted the two major strategies for coping with levels of environmental stimulation that depart from adaptation levels, the results of field studies indicate the power of "organic" responses in the form of shifting adaptation levels towards the prevailing degree of environmental warmth. On the other hand, climate chamber studies and their associated "thermal constancy" hypothesis emphasise external adjustment of the stimulus itself as the primary coping mechanism; viz, clothing adjustments and more importantly, HVAC

technology. The contrasts are sufficiently sharp that any review of applied comfort research would be incomplete without some attempt to reconcile the two approaches. Each has its methodological strengths and weaknesses which have inevitably been brought into focus by the protagonists in the debate so far (e.g. Cooper, 1982a; Auliciems, 1981c; 1983). Other attempts at an explanation have suggested that no contradiction exists since the two approaches have been addressing different questions. This final section of Chapter 3 reviews each of these possibilities.

One of the most fundamental methodological contrasts between the two approaches concerns validity. Laboratory research designs maximise internal validity whilst field studies emphasise external validity (Cook and Campbell, 1979). Laboratories permit careful control and measurement of dependent and independent variables without the threat of confounding influences disrupting their causal connection. The main drawback however, is the artificiality of the research setting and the unrepresentative samples of respondents that have been used in climate chambers. These features severely restrict the extent to which the research results can be generalised to outside populations. This shortfall in external validity seems ironic in view of the comfort standards which have been developed on the basis of the chamber studies. For example, the universality of an international standard, ISO 7730, depends largely on the results of a study of only 16 long-term residents of the tropics (Fanger, 1972).

At the opposite end of the spectrum, field studies that have often been conducted in response to specific problem buildings, have much more representative respondents in larger numbers and in natural settings.

Therefore, their results are of general applicability. Their major shortcoming arises from the difficulties involved in controlling or even measuring accurately all of the relevant independent variables. This makes comparison of field study results with chamber research models difficult. Humphreys (1975) addressed these issues in an attempt to explain the 13K variation in observed field survey neutralities. In terms of heat-balance models such as Fanger's (1970) comfort equation, either metabolic rate or clothing differences between the surveys could account for variability in neutralities. The former was ruled out on the grounds that the original researchers of the various comfort surveys classified their respondents as sedentary or lightly active. Humphreys considered the maximum difference in clothing insulation that could reasonably be expected across the various field studies was about one clo unit (one clo equals approximately the same insulation value of a business suit with normal underwear). This magnitude of manipulation on the clo parameter in Fanger's comfort equation is capable of changing predicted neutralities by as much as 5 to 6K, or about half the range in neutralities observed by Humphreys. This led to the conclusion that some other factor, unrelated to the body's heat-balance, was partly responsible for shifts in the temperatures which people called neutral or comfortable. Humphreys deduced that it was variability in the physiological state that people considered neutral (1975).

Nevertheless, the estimates of unmeasured heat-balance variables in post hoc interpretations of field study results leaves much to be desired, and the typical defence of the "thermal constancy hypothesis" has usually consisted of emphasising this shortcoming (Fanger, 1970, p.83). While Humphreys (1975) may have been reasonably accurate in

estimating clothing and metabolic variables, relative air velocity was completely overlooked. Fanger (1970, p.83) confined comparisons of the comfort equations predictions to those field studies in which most of the important heat-balance variables could be inferred with some degree of accuracy. First, the study by Ellis (1953) on residents of Singapore was examined. The observed neutrality at 80% RH, mean velocity of 0.4m/s, and clothing at about 0.4clo was 27degC, which compared favourably with the comfort equation's predicted neutrality of 27.4degC. Another tropical field study, this time conducted in Port Moresby, Papua New Guinea, provided further empirical support for the comfort equation (Ballantyne et al., 1967). However, in a follow-up publication of some data obtained from Melanesian subjects during the same research series, the empirically derived thermal neutrality was 1.4K higher than that predicted by Fanger's comfort equation (Ballantyne et al., 1979, p.20). Therefore the inconsistencies between the two approaches cannot solely be attributed to parameters of the heat-balance equation that are not measured in field studies.

A more pragmatic approach to the seeming contradiction in the results of chamber and field studies has been put forward by McIntyre (1978a; 1982). Essentially, his argument represents a restatement of the "semantic set" criticism levelled at the adaptation-level theorists in psychophysics by Stevens (1958) (see Appendix A). It was suggested that the neutral temperature derived from either a probit or regression analysis of field survey data was a different concept to the self-determined preferred temperature obtained in laboratory studies. The assumption that the mid-point of the fourth category on the seven-point scales of warmth constituted the group neutrality was

questioned by McIntyre who suggested that local climatic conditions could interfere with the semantics of these scales. Residents of warm climates may in fact prefer what they call a "slightly cool" environment indoors (relative to outdoor conditions) whilst the converse might be true for residents of cold climates. In effect, McIntyre was saying that the regression Equations (3.7-3.10) that relate neutrality to prevailing levels of warmth were simply expressing the semantic effects of climate and had nothing to do with people of differing thermal histories altering their affective response to constant thermophysiological states.

Fisk (1981) offered a possible cultural explanation for this shift in semantic set with climate by saying that the gradient between indoor and outdoor climates could act as an exhibition of economic status. The person who is "...warm in a cold climate or cool in a warm climate, is obvious to society as...[one]...with resources to spare" (Fisk, 1981, p.29). This line of reasoning has a certain intuitive appeal in that the "grass is always greener on the other side of the fence" mentality is a familiar one when it comes to climatic preferences. However, the argument doesn't withstand close analytical scrutiny: If the local climate of a place affects the way people use seven-point scales of warmth in field studies, it would seem reasonable to expect the same semantic artifact to contaminate the data of laboratory studies that employ these scales also.

Referring back to Section 3.1.2 in which these studies were reviewed, it was not noted that McNall, Ryan and Jaax (1968) investigated the possibility of there being a difference between winter and summer thermal environments providing comfort for similar lightly clothed college-age subjects in a sedentary activity for exposures of three hours

in the Kansas State University climate chamber. Their summer study replicated the winter study of Nevins et al. (1966) but it was preceded by a three-week heat wave. By taking the average between the published mean high and mean low temperatures for Manhattan Kansas, the mean monthly winter temperature was -1.1degC while the mean monthly temperature for the summer study was somewhere between 23.3degC (June) and 29.2degC (July) (McNall, Ryan and Jaax, 1968, p.IV.2.6). Despite these substantial climatic differences, there was no difference between the summer and winter neutralities, as derived from regression analysis of ASHRAE scale votes. Furthermore, Rohles and Wells (1977) found that prior exposure to hot and cold conditions had no effect on how subjects responded on the ASHRAE scale during exposures in a climate chamber. Consequently, the "semantic set" reconciliation of the conflicting laboratory-field study results doesn't appear to be entirely satisfactory.

CHAPTER 4

RESEARCH QUESTIONS AND HYPOTHESES

A recurring theme throughout the preceding review of the human relationship with the atmospheric environment has been the potential of indirect processes to influence the magnitude of strain elicited at various levels of the human response system. This notion was most clearly expressed in the discussion of acclimatisation adjusting set points in the physiological control system. However, the concept of thermal history influencing thermal response seems general enough to be extended to other aspects of man's relationship with climate. The notion of habituation and the shifting of adaptation levels towards prevailing

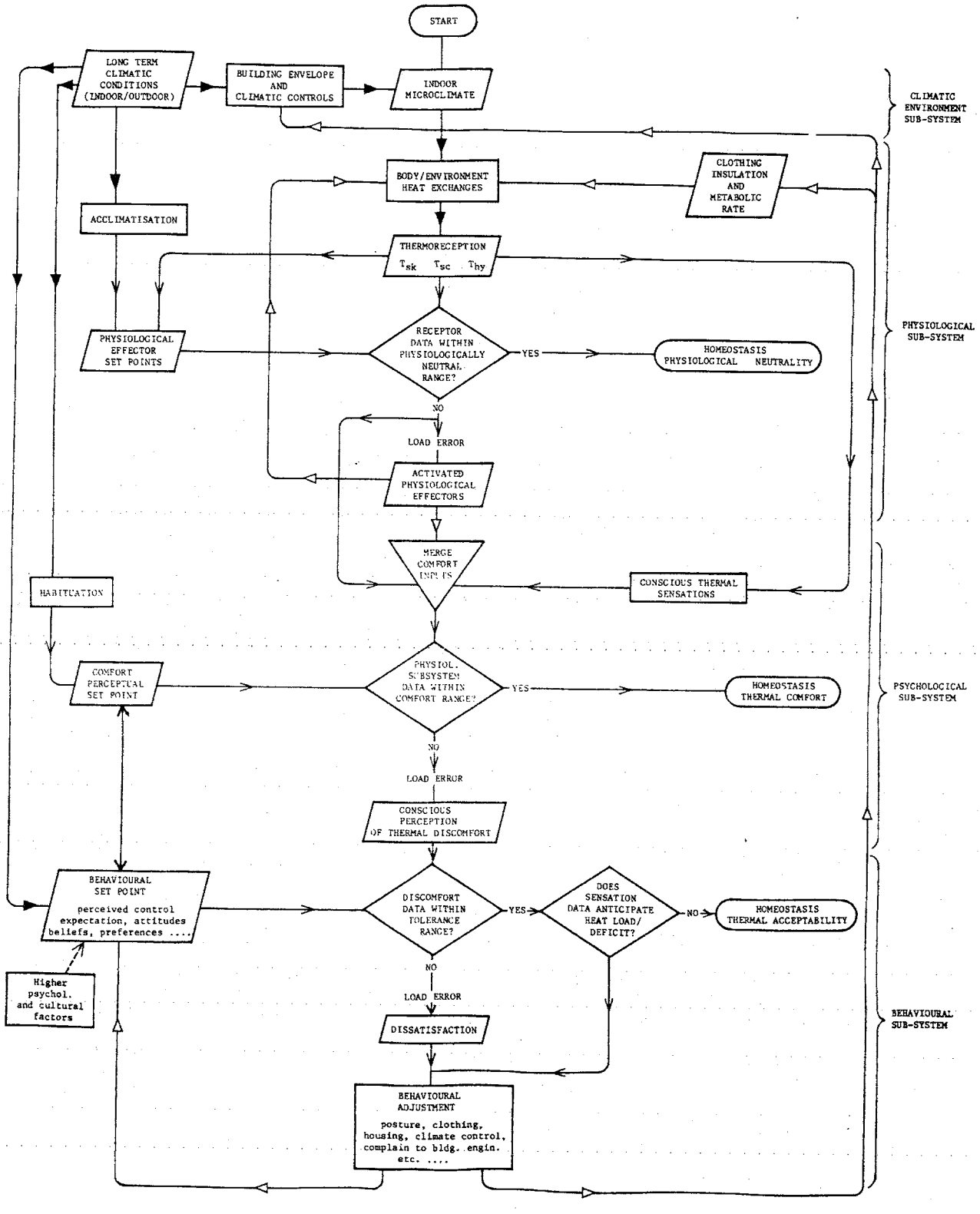


FIGURE 4.1 : Flow chart of the various relationships in the man-climate system
(——→ information flows)
(——▷ action)
(——▶ heat flows)

levels of environmental stimulation has support from certain aspects of the thermal biometeorology literature. Finally, the response of larger aggregations of people to their thermal milieux has been depicted in parts of the literature as being conditioned by technological factors and cultural norms as much as immediate levels of thermal stress and physiological strain.

These ideas have been schematically presented in Figure 4.1, which contains three tiers of human response; 1) physiological, 2) psychological, and 3) behavioural subsystems. Each of these has its own process of set point adjustment; 1) acclimatisation, 2) habituation, and 3) higher psychological and cultural dimensions. The flow lines connecting the system's components represent causal links, and are classified into three broad categories of; 1) information, 2) thermal, and 3) action. The broad concepts depicted in Figure 4.1 generate the following research questions and hypotheses to be addressed in the current thesis.

4.1 Thermal Comfort Surveys

Dealing first with the "climatic environment subsystem," the review of field studies in Chapter 3 identified the absence of thermal comfort/microclimate surveys in air-conditioned buildings in outdoor climates with mean monthly temperatures warmer than 23degC. It is proposed to fill this gap with three such surveys in monsoonal and sub-tropical climates of Australia. For comparative purposes, three additional surveys were conducted in free-running and air-conditioned buildings in mid-latitude and sub-tropical climates. Specific research questions addressed by these six surveys include:

1. How is air-conditioning practised in three climatically disparate cities (Darwin, Brisbane and Melbourne), vis-a-vis the comfort standards reviewed in Section 1.3.3?

2. How do these practices compare with the microclimates prevailing in free-running buildings in the same cities?

3. What potential is there for energy conservation in current practices? Further, does the comparison of practices with standards suggest any energy conservation strategies for the HVAC systems surveyed?

4. How do indoor climatic conditions relate to those prevailing outdoors in both air-conditioned and non-air-conditioned buildings? What role if any, does clothing insulation play in linking outdoor and indoor thermal environments?

5. How are the microclimatic conditions observed in the six surveys subjectively perceived by their respective occupant samples?

6. Do the sophisticated rational indices of thermal comfort correlate more closely with subjective assessments than the simple measures such as dry bulb or operative temperatures?

7. Are there any systematic differences in the neutralities identified by the ASHRAE sensation and Bedford comfort scales? Further, do these scales' neutralities differ from that of a scale dealing with temperature preferences?

8. Are there any differences between the sensitivity of the three subjective scales to variations in microclimatic warmth? Also, are field study respondents subjectively less sensitive to temperature differences than their climate chamber counterparts?

4.2 Thermal Constancy Versus the Adaptation Hypothesis

Arising from the psychological subsystem depicted in Figure 4.1 are several research questions relating to the two main comfort hypotheses discussed in Chapter 3:

1. Are there any between-survey differences in observed neutrality?

2. Are there any between-survey differences in subjective sensitivity to variations in environmental warmth?

3. Are there any between-survey differences in subjective acceptability of sub-optimal thermal environments?

4. Are there any between-survey differences in the level of homogeneity or consistency of subjective warmth assessments in a given thermal environment?

5. Which of the two main comfort hypotheses, constancy or adaptation, best predicts the neutralities observed in field studies?

6. Does the "semantic set" hypotheses account for between-survey differences in subjective warmth?

4.3 Attitudes on Indoor Climatic Issues

The European and American literature dealing with human responses to air conditioning (Section 1.3.4) indicates that the benefits of technologically sophisticated climate controls were coming under critical scrutiny by building occupants. Because little research of this type has been done in warmer climates (Pepler, 1962), this thesis investigated the psychological aspects of air conditioning in various Australian climates. Recognising that attitudes comprise cognitive, affective and behavioural components, the following research questions were addressed:

1. How important is the indoor climate factor as perceived by building occupants vis-a-vis other aspects of the physical office environment?

2. What are the costs and benefits of air conditioning in the work-place as perceived by building occupants?

3. Do occupants believe in adverse health effects of air conditioning? In particular, what ailments are attributed to air conditioning during summer by building occupants?

4. Does air conditioning exacerbate the perceived passive smoking problem?

5. Does the affective component of building occupants' attitudes toward air conditioning interact with the cognitive issue of adverse health effects of air conditioning or occupant preferences for either air-conditioned or free-running buildings?

6. How does the behavioural component of air conditioning attitude (as indicated by stated preference) relate to outdoor climate, season and respondents' experience?

7. What are the microclimatic adjustments available to occupants of air-conditioned and free-running buildings? Are the occupants of the latter more satisfied with their degree of participation in regulating their microclimate than their air-conditioned counterparts?

8. How does the perceived microclimatic control factor relate to thermal characteristics in buildings?

9. How do long-term thermal impressions and overall occupant thermal satisfaction relate to microclimatic characteristics in buildings and instantaneous thermal assessments?

10. What are the likely responses of building occupants to energy conservation strategies for air conditioning?

4.4 Interaction Between Instantaneous Thermal Assessments and Non-Thermal Factors

The third subsystem in the proportional control model of thermal perception (Figure 4.1) depicts an interaction between higher psychological processes and immediate thermal perceptions. Several research questions arise from this connection:

1. Can the length of a person's residence in a stressful climatic region influence their instantaneous assessments of indoor thermal climates? That is, can thermal history influence the processes of thermal perception?

2. Can the thermal exposure of people in one place influence their instantaneous assessments of microclimatic conditions in another place?

3. Does the level of microclimatic control that building occupants perceive themselves as having in the workplace correlate with their immediate thermal perceptions in that microclimate?

4. What are the interactions, if any, between the cognitive, affective, and behavioural components of air conditioning attitudes and instantaneous thermal perceptions?

CHAPTER FIVE

THESIS METHODS

The two key independent variables that emerge from Chapter 4 are outdoor climate and building climate controls (air-conditioned versus free-running). The resources available for the current investigation suggested that six field studies, conducted in climatically and architecturally diverse contexts was a feasible rsearch design. The unique feature of this design that enhanced the validity of any conclusions concerning group differences in comfort and other responses to environment, was that the instruments, procedures and research personnel employed to collect the data were reasonably constant across

the six surveys, thereby minimising the risk of systematic methodological artifacts contaminating the data (MacPherson, 1962b).

Before describing in detail the methods used, it needs to be emphasised that the research design suffers from the difficulty of satisfying simultaneously the descriptive and analytical (hypothesis testing) research objectives identified in the preceding chapter. The research design finally adopted represents a compromise between the two competing requirements, but whenever their demands were irreconcilable, priority was given to the testing of hypotheses. This has meant that the methods were chosen to answer research questions in Section 4.2 first and foremost, while endeavouring to maintain the generalisability of the answers to those in Sections 4.1, 4.3 and 4.4.

5.1 Research Design and Samples

5.1.1 Selection of cities: The outdoor climatic variable

The resources available to the current research project dictated a maximum of three survey cities. The selection of a clerical population for the study (see Section 5.1.3) further reduced the possible survey cities to those with sizeable office work forces, namely the Australian capital cities. Following from the plea by Humphreys (1976; 1981) for comfort studies to be conducted in air-conditioned buildings in climates where the mean monthly outdoor temperature exceeded 23degC, sub-tropical Brisbane and tropical Darwin were selected. The latter location experiences mean monthly temperatures greater than 23degC all year round and it was therefore decided for comparative purposes to conduct two

TABLE 5.1 : Long-term averages of weather variables in the survey cities

	D A R W I N				BRISBANE		MELBOURNE	
	"The Dry"		"Build-up"		Summer		Summer	
	JUL	AUG	OCT	NOV	JAN	FEB	JAN	FEB
Mean monthly air temp. #	24.7	25.8	28.1	29.1	25.0	24.7	19.9	20.0
Mean 9AM vapour press. (mmHg)$	13.2	15.5	20.8	21.1	16.4	16.6	9.8	10.6
Mean daily hours sunshine *	9.8	10.4	9.5	8.6	7.6	7.0	8.1	7.5
Mean monthly wind speed at 28m above ground (Km/h) @	10.1	8.9	9.8	8.6	11.9	11.6	12.2	11.8

(Source : Bureau of Meteorology, 1983)
based on > 95 year records; $ based on > 74 year records
* based on > 26 year records; @ based on > 25 year records

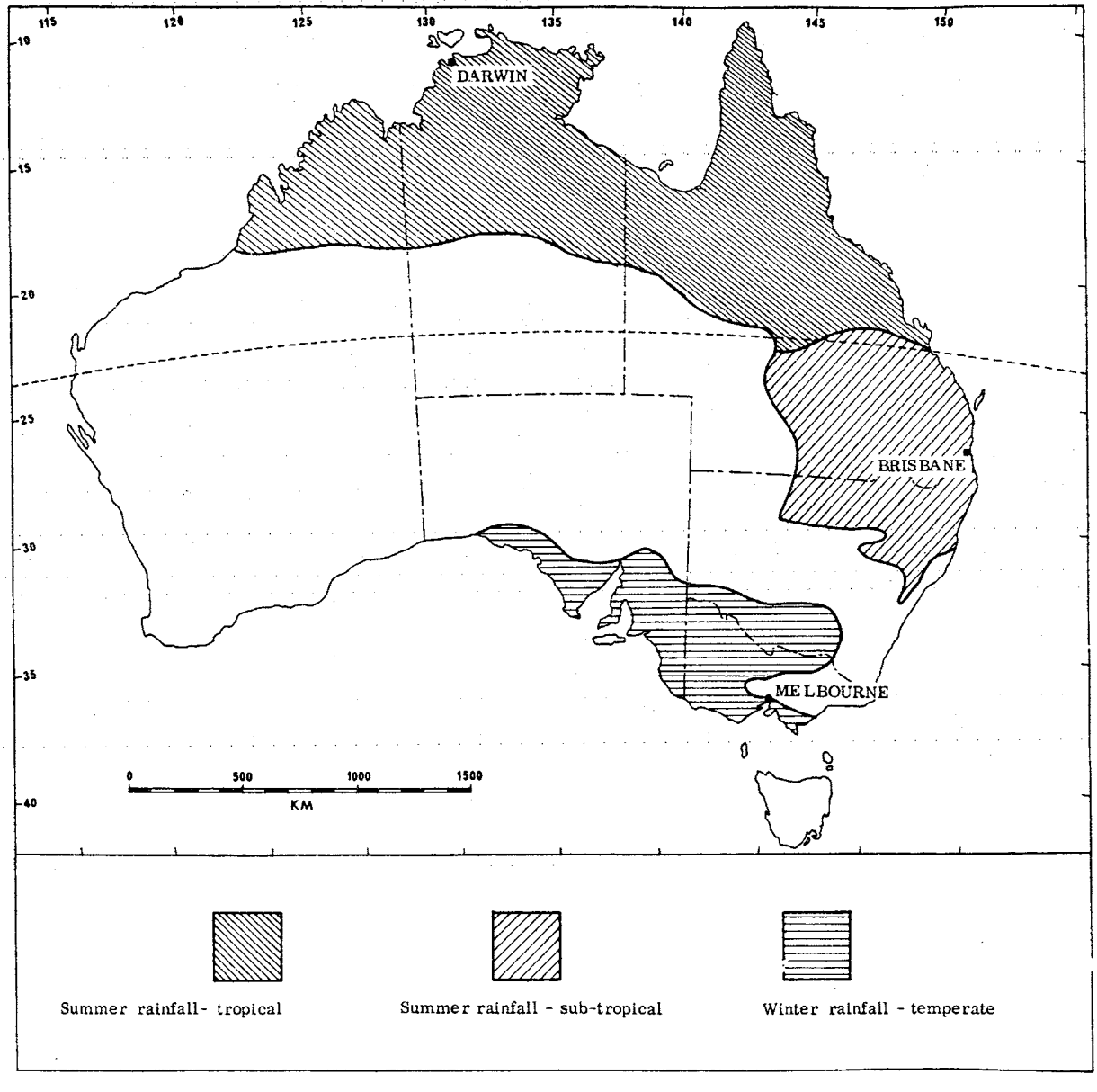


FIGURE 5.1 : Location map showing climatic zones of the three cities surveyed
(After Bureau of Meteorology, 1983, p.10)

air-conditioned building surveys there in 1982; one during the least stressful time of year, hereafter referred to as the "Dry" season, and the other during the most uncomfortable time of the year, known locally as the "Build-up". The latter occurs on the shoulder between the "Dry" and "Wet" seasons and it derives its name from the oppressive increases in heat and humidity during the six to eight weeks immediately before the onset of monsoonal rains in December. One would expect the respondents in the "Build-up" season to be only partially acclimatised to the hot-moist atmosphere of the summer, thereby contributing to the popular reputation of November for high discomfort. The Brisbane field work was conducted during the summer of 1983-84. Finally, for the purpose of comparison, the third survey city was mid-latitude Melbourne. Surveys in this location were conducted in January and early February 1983. The locations and their general climatic zones are depicted in Figure 5.1. Long-term average values of certain meteorological variables are given in Table 5.1 for the three cities during the months in which surveys were conducted.

5.1.2 Selection of buildings: The climate-control variable

The buildings used in the current study were all occupied by clerical or administrative workforces with the one exception being a free-running university class room in the Brisbane surveys. The restriction to office work forces was determined by the need for comparability with other field studies (Humphreys, 1975) and also the requirement for reasonably accurate estimates of metabolic heat production. Such estimates become significantly prone to error in activities more variable than office work.

All but one of the air-conditioned buildings selected in the current surveys were occupied by government departments. The strategy adopted was to first get approval from the head of the government departments that were responsible for public service accomodation. An officer in each of these departments was then assigned to be a survey co-ordinator and their chief task was the selection of major buildings that represented the "typical" standard of air-conditioned accommodation for their government. The survey co-ordinator in each city then requested permission for the survey to proceed in the individual departments occupying the selected buildings. The number of air-conditioned buildings selected for study in the two Darwin surveys was larger than in the other two cities due to the greater emphasis on the descriptive research questions contained in Section 4.1.

Selection of free-running buildings containing reasonably large concentrations of sedentary office or administrative staff (greater than 50) was made very difficult by the scarcity of such establishments. None existed in Darwin, while in Melbourne, the only three premises in the entire range of Commonwealth and Victorian government accommodations that met the above criteria were used in the survey. In Brisbane, the survey of free-running buildings was confined to the administration building of the University of Queensland, a further three buildings occupied by a large organisation that has requested its name be withheld, and finally, a large teaching classroom at the University of Queensland.

To sum up, the air-conditioned buildings did not constitute a sample in the normal usage of the term. However, the various people used to purposively compile the selection were well qualified to judge whether or not any building was "typical" of office accommodation within the public

TABLE 5.2 : Air-conditioned buildings selected for study in Darwin, Brisbane and Melbourne

Survey	Building name	# subj.	Location	Comments
Darwin "Dry"	1 Rapid Ck Libry	5	Suburban	Small local library with single occupied zone. All staff interviewed. Leased
	2 Catterthun St	5	Suburban	Single occupied zone with three single-package roof-top units with ducting to open-plan work area. Leased.
	3 Paspalis Centrepoint	46	CBD	Four zones (N,S,E,W). Cooling capacity of 156 tons. Constant volume all-air distribution air conditioning. Set temperature 24degC +-1K. Leased.
	4 Minerals Hse	29	CBD	Three zones (E,NS,W). Variable air volume air conditioner with constant supply air temp. Set temp.= 21degC +-1K. Leased.
	5 Palmerstone	33	CBD	Leased.
	6 MLC	18	CBD	Six perimeter zones. 200 tons of cooling capacity. Constant volume all-air distribution. Set temp.=23degC +-1K. Leased.
	7 Tamar Hse	20	CBD	Leased.
	8 Plaza	18	CBD	Three zones (NE perimeter, SW perimeter and core). 398 tons of cooling capacity (includes shopping plaza). Economiser control system with outdoor thermosensors. Chiller switching on basis of indoor-outdoor temp. gradient. Set temperature 25degC +-1K. Leased.
Darwin "Buildup"	8 Plaza	16	CBD	Same building as above.
	9 Moonta Hse	30	CBD	Air conditioning system completely refurbished 2 months before the survey. Leased.
	10 Gregory/Leichdt	36	CBD	Constant volume variable air temperature distribution system. Set temp. 23.5degC +-0.5K. Owned by the depart. surveyed.
	11 Safety Hse	22	CBD	Conditioned supply air emitted via terminal units over which respondents exerted some control. Leased.
	12 Sturt Hse	55	Suburban	Variable air volume distribution system. Set temperature 23degC +-1K. Leased.
	13 Development Hse	21	CBD	Air conditioning system broke down on one of the survey days. Leased.
	14 Commnty College	17	Suburban	Four medium sized room air conditioners mounted in windows. Owned.
Brisbane AC	1 Commwlth Centre	74	CBD	Building owned by Commonwealth.
	2 Commwlth Courts	38	CBD	Leased.
	3 Statistics Hse	26	CBD	Leased.
	4 Taxation Hse	42	CBD	Leased.
	5 167 Eagle St	31	CBD	Leased.
Melbourne AC	1 Commonwealth Centre Block 1 and Link wing	31	CBD	Eleven zones. Perimeter zones have all-air, high velocity dual duct distribution with hot/cold mixing at each zone's plenum. Central core zone supplied with constant temp. air at variable volumes. Set temp.=22degC +-1K. Building owned by Commonwealth.
	2 Macarthur St number one	87	CBD	Three zones (N.E.perimeter, S.W.perimeter, central core). Central zone has modulating mixing boxes supplied with high velocity primary air. Perimeter zones have high velocity induction units supplied with chilled air, and also separate induction units, supplied with chilled water and mounted in every second window bay. Economiser control varies intake air according to outdoor temp. Heating coil was in use at some stages of summer, to maintain set temperature of 21degC all year round. Building owned by Victorian government.
	3 Saint Andrews Place number 33	37	CBD	Five zones (N,S,E,W,central core). All-air variable volume single duct system installed after the building was commissioned. Set temperature 21degC +-1K. Owned by Victorian government.
	4 Tivoli Court			Five zones (N,S,E,W,central core). High velocity all-air distribution, constant volume pre-mixed air supplied by separate air handlers each floor. Set temperature 22.2-22.5degC. Building leased.

CBD indicates Central Business District location

sector, because they were responsible for administering leases for such space if rented, or general maintenance requirements in the case of freehold premises. Moreover, in Darwin, the risk of bias in building selection was further minimised by using a large number of buildings out of a smaller range of possibilities (Darwin's population in 1982 was 61000 in comparison to 1.1 million in Brisbane and 2.8 million in Melbourne). As for free-running buildings, selection was simply a question of using all the options that were available. In terms of the overall research design, the small numbers of non-air-conditioned buildings are not critical because the descriptive research objective is de-emphasised in comparison with the air-conditioned surveys. Figures 5.2 through 5.6 depict the various buildings used in the six surveys and Table 5.2 briefly describes the air-conditioned selection, Table 5.3 the free-running premises.

TABLE 5.3 : Non-air-conditioned buildings selected in Brisbane and Melbourne

Survey	Building name	# subj.	Location	Comments
Melbourne NAC	1 Treasury Pl # 2	46	CBD	Old, thermally massive building with high ceiling and small windows.
	2 Commonwealth Centre Block 1	142	CBD	Light-weight, high-rise structure. Extensive glazing. Identical design as building # 1 and physically connected to it by a linking wing.
	3 Saint Andrews Place number 2	6	CBD	Medium-weight construction. Solar ingressions in afternoon created a thermally uncontrolable interior.
Brisbane NAC	1 Univ of Qld Administration	59	Suburban	Modern, light-weight construction typical of air-conditioned buildings. Double-glazed hopper windows.
	2 "Annexe"	43	CBD	Light-weight "temporary" structure in the courtyard of building # 3. Metal cladding and glass external walls.
	3 "Sandstone-A"	24	CBD	Heavy construction with thermal mass. Early 20th century pre-air conditioning design.
	4 "Sandstone-B"	75	CBD	As above
	5 Univ of Qld lecture theatre	17	CBD	Medium sized teaching space on the top floor (3rd) of a 1960s design. External solar shades. This building was only used for thermal questionnaires.

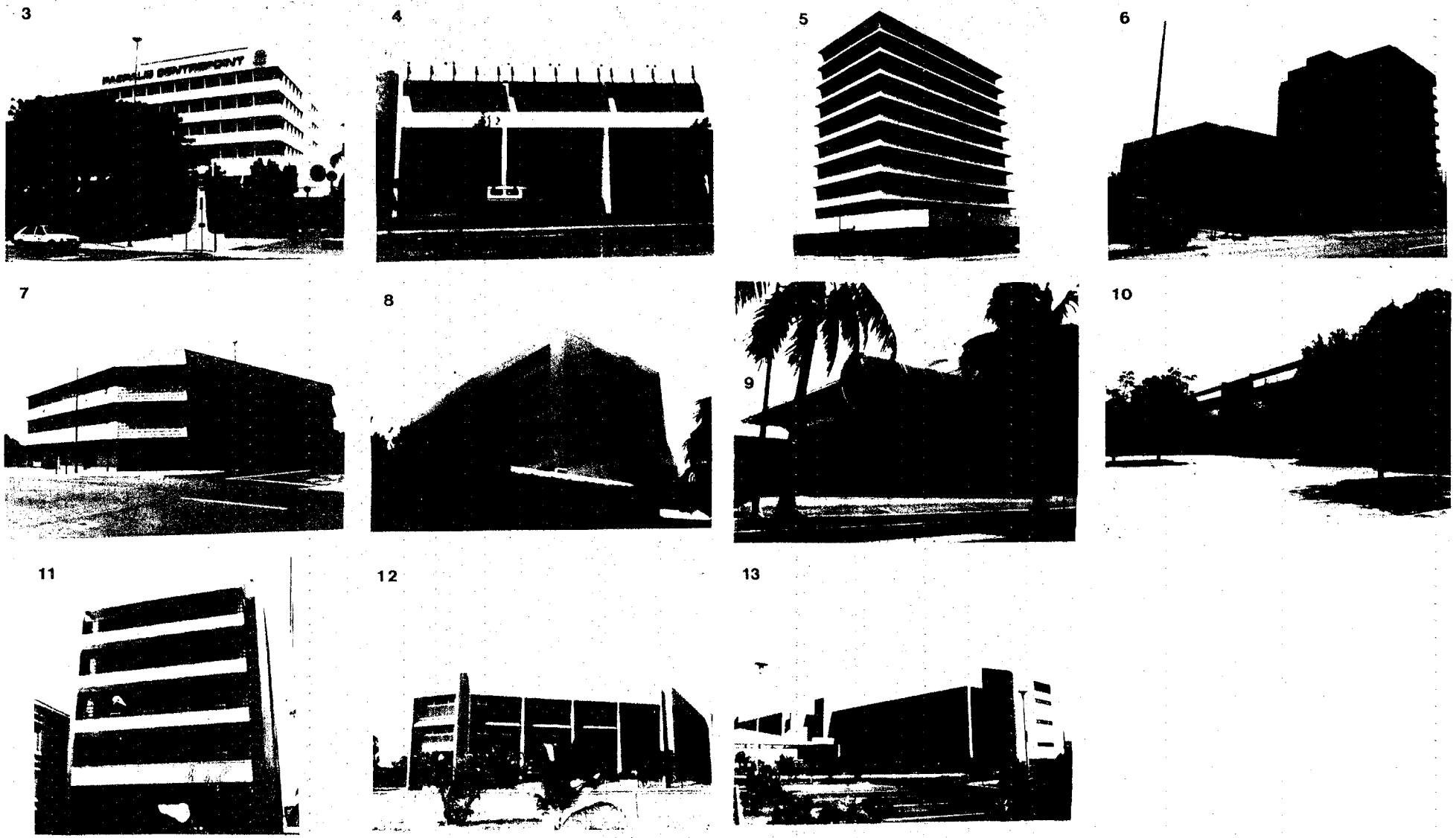


FIGURE 5.2 : Air-conditioned buildings in Darwin surveys (Numbers refer to Table 5.2)

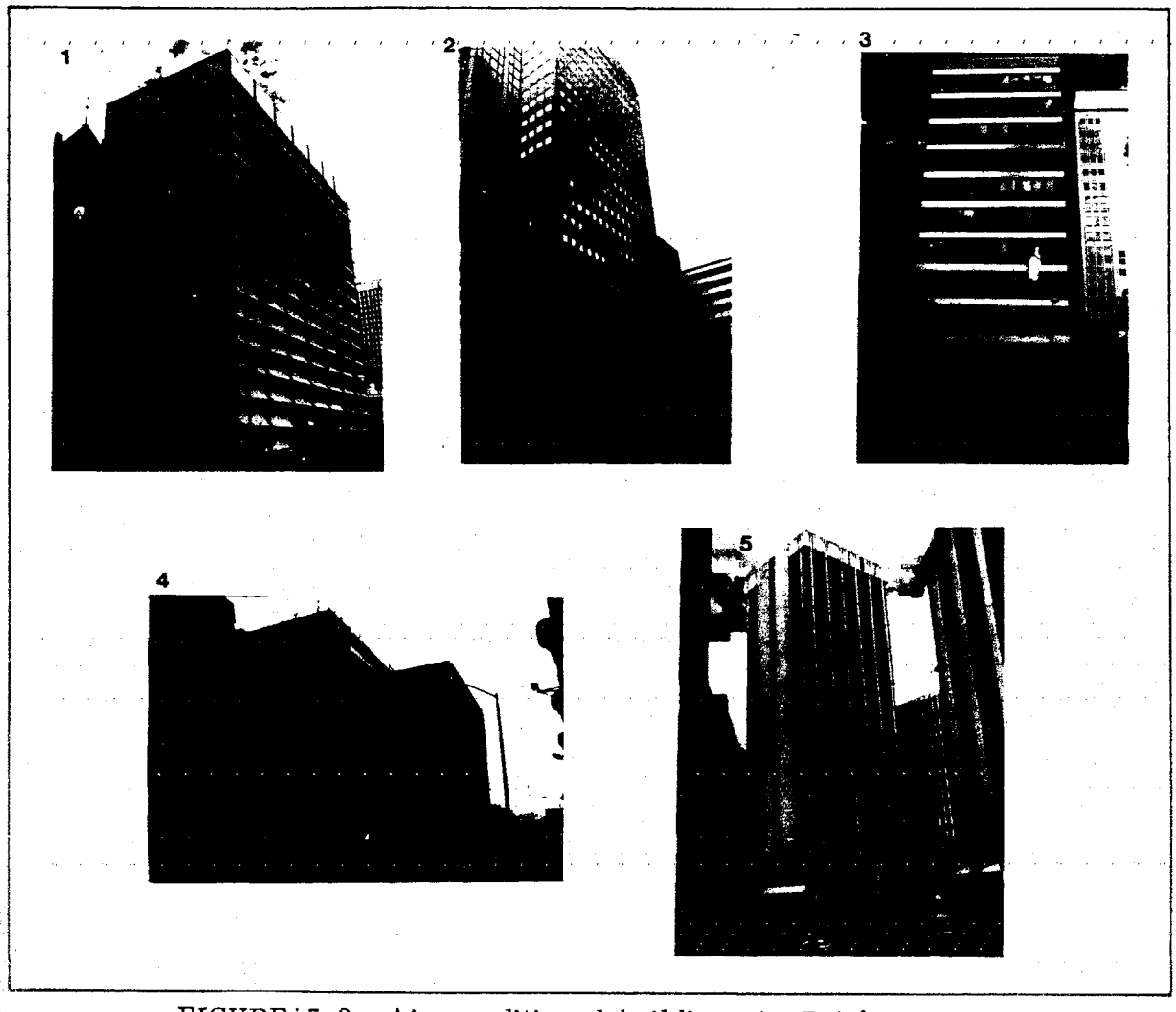


FIGURE 5.3 : Air-conditioned buildings in Brisbane
(Numbers refer to Table 5.2)

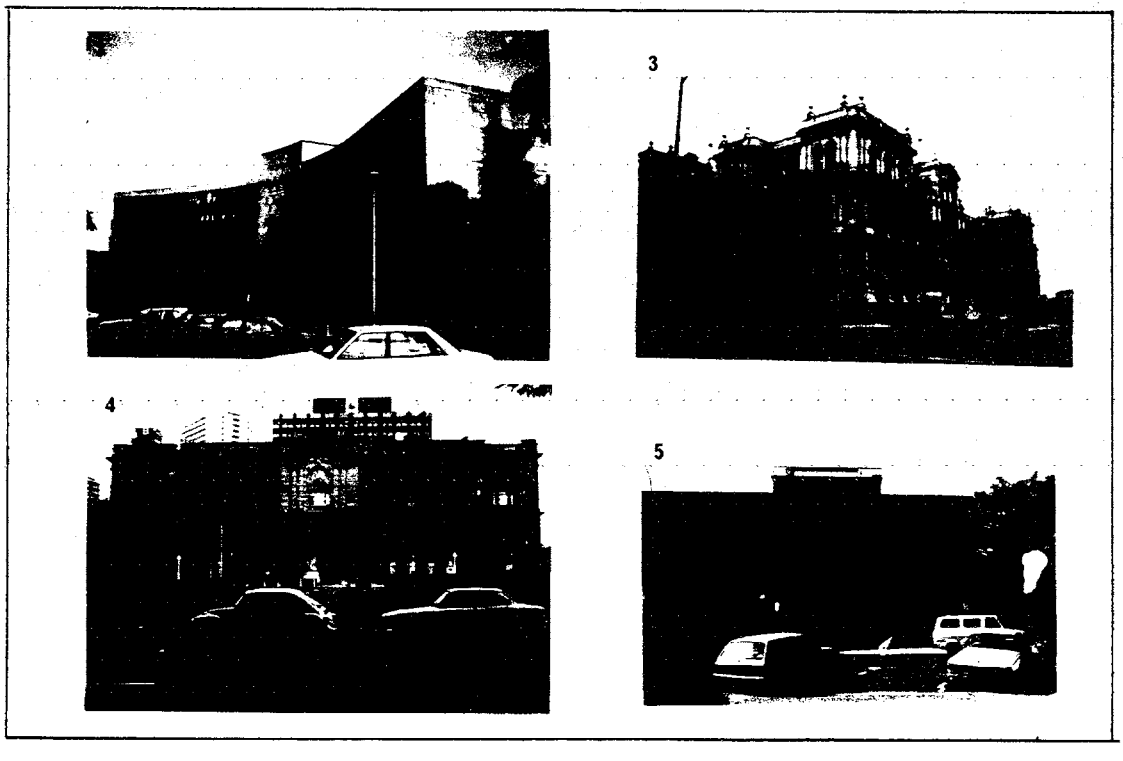


FIGURE 5.4 : Non-air-conditioned buildings in Brisbane
(Numbers refer to Table 5.3)

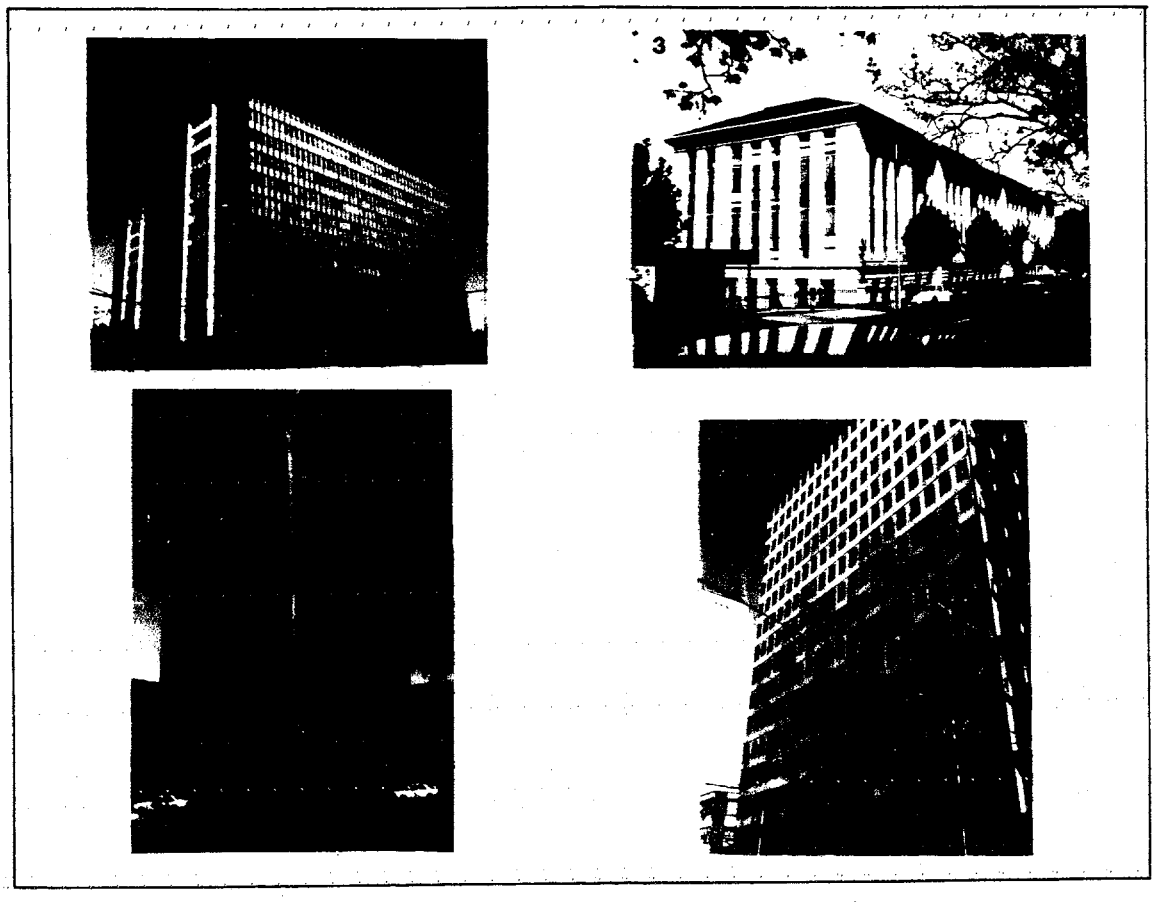


FIGURE 5.5 : Air-conditioned buildings in Melbourne
(Numbers refer to Table 5.2)

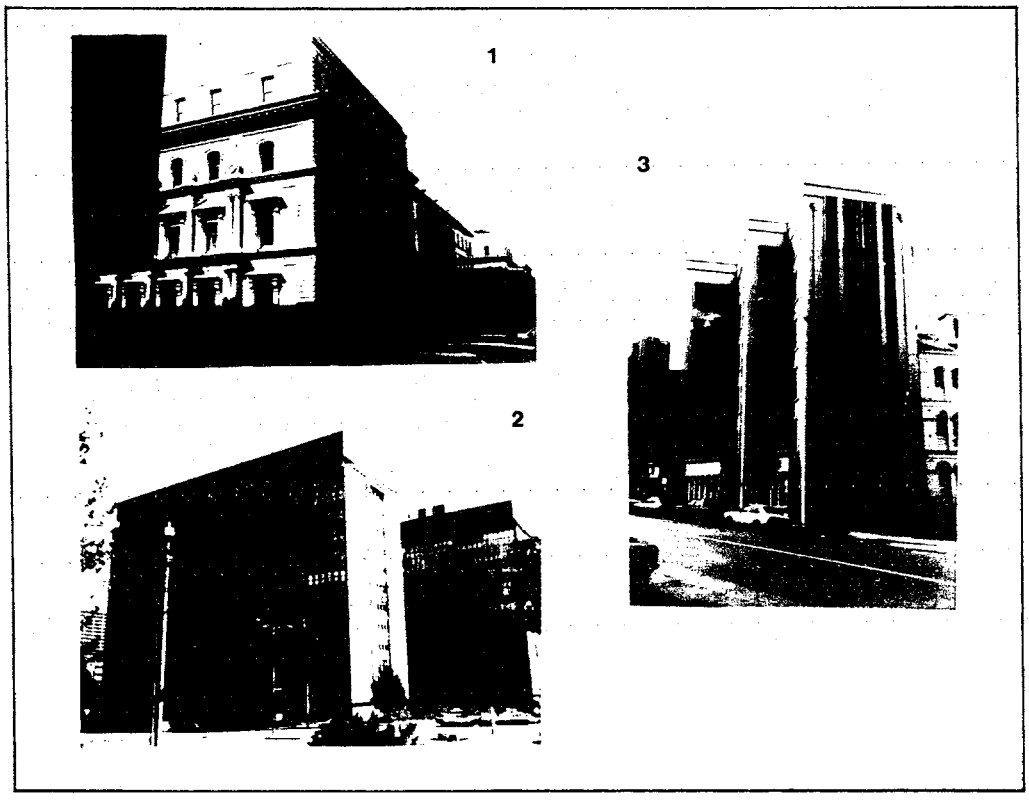


FIGURE 5.6 : Non-air-conditioned buildings in Melbourne
(Numbers refer to Table 5.3)

5.1.3 Samples of respondents

The various departments and sections that finally agreed to participate in the research were initially requested to circulate an internal memo outlining briefly the nature of the research and the possibility that staff members could be selected for participation in the survey. The memos stressed that while relevant departmental authorities and also the appropriate union officials approved the research, participation was entirely voluntary. This pre-sample "groundwork" proved to be instrumental in securing a small refusal rate (approximately 3% across the entire six surveys), and also a high level of interviewer cost-effectiveness. The latter benefit resulted from not having to brief each potential respondent about the nature of the research before getting their decision on whether or not to co-operate.

Before the sample of respondents could be drawn, a selection of rooms within each participating department had to be made. The sampling frame of rooms resembled that used in Langdon's (1965) survey of modern offices in London, with a preponderance of open-plan office spaces. However, the following types of room were excluded from the sampling frame:

1. Rooms used only for waiting or reception
2. Conference rooms
3. Exhibition rooms and cinemas
4. Rest and sick rooms

5. All other rooms that departmental officials requested the interviewer to leave undisturbed.

TABLE 5.4 : Biographical characteristics of the six building occupant samples

	DARWIN AC		BRISBANE		MELBOURNE	
	The Dry	Buildup	AC	NAC	AC	NAC
Number of respondents	174	197	211	218	186	194
Percentage females	57%	53%	48%	48%	34%	38%
Percentage males	43%	47%	52%	52%	66%	62%
Median age (Yrs)	31	32	29	26	31	27
Mean length of residence in survey city (Yrs)	9	10	18	19	24	21
Total no. of completed thermal questionnaires	493	555	564	611	512	555

Within each of the selected rooms, the interviewer made a preliminary sketch-plan of the area, indicating approximately where each work-station was located. These work-stations, which were treated as the final sample units, were then assigned a number on the sketch-plan. Using a table of random numbers, a very approximate sample-fraction of one third was aimed for. If a sampled work-station was unattended at the time of interview and was unlikely to become so within a reasonable period of time, an adjacent work-station was substituted.

Finally, in each of the six surveys, the multi-stage sampling procedure aimed for a total of about 200 respondents. The total numbers of respondents in each of the selected buildings are included in Tables 5.2 and 5.3. Biographical details of the respondents comprising the six samples of building occupants are also contained in Table 5.4.

5.2 Measurement of Heat-Balance Variables

It was pointed out earlier (Section 3.1.1) that there are six basic variables that govern the thermal exchange between environment and body. Four of these concern the microclimate; ambient air temperature, humidity, mean radiant temperature, and relative air velocity. The remaining two concern various attributes of the person; clothing factors and metabolic heat production. For detailed reviews of microclimatic measurement and instrumentation see Meteorological Office (1956), McIntyre (1980), Madsen (1976; 1979), Fanger (1970) and ASHRAE (1981a; 1981b).

5.2.1 Air temperature and humidity

Both wet- and dry-bulb temperatures were measured in the current study with an Assman Psychrometer (Casella Type 8900/1) as depicted in Figure 5.7. The bulbs of the two thermometers in the instrument are shielded from thermal radiation by two highly polished co-axial chromium tubes. The manufacturer's specification for the ambient air temperature accuracy of the psychrometer is $\pm$ 0.2K and this is attainable within two minutes of use. A clockwork motor and fan mechanism at the top of the psychrometer draws air over the two thermometer bulbs at a rate of

between 4-5m/s, which is above the speeds at which wet-bulb depression is reported to be sensitive to air flow variations (Meteorological Office, 1956, p.164). The instrument was read after being aspirated for three minutes at a level 0.6m above floor level. Its muslin sheath was changed every three days and distilled water was used to moisten it just prior to each recording in accordance with the guidelines set out in Meteorological Office (1956).

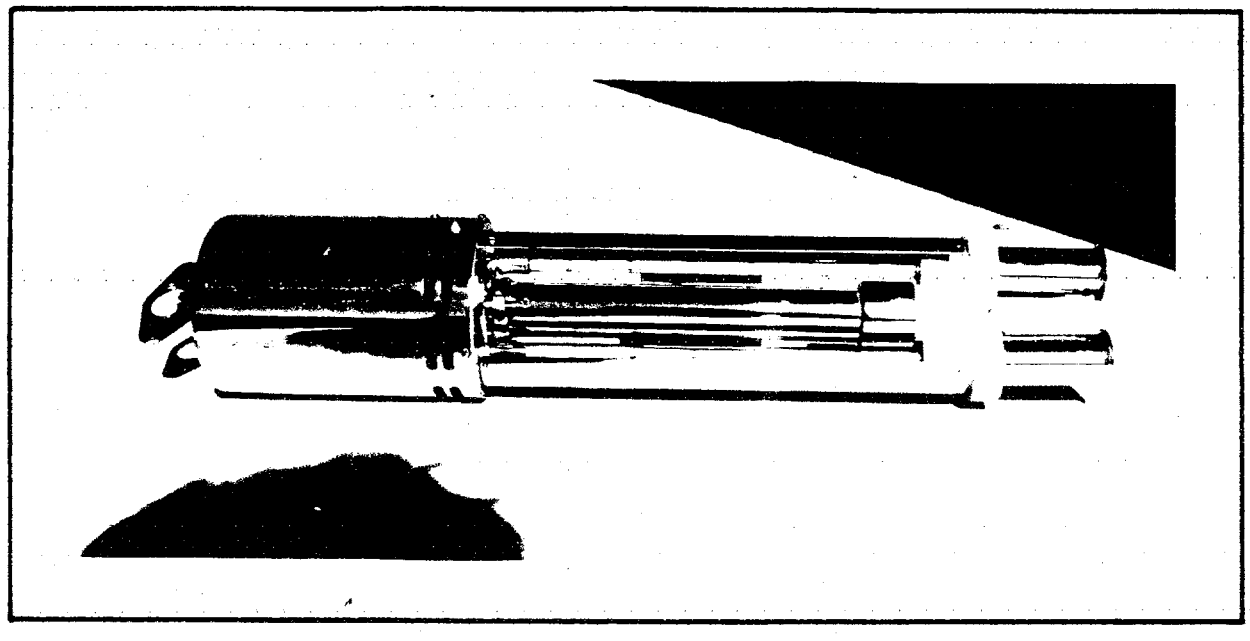


FIGURE 5.7 : Assman aspirated psychrometer

In order to calculate the partial vapour pressure it was first necessary to obtain the saturation vapour pressure (SVP) with the use of the Antoine Equation (McIntyre, 1980; Nishi and Gagge, 1977):

$$SVP(T_{wet}) = \exp[18.6686 - 4030.183/(T_{wet}+235)] \quad (mmHg) \qquad (5.1)$$

where T_{wet} is wet-bulb temp at which saturation is required

The partial vapour pressure was then calculated with the following expression:

$$P_a = [SVP(T_{wet}) - 0.5(T_a - T_{wet})] / SVP(T_a) \quad (mmHg) \quad (5.2)$$

where T_a is dry-bulb temperature

$SVP(T_a)$ is saturated vapour pressure at T_a

With equations 5.1 and 5.2 it was possible to obtain the relative humidity (RH) from just dry- and wet-bulb temperatures by dividing partial vapour pressure by the saturation vapour pressure:

$$RH = [P_a / SVP(T_a)] * 100 \quad (\%) \quad (5.3)$$

5.2.2 Relative air velocity

Of the microclimatic parameters recorded, air velocity posed the most difficult measurement problems due to its tendency to fluctuate dramatically both spatially within a room and across time at any one recording site. This variability necessitated a recording at the work-station of each respondent while they completed the questionnaire. The Kurz 441M instrument used (see Figure 5.8) is of the constant wire temperature variety with automatic ambient temperature compensation. Of the three velocity ranges available, the zero to 1.5m/s bandwidth was most frequently used, and the manufacturer's specifications claim an accuracy of $\pm$0.03m/s at these velocities. The device was furnished with a calibration certificate traceable to the U.S. National Bureau of Standards (Test Numbers 213-21/190522). The sensing element is non-directional as long as the window of the tip cage is oriented within

±20 degrees of being normal to the flow direction.

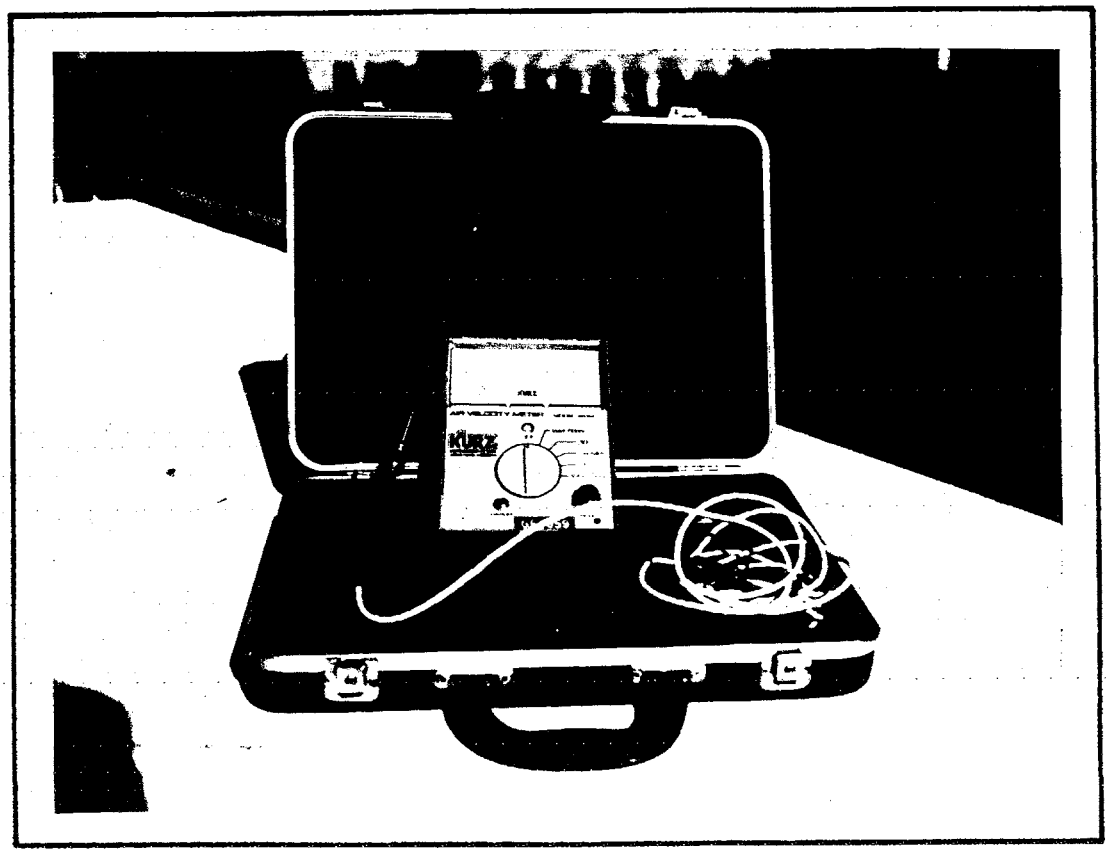


FIGURE 5.8 : Hot-wire anemometer

In trying to estimate the average ambient velocity of a particular recording site, a rudimentary sampling procedure was employed, consisting of three separate estimates at 0.1, 0.6 and 1.1m levels above the floor for sedentary respondents. Due to the high variability of air velocity, each of these three estimates was based on an average of the stable-high-point and stable-low-point readings on the anemometer's analogue scale during the course of the observation period. This procedure was based on the prescription set out in ASHRAE Standard 55-81 (ASHRAE, 1981b). In the more complicated case of a responder sitting in the path of an oscillating fan, the air velocity sampling procedure was stratified to yield a separate set of readings for both conditions; fan

directed at respondent and fan off. The final velocity was simply a time-weighted mean of all six estimates.

5.2.3 Mean radiant temperature

Miniature, "home-made" globe thermometers as described by Humphreys (1977) were used in the current surveys. However, Humphreys only recommended the use of the instrument as a unitary index of human warmth; not as a method of deriving mean radiant temperature. Since the most useful measure of radiant fields indoors is the mean radiant temperature, an experiment was conducted in which the performance of both sizes of globe thermometers - 40mm and 150mm - was compared (see Appendix B). The data obtained in that experiment suggested that ping-pong globe thermometers could be successfully used in field conditions. The instrument reached thermal equilibrium with most typical environments in less than 10 minutes of exposure time.

The mercury-in-glass thermometers employed in the instrument were manufactured by Zeal and calibrations were in accordance with British Standard 2842/66. In use, the thermometer was inverted and supported by a small wooden base as depicted in Figure 5.9. Inversion of the mercury-in-glass thermometer had no effect on the reading it gave. The instrument was placed about 0.6m above floor level (ASHRAE, 1981b), which usually amounted to being on the respondent's desk, about the same distance from obvious heat sources such as lamps and visual display units as the respondent him/herself.

The mean radiant temperature of the recording site was derived with Equation 5.4:

$$T_{mrt} = \frac{T_g - T_a \left[1-\left(\frac{1}{1+1.13\ v^{0.6}\ d^{-0.4}}\right)\right]}{\left(\frac{1}{1+1.13\ v^{0.6}\ d^{-0.4}}\right)} \quad \text{(degC)} \qquad (5.4)$$

where T_{mrt} is mean radiant temperature

T_g is globe temperature

T_a is air temperature
v is air velocity (m/s)
d is globe thermometer diameter (m)

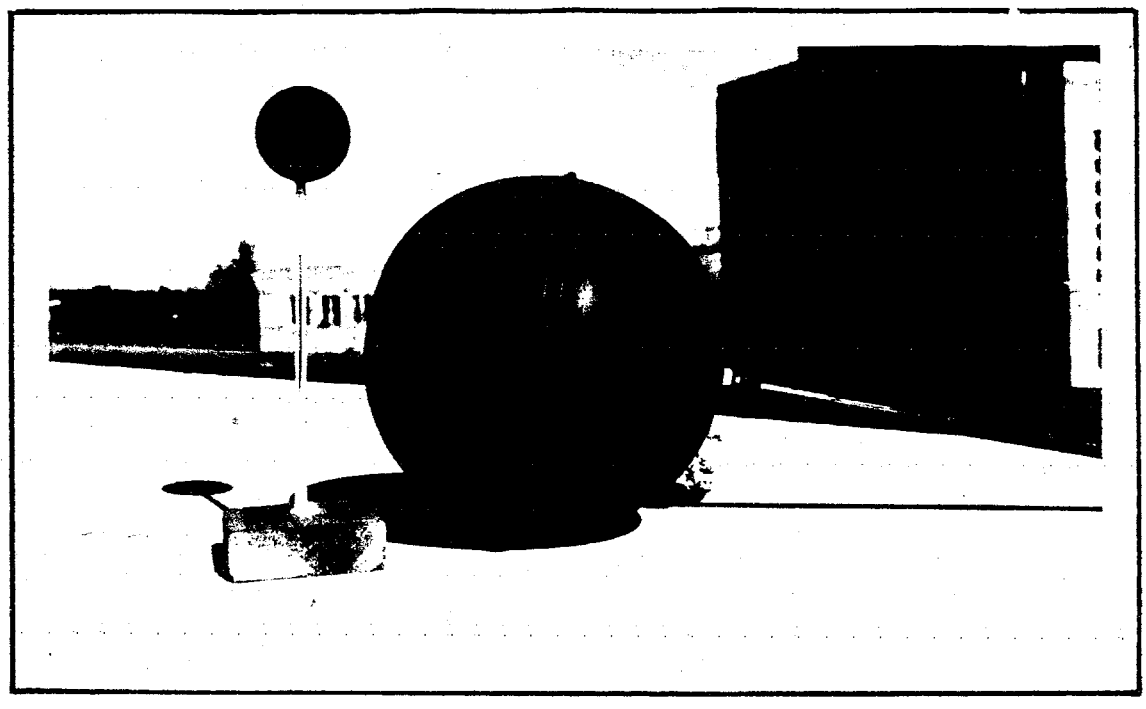


FIGURE 5.9 : Ping-pong globe thermometer compared with traditional 150mm version

5.2.4 Metabolic heat production

Metabolic rates were estimated by consulting published tables for the relevant activity types observed in the offices (Bruce, 1960; ASHRAE, 1981a; Fanger, 1970; Astrand and Rodahl, 1977; Katch and McArdle, 1977; Durnin and Passmore, 1967). An assumption was made that the external mechanical efficiency of office workers was zero and the specific dynamic action of food absorption had to be treated as random error. The frequently encountered activities in office surveys are summarised in Table 5.5 along with their associated metabolic rates.

The questionnaire items that elicited activity descriptions from respondents are attached to the end of the Thermal Questionnaire in Appendix D. The interviewer attempted to get a break-down of activities

TABLE 5.5 : Metabolic rates of typical office tasks and related activities

Activity	Metabolic rate M/A_{Du} (W/m^2)
Seated reading	58
Seated writing	62
Seated typing	66
Seated filing	70
Seated talking	65
Standing still	70
Draughting	70
Standing filing	80
General office duties-on feet & mod. active	79
Walking indoors - strolling	104
Walking normal pace outdoors	116
Lifting/packing - light weights	120
Driving car in moderate traffic	87

Compiled from various sources cited in the text. Where different authors have given discrepant estimates for the same activity, an average was used.

for four time periods immediately preceding the time of interview; the last 10 minutes, 10 minute period before then, 10 minutes before then, and finally, the half hour immediately before the last half hour. Within each period, the interviewer attempted to construct a time-weighted average if more than one activity type was reported by the respondent (ASHRAE, 1981a, p.8.12). The four time period estimates were then averaged and the result was used for input to the PMV and SET indices. The procedure does not take into account the duration of exposure effect discussed in some three-hour long chamber studies (Rohles and Nevins, 1968; Rohles, 1971).

5.2.5 Clothing factors

Interest in the quantification of clothing was originally stimulated by

the requirements of armed forces fighting in unfamiliar climates (Fourt and Hollies, 1970; Lee and Lemons, 1949). The clo unit was introduced by Gagge, Burton and Bazett (1941), defining it as the amount of insulation necessary to maintain comfort and a mean skin temperature of 33degC in an ambient dry bulb temperature of 21degC, air velocity less than 0.1m/s, humidity less than 50% and metabolic heat production of 58W/m^2. In heat-flow terms, this amounts to a resistance of 0.155W/m^2.degC (Nishi and Gagge, 1977, p.98).

More recent interest in the quantification of clothing has come from the HVAC industry and has led to the development of the Clo Value Index (Seppanen et al., 1972). The total ensemble insulation of a system of clothing garments is derived by inputting the sum of individual garment clo to the two regression equations (one for each sex) derived by Sprague and Munson (1974):

$$\text{womens' ensemble } I_{clo} = 0.770(\Sigma \text{ garment } I_{clo}) + 0.05 \qquad (5.5)$$

$$\text{mens' ensemble } I_{clo} = 0.727(\Sigma \text{ garment } I_{clo}) + 0.113 \qquad (5.6)$$

These statistical models had standard errors of estimates at about 0.05 clo which would amount to the thermal effect on comfort of about 0.3K.

Table 5.6 shows the individual garment clo values that were used in the current study to code the clothing item check-lists presented to respondents in the Thermal Questionnaire (Appendix D). The adjectives "light", "medium" and "heavy" were assigned to garments by the respondents in consultation with the interviewer on the basis of material thickness, fibre construction and fabric weight.

TABLE 5.6 : Individual clothing garment insulation values (clo)

men				women			
item	light	med.	heavy	item	light	med.	heavy
underpants		.05		bra and panties		.05	
singlet		.06		slip (half)		.13	
"t" shirt		.09		slip (full)		.19	
shirt(shortsleev)	.14	.20	.25	dress(no sleeve,above knee)	.18	.38	.58
shirt(longsleeve)	.22	.26	.29	dress(no sleeve,kneelength)	.19	.41	.61
tie(+ 5% of shirt)				dress(no sleeve,belowknee)	.20	.42	.63
vest	.15	.22	.29	dress(sh.sleeve,above knee)	.19	.40	.60
shorts		.10		dress(sh.sleeve,kneelength)	.20	.42	.63
trousers	.26	.29	.32	dress(sh.sleeve,below knee)	.21	.44	.66
pullover(sh.sleeve)	.18	.26	.33	dress(longsleeve,above knee)	.21	.44	.66
pullover(l.sleeve)	.20	.29	.37	dress(longsleeve,kneelength)	.22	.46	.69
jacket	.22	.36	.49	dress(longsleeve,below knee)	.23	.48	.73
socks(anklelength)		.04		blouse(short sleeve)	.18	.23	.26
socks(knee high)		.10		blouse(long sleeve)	.20	.25	.29
sandals		.02		skirt(above knee)	.10	.15	.21
shoes		.04		skirt(knee length)	.10	.16	.22
boots		.08		skirt(below knee)	.11	.17	.23
				shorts		.10	
				slacks	.26	.35	.44
				jacket	.17	.27	.37
				pullover(short sleeve)	.15	.24	.33
				pullover(long sleeve)	.17	.27	.37
				stockings		.01	
				socks		.01	
				sandals		.02	
				shoes		.04	
				boots		.08	

Table entries interpolated from data in ASHRAE,1981a; Seppanen et al., 1972; Sprague and Munson, 1974; Nishi et al., 1976

Because the outer layer of a clothing system is the site at which most of the body's heat is lost to the environment, the amount of surface area available for these transactions becomes an important variable when modelling heat balances. The area is related to the bulkiness of the clothing, and Fanger (1970, p.33) reported that it increased by 15% over

the DuBois body surface area for each clo unit of ensemble insulation:

$$F_{cl} = 1 + 0.15(I_{clo}) \qquad (5.7)$$

where F_{cl} is the clothing area factor
I_{clo} is ensemble clothing insulation

The clothing factor is treated in more detail by the SET index than the PMV model. The latter simply uses an I_{clo} estimate from either Equation (5.5) or (5.6) and the F_{cl} from Equation (5.7). These are satisfactory to describe the dry heat exchange between the skin surface and outer clothing layer, but they do not take into account the boundary layer outside the clothing system. The SET uses another parameter, effective insulation, to incorporate this effect and it is related to the ensemble clothing insulation by the following equation (Nishi and Gagge, 1977):

$$I_{cle} = I_{clo} - (F_{cl}-1) / (0.155 * F_{cl} * h) \qquad (5.8)$$

where I_{cle} is effective insulation (clo)
I_{clo} is ensemble insulation (Eq.5.5-5.6)
F_{cl} is clothing area factor (Eq.5.7)
h is combined dry heat transfer coefficient (radiant h_r + convective h_c)

The SET index goes beyond dry heat transfers through clothing and its boundary layer to include the effects on vapour movements as well. Nishi and Gagge (1970) introduced the term permeation efficiency factor to denote the cooling efficiency of sweating on the skin for a clothed human body. This factor can be estimated from a knowledge of the

effective insulation value of the ensemble and also the convective heat transfer coefficient (Nishi and Gagge, 1970; Nishi et al., 1975):

$$F_{pcl} = 1 / (1 + 0.143\ h_c\ I_{cle}) \qquad (5.9)$$

where F_{pcl} is permeation efficiency factor
h_c is convective heat transfer coefficient
I_{cle} is effective clothing insulation

5.3 Derivation of Heat-Balance Comfort Index Values

The two main mathematical models of thermal response to be used in the current investigation were conceptually outlined in Section 3.2. The current section simply describes how they were applied to the current data. Fortran IV and BASIC programs for Fanger's predicted mean vote (PMV) index, predicted percentage dissatisfied (PPD) index, and the Pierce two-node model with Standard Effective Temperature (SET) index are listed in Appendix C.

Referring first to the PMV index, it will be noted that Equations (3.3), (3.5) and (3.6) which define PMV are interconnected in such a way that there is no simple solution. The approach used in Appendix C begins by factoring the equations as far as possible by letting:

$$\begin{aligned} ALPHA = {} & M/A_{Du}\ (1-\eta) - 0.35\ [43 - 0.061\ M/A_{Du}\ (1-\eta) - P_a] \\ & - 0.42\ [M/A_{Du}\ (1-\eta) - 50] - 0.0023\ M/A_{Du}\ (44-P_a) \\ & - 0.0476\ M/A_{Du} \end{aligned} \qquad (5.10)$$

Substituting ALPHA into Equation (3.3):

$$PMV = (0.352^{-0.42M/A_{Du}} + 0.032\,[ALPHA + 0.0014\,M/A_{Du} * T_a - 3.4 * 10^{-8}\,F_{cl}\,[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] - F_{cl}\,h_c\,(T_{cl} - T_a)] \quad (5.11)$$

Equation (5.11) is a fourth degree polynomial in T_{cl} and may be solved iteratively by the Newton-Raphson method; if XO is an approximation to a root of F(X)=0, then a better guess (X1) is:

$$X1 = XO - F(XO) \,/\, [\frac{df(XO)}{dx}]$$

and an even better guess (X2) is given by:

$$X2 = X1 - F(X1) \,/\, [\frac{df(X1)}{dx}]$$

and so on to the nth approximation:

$$X_n = X_{n-1} - F(X_{n-1}) \,/\, [\frac{df(X_{n-1})}{dx}] \quad (5.12)$$

Rewriting the expression T_{cl} (3.4) to equal zero gives:

$$F(T_{cl}) = 0.612 * 10^{-8}\,I_{clo}\,F_{cl}\,(T_{cl}+273)^4 + (0.18\,I_{clo}\,F_{cl}\,h_c + 1)T_{cl} - 0.18\,I_{clo}\,F_{cl}\,[h_c\,T_a + 3.4 * 10^{-8}\,(T_{mrt} + 273)^4] - 35.7 + 0.032\,M/A_{Du}\,(1-\eta) = 0 \quad (5.13)$$

Equation (5.13) may readily be differentiated to give:

$$F'(T_{cl}) = 4 * 0.612 * 10^{-8}\,I_{clo}F_{cl}\,(T_{cl}+273)^3 + 0.18 I_{clo}F_{cl}h_c + 1 \quad (5.14)$$

The Newton-Raphson iterative solution in Equation (5.12) may be applied as often as desired to Equations (5.13) and (5.14) and each new iteration

should yield a better estimate of the outer surface temperature of a clothing ensemble than its predecessor. However, to start the process off, it is necessary to seed an initial guess of T_{cl}. The programs in Appendix C started with 20degC and they make an initial assumption that the forced convective heat transfer coefficient from Equation (3.6) applies. If the iterative process yields a better approximation for each cycle, then the magnitude of the improvements must diminish as the true solution is approached. This feature has been used in the programs to terminate the iterations when the absolute value of the difference between the new estimate and its predecessor was less than 0.01K.

After arriving at solutions for clothing surface temperature and the convective heat transfer coefficient, their values are simply substituted into Equation (3.3) to give Predicted Mean Vote (PMV).

Fanger's preferred temperature was derived from the PMV programs listed in Appendix C by iteration until PMV=0, while incrementing or decrementing the operative temperature by 0.1K for each new loop. Fanger's Predicted Percentage Dissatisfied index (PPD) is, according to ISO (1984), a simple function of PMV:

$$PPD = 100 - [95 * \exp(-0.03353PMV^4 - 0.2179PMV^2)] \qquad (5.15)$$

Finally, the Fortran IV and BASIC implementations of the Standard Effective Temperature index included in Appendix C are based on 60 loops around the Pierce 2 node thermoregulatory model; one loop for each real-time minute of an hour's exposure in the specified thermal environment. At the end of that hour, the model arrives at final values for $\bar{T}_{sk}$ and w which are then used to deduce the SET that would be

necessary during an hour of steady-state exposure in the standard environment to induce the same magnitude of thermoregulatory response.

5.4 The Outdoor Meteorological Environment

External data were required for two main purposes:

1. Mean monthly temperatures for the duration of each field study were required in order to use the predicted neutrality Equations (3.7), (3.8), (3.9) and (3.10).

2. Basic meteorological variables occuring at the time of each interview were required to investigate the possibility of indoor thermal responses such as clothing behaviour, thermal sensation, comfort and preference being related to external conditions. In effect, "spot values" of meteorological conditions were required.

The mean monthly temperatures were readily obtained by averaging the mean monthly minimum and maximum published by the Bureau of Meteorology for each survey city. The recording sites for these data were the city observatories in Brisbane and Melbourne and therefore representative of most building locations listed in Tables 5.2 and 5.3. The Darwin data were recorded at the airport which was about 4km from the central business district (CBD). In the case of surveys that extended beyond a single month, the mean monthly temperature was derived by taking a weighted average, with weights being determined by the number of survey weeks in each month. While this method yielded only a crude estimate, it

exceeds the accuracy of Humphreys' (1976) and Auliciems' (1983) technique. They used long-term average data as their $T_{\overline{m}}$ values that could in some cases be considerably different from actual levels of warmth prevailing outdoors at the time when the field studies were being conducted.

The second type of external meteorological data, "spot values", were more difficult to obtain than the mean monthly temperatures. In Melbourne, an hourly observation sheet containing wet- and dry-bulb temperatures and relative humidity was obtained from the Bureau of Meteorology for each day on which interviewing was conducted. The Bureau's CBD observatory was the recording site and therefore these data would be close to the actual conditions outside the survey buildings. No Melbourne interview was conducted any more than half an hour before or after its associated "spot values" for external meteorological variables. A similiar data source was provided for the Darwin surveys by the Bureau of Meteorology's airport observatory. The major difference was that the recordings were three hourly, consequently it was possible for a Darwin interview to have been conducted as much as one and a half hours away from the corresponding outdoor data recordings. A simple method of mitigating this difficulty was to linearly interpolate between successive Bureau of Meteorology recording times.

The "spot values" for the Brisbane surveys were obtained from the University of Queensland's weather station, which was situated on top of one of the free-running survey buildings used in that city (building number 5 in Table 5.3). These data were supplied as continuous thermohygrograph traces of dry-bulb temperature and relative humidity for each week in which interviews were conducted in the Brisbane surveys. It

is acknowledged that the data obtained from the University observatory in Brisbane would be, in some cases, different from Bureau of Meteorology city observations. However, the error would, in all probability, be no more than that resulting from interpolation between three-hourly Bureau of Meteorology observations, as in the Darwin case.

5.5 The Questionnaires

The research design required each respondent in the six surveys to be interviewed on three separate days. During the first session they were required to fill in a "thermal questionnaire" that dealt exclusively with subjective assessment of their immediate microclimate. Also on the first contact, each respondent was taken through a lengthy interview schedule dealing with a variety of long-term perceptions of microclimate, attitudes and beliefs regarding various microclimate control practices and finally, a battery of classification questions. On the second and third contact with each respondent, the thermal questionnaire was completed again.

5.5.1 Thermal questionnaire

The data collected in each thermal questionnaire session can be classified into three components:

1. Each session was opened with the interviewer's questions about activities that the respondent had perf`rmed in the hour preceding the interview. The interviewer's opening comments are printed on the data sheet attached to the specimen thermal questionnaire in Appendix D.

2. Subjective assessments of various aspects of the immediate microclimate.

3. A garment by garment description of the clothing ensemble being worn at the time of interview (see Section 5.2.5).

The subjective assessments of microclimate were obtained by a battery of questions dealing with thermal comfort, thermal sensation, thermal preference, perceived humidity, air motion and stuffiness, but only the first three of these are dealt with in the current thesis. After initial versions of the questions were pilot tested on a second year Geography class at the University of Queensland, the final questionnaire was sufficiently concise to be completed during the time that it took the interviewer to record the microclimatic variables discussed in Section 5.2. Each of the assessment scales was presented to the respondent as a continuum, along which there were various descriptive labels. Respondents were informed they could use these "thermometer" scales by placing a mark either directly on one of the labelled points, or anywhere in between, thereby allowing a high degree of sensory discrimination to be expressed, and also bringing the data up from the ordinal towards the interval level of measurement.

In the interests of compatability with previous work, the basic ASHRAE and Bedford scales in their original seven-point form (c.f. the nine-point versions proposed by Roberts, 1959; Rohles, 1974) were adopted in the current investigation. In deference to Humphreys (1975), the two scales were prefaced with questions that focused on subjective warmth and comfort instead of asking for objective assessments of the

microclimate. This is in compliance with the procedure typically employed in chamber studies (e.g. Nevins et al., 1966; McNall, Ryan and Jaax, 1968). For a review of seven-point scales of warmth, the interested reader is directed to McIntyre (1978c).

In order to investigate the validity or otherwise of the "semantic set" criticism levelled at field studies by McIntyre (1978a) (see Section 3.4), a new rating scale was developed to assess thermal preferences of building occupants (PREFV). The prefacing question to this item asked respondents if, dressed as they were at the time of interview, they would prefer the temperature of the room to be warmer or cooler than what it was at that time. The "dressed as you are" clause was included to disentangle thermal preference from the non-thermal preference for wearing a particular level of clothing insulation. Fisk's (1981, p.27) anecdotal example can help clarify this distinction between preferred temperature and preferred state: An appropriately dressed office worker waiting for a bus in winter should give a "comfortable" or "neutral" assessment on the Bedford or ASHRAE scale. Yet, when asked whether they would prefer it warmer, the office worker would probably say "yes", because of an implicit assumption that they could remove their overcoat in the warmer weather.

Apart from the actual items included in the thermal questionnaire, other variables were subsequently derived from the data in the completed schedule. One of these was the discrepancy (DISCR) between the respondents actual ASHRAE scale vote and what the Fanger model (1970) predicted an "average" person would vote in the specified environment at the same level of metabolic heat production and clothing insulation (PMV). Thus an ASHRAE vote of +1.6 and a PMV score of +0.7 yielded a

DISCR score of +0.9, which indicates that the respondent expressed personal warmth almost one full category warmer on the seven-point scale than their heat-balance status should have induced according to Fanger's model. Since each respondent ideally completed three thermal questionnaires during the course of a survey, three separate DISCR scores could be calculated. The average of these three (or how ever many questionnaires were completed) discrepancies between predicted and actual warmth assessments was called DISPO, and was used as an indicant of each respondent's thermal disposition vis-a-vis the mathematical model of human comfort. It thus provided a means of classifying respondents into "warm" and "cool" groups after the peculiarities of the thermal environment in which they were questionnaired had been partialled out.

Finally, numerous statistical techniques were employed in the analysis of data elicited by the scales described above. For a detailed discussion of the most important method, probit analysis, see Appendix E.

5.5.2 Attitudinal, cognitive and behavioural questionnaire

The actual format of the thermal questionnaire was replicated in each of the six surveys. This was not true of the attitudinal, cognitive and behavioural questionnaire (hereafter referred to as the "attitude questionnaire" for simplicity). Unlike the thermal questionnaire in which the design emphasis was on inter-survey compatibility, the attitude schedule was adapted to each survey's general context. For example, in view of the anticipated high levels of home air-conditioning ownership in Darwin, certain questionnaire items were specifically directed to this feature in that city but not in the other two. The current section describes the main items on the attitude questionnaires that are

reproduced in Appendix F.

Being an hypothetical construct, considerable confusion exists regarding the definition of attitude. It falls somewhere within the area of personality theory, being less enduring than temperament, but more lasting than mood. Attitude is defined for the present purpose as an enduring organisation of emotional, cognitive and motivational processes with respect to some aspect of the individual's world (Scott, 1969). These three components of the construct; 1) affect, 2) belief, and 3) behaviour, form the focus of the methods to be described in the current section. The individual scales and questionnaire items used in the study were formatted on the basis of pilot testing among university students and about twenty Darwin public servants. Pilot testing also indicated that an interview length of 15 to 20 minutes was the upper limit of respondents' patience after the thermal questionnaire had been completed.

Following the general design principles for questionnaires in Oppenheim (1966) and Hymen (1955), the schedule proceeded from general, open-ended questions at the beginning, to specific and detailed items at the end. However, before any questions were asked, the respondents were given an operational definition of air-conditioning as involving a "refrigeration process by which the temperature, humidity and circulation speed of air within an enclosed space could be controlled."

Following a lead from Wanner (1973), respondents in all six surveys were asked open-ended questions concerning their beliefs in the costs and benefits of air-conditioning in the work-place. The questior format was; "What are the (disadvantages/advantages) in your opinion, of summer air conditioning in the workplace?" Respondents were prompted for three

advantages and three disadvantages and their answers were subsequently classified into a coding frame established on the basis of a sub-sample (N=50) of completed questionnaires in each of the six surveys. In anticipation of a greater degree of home air-conditioning ownership in Darwin than in either Melbourne or Brisbane, the Darwin questionnaire also applied the open-ended advantage/disadvantage question to domestic air-conditioning, which was defined as anything from room air-conditioners up to full-house ducted systems.

A specific cognitive issue addressed by the Brisbane and Melbourne questionnaires was the respondents' belief or otherwise in the deleterious effects of air-conditioning on building occupants' health: "Do you believe that working in refrigerated air-conditioned buildings is bad for your health, or that there is no connection between health and air-conditioning?" Respondents answering with a "definitely" or "possibly yes" were prompted for three medical conditions that they attributed to exposure to air-conditioning in summer. These too were classified into a coding frame after each survey. This issue was followed up later in the Brisbane and Melbourne schedules with a question in which respondents rated their general level of health at the time of interview. Also related to health issues in indoor climates, respondents were questioned about their attitudes on passive smoking.

Another cognitive issue investigated in the Melbourne and Brisbane questionnaires concerned the relative importance that building occupants attached to indoor climatic factors vis-a-vis other elements of the built environment. The question attempted to measure the salience dimension (Scott, 1969, p.208) of the attitude. Hershberger (1972) has shown by factor analysis that there are eight major dimensions in the meaning of

architectural environments: 1) location, 2) privacy, 3) spaciousness, 4)HVAC, 5) equipment and furniture, 6) lighting, 7) windows and view, and 8) aesthetics (appearance and decor). Farrenkopf and Roth (1980) assessed the relative importance of these dimensions in determining occupant satisfaction with university faculty offices by getting respondents to rank them. They found that HVAC and equipment were in the middle of the ranking. The current investigation requested the occupants of air-conditioned and free-running buildings in Brisbane and Melbourne to indicate their subjective assessments of the importance of these dimensions by rating each on a four-point scale (Oppenheim, 1966, p.90). Pilot testing indicated that this task was faster for respondents to complete than ranking. The only modification to Hershberger's (1972) eight-point list of dimensions was the HVAC item being split into two components: 1) thermal aspects of indoor climate, and 2) air quality. This change ensured that the rating scales would be applicable to free-running buildings as well as air-conditioned.

The hypothesis concerning effects of micro-climatic controls on building occupant expectations and their ability to adapt to sub-optimal conditions was investigated by requesting respondents in all six surveys to indicate their overall impression of the environmental warmth at their work-place during the season in which the survey was conducted. The linear format of the ASHRAE scale (as discussed in Section 5.5.1) was used to record these overall assessments of the respondent's home as well as their working environment. A further extension of this line of questioning in Melbourne and Brisbane was achieved by the inc.usion of a linear formatted scale of acceptability for the respondent's overall seasonal warmth impression. The points on the scale were: 1)

satisfactory, 2) slightly unsatisfactory, 3) unsatisfactory, 4) very unsatisfactory, and 5) intolerable.

In dealing with the effective or "quasi-behavioural" component of attitudes on air-conditioning, respondents were asked whether or not they preferred working in air-conditioning. Pilot testing revealed this question to be sensitive to wording and format details and it was stressed that the options were not simply the current building with or without air-conditioning, but rather "typical" structures designed specifically for their mode of climate control. Pilot testing in Darwin indicated an overwhelming preference for air-conditioning in working environments for at least some part of the year. Therefore, in that city, it was decided to ask for more specific detail about which months of the year were so bad that it was considered preferable to have air-conditioning at work.

Behavioural adjustments to the thermal environment were investigated by means of a check list that was compiled on the basis of responses to an open-ended question in the Darwin "Dry" survey. The check list was included on the Darwin "Build-up", both Brisbane and both Melbourne questionnaires. Respondents were questioned on the degree of control they felt they had over the conditions of warmth or coolness in the work environment. Preliminary tests with this line of questioning again indicated a sensitivity to wording, with most people thinking only of direct temperature control when answering. There appeared to be no way of avoiding this tendency without biasing the responses unduly, so the final question was put as simply as possible: "Do you think you have enough CONTROL over conditions of warmth or coolness in your workplace?" If further information was requested by the respondent before answering,

the following standardised cue was issued by the interviewer: "When you find the warmth or coolness of your workplace unsuitable, is it usually possible for you to correct the situation?"

The research questions in Sections 4.3 and 4.4 call for a scale by which respondents could be classified according to the intensity of their favourability towards air-conditioning. Accepting Fishbein's (1967a) contentions that the evaluative or affective component is the essence of attitudes and that affect is the only truly unidimensional part of attitude, it was decided in the current study to construct an air-conditioning affective scale. Quite a lot has been written on the variety of unidimensional scaling techniques available, such as Likert, Guttman, Thurstone and successive interval methods (e.g. Remmers, 1954; Torgerson, 1958; Maranell, 1974; Guilford, 1954; Edwards, 1957; Dawes, 1972; Proshansky, 1977). The choice of technique in the current investigation was guided by the need for interval level measurement and also that the main purpose of the scale was investigating group differences. Accordingly, the Thurstone method was initially selected (Oppenheim, 1966, p.123) and then further refined by application of the successive interval transformation (hereafter referred to as the "Thurstone" method for simplicity).

The 49 attitude statements that formed the initial item pool (Table G.1) were generated in unstructured pilot interviews in Darwin public service departments and in Brisbane. They were rephrased as much as possible to stay within Payne's (1951) 3000 word vocabulary of familiar English without stilting the expressions unduly. The statements included in the item pool dealt mainly with affect, and those that had a cognitive component were eventually deleted. The scaling process applied to the

item pool as discussed in Appendix G, therefore yielded an instrument that was used to classify respondents on an equal-interval continuum of affective disposition toward air-conditioning.

Finally, all of the questionnaires used in the current investigation contained various biographical questions such as age, sex, general health assessment and length of residence in the city of the survey. Along with these standard questions were various items relating to the thermal characteristics of the respondent's home, such as the building materials used in construction and the presence of ceiling insulation. Information was also sought on active climate controls such as ownership of air-conditioning, evaporative cooling, mechanical ventilation systems and fans.

5.6 Summary of Methods and Procedures

The overall procedure within each of the six surveys consisted of approaching each building occupant who was drawn in the sample with a covering letter (Appendix F) that indicated the institution from which the investigator came, the broad purpose of the study, and the confidentiality of any data supplied. Once co-operation was secured, the interviewer noted the respondent's name and the location of their work-station. Part of the attitude questionnaire was then verbally administered by the interviewer. This usually required up to ten minutes, which was considered sufficient time for metabolic rates to stabilise before administering the thermal questionnaire. Before being left to complete the thermal questionnaire on their own, respondents were verbally questioned about activities they had performed in the preceding

hour. This was followed with the clothing check-list, which was completed by the respondent, but briefly scrutinised for any obvious inaccuracies by the interviewer. The thermal questionnaire was then introduced with a demonstration of how to use the linear formatted rating scales. While this questionnaire was being filled in, the interviewer began recording the microclimatic variables. Under no circumstances did the interviewer attempt to modify any aspect of the thermal conditions. However, if a respondent was sitting directly in sunshine, they were automatically excluded from the sample and replaced with an adjacent worker, because the mean radiant temperature could not be estimated in such situations with a simple globe thermometer. The Assman psychrometer had its wet-bulb wick moistened with distilled water and a reading was obtained at the respondent's work-station at a height of about 0.6m above floor level (ASHRAE, 1981b). The globe thermometer was placed on the respondent's desk and a reading was taken after 15 minutes of exposure. Air velocities were then recorded as near as possible to the respondent.

After the thermal questionnaire was completed, the biographical questions were administered by the interviewer, followed by instructions on how to complete the remainder of the attitude questionnaire, which was left with the respondent to do on their own while another sample member was interviewed. When the interviewer returned for the completed attitude questionnaire, the globe thermometer on their desk was read, thus completing the first session with the respondent. Arrangements were then made for two call-back sessions to take place in the two to three weeks after the first contact. Only the thermal questionnaire was administered on the two call-backs under an identical procedure to that described above. On several occasions the respondent was unavailable at

the time of call-back and the interviewer returned as often as was feasible to ensure that each person completed three separate thermal questionnaires. This procedure was not completely successful as indicated by the numbers of respondents and completed thermal questionnaires in Table 5.4.

The only exceptions to the procedure of administering one attitude and three thermal questionnaires to each respondent were the 17 university students from building number five in the Brisbane non-air-conditioned survey. These students each completed three thermal questionnaires on separate days but were not given the attitude interview. Their inclusion in the study was to increase the number of responses and therefore the accuracy with which probit analysis could estimate the survey's neutral temperature. This was necessary due to the skew of temperatures in the warmer-than-neutral region in the non-air-conditioned buildings of Brisbane. The building in which they were interviewed was considered to be reasonably representative of their thermal experiences as the university has a policy of no air-conditioning except in some libraries.

While the surveys were conducted exclusively in the public sector, the buildings sampled are considered to be representative of "typical" office environments in Australia. The building occupant samples are also considered to be typical of Australian office workers. The microclimatic data collected are considered to be representative samples of spatial variations in conditions within buildings, as experienced by the occupants of those buildings. No attempt was made to randomise the temporal sequence of microclimatic recordings, but since each survey lasted for at least six weeks, the data are representative of seasonal

conditions. Within each building, the temporal distribution of recordings was spread over a period of at least two to three weeks, as required by the call-back procedures. All data collection was between the usual office hours of 8.30 a.m and 5.30 p.m for the six surveys.

The data structure than emerged out of each survey consisted of two separate sets; one containing all of the attitude questionnaire responses (one record per respondent), while the second contained the thermal questionnaire responses, microclimatic data and the various derived indices (three separate records per respondent). Mapping between the two data sets was via a respondent identity number. Management of these files was by the 1022 Data Base Management System (Software House, 1980) running on the University of Queensland's Digital Equipment PDP 1090 computer. Other data analysis was done with the GLIM 3.10 (Baker and Nelder, 1978) and SPSS (Nie et al., 1975) software packages.

CHAPTER SIX

RESULTS AND DISCUSSION I - THERMAL QUESTIONNAIRE

6.1 Climatic Data

6.1.1 Outdoor meteorological variables

Salient features of the outdoor atmospheres prevailing during each of the six surveys are summarised in Table 6.1. Since the format of this table will be repeated throughout the two results chapters, a word of explanation is desirable at this point. The actual variables in the table are listed in the left-hand column, and for each variable, four statistics have been calculated; mean, standard deviation (stdev), standard error of the mean (sterror), and range. There are six columns

of figures in each table; one for each field study. In Table 6.1, the two Darwin surveys' mean monthly outdoor temperatures of 25.0 and 28.8degC, closely resemble the long-term average temperatures for those months, as recorded in Table 5.1. The mean monthly temperatures recorded for the other four surveys in Table 6.1 also closely approximate the "typical" seasonal conditions summarised in Table 5.1.

TABLE 6.1 : Outdoor meteorological conditions during the six surveys

		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
Office hours outdoor temp.	Mean	27.9	30.6	27.1	27.2	21.1	23.7
	Stdev	2.3	1.8	1.6	1.9	4.8	8.5
	Sterror	0.11	0.08	0.07	0.08	0.21	0.36
	Range	11	12	10	7	29	29
Outdoor relative humidity (%)	Mean	38% *	66% *	52.8%	56.7%	50.4%	38.6%
	Stdev	NA	NA	8.3	6.7	15.4	16.5
	Sterror	NA	NA	0.36	0.35	0.68	0.70
	Range	NA	NA	60	46	86	79
Office hours part. vapour pressure outdoors (mmHg)	Mean	10.6 *	22.0 *	14.6 *	15.8 *	9.7 *	8.8 *
Mean monthly outdoor temperature ($T_{\overline{m}}$)		25.0	28.8	24.4	25.0	20.0	20.0

* calculated from mean office hours outdoor dry- and wet-bulb temperatures
NA indicates data were Not Available

The difference between Darwin "Dry" and "Build-up" mean monthly temperatures in Table 6.1 (3.8K) was smaller than the differ nce between these surveys' mean office hour outdoor temperatures (2.7K), suggesting that much of the Darwin "Build-up's" reputation for discomfort is due to the elevation of night temperatures. In fact, the mean nightly minimum

temperature in the "Dry" survey was 19.1degC, which was much cooler in comparison with the "Build-up" temperature of 24.5degC (Bureau of Meteorology Monthly Weather Reviews).

The Brisbane surveys' outdoor office-hours and mean monthly temperatures were broadly comparable to those of the Darwin "Dry", but the humidities in the latter survey were lower. Although the two Brisbane surveys were conducted in the same summer, only the air-conditioned building survey was initiated in the last weeks of December, which were slightly cooler than January. This explains the 0.6K difference between the two Brisbane surveys' mean monthly temperatures.

The outdoor atmospheric conditions prevailing during the two Melbourne surveys were definitely cooler than the other four surveys in Table 6.1. However, the vastly increased standard deviations and ranges of Melbourne's outdoor office-hour temperatures suggest that the mild weather was punctuated by hot spell. Indeed, the highest outdoor temperature recorded during the surveys in that city was 42.8degC on February 16th 1983. Because more thermal questionnaires were administered in free-running buildings than in air-conditioned buildings during that three-day hot spell, the mean office-hours outdoor temperature was 2.6K higher ($t=6.21$, $p < 0.01$) in the non-air-conditioned survey.

6.1.2 Indoor microclimatic variables

The first row of Table 6.2 indicates that a very uniform air temperature of about 23.5degC was provided in all four of the air-conditioned building surveys, regardless of the considerable variability in outdoor

TABLE 6.2 : Summary statistics for indoor microclimatic variables

		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
Air temperature	Mean	23.3	23.7	23.7	27.9	23.4	24.3
	Stdev	1.4	1.5	1.2	1.2	1.4	3.2
	Sterror	0.06	0.07	0.05	0.05	0.06	0.14
	Range	10	8	7	6	8	14
Wet-bulb temperature	Mean	16.2	17.8	17.4	21.6	15.7	15.6
	Stdev	1.2	1.6	1.0	1.9	1.5	2.2
	Sterror	0.05	0.07	0.04	0.08	0.07	0.09
	Range	6	8	5	11	7	10
Globe temperature	Mean	23.5	24.1	23.9	27.9	23.8	24.5
	Stdev	1.5	1.6	1.2	1.3	1.5	3.1
	Sterror	0.07	0.07	0.05	0.05	0.07	0.14
	Range	11	9	8	10	6	14
Air velocity (m/s)	Mean	0.07	0.14	0.15	0.31	0.11	0.17
	Stdev	0.13	0.13	0.10	0.15	0.06	0.16
	Sterror	0.01	0.01	0.00	0.01	0.00	0.01
	Range	1.5	1.8	0.9	1.2	0.4	2.3
Mean radiant temperature	Mean	23.7	24.5	24.1	27.8	24.0	24.6
	Stdev	1.8	2.1	1.4	1.4	1.7	3.1
	Sterror	0.08	0.09	0.06	0.06	0.08	0.13
	Range	15	14	10	10	18	10
Operative temperature $	Mean	23.5	24.1	23.9	27.9	23.7	24.5
	Stdev	1.5	1.7	1.2	1.4	1.5	3.1
	Sterror	0.05	0.07	0.05	0.06	0.07	0.13
	Range	12	9	8	6	11	13
Partial vapour pressure (mmHg)	Mean	10.2	12.5	11.7	16.3	9.5	9.0
	Stdev	1.3	1.8	1.5	2.7	1.6	1.8
	Sterror	0.06	0.07	0.05	0.11	0.07	0.08
	Range	8	11	7	16	8	9
Relative humidity #	Mean	47%	56%	53%	58%	44%	39%
Bivariate relationship between indoor operative temp. & outdoor temp.	(r)	0.01	0.21*	0.02	0.65*	0.34*	0.83*
	(b)	0.00	0.19	0.01	0.44	0.11	0.31
Sample size		493	555	564	611	512	555

$ Calculated by $(T_a + T_{mrt})/2$
# Estimated from mean dry- and wet-bulb temperatures
* Probability less than 0.01

climate as discussed earlier. The closeness of this temperature control was also very constant across those four surveys, with standard deviations in air temperature at about 1.4K. Slightly more variable in these four air-conditioned surveys were the mean radiant temperatures, which were generally about 0.5K warmer than the air temperatures. Hence the operative temperatures in the air-conditioned buildings closely approximated the uniform 24degC summer recommendation in the Australian edition of Carrier's system design manual (undated). Similarly, the relative humidities and air velocities observed in the four air-conditioned surveys were all within the 40-60% RH and less than 0.15m/s velocity ranges respectively, as prescribed by the manual. It is possible that the low relative air velocity recorded in Darwin's air-conditioned buildings during the "Dry" was due to the variable air volume (constant temperature) systems running at considerably less than full capacity during that season in comparison to the other three air-conditioned surveys which were all conducted during seasons of maximum heat-load and therefore maximum fan-pressure.

Comparison of the mean indoor air temperatures recorded in the air-conditioned surveys (Table 6.2) with the mean office-hours outdoor temperatures (Table 6.1) shows a pronounced negative gradient in the cases of Darwin and Brisbane but a moderate positive gradient of 2.3K for the Melbourne survey. Although the Melbourne air-conditioned study was conducted at the height of summer, there was an HVAC system in one of the main buildings (number 2 in Figure 5.5 and Table 5.2) that switched on the heating coil if the intake air temperature dropped below 21degC. The positive outdoor/indoor temperature gradient was possibly due also to the thermal design of the air-conditioned buildings studied in Melbourne,

with large expanses of unshaded glazing and low thermal mass being typical.

The bivariate relationships between indoor operative temperature and outdoor air temperature in the six surveys are summarised by the correlation and regression coefficients at the bottom of Table 6.2. In the air-conditioned surveys in Darwin during the "Dry" and in Brisbane, the indoor-outdoor relationship was not statistically significant ($p > 0.05$), indicating that the HVAC equipment in the buildings surveyed was of sufficient capacity to isolate indoor climate from external meteorological events. However, in the air-conditioned surveys in the Darwin "Build-up" and Melbourne surveys, there were moderately weak, positive correlations between indoor operative temperature and outdoor air temperature ($r=0.21$ and 0.34 respectively). In Darwin, the positive correlation possibly reflects the increased proportion of HVAC cooling capacity being devoted to latent heat loads in the "Build-up" season. In the Melbourne air-conditioned survey, the correlation of indoor temperatures with outdoor conditions suggests that cooling plant was sized according to modal loads, but not the extreme temperatures occurring during Melbourne's hot spells. The slightly higher correlation coefficient in Melbourne could possibly be attributed to the higher standard deviation in outdoor temperatures in comparison to Darwin "Build-up" (4.8K and 1.8K respectively). The regression coefficients for these two surveys in Table 6.2 indicate that indoor operative temperature increased 1K for a 5K increase in outdoor temperature in Darwin during the "Build-up", whereas a 10K outdoor change was necessary for a 1K indoor change in Melbourne's air-conditioned survey buildings.

Predictably the indoor temperatures recorded in the two non-air-conditioned surveys show a much greater dependence on outdoor temperatures than was the case for the air-conditioned surveys (Table 6.2). The correlation coefficient for indoor operative and outdoor air temperatures was moderately strong ($r=0.65$) in Brisbane and very strong ($r=0.83$) in Melbourne, although the difference, again, could be attributed to the very high standard deviation in Melbourne outdoor air temperatures. The regression coefficients in these two non-air-conditioned surveys indicate that indoor temperatures were more sensitive to outdoor fluctuations ($b=0.44$) in Brisbane than in Melbourne ($b=0.31$).

In both free-running building surveys there was a slightly positive outdoor/indoor temperature gradient of about 0.7K on average. In order to more closely investigate the thermal performance of individual buildings, the Brisbane non-air-conditioned buildings were disaggregated into those of "light" construction (nos. 1 and 2 in Table 5.3 and Figure 5.4), and heavy-weight (nos. 3 and 4 in Table 5.3 and Figure 5.4). The slightly positive outdoor/indoor temperature difference remained the same in Brisbane's free-running buildings despite differences in the thermal mass of their construction. However, the heavy non-air-conditioned building in Melbourne (number 1 in Table 5.3 and Figure 5.6) had a mean indoor operative temperature that was 2K cooler than mean outdoor air temperature, whereas the low thermal mass free-running building in Melbourne (number 2 in Table 5.3 and Figure 5.6) was actually 1.5K warmer inside than out.

Air velocity in the two non-air-conditioned surveys was clearly used to control thermal comfort, particularly in Brisbane where its mean value (0.31m/s) was at least twice as much as in the other surveys. Desk-top, ceiling and pedestal-type fans were commonly encountered during the non-air-conditioned surveys.

There was a very close relationship between indoor and outdoor humidities in the two non-air-conditioned surveys. This was also true of the Darwin "Dry" and Melbourne air-conditioned surveys, in contrast to the Darwin "Build-up" and Brisbane air-conditioned surveys where there was a definite negative outdoor/indoor partial vapour pressure gradient (Tables 6.1 and 6.2). Obviously the HVAC plant in these two surveys was responsible for the dehumidification observed, whereas the Darwin "Dry" and Melbourne HVAC systems were only controlling sensible heat loads at temperatures above the intake air's dew point.

6.1.3 Other heat-balance data : Metabolism and clothing

The mean metabolic rates recorded in all six surveys were virtually identical at about $69W/m^2$ (1.2met), which coincides with the typical office-work level suggested in the ASHRAE Fundamentals (1981a, p.8.11).

Table 6.3 indicates that clothing insulation varied considerably between the six surveys, with Darwin's air-conditioned survey in the "Build-up" and Brisbane's non-air conditioned surveys having the lowest I_{clo} mean at about 0.44, while Melbourne's two surveys had the highest, at about 0.56. The difference between the Melbourne non-air-conditioned and Darwin "Build-up" surveys' mean I_{clo} values was statistically significant ($t=19.4$; $p < 0.01$).

TABLE 6.3 : Human variables involved in microclimatic heat balance

		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
Metabolic rate in hour before interview (W/m^2)	Mean	69.9	68.7	69.3	68.7	67.8	68.4
	Stdev	8.6	8.7	8.2	6.5	8.3	7.4
	Sterror	0.39	0.37	0.34	0.26	0.36	0.31
	Range	61	140	58	46	100	58
Intrinsic clothing insulation at time of interview (clo)	Mean	0.49	0.43	0.48	0.45	0.55	0.57
	Stdev	.133	.094	.105	.099	.113	.141
	Sterror	.006	.004	.004	.004	.005	.006
	Range	0.79	0.57	0.87	0.60	0.67	0.71

Table 6.4 : Mean clothing insulation in Darwin disaggregated by sex

	"The Dry"	"The Build-up"	
Women	Mean clo=0.47 Stdev =0.14 Sterror =0.01 n =288	Mean clo=0.41 Stdev =0.11 Sterror =0.01 n =301	t=5.64 (p<0.01)
Men	Mean clo=0.52 Stdev =0.10 Sterror =0.01 n =211	Mean clo=0.46 Stdev =0.07 Sterror =0.00 n =254	t=7.44 (p<0.01)
	t = 4.70 (p < 0.01)	t = 6.20 (p < 0.01)	

TABLE 6.5 : Mean clothing insulation in Brisbane disaggregated by sex

	AC	NAC	
Women	Mean clo=0.42 Stdev =0.11 Sterror =0.01 n =267	Mean clo=0.37 Stdev =0.09 Sterror =0.01 n =260	t=5.61 (p<0.01)
Men	Mean clo=0.53 Stdev =0.06 Sterror =0.00 n =294	Mean clo=0.50 Stdev =0.05 Sterror =0.00 n =299	t=6.90 (p<0.01)
	t = 14.3 (p < 0.01)	t = 21.1 (p < 0.01)	

TABLE 6.6 : Mean clothing insulation in Melbourne disaggregated by sex

	AC	NAC	
Women	Mean clo=0.46 Stdev =0.14 Sterror =0.01 n =174	Mean clo=0.49 Stdev =0.16 Sterr =0.01 n =210	t=2.0 (p<0.05)
Men	Mean clo=0.59 Stdev =0.08 Sterror =0.00 n =338	Mean clo=0.62 Stdev =0.11 Sterror =0.01 n =345	t=4.2 (p<0.01)
	t = 11.9 (p < 0.01)	t = 10.5 (p < 0.01)	

Apart from these between-survey differences in clothing insulation, there were significant variations between the sexes, as indicated by the t tests in Tables 6.4, 6.5 and 6.6, with women being consistently "less dressed" than men. Insulation differences between the sexes were most pronounced in Melbourne ($t=11.9$ and 10.5 in air-conditioned and non-air-conditioned respectively), while being smallest but still significant in Darwin ($t=4.7$ and 6.2 in the "Dry" and "Build-up" respectively). Another difference observed in clothing behaviour in all six surveys was a lower standard deviation for men's ensemble insulation. For example, the standard deviation of the I_{clo} value for men's ensemble in Melbourne's air-conditioned buildings (Table 6.6) was 0.08 in comparison to 0.14 for the women in the same survey ($F=3.06$, $d.f.=173,337$, $p < 0.01$). On the basis of the greater variance in their clothing insulation, women were possibly exercising a greater degree of behavioural thermoregulation through clothing adjustment than men.

By making the assumption of causal order from outdoor temperature --> indoor temperature --> clothing insulation level (I_{clo}), it was possible to conduct path analyses for the six surveys, as depicted in Figure 6.1. Following the conventions suggested by Nie et al. (1975, p.387), the path coefficients were defined by the standardised beta regression coefficients. Furthermore, the path coefficients exogenous to the three-variable models are from all residual causes (called "latent" variables). By squaring these latent path coefficients, an estimate was obtained for the amount of variance in the relevant variable unexplained by the causal relations explicitly included in the model. Only those path coefficients that reached statistical significance ($p < 0.05$) were included in the causal diagrams to simplify visual interpretation.

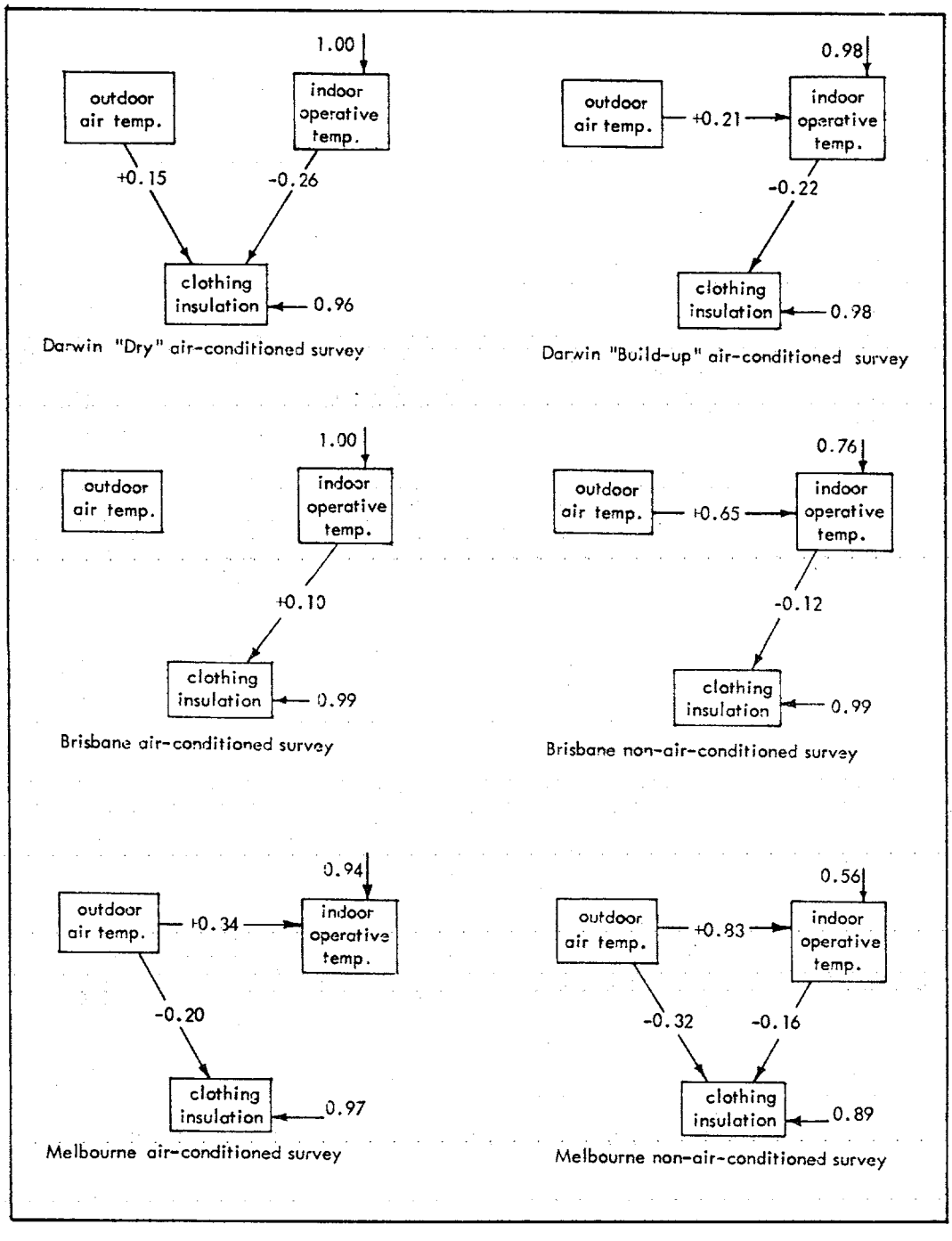


FIGURE 6.1 : Path analyses for clothing insulation with indoor and outdoor temperatures
Path coefficients are standardised regression coefficients (beta).

Of the four air-conditioned surveys, those in Darwin "Dry" and Melbourne had the greatest amount of clothing insulation variance explained by indoor and outdoor temperatures, with 8% and 6% respectively. In the remaining two air-conditioned surveys, Darwin "Build-up" and Brisbane, only about 3% of I_{clo}'s variance was explained by indoor temperatures.

Only 2% of I_{clo}'s variance was explained in the Brisbane non-air-conditioned model in Figure 6.1, which is much less than the 21% figure for the Melbourne non-air-conditioned survey. That survey's model in Figure 6.1 shows that both indoor and outdoor temperatures had direct negative relationships wih I_{clo}. Outdoor temperature also exerted an indirect influence on clothing insulation by virtue of its very strong association with indoor operative temperature.

6.1.4 Rational indices of warmth

As discussed in Section 3.2, the six variables of air- and mean-radiant-temperatures, humidity, relative air velocity, metabolic rate and clothing insulation are the necessary inputs to mathematical models of comfort based on heat-balances. In the current study, the PMV and SET indices were calculated for each thermal questionnaire, along with Fanger's "preferred temperature" according to the comfort equation (Fanger, 1970). Table 6.7 contains the summary statistics for these calculations in each survey.

The first noteworthy feature of Table 6.7 is the close similarity in mean values for these heat-balance models in the four air-conditioned surveys. PMV was between -0.5 and -0.4, and SET between 22.6 and 23.2degC, while Fanger's preferred temperature was fairly constant at

TABLE 6.7 : Summary statistics for rational indices of warmth

		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
Fanger's PMV	Mean	-0.46	-0.48	-0.49	0.66	-0.39	-0.20
	Stdev	0.67	0.63	0.67	0.53	0.60	0.85
	Sterror	0.03	0.03	0.03	0.02	0.03	0.04
Fanger's Preferred Temperature	Mean	24.7	25.3	25.1	26.2	24.8	25.0
	Stdev	1.4	1.2	1.2	1.0	1.3	1.5
	Sterror	0.06	0.05	0.05	0.04	0.06	0.06
PPD (based on mean PMV)		9.4%	9.8%	10.0%	14.2%	8.2%	5.8%
SET	Mean	22.6	23.0	23.0	26.4	23.2	23.6
	Stdev	1.6	1.8	1.7	1.8	1.6	2.4
	Sterror	0.07	0.08	0.07	0.07	0.07	0.10

about 25degC. The standard deviations for these indices were approximately equivalent in the four air-conditioned surveys, with PMV's being about 0.65 scale units and SET's at about 1.6K.

It would be reasonable to conclude on the basis of these data that the air-conditioned building occupants surveyed in three cities were all exposed to uniform thermal loads that were on the cool side of the comfort optimum predicted by heat-balance models. In the case of PMV, the optimum is obviously zero at which the Predicted Percentage Dissatisfied (PPD) is 5%. The PPD values for the six surveys' mean PMV scores are also listed in Table 6.7, and the four air-conditioned surveys all fall just within the comfort recommendations of ISO 7730 on moderate thermal environments (International Organisation for Standardisation, 1984). The SET means observed in the four air-conditioned surveys all cluster around the lower limit of the ASHRAE Standard 55-81 for summer comfort and 80% thermal acceptability (22.2-25.7degC) (ASHRAE, 1981b,

p.3).

The non-air-conditioned survey in Melbourne had mean PMV at -0.2, being slightly warmer than its air-conditioned counterpart, while the free-running buildings in Brisbane were on average almost one full PMV scale unit (0.9) warmer than the next warmest survey. The PPD values associated with these mean PMV scores were 5.8% in Melbourne and 14.2% in Brisbane. The latter value falls well outside the ISO 7730 comfort recommendation while the Melbourne PPD is the closest to index optimum of all six surveys, regardless of climate controls. The variability of PMV scores in Brisbane's non-air-conditioned survey was actually lower than all the other surveys while the standard deviation of PMV in Melbourne's non-air-conditioned study was the highest at 0.85 scale units. The SET statistics for the free-running building surveys lead to much the same conclusions as did the PMV index, with Brisbane having the highest mean at 26.4degC (which falls outside the upper limit of ASHRAE 55-81 summer acceptability range), while Melbourne came closest to the theoretically optimum SET of 24degC.

6.2 Seven-Point Scales of Subjective Warmth

6.2.1 Descriptive statistics

The summary statistics for the ASHRAE, Bedford and PREFV scale instantaneous responses are contained in Table 6.8. Dealing with the differences between these three scales in each survey, there would seem to be no systematic displacement of Bedford from ASHRAE means. In the two Darwin surveys, the Bedford mean was about 0.1 unit warmer than the

ASHRAE mean but this failed to reach statistical significance ($t=0.94$ in "Dry"; 1.42 in "Build-up"; $p > 0.05$). However, the displacement of the PREFV scale's means above ASHRAE's ranged from 0.17 scale units in the Brisbane air-conditioned survey ($t=2.93$, $p < 0.01$), through to 0.31 units in the Darwin "Build-up" survey ($t=4.89$, $p < 0.01$), suggesting that the two scales were in fact used in different ways by respondents in these surveys. The difference diminished to insignificance in the Brisbane non-air-conditioned survey ($t=1.05$, $p > 0.05$) and the Melbourne air-conditioned survey ($t=0.73$, $p > 0.05$), whereas the mean vote on the PREFV scale vote in the Melbourne non-air-conditioned survey was 0.11 units cooler than the mean ASHRAE vote ($t=1.67$, $p < 0.05$).

TABLE 6.8 : Summary statistics for rating scale responses to microclimatic conditions

		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
ASHRAE	Mean	-0.43	-0.16	0.04	0.80	0.27	0.74
	Stdev	1.24	1.15	1.05	1.08	0.95	1.13
	Sterror	.056	.049	.044	.044	.042	.048
Bedford	Mean	-0.36	-0.06	0.01	0.75	0.24	0.67
	Stdev	1.20	1.20	1.10	1.06	1.11	1.15
	Sterror	.054	.051	.046	.043	.049	.049
PREFV (-ve=cold;+ve=hot)	Mean	-0.19	0.15	0.21	0.86	0.31	0.63
	Stdev	0.93	0.96	0.90	0.88	0.79	1.06
	Sterror	.042	.041	.038	.036	.035	.045
DISCR	Mean	0.28	0.30	0.53	0.19	0.6,	0.93
	Stdev	1.16	1.00	0.99	0.97	0.91	0.84
	Sterror	0.05	0.04	0.04	0.04	0.04	0.04

Between-survey differences that were considered as potential explanations of these varying discrepancies included; 1) variations in outdoor climate, 2) variations in indoor warmth, and 3) variations in levels of clothing insulation being worn, since the PREFV scale was prefaced by a "Dressed as you are now..." clause. The first of these explanations seems inadequate in that the mean monthly outdoor temperature was approximately the same for both the Darwin "Dry" air-conditioned, Brisbane air-conditioned and Brisbane non-air-conditioned surveys, and yet the discrepancy between ASHRAE and PREFV scale means was negligible in the latter study. The second possible explanation was assessed by comparing each survey's ASHRAE - PREFV scale difference with their mean PMV scores recorded in Table 6.7. In the three surveys that had a significant positive discrepancy between PREFV and ASHRAE scale means (Darwin and Brisbane air-conditioned), the PMV index mean was about -0.5, whereas the remaining surveys' mean PMV scores ranged from -0.4 through to +0.7. The Melbourne non-air-conditioned survey, having the only significant negative discrepancy between mean PREFV and ASHRAE, had a mean PMV at -0.2. Consequently, it would seem highly unlikely that mean levels of microclimatic warmth had anything to do with the differences between these two scales' usage in the six surveys. Finally, insulation levels for each survey (Table 6.3) also seem unlikely to provide an explanation in that the respondents of both the air-conditioned and non-air-conditioned surveys in Brisbane were wearing, on average, about the same insulation of 0.46 clo. Hence the between-survey variations in the discrepancy between mean ASHRAE and mean PREFV scale votes remains unexplained by heat-balance calculations.

Table 6.8 indicates that there was considerable variation in mean subjective assessments of warmth between the six surveys. Referring to the ASHRAE and Bedford scales, the Darwin "Dry" air-conditioned survey was assessed as the coolest at about -0.4, followed by the Darwin "Build-up" survey with a mean of about -0.1. The other two air-conditioned surveys in Brisbane and Melbourne recorded mean votes that were either neutral or about 0.3 units on the warm side of the scales' mid-points, whereas the two non-air-conditioned surveys recorded mean assessments at about 0.7 to 0.8 scale units warmer than neutral-comfortable.

The standard deviations for the ASHRAE and Bedford scales were about one scale unit in all but the Darwin air-conditioned surveys, where 1.2 was typical. These between-survey differences in variability of subjective warmth (e.g. ASHRAE scale $F=1.7$, d.f.=492,511, $p < 0.01$ between Darwin "Dry" and Melbourne air-conditioned) seem only partially related to actual variability in microclimatic warmth. The Melbourne non-air-conditioned survey had the greatest variance in temperature or PMV values, while the Darwin surveys had relatively stable indoor conditions. The standard deviation for PREFV scale votes was lower than either that of the ASHRAE or Bedford scales in all six surveys. The survey that recorded the greatest variability in PREFV votes, Melbourne non-air-conditioned, was also the survey with greatest microclimatic variability.

Summary statistics for the DISCR variable, based on each thermal questionnaire's ASHRAE vote minus PMV index value, are also contained in Table 6.8. The mean DISCR scores were positive in all six surveys, ranging from +0.2 in the non-air-conditioned Brisbane survey, through

+0.3 in the two Darwin surveys, up to the highest values in Melbourne, at +0.7 and +0.9 for the air-conditioned and non-air-conditioned surveys respectively. This finding indicates that respondents were, on average, feeling warmer than what their heat-balance status would predict, but the size of the discrepancy varied considerably between surveys. Further discussion of the DISCR variable will be given in Section 6.3.

6.2.2 Correlation and regression of subjective warmth on microclimatic variables

In order to more fully understand both the differences between each of the seven-point scales and also the way these scales were used in the six surveys, several bivariate analyses were conducted using microclimatic indices as the independent variable. By using more than one index; air temperature, operative temperature, PMV and SET in turn, it was also possible to compare the relative merits of each in explaining the variance in subjective warmth assessments. Table 6.9 contains the Pearson correlation coefficients (r), the chi square tests for homogeneity of those correlation coefficients across the six independent samples, and also the regression coefficients (b) associated with each correlation.

Dealing first with a comparison of the ASHRAE, Bedford and PREFV scales in Table 6.9, there seems to be very little difference in the strength of their association with environmental warmth, regardless of which index was used to measure the latter. Indeed, looking at the averages for each row of six correlation coefficients in Table 6.9, the ASHRAE and Bedford scales were identical on all four indices, thereby supporting the contention of McIntyre (1978c) and Humphreys (1975) that

TABLE 6.9 : Correlation (r) and regression (b) coefficients for the bivariate relationships between seven-point scales of subjective warmth and four indices of microclimatic warmth *

Depend--ent var	Independ--ent var.		Darwin		Brisbane		Melbourne		χ^2 test of 6 r #/	Mean of 6 r or b
			Dry	Buildup	AC	NAC	AC	NAC		
ASHRAE scale	Air temp	r	0.51	0.55	0.47	0.48	0.50	0.70	49.7	0.54
		b	0.45	0.42	0.43	0.42	0.33	0.25		0.38
	Op temp	r	0.53	0.54	0.49	0.45	0.48	0.69	47.4	0.53
		b	0.43	0.38	0.42	0.36	0.30	0.26		0.36
	PMV	r	0.40	0.47	0.38	0.44	0.39	0.68	72.4	0.46
		b	0.87	0.87	0.64	0.90	0.62	0.92		0.80
	SET	r	0.35	0.47	0.42	0.39	0.40	0.64	54.5	0.44
		b	0.27	0.31	0.27	0.25	0.24	0.32		0.28
Bedford scale	Air temp	r	0.50	0.53	0.47	0.54	0.48	0.70	48.0	0.54
		b	0.42	0.42	0.45	0.46	0.34	0.26		0.39
	Op temp	r	0.51	0.52	0.49	0.52	0.43	0.70	53.0	0.53
		b	0.39	0.37	0.44	0.40	0.31	0.26		0.36
	PMV	r	0.34	0.47	0.38	0.49	0.43	0.68	76.3	0.46
		b	0.71	0.99	0.67	0.98	0.73	0.93		0.84
	SET	r	0.30	0.44	0.42	0.44	0.42	0.66	68.8	0.44
		b	0.22	0.30	0.28	0.27	0.27	0.33		0.28
PREFV scale $	Air temp	r	0.51	0.51	0.43	0.50	0.45	0.73	80.2	0.52
		b	0.33	0.33	0.33	0.36	0.25	0.25		0.31
	Op temp	r	0.51	0.50	0.44	0.46	0.45	0.72	75.2	0.52
		b	0.31	0.29	0.34	0.30	0.23	0.25		0.29
	PMV	r	0.33	0.37	0.33	0.47	0.38	0.70	111.0	0.43
		b	0.54	0.57	0.47	0.78	0.52	0.89		0.63
	SET	r	0.29	0.38	0.37	0.41	0.38	0.67	87.7	0.41
		b	0.17	0.21	0.20	0.21	0.19	0.30		0.21

* All correlations significant at $p < 0.01$ level

\# The χ^2 test for homogeneity of 6 independent correlation coefficients was based on Fisher's Z' transformation of r. All χ^2 tests were significant ($p < 0.01$, d.f.=5)

$ The coding of the PREFV scale was reversed so that a +ve vote indicated that the respondent wanted cooler conditions

the different wording of these two scales had a negligible effect on the way they were used in practice. The means of the six surveys' PREFV correlations with each of the four indices were slightly lower than those of either the ASHRAE or Bedford scales', but the difference in r squared was less than 3% on all four indices.

Inspection of the regression coefficients in Table 6.9 leads to the same conclusion about the similarity of ASHRAE and Bedford scales as did the correlations. These two scales of subjective warmth seemed to be equally sensitive to increases of microclimatic warmth, as indicated by the mean regression coefficients for each of the four indices in the last column of Table 6.9. The gradient of the PREFV scale when regressed on the various indices was smaller than either the Bedford or ASHRAE scale, suggesting that the subjective differences between successive points of the PREFV scale were larger than those on the sensation (ASHRAE) or comfort (Bedford) scales. In short, the PREFV scale was less sensitive to microclimatic warmth than either the ASHRAE or Bedford scales.

Table 6.9 allows the four indices of microclimatic warmth to be compared for their strength of association with subjective warmth. While PMV has hitherto been used mainly to predict mean group responses, it is conceptually an index of warmth and as such, should be capable of explaining at least as much of the within-group variance in subjective warmth as the simple indices such as air temperature. Inspection of the mean correlations at the right-hand side of the table shows that air temperature and operative temperature (based on an average of mean radiant and air temperatures) were equally well correlated with all three subjective scales, with coefficients in the moderate region between 0.50 and 0.55. This general equivalence between air- and

operative-temperature probably reflects the high degree of similarity between mean radiant temperature and air temperature in most field settings encountered.

Correlations for the simple indices were higher than those for the complex heat-balance indices (PMV and SET), with the difference in r squared being on average about 10% more variance in subjective warmth being explained by the simpler indices. For example, the mean correlation coefficient for ASHRAE scale with air temperature was 0.54, while the same scale's mean correlation with the SET index was 0.44.

Before drawing the obvious conclusion that simple indices are better than sophisticated heat-balance models at explaining variance in people's subjective warmth, a few alternative explanations need to be examined:

1. It could be hypothesised that large degrees of measurement error contaminated the data obtained on the heat-balance variables other than air- and radiant-temperatures, and these errors counteracted any improvements that the variables made to the explained variance in subjective warmth votes. The variables most likely to be susceptible to error in the field setting would be air velocity, clothing insulation and perhaps metabolic rate.

2. The shapes of the frequency distributions of PMV and SET were more severely skewed than either air- or operative-temperatures'. The greater the departure from distribution similarity, the more severe will the restriction be on the maximum possible correlation (Cohen and Cohen, 1975, p.59).

3. The PMV and SET indices were more restricted in range than were simple temperatures, thereby limiting their maximum possible correlation.

Dealing with each of these possible explanations in turn, the suggestion that unreliable measurement of air velocity, I_{clo} and metabolic rates could explain the relatively weak correlations for PMV and SET seems implausible on the following grounds: Since the instruments used to measure these variables were identical in all six surveys, their susceptibility to error must be considered as a constant. However, the discrepancy between heat-balance index correlation with subjective warmth and simple temperature correlations fluctuated dramatically between surveys. For example, the correlation of ASHRAE scale votes with air temperature was 0.51 in the Darwin "Dry" survey, but fell to 0.35 when SET was used. Yet the correlation of ASHRAE scale votes in Brisbane's air-conditioned survey dropped a relatively small amount from 0.47 when air temperature was used, to 0.42 when SET was used. Consequently, the measurement-error explanation seems unsatisfactory.

The skewness of the frequency distributions of PMV, air temperature and Bedford votes was investigated in the six surveys with the third moment statistic as defined by Nie et al. (1975, p.185). A value of zero indicates a perfectly symmetrical distribution for the variable. The Bedford distributions were all very close to normal in that the third moment only ranged between -0.07 in Brisbane's non-air-conditioned survey up to +0.12 in the Darwin "Build-up". The survey that had the largest difference between third moments for PMV and air temperature was Darwin's

"Build-up". Given that the air temperature skewness (+0.72) was the larger of the two (PMV skewness was +0.40), the relatively poor correlation between PMV (and SET) with subjective warmth seems unlikely to be due to dissimilarity in frequency distributions.

The third hypothesis, that restriction of range in PMV and SET differences caused a reduction of these variables' correlation with subjective warmth, has an intuitive appeal insofar as thermoregulatory behaviours of clothing and air velocity adjustments would limit the range of PMV and SET values recorded in field surveys. However, there still remains a logical inadequacy in this explanation; that the behavioural regulations mentioned above, when integrated into the index of warmth, should ipso facto, bring to the index a more accurate representation of total bodily warmth than simple air temperature. Therefore, the failure of each of these alternative explanations for the relatively poor correlations of PMV and SET with subjective warmth lends support to the initial interpretation; that simple indices such as air temperature or operative temperature are better indices for statistically relating individual subjective warmth assessments with environmental warmth.

While between-scale differences and between-index differences in the bivariate relationships of Table 6.9 have been discussed, the between-survey differences are yet to be dealt with. The chi square tests for the homogeneity of correlation coefficients in each row of the table were calculated according to the formula set out in Snedecor (1946, p.154). The reasonably large sample size in each of the six current surveys ensured that heterogeneity in correlation coefficients between surveys reached statistical significance in each row of the table ($p < 0.01$). Melbourne's non-air-conditioned survey was the most clearly

differentiated by the correlation coefficients, with the r squared value being between 19% and 36% superior to that of the nearest rival survey. This result could probably be attributed to the greater amount of variance in the Melbourne non-air-conditioned microclimatic variables.

Since under conditions of homoscedasticity (equality of variance in Y along the range of X values) and linearity, regression coefficients are not affected by range restriction or differences in the variance of independent variables, the b statistic should be more useful in making between-survey comparisons than r. Dealing with air- and operative-temperatures in the four surveys in Darwin and Brisbane, the regression of both the ASHRAE and Bedford votes on these indices produced fairly stable slopes of between 0.36 and 0.45. However, this dropped to between 0.30-0.34 in the air-conditioned Melbourne survey, and to a low 0.25 in the non-air-conditioned survey of the same city. The same trend was true of the regression of PREFV scale votes on air and operative temperatures, but as noted earlier, the overall sensitivity of this scale to variations in microclimatic warmth was lower than was the case for either Bedford or ASHRAE scales. One possible explanation for the decreased sensitivity of Melbourne respondents' warmth assessments to simple temperatures is that in that city there was greater use of clothing to maintain comfort. The path coefficients for Melbourne's I_{clo} variable in Figure 6.1 generally support this line of reasoning, particularly in the non-air-conditioned survey.

Further clarification of the complex pattern of bivariate relationships between various measures of subjective and objective warmth was sought by the application of multiple regression techniques to the data. The dependent variable still being subjective warmth (ASHRAE,

Bedford and PREFV scales), while the independent variables were operative temperature (to avoid multicollinearity between air- and radiant-temperatures), air velocity (m/s), partial vapour pressure (mmHg), clothing insulation (clo) and metabolic rate (W/m^2). The modelling procedure was stepwise with forward inclusion. The variable entered at each step was the one that explained the greatest amount of variance in the seven-point scale of warmth that was unexplained by the independent variables already included; that is, the largest squared partial correlation criterion. Table 6.10 contains the 18 "best models", defined as the last step in the forward selection procedure that had statistically significant partial F ratios ($p < 0.05$) for all independent variables. For simplicity of interpretation, no attempt was made to investigate interaction terms or polynomial expressions, and there was no attempt to normalise each of the independent variable's frequency distributions, but these shortcomings of the analysis are acknowledged.

Predictably, the most important variable in each of the 18 models in Table 6.10 was operative temperature, as reflected by the last column of incremental R squared. More surprising is the seemingly trivial contribution to explained variance in subjective warmth by air velocity, humidity, metabolic rate and clothing insulation. While entering the equation first conferred some advantages on operative temperature, it still seems unusual that none of the variables entered on subsequent steps could change R squared by any more than 0.028 (i.e. 2.8%).

Examining the differences between the three scales of subjective warmth, a salient feature of Table 6.10 is the similarity in b coefficients for operative temperature in ASHRAE and Bedford models once the effects of the other independent variables have been partialled out.

TABLE 6.10 : Stepwise regression of subjective warmth on indoor operative temperature, partial vapour pressure, air velocity, metabolic rate and clothing insulation

Survey	Dependent variable	Independent variables	Partial (b)	Sterror (b)	Partial F ratio*	Total model F ratio	Change in R sqrd**
Darwin Dry	ASHRAE scale	T_o	0.408	0.032	164.8		0.284
		M/A_{Du}	0.007	0.002	6.0		0.009
		I_{clo}	-.870	0.390	5.0		0.007
		constant	-10.1			69.5	0.300
	Bedford scale	T_o	0.363	0.031	136.5		0.255
		I_{clo}	-1.27	0.381	11.1		0.017
		M/A_{Du}	0.006	0.003	5.6		0.008
		constant	-8.71			63.2	0.280
	PREFV scale ***	T_o	-.283	0.024	136.4		0.257
		I_{clo}	1.258	0.298	17.8		0.026
		constant	6.217			96.0	0.283
Darwin Build-up	ASHRAE scale	T_o	0.294	0.032	84.5		0.292
		V	-1.42	0.319	19.8		0.023
		P_a	0.134	0.030	20.6		0.024
		M/A_{Du}	0.015	0.005	10.0		0.012
		I_{clo}	-1.09	0.414	6.9		0.008
		constant	-9.26			61.7	0.360
	Bedford scale	T_o	0.295	0.034	76.9		0.267
		M/A_{Du}	0.020	0.005	17.2		0.023
		V	-1.34	0.334	16.2		0.019
		P_a	0.124	0.031	16.0		0.019
		I_{clo}	-1.03	0.434	5.6		0.007
		constant	-9.45			55.4	0.335
	PREFV scale	T_o	0.214	0.028	59.9		0.253
		I_{clo}	1.685	0.359	22.0		0.028
		P_a	-.086	0.026	11.1		0.014
		constant	5.339			76.8	0.295

continued/

* Critical F ratio for inclusion at 0.05 level is 3.82

** The last R sqrd for each model represents the total model statistic

*** The PREFV scale was numbered such that a +ve vote indicated the respondent wanted warmer conditions, while a -ve vote indicated a desire for cooler conditions

TABLE 6.10 Continued

Survey	Dependent variable	Independent variables	Partial (b)	Sterror (b)	Partial F ratio*	Total model F ratio	Change in R sqrd**
Brisbane AC	ASHRAE scale	T_o	0.414	0.032	170.1		0.239
		V	-1.24	0.401	9.7		0.013
		constant	9.674			94.0	0.252
	Bedford scale	T_o	0.421	0.035	147.9		0.242
		V	-.885	0.423	4.4		0.005
		P_a	0.073	0.037	3.9		0.005
		constant	-10.79			63.0	0.252
	PREFV scale	T_o	-.328	0.028	136.6		0.196
		constant	7.639			136.6	0.196
Brisbane NAC	ASHRAE scale	T_o	0.326	0.032	104.0		0.205
		P_a	0.038	0.016	5.6		0.007
		constant	-8.90			81.4	0.212
	Bedford scale	T_o	0.371	0.030	153.2		0.266
		P_a	0.041	0.015	7.7		0.008
		V	-.427	0.190	5.1		0.006
		constant	-10.15			78.6	0.280
	PREFV scale	T_o	-.265	0.026	103.8		0.209
		P_a	-.036	0.013	7.9		0.010
		constant	7.124			85.1	0.219
Melbourne AC	ASHRAE scale	T_o	0.301	0.024	153.1		0.232
		constant	-6.87			153.1	0.232
	Bedford scale	T_o	0.311	0.029	115.5		0.185
		constant	-7.12			115.5	0.185
	PREFV scale	T_o	-.234	0.021	129.2		0.203
		constant	5.249			129.2	0.203
Melbourne NAC	ASHRAE scale	T_o	0.252	0.014	318.5		0.478
		M/A_{Du}	0.018	0.005	14.7		0.012
		P_a	0.055	0.023	5.5		0.005
		I_{clo}	0.622	0.278	5.0		0.004
		constant	-7.49			136.2	0.500
	Bedford scale	T_o	0.250	0.014	326.0		0.493
		M/A_{Du}	0.016	0.005	11.7		0.009
		P_a	0.064	0.023	7.6		0.005
		I_{clo}	0.603	0.278	4.7		0.004
		constant	-7.57			143.4	0.511
	PREFV scale	T_o	-.247	0.013	390.8		0.523
		M/A_{Du}	-.018	0.004	18.3		0.014
		I_{clo}	-.615	0.246	6.3		0.004
		P_a	-.047	0.021	5.3		0.004
		constant	7.408			164.1	0.546

This result reinforces the conclusions of the bivariate analyses in Table 6.9. Again the PREFV scale yielded smaller regression coefficients in all surveys except the Melbourne non-air-conditioned, suggesting that the psychological distances between successive points are generally greater on this scale than on the more familiar ASHRAE and Bedford scales. In view of the small increments in R squared after operative temperature was entered in the equations, not a great deal of emphasis should be placed on the between-scale differences in "best model" compositions, but it would appear as though the PREFV scale's models were more parsimonious than either the ASHRAE or Bedford scales' (except in the Melbourne surveys).

Turning more specifically to the between-survey differences in the models of Table 6.10, one can more readily interpret subjective warmth's sensitivity to actual temperature differences than was the case in the discussion of simple bivariate relationships. Of particular interest is the hypothesis that respondents whose recent thermal experiences were more varied should be less sensitive to variations in environmental warmth than people with homogeneous thermal experiences. Inspection of the operative temperature partial regression coefficients and their associated standard errors in Table 6.10 provides reasonable support for the hypothesis, particularly when the comparisons involve the Melbourne non-air-conditioned survey. For example, the Brisbane air-conditioned survey's standard deviation for indoor operative temperature was the lowest of all surveys, at 1.2K, while the opposite was true of the 3.1K standard deviation in the Melbourne non-air-conditioned survey. The partial regression coefficient for operative temperature in the Bedford scale's multivariate model in the Brisbane air-conditioned survey was

0.414 (the 95% confidence limits being 0.351-0.477), while the same statistic in the Melbourne non-air-conditioned survey was 0.250 (0.223-0.277). Given that the 95% confidence intervals of these partial regression coefficients don't overlap, it would seem likely that the difference was statistically significant. All else being equal, Brisbane air-conditioned respondents changed their mean Bedford vote by one scale unit for every 2.4K change in operative temperature, whereas the operative temperature changed by 4K in Melbourne's non-air-conditioned survey before the same shift in mean subjective warmth was induced.

A comparison of the operative temperature partial regression coefficients for the two Darwin surveys in Table 6.10 indicates that the respondents in the "Build-up" were less sensitive to temperature variations than their counterparts in the "Dry" survey. This cannot be accounted for by any increased variance in the indoor or outdoor temperatures of the "Build-up", but the magnitude of the indoor-outdoor thermal gradient in that survey possibly contributed to the "de-sensitisation" of building occupants to microclimatic fluctuations.

Finally, the operative temperature partial regression coefficients for the two non-air-conditioned surveys in Table 6.10 also reinforce the hypothesis put forward concerning the nexus between variability of thermal experience and the sensitivity of subjective warmth as measured by the ASHRAE and Bedford scales at least. The same is true of a comparison between the two Melbourne surveys. The operative temperature partial coefficient for Bedford and ASHRAE regressions in the air-conditioned Melbourne survey were higher than their counterparts in the non-air-conditioned survey, although the statistical significance of this is unclear because of the overlap in 95% confidence intervals for

TABLE 6.11 : Partial regression coefficients for operative temperature in models of subjective warmth that have five independent variables *

Dependent variable		DARWIN AC		BRISBANE		MELBOURNE	
		The Dry	Buildup	AC	NAC	AC	NAC
ASHRAE scale	Partial (b)	.397	.294	.396	.324	.285	.254
	Sterror (b)	.032	.032	.033	.033	.028	.014
Bedford scale	Partial (b)	.350	.295	.419	.368	.295	.256
	Sterror (b)	.032	.033	.034	.031	.033	.014
PREFV scale	Partial (b)	-.271	-.219	-.308	-.264	-.227	-.243
	Sterror (b)	.025	.027	.029	.026	.023	.013

* The five independent variables forced into the models were; operative temperature, partial vapour pressure, air velocity, clothing insulation and metabolic rate.

these slope estimates. The PREFV scale's partial regression coefficients fail to support the above hypothesis in the two Melbourne surveys.

One statistical problem with the preceding comparisons between different surveys' partial regression coefficients for operative temperature is that quite often the models from which the coefficients were drawn had very different sets of independent variables. Since the standard error of a particular independent variable's partial regression coefficient tends to increase simply by the addition of more independent variables into the equation, the 18 best models of Table 6.10 were re-run while forcing all five independent variables in; operative temperature, partial vapour pressure, relative air velocity, clothing insulation and metabolic rate. The new partial regression coefficients for operative temperature and their associated standard errors are listed in Table 6.11. A comparison of the new estimates with their counterparts in the "best models" of Table 6.10 indicates that there was insufficient

difference in all 18 of the regression coefficients and standard errors to invalidate the earlier conclusions regarding between-survey differences in the sensitivity of subjective warmth to changes in operative temperature.

6.2.3 Probit analysis of subjective warmth on microclimatic variables

So far in the discussion of the thermal questionnaire results, the seven-point scales of warmth have been analysed as if they were of the interval level of measurement. However, as discussed in Appendix E, there are alternative modes of analysis of rating scales that make much weaker assumptions about the data. The current section discusses the results of probit analysis on the subjective scales of warmth under four headings; 1) neutralities, 2) within-survey consistency of responses, 3) category temperature widths, and 4) thermal acceptability. (See Appendix E for an explanation of the probit methods used to derive these results).

Neutralities: Two separate estimates of each neutrality were obtained by using both air temperature and standard effective temperature as the independent variable. Table 6.12 contains the 36 neutralities and their associated 95% confidence limits, and the actual models that these neutralities were derived from are depicted in Appendix H. All 36 probit models were statistically significant ($p < 0.05$) using the chi square test.

Looking first at the between-scale differences in air temperature neutralities, the ASHRAE and Bedford scales had virtually identical values in all six surveys, thereby reinforcing the conclusions drawn earlier about the similarity of these two scales. The congruity of the two scales reduced slightly when standard effective temperature (SET) was

TABLE 6.12 : Neutralities observed on seven-point scales of warmth using either air temperature or standard effective temperature as independent variable *

Depend--ent var.	Independ--ent var.	Darwin		Brisbane		Melbourne	
		"The Dry"	"Build-up"	AC	NAC	AC	NAC
ASHRAE scale	Air temp	24.2 23.9-24.5	24.1 23.8-24.4	23.8 23.6-24.0	25.5 24.9-26.1	22.6 22.2-22.9	21.3 20.7-21.8
	SET	24.0 23.4-24.7	23.5 23.1-23.9	23.0 22.7-23.3	23.5 22.7-24.2	22.2 21.7-22.7	21.3 20.8-21.7
Bedford scale	Air temp	24.2 23.8-24.6	23.9 23.6-24.2	23.9 23.6-24.1	25.6 25.0-26.2	22.7 22.3-23.2	21.8 21.3-22.3
	SET	24.1 23.3-24.9	23.3 22.9-23.7	23.5 23.1-24.0	23.6 22.8-24.4	22.4 21.9-22.9	21.7 21.3-22.1
PREFV scale	Air temp	24.1 23.8-24.5	23.2 22.8-23.5	23.4 23.1-23.6	25.2 24.8-25.7	22.1 21.6-22.6	21.6 21.1-22.2
	SET	24.1 23.2-25.0	22.2 21.7-22.7	22.6 22.1-23.1	23.1 22.3-23.8	21.6 20.9-22.2	21.6 21.1-22.0

* Each cell entry consists of a neutality (ED50), below which is its 95% confidence interval estimate (see Appendix E for details of method). Plots of the 36 models that were used to generate table entries are depicted in Appendix H.

used as the independent variable instead of dry bulb temperature, but in no survey was the difference between ASHRAE and Bedford's SET neutrality any more than 0.5K. The PREFV scale neutrality also seemed to have comparable neutralities to ASHRAE and Bedford in the Darwin "Dry" air-conditioned and Melbourne non-air-conditioned surveys, but in the two Brisbane surveys and also the Melbourne air-conditioned surveys, PREFV scale neutrality was about half a degree (dry bulb or SET) cooler than the other two scales' neutralities. In the Darwin "Build-up" air-conditioned survey, PREFV scale neutrality was depressed even further (about 1K) below the ASHRAE and Bedford scales'. These inconsistent

differences between the subjective scales' neutralities will be discussed in Section 6.3 in relation to the "semantic set" hypothesis.

A clearer representation of the between-survey differences in neutralities from Table 6.12 was obtained by graphing them in Figures 6.2 through 6.4. Referring first to the dry bulb temperature neutralities for the ASHRAE and Bedford scales, it is noted that the three Darwin and Brisbane air-conditioned surveys all had similar neutralities around 24.0degC. In contrast, Melbourne's air-conditioned neutrality was about 1.4K cooler than this figure, while the non-air-conditioned neutrality was even cooler at about 21.5degC air temperature. At the other extreme were the Brisbane non-air-conditioned survey neutralities for the ASHRAE and Bedford scales at about 25.6deg.

Interpreting these between-survey differences in dry bulb temperature neutralities in the context of the body's heat-balance, one might expect the Brisbane non-air-conditioned neutrality to be elevated above the other surveys' due to the higher-than-normal air velocities. Further, the heavier clothing insulation worn by Melbourne respondents might be expected to lower their neutrality. To investigate these explanations, the probit analyses on ASHRAE and Bedford scale votes were performed again using the standard effective temperature as the independent variable. The results are included in Table 6.12 and illustrated in Figures 6.2 and 6.3. The Brisbane non-air-conditioned survey had its neutrality brought well down to become comparable with the other samples' at around 23.6 degC SET. However, the Melbourne non-air-conditioned survey at the other extreme still yielded a considerably cooler ASHRAE and Bedford neutrality under the "all else being equal" conditions of the SET probit analysis. As for the four

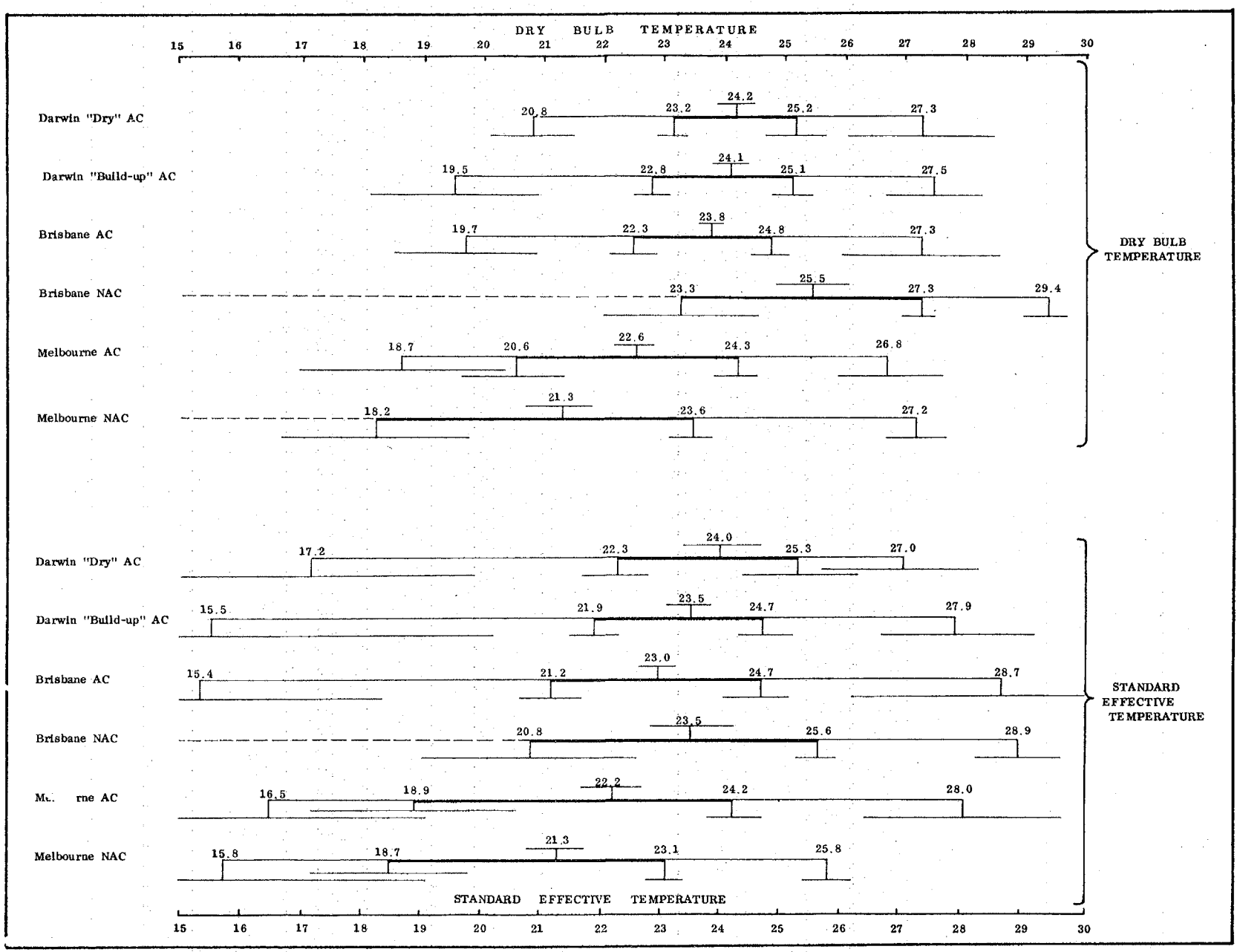


FIGURE 6.2 : Neutralities and transition temperatures on the ASHRAE scale
(Dotted line indicates that the transition temperature could not be estimated)

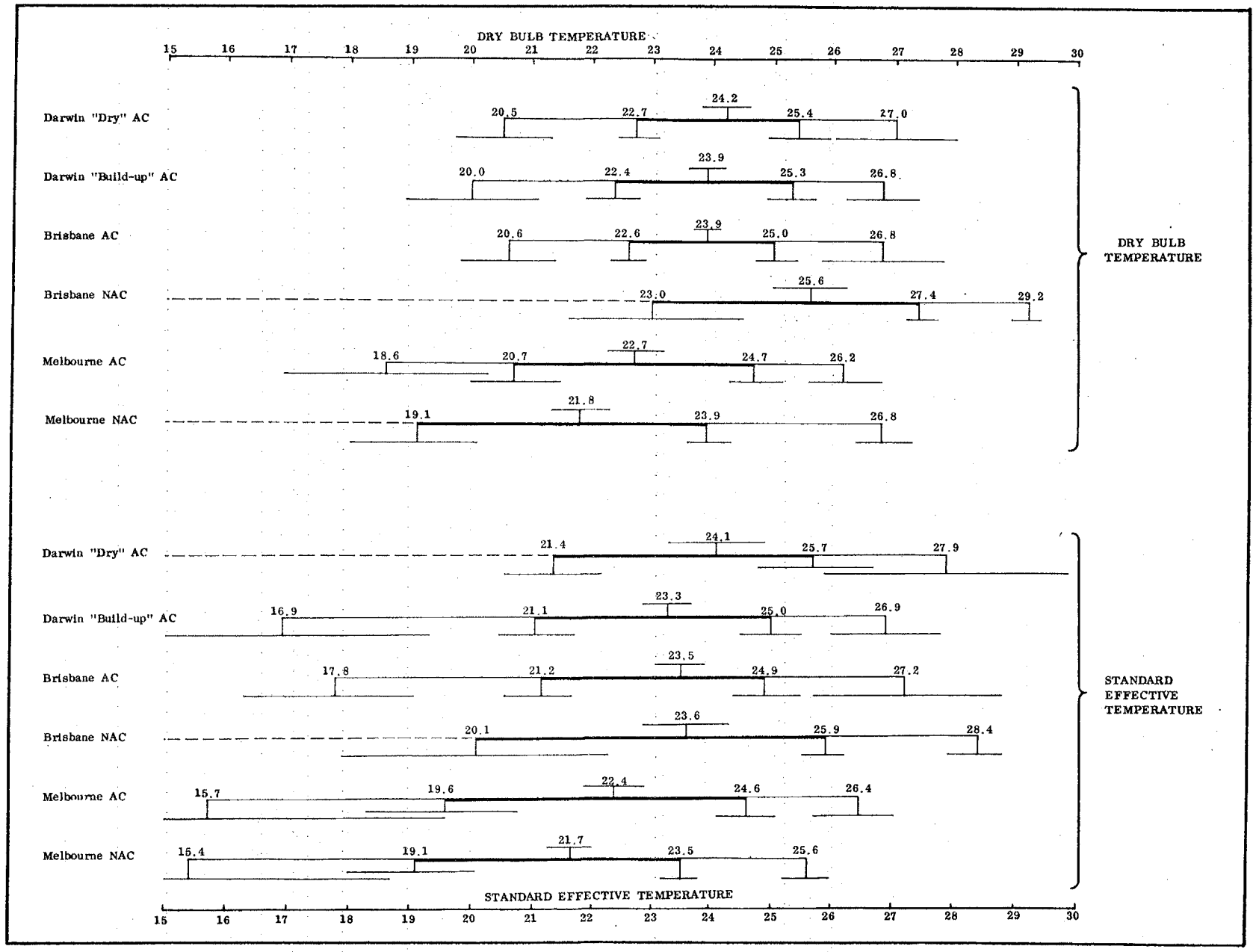


FIGURE 6.3 : Neutralities and transition temperatures on the Bedford scale

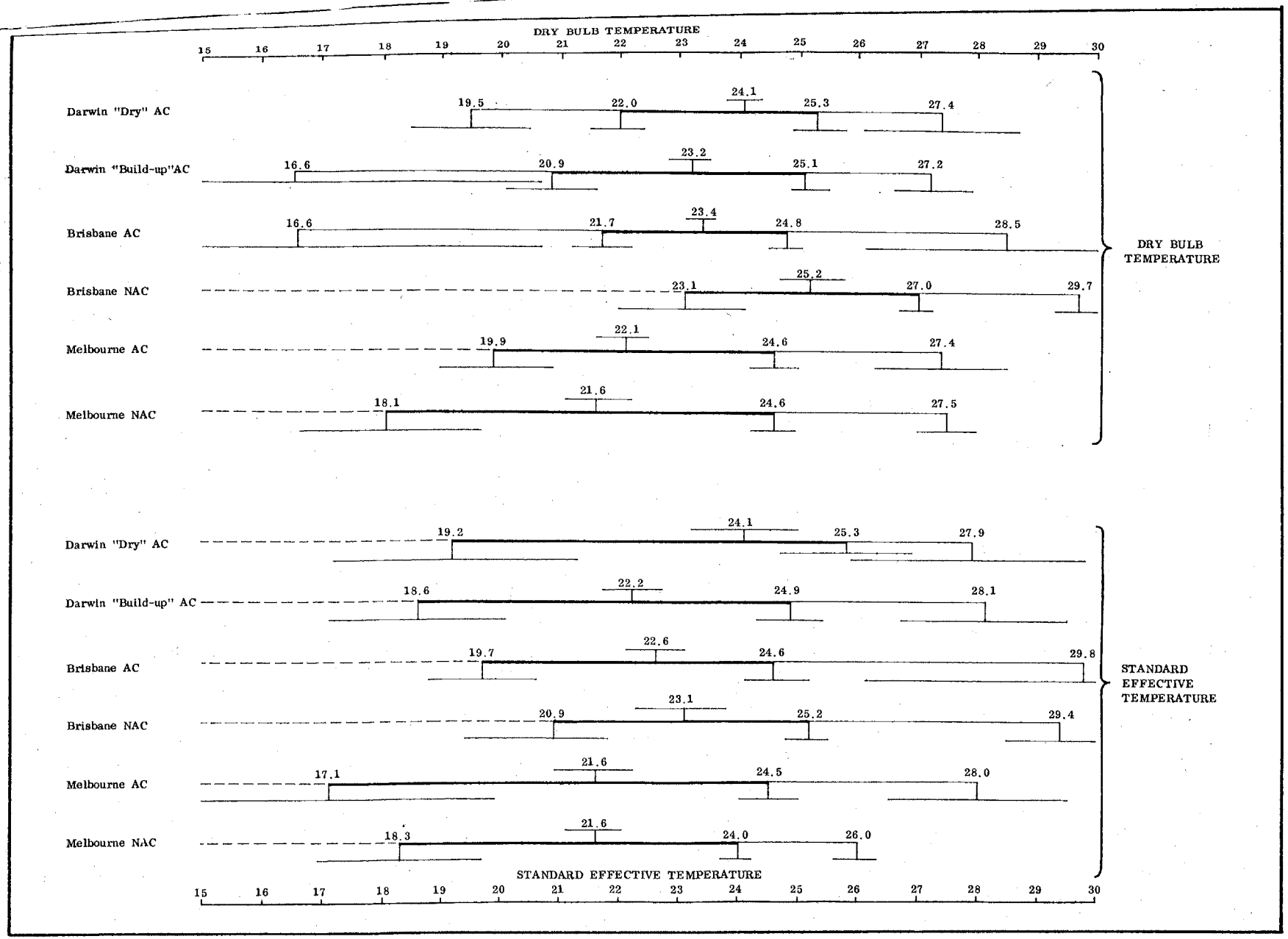


FIGURE 6.4 : Neutralities and transition temperatures on the PREFV scale

air-conditioned surveys, there seemed to be a gradual diminution of SET neutralities in the following order: Darwin "Dry" > Brisbane and Darwin "Build-up" > Melbourne. The drops in SET neutralities between these three levels were in the region of 1K, but due to SET's weaker statistical association with subjective warmth in comparison with air temperature (see Table 6.9), the 95% confidence limits of the SET neutrality estimates overlap in some of these between-survey comparisons.

Within-survey consistency of responses: The reciprocal of each probit neutrality model's gradient (1/b) was used as an indication of variability between respondents' subjective warmth at neutrality. These reciprocals, referred to as standard deviations for neutrality, are listed in Table 6.13. Referring to the two Brisbane surveys first, there is a clear increase from the standard deviations of neutrality probit models in the air-conditioned survey to the non-air-conditioned survey, regardless of which scale of subjective warmth or index of environmental warmth was used. By making the assumption that when two independent surveys have a statistically significant difference in their probit model gradients, they also have significantly different reciprocals of the gradients, it becomes possible to test the difference between the Brisbane surveys using the Z test, in which the discrepancy between gradients is divided by the square root of the sum of their variance. These variances were obtained by squaring the standard errors of the model gradients in Appendix H. The Z tests were significant ($p < 0.05$) for the difference between air-conditioned and non-air-conditioned ASHRAE and Bedford scale gradients using air temperature as the independent variable in probit analysis ($Z=2.73$ and 2.47 respectively). However, this finding fails to acknowledge the contribution of other heat-balance

variables to the neutrality models' standard deviations. Substituting the gradients of the SET neutralities for ASHRAE and Bedford scales into the Z tests, it was found that neither was significant ($p > 0.05$). Furthermore, none of the comparisons based on the PREFV scale SET neutrality model gradients were significant either.

TABLE 6.13 : Standard deviations of the probit regression neutrality models *

Dependent var.	Independent var.	Darwin		Brisbane		Melbourne	
		"The Dry"	"Build-up"	AC	NAC	AC	NAC
ASHRAE scale	Air temp	2.38	2.42	2.00	3.24	2.79	3.52
	SET	4.22	3.16	2.99	3.95	3.64	3.04
Bedford scale	Air temp	2.76	2.78	2.23	4.65	3.57	3.53
	SET	5.13	3.76	3.95	4.31	4.13	2.95
PREFV scale	Air temp	2.66	3.01	2.25	2.65	3.41	3.69
	SET	5.78	4.22	4.15	3.38	4.17	3.05

* Standard deviation is the reciprocal of the models' gradients as depicted in Appendix H (with sign ignored).

The lack of significant differences between SET neutrality standard deviations of air-conditioned and non-air-conditioned surveys in Brisbane is not particularly surprising in view of the fact that microclimatic variability was broadly comparable in absolute terms across both surveys. More substantial were the between-survey differences in microclimatic variability in Melbourne (see Table 6.2). Applying the Z test to the differences between these surveys' neutrality probit model gradients, it was found that none were significant ($p > 0.05$). Indeed, Table 6.12 shows that some of the standard deviations in the air-conditioned Melbourne survey were larger than their non-air-conditioned counterparts.

Humphrey's (1975) suggested on the basis of six air-conditioned surveys and 20 non-air-conditioned surveys that personal variability and the differences between subjective warmth assessments at group neutrality were considerably greater in less controlled indoor climates. He concluded that the uniformity of air-conditioned microclimates caused people to become homogeneous and very finely "tuned" to the normal temperature, and therefore, any slight departure from this would be consistently noticed by them. However, the probit models from which Humphrey's (1975) drew this conclusion used either dry bulb- or globe-temperature as their independent variable.

The present study's SET neutrality standard deviations fail to support the hypothesis suggested by Humphrey's (1975). It would appear that the differences between building occupants' subjective warmth assessments of group neutralities were unrelated to the degree of homogeneity prevailing in the building microclimatic conditions. The higher degree of personal variability observed by Humphreys (1975) in non-air-conditioned building surveys should be attributed to the unmeasured influence of other heat-balance variables such as air velocity and clothing. These variables would be expected to vary more in free-running buildings than in climate-controlled buildings.

Category temperature widths: In discussing multiple regression models of subjective warmth on the independent variables of microclimate in Section 6.2.2, it was noted that there were considerable differences between the various surveys in relation to the sensitivity of subjective warmth to variations of temperature. By making the assumption that the difference between successive transition temperatures on the seven-point scales is inversely proportional to the thermal sensitivity of survey

respondents, an alternative to the multiple regression method of assessment was obtained that made weaker assumptions of the data. Referring back to Figures 6.2 through 6.4, the transition temperatures that circumscribe the central three categories of each scale are depicted along with their neutralities.

Inspection of the 95% confidence interval estimates of transition temperatures in Figures 6.2 through 6.4 suggests that the comparisons of category widths should be confined to the zero category only ("neutral", "comfortable" and "no change" categories on the ASHRAE, Bedford and PREFV scales respectively). The lack of precision in estimates of transition temperatures at the -1.5 and +1.5 boundaries reflects the paucity of votes cast outside these central three categories in field studies.

First of all, the between-scale comparisons of zero category widths suggests a general equivalence of the ASHRAE and Bedford scales; the average air temperature width of the six surveys' ASHRAE scale zero category was 3.3K compared with 3.4K for the Bedford zero category. Also, the average SET width of the six surveys' ASHRAE scale zero category, holding all other heat-balance variables constant, was 4.0K compared to the marginally wider 4.5K mean for the Bedford scale. In Chapter 3 it was noted that laboratory respondents changed their ASHRAE scale vote by one unit for every 3K, all else being equal. The SET category widths observed in the current study at about 4K, suggest that field study respondents are about one third less sensitive to changes in temperature than their climate chamber counterparts.

The PREFV scale had a considerably wider zero category than either ASHRAE or Bedford scales, with a mean dry bulb temperature width of 4.3K and a mean SET width of 5.9K. This finding reiterates the conclusions made earlier about the relative sensitivity of the three scales of subjective warmth as discerned by normal multiple regression analysis; namely, that temperature had to deviate further from the optimum to induce a request for actual change, than was necessary for people to describe their personal warmth as neither "comfortable" nor "neutral". This suggests that there is no real difference in the way descriptive scales of subjective warmth (ASHRAE) and affective scales (Bedford) are interpreted in field studies. However, active scales such as PREFV seem less sensitive to microclimatic variations.

Juxtaposition of the six surveys' category widths in Figures 6.2 through 6.4 facilitates the detection of between-survey differences in subjective warmth sensitivity. In the earlier discussion of multiple regression coefficients, the hypothesis that microclimatic homogeneity induced increases in subjective sensitivity was generally supported. The hypothesis also has broad support from the category widths of Figure 6.2 through 6.4. First, the three air-conditioned surveys of Darwin and Brisbane had the most narrow zero categories on the ASHRAE and Bedford scales in dry bulb temperature terms (2.2K on average), and this pattern persisted when the "all else being equal" SET was used as the index of environmental warmth (3.6K on average). Reference back to the basic microclimatic variability statistics in Table 6.2 indicates that the Darwin and Brisbane air-conditioned indoor climatic conditions were relatively homogeneous.

Whereas the air-conditioned surveys' category widths were readily interpreted in terms of the sensitivity hypothesis, the two non-air-conditioned surveys are less consistent. The Brisbane non-air-conditioned survey's ASHRAE and Bedford category widths seem clearly wider than their air-conditioned counterparts. However, it was noted earlier that the free-running buildings had roughly the same degree of variability in their indoor climates as the air-conditioned buildings had in Brisbane. Possibly the degree of microclimatic homogeneity and the expectation of constancy each contributed to the sensitisation of subjective warmth in air-conditioned buildings.

In Melbourne, where the air-conditioned indoor climate was clearly more uniform than that of the free-running buildings, the ASHRAE and Bedford zero categories were clearly wider in dry bulb temperature terms in the non-air-conditioned survey (by 1.6K for ASHRAE and 0.8K for Bedford). This finding supports the hypothesised relationship between microclimatic variability and subjective warmth sensitivity. However, when SET was used to measure the category width, this between-survey difference was reversed. Rejection of the sensitivity hypothesis on the basis of these data seems unwarranted though, given that the lower transition SET for the Melbourne surveys were very inaccurately estimated (see Figures 6.2 and 6.3).

Thermal acceptability: To date in discussions of thermal satisfaction, the general assumption has been that a vote within the central three categories of ASHRAE and Bedford scales represented an expression of thermal acceptability (Fanger, 1970; Berglund, 1979). In the current study, the upper limit of the central three categories has been defined as a vote of +1.5, and the preceding section discussed the

transition temperatures associated with this boundary. However, in most comfort standards, 20% dissatisfaction has been the usual criterion for an acceptable indoor climate. Probit analysis was used to find the temperatures that were associated with 20% warmth dissatisfaction (called ED20) in the current six surveys. (See Appendix E for details of ED20 derivation).

Using air temperature and SET in turn, the ED20s (and their 95% confidence limits) of warmth dissatisfaction on the ASHRAE and Bedford scales are listed for each of the six field studies in Table 6.14). Dealing first with the ASHRAE scale, it is noticed that the three air-conditioned surveys of Darwin and Brisbane again cluster together in the middle of the range at about 25.5degC using air temperature as the independent variable. The two non-air-conditioned surveys were the outliers, with Brisbane's survey having an air temperature ED20 about 2 to 3K warmer, while Melbourne's was at least 1K cooler than the middle range of ASHRAE ED20s. However, when the SET index was used to standardise the microclimatic data, the ASHRAE ED20s were much more homogeneous in the 25.0-25.7degC range, except for Melbourne's non-air-conditioned survey, which became even more clearly differentiated with ED20 at 23.7degC.

Turning to the Bedford scale, a slightly different pattern emerged insofar as the air temperature ED20s seem to be more homogeneous across the six surveys than the SET ED20s. Regarding the latter, the three air-conditioned surveys in Melbourne, Brisbane and Darwin ("Build-up") were close to the overall mean ED20 at about 24.5degC SET, but the Darwin "Dry" survey was about 1K higher and the Brisbane non-air-conditioned survey was about 1K cooler than the overall mean SET ED20 for the Bedford

TABLE 6.14 : Acceptable temperatures as derived by probit analysis of the 20% warmth dissatisfaction criterion (ED20)

Depend--ent var.	Independ--ent var.	Darwin		Brisbane		Melbourne	
		"The Dry"	"Build-up"	AC	NAC	AC	NAC
ASHRAE scale	Air temp	25.6 25.0-26.2	25.7 25.3-26.1	25.4 24.8-25.9	27.6 27.3-27.8	24.8 24.4-25.2	24.4 24.0-24.9
	SET	25.1 24.4-25.8	25.4 24.8-26.1	25.5 24.4-26.6	25.7 25.2-26.2	25.0 24.4-25.7	23.7 23.4-24.0
Bedford scale	Air temp	25.3 24.7-25.8	24.9 24.6-25.2	24.8 24.4-25.2	27.7 27.5-27.9	24.3 24.0-24.6	24.3 23.9-24.7
	SET	25.2 24.2-26.1	24.4 23.9-24.8	24.4 23.9-25.0	25.9 25.5-26.3	24.3 23.9-24.7	23.6 23.3-23.8
PREFV scale	Air temp	25.8 25.1-26.5	25.6 25.2-25.9	25.8 24.8-26.7	27.7 27.4-28.0	25.4 24.9-26.0	25.1 24.6-25.5
	SET	25.7 24.6-26.7	25.4 24.7-26.0	25.9 24.3-27.4	25.9 25.4-26.4	25.4 24.8-26.0	24.2 23.8-24.4

* Each cell entry consists of an ED20, below which is its 95% confidence interval estimate

scale.

While the PREFV scale has not previously been used in the literature on thermal acceptability, it is interesting to note the between-survey uniformity of the ED20s for this scale in Table 6.14. Only the Brisbane non-air-conditioned survey stands out when air temperature is the independent variable, while only Melbourne's non-air-conditioned survey stands apart when SET was used. However, this relative homogeneity is misleading insofar as the PREFV ED20 confidence limits are wider apart

than was the case for the ASHRAE and Bedford scales. This was no doubt due to the increased temperature width of categories on the PREFV scale pushing the +1.5 transition temperature further away from the mean temperature, causing fewer data points to be involved in the probit model, leading in turn to unreliable model estimates.

To summarise the analysis of thermal acceptability, the two non-air-conditioned surveys had ED20s clearly different from the air-conditioned surveys'. In Melbourne, the difference was that 20% warmth dissatisfaction was achieved at a cooler temperature than in the other surveys, while in Brisbane, 20% dissatisfaction was expressed at a warmer temperature than in the other surveys.

6.3 Thermal Constancy Versus the Adaptation Hypothesis

The thermal constancy hypothesis of comfort has indirectly been under discussion in Section 6.2.3 where standard effective temperature neutralities observed in the six surveys were examined. The critical feature of the SET index is that it partials out the influences of clothing, air velocity and other heat-balance differences between the surveys. Therefore, according to the constancy hypothesis, the SET neutralities should be uniform across the six surveys. Referring back to Table 6.12 it is observed that, using the ASHRAE and Bedford scales, the range in SET neutralities was about 2.5K across the six surveys.

Using another operationalisation of the constancy hypothesis in the form of the PMV model, it was observed in Table 6.7 that the mean integrated thermal load being placed upon the respondents of the four

air-conditioned surveys was relatively stable between -0.5 and -0.4 PMV (meaning a predicted vote about half-way between "neutral" and "slightly cool"). However, the mean subjective responses actually observed in those four air-conditioned surveys fluctuated between a low of about -0.4 and a high of about +0.3 (using the observed mean ASHRAE and Bedford scale votes in Table 6.8). Furthermore, the mean observed ASHRAE and Bedford scale votes in the two non-air-conditioned surveys were between +0.7 and +0.8 (Melbourne and Brisbane respectively), while the corresponding mean PMV index scores diverged considerably, from -0.2 to +0.7 respectively. These between-survey differences in the discrepancy between predicted and actual votes are further illustrated by the survey means for the DISCR variable (actual ASHRAE scale vote minus the PMV calculated for conditions at the time of interview) in Table 6.8. All six surveys' mean DISCR values were positive, indicating that, on average, people said they were warmer than the PMV predicted them to be. Again the maximum mean DISCR was in Melbourne's non-air-conditioned survey and minimum occurred in Brisbane's non-air-conditioned survey.

These observations do not provide much support for the constancy hypothesis in the current six field studies. Perhaps a more direct test of the hypothesis is provided by a comparison of the neutralities predicted by the Fanger (1970) heat-balance model of comfort and the actually observed neutralities, as in Table 6.15. Also in that table are the neutralities predicted by the regression equations derived from 50 years of field studies (Equations 3.7 through 3.10). In Section 3.3 these equations were collectively referred to as the adaptation hypothesis of thermal comfort.

TABLE 6.15 : Comparison of six methods of assessment for the six surveys' neutralities

Method of assessment	Input	Eqn#	Darwin AC		Brisbane		Melbourne	
			Dry	Buildup	AC	NAC	AC	NAC
$T_{\psi 0}$ Observed neutrality	Bedford votes		24.2	23.9	23.9	25.6	22.7	21.8
$T_{\psi i}$ Humphreys 1975	T_i	3.7	21.9	22.3	22.3	25.7	22.0	22.8
$T_{\psi ii}$ Humphreys1976 free-running bldg	$T_{\overline{m}}$	3.8				25.3		22.6
$T_{\psi iii}$ Humphreys1976 climate-controlled	$T_{\overline{m}}$	3.9	24.8	25.8	24.6		23.3	
$T_{\psi iv}$ Auliciems1983 all buildings	$T_i, T_{\overline{m}}$	3.10	23.9	24.6	24.0	26.1	23.3	23.7
$T_{\psi v}$ Fanger 1970 PMV model	heat-bal. variables	3.3*	24.7	25.3	25.1	26.2	24.8	25.0

* PMV equation was iterated to equal zero for these neutrality predictions

Looking first at the accuracy of the Fanger (1970) model in each of the six surveys, the observed Bedford neutrality was cooler than that predicted by the heat-balance model, although the error amounted to only 0.5K in the Darwin "Dry" and Brisbane non-air-conditioned surveys. In the remaining four surveys, the overestimation by the model was on average 2.0K.

Referring to the adaptation model predictions in Table 6.15, in all six surveys they came closer to the observed neutralities than did the Fanger model's predictions. In both Darwin air-conditioned surveys, observed neutrality was about 2K warmer than that found in the average field study with the same mean indoor temperatures ($T_{\psi i}$), suggesting

that perhaps the high outdoor temperatures in Darwin were exerting an influence on neutrality. The $T_{\psi iii}$ relation predicted neutralities for the two Darwin air-conditioned surveys on the basis of their outdoor mean monthly temperatures that overshot the observed neutralities. It must be remembered though that the field surveys upon which Equation 3.9 ($T_{\psi iii}$) was based, did not have mean monthly temperatures any warmer than 23degC. Consequently, the Darwin surveys suggest the upward curving $T_{\psi iii}$ relation in Figure 3.3 to be inappropriate in warmer climates. The $T_{\psi iv}$ equation that incorporated outdoor and indoor temperature effects came closest to the neutralities observed in Darwin.

Similar conclusions can be drawn about the Brisbane air-conditioned surveys, where mean monthly temperature outdoors was about 1.4K out of the range of Humphrey's (1976) data set. Consequently, neutrality observed in that survey was warmer than expected on the basis of indoor temperature, yet cooler than predicted by outdoor warmth. Again, the $T_{\psi iv}$ equation that incorporates both these factors came closest to the observed neutrality. The last air-conditioned survey, in Melbourne, seemed to have its neutrality equally well predicted by equations $T_{\psi i}$, $T_{\psi iii}$ and $T_{\psi iv}$ in Table 6.15. This result no doubt reflects the fact that both the indoor and outdoor mean temperatures in this survey fell within the range of the independent variables used to generate the predictive equations.

Turning to the adaptation models' non-air-conditioned survey predictions in Table 6.15, the neutrality observed in Brisbane seemed to be fairly accurately predicted by $T_{\psi i}$, $T_{\psi ii}$ and $T_{\psi iv}$. High levels of warmth prevailing both indoors and outdoors in free-running buildings induced elevated neutralities, largely through the use of compensating

elements of microclimate such as increased air velocity and decreased clothing. However, the Melbourne non-air-conditioned survey result in Table 6.15 is more difficult to interpret. No matter which predictive method was used, the observed neutrality was cooler than expected, with the most accurate equation, $T_{\Psi ii}$ based on the mean monthly temperature, coming to within 0.8K.

A possible explanation could lie in the statistical distribution of outdoor temperatures upon which the monthly mean was based in that survey. The third-moment statistic for outdoor office-hours air temperature during the Melbourne non-air-conditioned survey as +0.8, indicating the positive skewing effect of extremely hot days (40+degC) on the distribution. Indeed, if the mid-February heat-wave week is excluded from the calculation of mean monthly temperature, a new $T_{\overline{m}}$ of 18.7degC is obtained. Inserting this figure into the $T_{\Psi ii}$ equation yields a predicted neutrality of 21.8degC, which coincides exactly with the observed Bedford scale neutrality. The February heat-wave occurred in the last week of the survey in Melbourne, so it would be unlikely that thermal perceptual processes would have had time to adapt to it during the field work. Consequently, the 18.7degC figure for $T_{\overline{m}}$ in the Melbourne non-air-conditioned survey is probably more representative of the respondents' thermal experience than the 20degC entry in Table 6.1.

Before concluding this chapter, attention needs to be directed at the "semantic set" reconciliation between the adaptation and constancy hypotheses of thermal comfort. For if this explanation of the between-survey differences in observed neutralities ($T_{\Psi 0}$) were to hold for the current data, one would expect the discrepancy between Bedford and PREFV scale neutralities to be a function of mean monthly

temperatures ($T_{\overline{m}}$). Turning back to Table 6.12, it can be noted that PREFV neutralities on SET deviated negatively from the Bedford scale counterparts by as much as 1.1K in the Darwin "Build-up" survey, which fits the semantic set hypothesis well, as that survey recorded the highest $T_{\overline{m}}$ of 28.8degC. However, the next highest discrepancy between the Bedford and PREFV scale neutralities of 0.9K was recorded in the Brisbane air-conditioned survey, which had only a middle ranking $T_{\overline{m}}$ of 24.4degC. Further evidence contradictory to the semantic set hypothesis was obtained in the Melbourne surveys where the Bedford-PREFV neutrality discrepancy ranged between 0.9K and 0.1K in the air-conditioned and non-air-conditioned surveys respectively, despite the similarity of their $T_{\overline{m}}$ entries at about 19-20degC. Consequently, there would appear to be little support in the current data for the hypothesis that the observed group differences were semantic artifacts.

CHAPTER SEVEN

RESULTS AND DISCUSSION II - ATTITUDE QUESTIONNAIRE

This chapter reports the results obtained by the attitude questionnaire (Appendix F), in each of the six field studies. It begins with a description of beliefs held by the respondents about air conditioning in the workplace, noting the prominent concern about health issues. This belief in adverse health effects is further explored in the second section where a list of common air conditioning-related symtoms is discussed. The third section reports occupants' attitudes towards passive smoking in the workplace, and their opinions about a particular indoor air quality regulatory measure involving the segregation of

smokers. Section four addresses various aspects of air conditioning-related attitudes, including their salience, affective intensity, and people's preferences for air-conditioned or free-running buildings. The degree of control that occupants perceive themselves as having over indoor microclimate is addressed in the fifth section, and this is followed by a section relating people's overall thermal satisfaction with various thermal and non-thermal characteristics of their buildings. The chapter finishes by relating people's instantaneous thermal perceptions to various attitudinal, behavioural and biographical factors. The data contained in this chapter relate to the research questions posed in Sections 4.3 and 4.4.

7.1 Free-Answer Beliefs About Air Conditioning in the Workplace

Respondents of all six surveys were asked open-ended questions concerning what they believed the advantages and disadvantages of air-conditioning to be.

7.1.1 Disadvantages

The coding of the free-answer disadvantages yielded nine clearly identifiable classes of response and one miscellaneous category, as depicted in Figure 7.1. The height of each bar in the graph represents the percentage of all total possible responses in each survey that fell within the coding category. The question was asked three times of each respondent, therefore the possible total was n times three. In the case of the two non-air-conditioned surveys, only those respondents who claimed to have previously worked in an air-conditioned building were

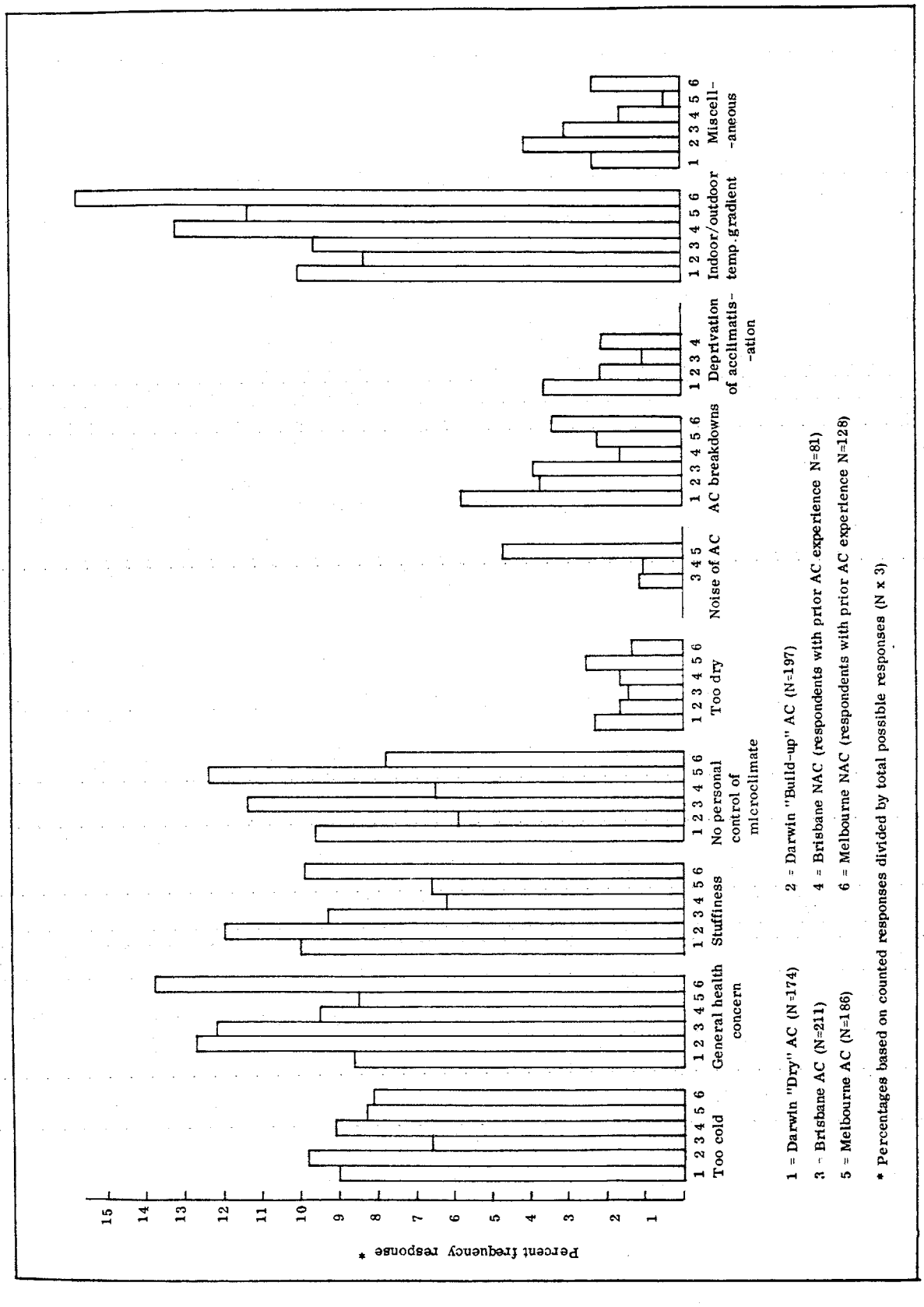


FIGURE 7.1 : Perceived disadvantages of air conditioning in the workplace: Open-ended responses coded into 10 classes

questioned on the matter (81 people in Brisbane and 128 in Melbourne non-air-conditioned surveys). The percentage of actual responses out of the total possible, was fairly constant in the four air-conditioned surveys, between 57% to 61%. The Brisbane non-air-conditioned respondents volunteered fewer disadvantages (53% of possible answers being given), while the Melbourne non-air-conditioned respondents remembered more negative features of air-conditioning than any other group, with 63% of possible answers being given.

One of the most frequently cited disadvantages was the thermal gradient between indoors and outdoors, attracting in the vicinity of 10% of total possible responses in the four air-conditioned surveys. Interestingly, the respondents of non-air-conditioned surveys remembered this disadvantage more frequently than their counterparts currently working in air-conditioned buildings. This was most noticeable in Melbourne (16% of all possible responses in this class), where, as pointed out in Section 6.1, the average indoor/outdoor thermal gradient was comparatively moderate. Possibly the response rate in this category was biased by the memory of the extreme thermal gradients that occur during that city's summer hot-spells. Regarding the types of answers that were coded into this class, there were many expressions of concern about the adverse health effects of "thermal shock". As one respondent in Darwin's "Build-up" survey put it:

> "I'm sure that plunging your body into arctic conditions after it has been running around in the tropics does no good for it."

Other typical answers in this category included:

> "Going in or out of this building knocks me around so much that I have to avoid doing it at lunch time."

> "Getting to work, you build up a sweat that just sticks to you in this cold, still environment...the best way to get a chill."

While many of the complaints about thermal gradients between indoors and outdoors had health implications, Figure 7.1 indicates that as many as 14% of all possible answers in some surveys referred to other health effects of working in air conditioning. Many related to low ventilation rates and the spread of infectious diseases, particularly of the upper respiratory tract. As with the thermal gradient complaint, the respondents in Melbourne's non-air-conditioned survey who had previously worked in an air-conditioned building were most vocal about health risks. Typical comments in this category of complaint were:

> "If anyone gets the flu in this place, the whole building gets infected within a fortnight."

> "Once you get a cold or the flu, it seems to take ages to shake it off when you work in air conditioning."

> "At least half the people in this building seem to have a cold or the sniffles at any one time."

Another of the most frequently cited grievances with air conditioning in Figure 7.1 focused on the problem of having no control over microclimatic conditions. The answers in this category conveyed the impression that modern building occupants, who had been deprived of any direct role in the control of their working environment, were particularly sensitive to even the most subtle departures from their comfortable or usual temperature. Thus, many of the responses in this category referred to spatial and temporal variability in indoor climatic conditions. The Darwin "Dry", Brisbane and Melbourne air-conditioned surveys polled in the 10-12% vicinity for this class of complaint, while the percentage of all possible responses falling into this category in

Darwin's "Build-up" and the two non-air-conditioned surveys ranged between 6 and 8%. The following three quotes convey something of the tenor of answers in this category:

> "I get rapped across the knuckles if I so much as look at the thermostat."
>
> "The temperature fluctuates wildly from one part of the building to another yet there's nothing we can do about it."
>
> "About all we can do when the system is out of balance is complain to the industrial officer, and then we get accused of being whingers [malcontents]."

A fairly consistent frequency of complaint about air conditioning being too cold was obtained in the six surveys, with between 6 and 10% of all potential responses falling into this category. Obviously some of these responses overlapped with the "thermal gradient" and "no personal control of microclimate" coding categories, but the following three quotes are representative of the unique responses in this class:

> "It's ridiculous that here in the tropics, during the hottest time of the year, we draughtsmen have to turn small radiators on to stay warm." [Darwin]
>
> "It always amuses me when I come in here after being boiled outside to see the typists wearing cardigans and legwarmers."
>
> "I suspect the fellow who runs this building's air conditioning system thinks he's short-changing us unless we're actually cold; its always colder than necessary."

The last major classification of air conditioning-related complaints dealt with air quality issues such as passive smoking, stuffiness and ventilation rates. The following comments were typical:

> "Every time I come into this building I imagine that something must have died in the air conditioning ductwork."

"They never give enough fresh air in this building and yet they still allow people to smoke in here."

"Sometimes I get so frustrated with the foul air in here that I feel like smashing a window open."

The remainder of the grievances about air conditioning in Figure 7.1 were distributed among the following categories; breakdowns of HVAC plant, noise of the HVAC systems, dryness of the conditioned air, deprivation of acclimatisation, and miscellaneous. The breakdown of air conditioning either through power black-outs or plant failure was particularly problematic in buildings with fixed windows. The noise of air conditioning was only a minor problem, attracting only 1% of total possible responses in the two Brisbane surveys. The 5% in Melbourne under this category was attributable mainly to one specific building (number 3 in Table 5.2) that seemed unusually noisy even to the researcher. Complaints of the conditioned air being too dry usually related to skin conditions, difficulties with contact lenses and dryness of nasal passages. While the role of air conditioning in depriving building occupants of their normal seasonal acclimatisation constituted one of the major hypothesis under analysis in the preceding chapter, the unsolicited confirmation of this disadvantage of air conditioning in Darwin and Brisbane was unexpected.

7.1.2 Advantages

There were eight clearly identifiable categories into which the free-answer advantages of air conditioning were coded. However, as seen in Figure 7.2, most responses fell into either the "comfort" or "productivity" categories. Respondents seemed less forthcoming with advantages than they were with disadvantages, as indicated by the

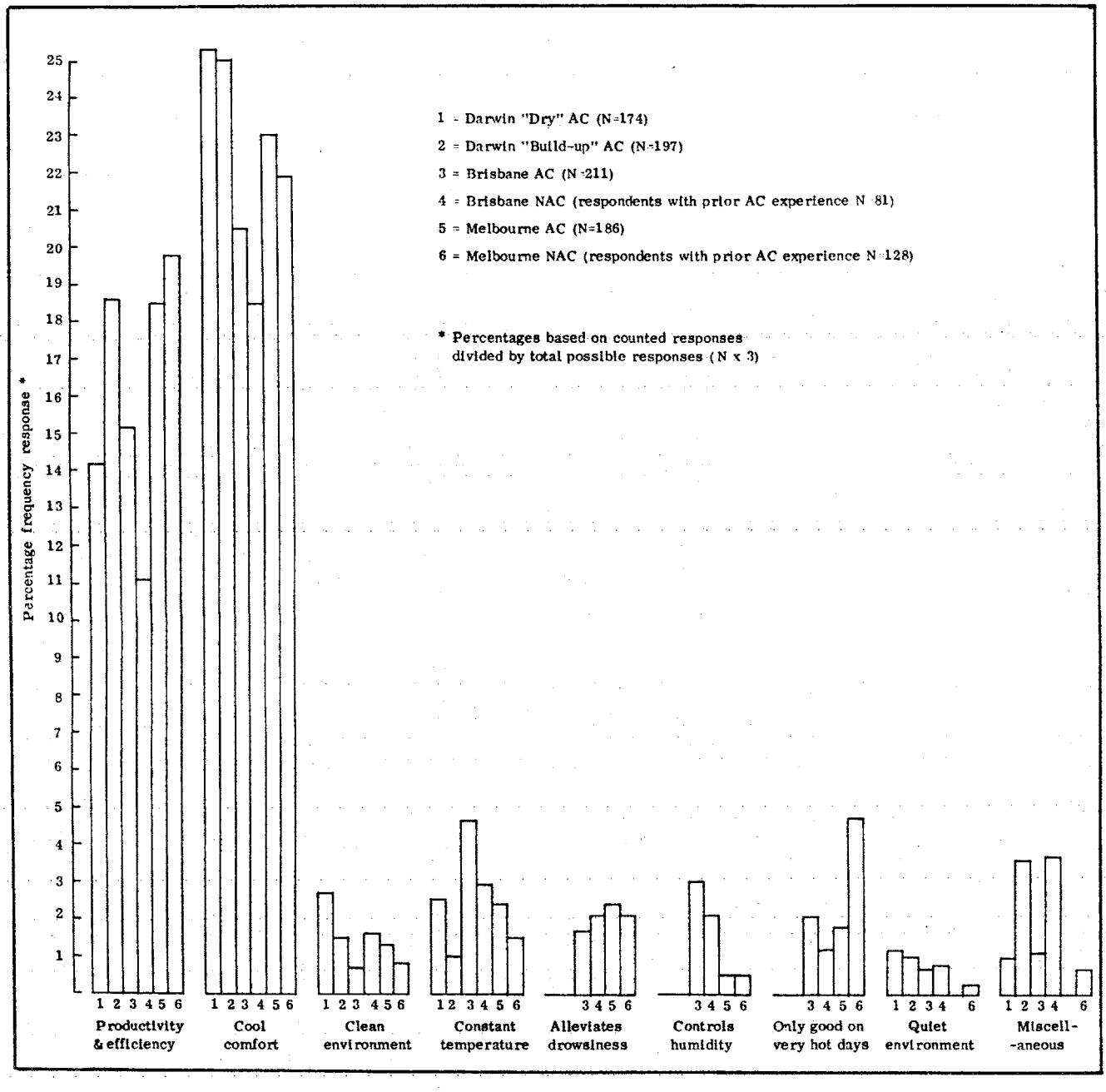


FIGURE 7.2 : Perceived advantages of air conditioning in the workplace : Open-ended responses coded into 9 classes

percentage of actual responses out of the total possible responses between 44% and 52% in the Brisbane and Melbourne non-air-conditioned surveys respectively.

The responses in the "comfort" category were not very diversified, with the following three being representative:

> "Its so nice to step into the office on really hot days."
>
> "The cool relief of air conditioning is the only reason for its existence isn't it?"
>
> "Before the Commonwealth built the first air-conditioned offices, we used to be accommodated in what looked like aircraft hangars that were incredibly uncomfortable." (Darwin)

Despite the paucity of evidence justifying air conditioning in terms of enhanced productivity (see Section 1.3.2), the respondents in the current survey clearly believed in this hypothesis. However, as the three quotes below indicate, some of their reasons relate to the practical difficulties of conducting paper work in high air velocities rather than thermal effects on performance:

> "It's so difficult being efficient in an office where every piece of paper has to be weighted because of the fans, and papers always stick to your forearms because of sweat - this never happens in air conditioning."
>
> "Being able to concentrate on the work instead of being distracted by the heat of summer must do something for an office worker's output in a working day."
>
> "Some days are so hot in Melbourne's summer that you would just melt into an unproductive pool of sweat were it not for air conditioning."

7.2 Air Conditioning and Health Issues

7.2.1 Belief in the adverse health effects of air conditioning

Several of the coding categories used in the preceding section to classify free-answer disadvantages of air conditioning had reference to adverse health effects; obviously the "general health" category was one, but there was also considerable concern over the health effects of thermal gradients between indoors and outdoors, and also the enforced passive smoking in low ventilation spaces (the "stuffiness" category). The respondents of the Brisbane and Melbourne air-conditioned surveys were questioned more specifically on these matters.

TABLE 7.1 : Belief in the adverse health effects of summer air conditioning

Count Row %	Definitely no connection	Possible connection	Definite connection	Don't know	Row total
Melbourne AC survey	48 25.8%	52 28.0%	75 40.3%	11 5.9%	186 100%
Brisbane AC survey	39 18.5%	64 30.3%	93 44.1%	15 7.1%	211 100%

Table 7.1 contains these two surveys' responses to the question:

> "Do you believe that working in refrigerated air-conditioned buildings is bad for your health, or that there is no connection between health and air conditioning?"

Referring to this table, less than a quarter of the occupants of air-conditioned buildings thought that there was no connection whatsoever between air-conditioning and health. Between 40% and 44% of occupants

held the opposite belief, that there was a definite causal connection. Brisbane respondents appeared to be more convinced about the causal nexus than were the Melbourne building occupants, but there was no statistically significant difference between the two survey's distribution of responses across the "definitely no connection", "possibly some connection" and "definite connection" categories (chi square=2.9, d.f.=4, $p>0.05$).

7.2.2 Identification of "sick buildings"

While the question that elicited the responses in Table 7.1 was about air conditioning in general, it was expected that most respondents would have based their answers on the buildings that they had worked in, and their current building would be foremost in their minds at the time of the interview. Accordingly, the responses of Table 7.1 were broken down on the basis of survey buildings and the resulting contingency tables (Tables 7.2 and 7.3) were examined with a view to identifying "sick buildings" (see Section 1.3.4). The "don't know" responses were excluded from the analysis.

The Brisbane buildings' contingency table (7.2) had one cell with an expected frequency of less than five, so a chi square statistic could not be calculated. However, a seemingly high percentage (87.5%) of respondents in Statistics House (building no. 3) believed that there was some connection between processes of air conditioning and ill health, suggesting that this was a possible "sick building". The Commonwealth Courts building (no. 2) in Brisbane was another possible "sick building" on account of the unusually high percentage of its occupants (60.6%) who felt there was a definite causal connection between air conditioning and

TABLE 7.2 : Belief in the adverse health effects of summer air conditioning in Brisbane's AC survey buildings

Count Row %	Definitely no connection	Possible connection	Definite connection	Row total
1 Commwlth Cntr	15 21.1%	23 32.4%	33 46.5%	71 100%
2 Commwlth Crts	6 18.2%	7 21.2%	20 60.6%	33 100%
3 Stats House	3 12.5%	9 37.5	12 50.0%	24 100%
4 Tax House	6 16.2%	18 48.6%	13 35.1%	37 100%
5 Eagle St 167	9 30.0%	7 23.3%	14 46.7%	30 100%

TABLE 7.3 : Belief in the adverse health effects of summer air conditioning in Melbourne's AC survey buildings

Count Row %	Definitely no connection	Possible connection	Definite connection	Row total
1 Commwlth Cntr (Block 2)	7 23.3%	7 23.3%	16 53.3%	30 100%
2 Macarthur Pl	22 27.2%	19 23.5%	40 49.4%	81 100%
3 St Andrews 33	10 29.4%	17 50.0%	7 20.6%	34 100%
4 Tivoli Court	9 32.1%	9 32.1%	10 35.7%	28 100%

health. There were no statistically significant differences between Melbourne buildings' response distributions in Table 7.3 (chi square=12.5, d.f.=6, $p>0.05$), so it would seem unlikely that any of them were "sick buildings".

There were no obvious differences between the thermal conditions prevailing in the two possible "sick buildings" and the remaining three buildings in Brisbane's air-conditioned survey. While the -0.56 mean PMV score recorded in Statistics House was not significantly cooler than the -0.51 mean PMV of the remaining three Brisbane air-conditioned buildings ($t=0.61$, $p>0.05$), the opposite was the case in the Commonwealth Courts building, which was significantly warmer by 0.15 PMV units than the remaining three buildings ($t=2.80$, $p<0.05$). Furthermore, the hypothesis that the "sick building" syndrome was related to the negative temperature gradient between outdoors and indoors was not supported by the Commonwealth Courts and Statistics buildings. The former building had an average temperature gradient of 2.6K and the latter, 3.3K. Both these were smaller than the 3.5K average gradient in the three remaining air-conditioned buildings. Consequently, if Brisbane's Statistics House and Commonwealth Courts were appropriately classified as "sick buildings", this characteristic can probably be attributed to non-thermal aspects of their indoor environments, if at all to environmental factors.

7.2.3 Ailments attributed to summer air conditioning

Respondents in the Brisbane and Melbourne air-conditioned surveys who believed there was either a definite, or possible adverse health effect of air conditioning were asked for three current or previous symptoms or ailments that they thought were causally linked to their having worked in

air conditioning during summer months. In Melbourne, 213 symptoms were elicited from 126 respondents, amounting to a 56% response rate, while only a 44% response rate was obtained from the 156 Brisbane respondents (chi square=12.7, d.f.=1, $p<0.01$). The responses were coded into 11 symptom categories and one miscellaneous class. The latter accounted for a substantial percentage of total possible responses, with 14.3% in Melbourne and 11.8% in Brisbane, giving some indication of the considerable variety of ailments attributed to air conditioning. The frequency of response and associated percentage of possible responses in each of the 12 coding categories are listed in Table 7.4.

TABLE 7.4 : Ailments attributed to summer air conditioning

	colds or 'sniffles'	nasal or sinus	respiratory infections	headaches	bronchial/asthma	dry skin or scalp	rheumatism or aches	thermal "shock" entering or leaving building	hayfever	tiredness	sore eyes	miscellaneous	Row totals
Melbourne AC survey	57 15.1%	12 3.2%	37 9.8%	9 2.4%	6 1.6%	16 4.2%	2 0.5%	3 0.8%	6 1.6%	11 2.9%	0 0%	54 14.3%	378 100%
Brisbane AC survey	65 13.9%	41 8.8%	37 7.9%	8 1.7%	12 2.6%	4 0.9%	3 0.6%	2 0.4%	10 2.1%	4 0.9%	5 1.1%	55 11.8%	468 100%

The "colds or sniffles" category attracted the greatest frequency of response, in the region of 14-15% of the possible total. The second most frequent class of ailment was "respiratory infections", with a response rate between 8 and 10%. "Nasal and sinus" problems were mentioned by large numbers of respondents, but there was a considerable difference between the Brisbane (8.8% of total possible responses) and Melbourne

(3.2%) surveys. It cannot be established without indoor air quality data whether this between-city difference isn't simply the result of the Brisbane region's greater incidence of hayfever-type ailments.

TABLE 7.5 : Self-assessments of general health status at time of interview

Count (Column%)	BRISBANE		MELBOURNE	
Current health	AC	NAC	AC	NAC
Excellent	31 (14.7%)	27 (13.4%)	28 (15.4%)	36 (19.3%)
Good	115 (54.5%)	124 (61.7%)	113 (62.1%)	94 (50.3%)
Fair	57 (27.0%)	43 (21.4%)	37 (20.3%)	50 (26.7%)
Poor	8 (3.8%)	7 (3.5%)	4 (2.2%)	7 (3.7%)

If there was in fact a pathological basis to the widespread belief in the adverse health effects of air conditioning, one would expect the health status of free-running building occupants to be better than their air-conditioned counterparts. While no medical examinations were actually conducted, the respondents of the Brisbane and Melbourne surveys were asked to give their own assessment of their health status at the time of interview. The distributions of these assessments on a four-point scale ranging from "poor" to "excellent" are given in Table 7.5. The modal response in all surveys was "good", with percentages ranging between 50% and 62% in the Melbourne and Brisbane non-air-conditioned surveys respectively. Since there was no statistically significant between-survey difference in the distribution of self-assessed health status (chi square=9.6, d.f.=9, $p>0.05$), three deductions may be made:

1. The two air-conditioned surveys were of insufficient duration to pick up any significant numbers of respondents afflicted with air-conditioning related ailments or symptoms,

2. Occupants of air-conditioned and free-running buildings alike had the same incidence of ailments as listed in Table 7.4 and similar general health status, but the occupants of air-conditioned buildings had an obvious scapegoat for their health problems,

3. Respondents used the assessment scale so conservatively that even if they were afflicted with a minor ailment or symptom, they considered it not sufficiently serious enough to downgrade their health status from "good".

Since a total of 393 occupants of air-conditioned buildings were asked for their health status over survey periods amounting to at least half of the summer season, the last two explanations would seem to be the most plausible. Without clinically validating the questionnaire item, it is not possible to assess their relative merits though.

7.3 Passive Smoking in the Workplace

One of the most frequently volunteered disadvantages of air conditioning as discussed earlier in Section 7.1.1, was that of "stuffiness" and other aesthetic issues concerning indoor air quality. Cigarette sidestream smoke was mentioned in many of the responses that were coded into this category. Presumably, passive smoking is of more

concern to non-smokers than to smokers, so the former were targeted for a series of specific questions on the issue in the four Darwin and Melbourne surveys. The actual percentage of non-smoking respondents varied between a low of 60% in the Darwin "Dry" survey, and a high of 73% in the Melbourne air-conditioned survey.

TABLE 7.6 : Non-smokers' sensory irritation resulting from exposure to cigarette smoke in the work-place

Count (Column%)		DARWIN AC		MELBOURNE	
Irritation assessment		"Dry"	"Build-up"	A C	N A C
No smoke	0	50 (47.2%)	40 (32.2%)	59 (43.4%)	35 (27.3%)
Unnoticeable	1	8 (7.5%)	17 (13.7%)	15 (11.0%)	15 (11.7%)
Acceptable	2	22 (20.8%)	34 (27.4%)	29 (21.3%)	35 (27.3%)
Slightly irritating	3	18 (17.0%)	15 (12.1%)	20 (14.7%)	18 (14.1%)
Irritating	4	4 (3.8%)	10 (8.1%)	4 (2.9%)	14 (10.9%)
Very objectional	5	3 (2.8%)	4 (3.2%)	7 (5.1%)	10 (7.8%)
Intolerable	6	1 (0.9%)	4 (3.2%)	2 (1.5%)	1 (0.8%)

The assessment of sensory irritation resulting from passive smoking was elicited with the question:

> "How would you rate the overall irritation (if any) resulting from exposure to smoke in the air at work?"

The responses were placed on a seven-point rating scale, and the frequency totals for this scale are presented in Table 7.6. The modal rating in all four surveys was "no smoke present", with response rates between 27% in Melbourne's non-air-conditioned survey and 47% in the Darwin "Dry" air-conditioned survey. Assuming that a rating of 2 or less was acceptable, and that 3 "slightly irritating" or higher were

unacceptable assessments, a considerable majority of non-smokers in each survey (66-77%) found the level of cigarette smoke in their workplace to be acceptable. This was a little surprising in that several of the buildings surveyed were discussing the implementation of a smoke-free environment policy at the time.

In view of the lower ventilation rates in air-conditioned buildings as compared with free-running structures, the Melbourne NAC respondents in Table 7.6 were expected to have a greater percentage of their sensory irritation assessments in the first three acceptable categories compared to the air-conditioned respondents. Inspection of Table 7.6 suggests the opposite to be the case, with only 66% of Melbourne's non-air-conditioned respondents in this class, compared with 76% in the Darwin "Dry" air-conditioned study. However, there was no statistically significant difference in the distribution of the acceptable and unacceptable assessments across the four surveys (chi square=3.6, d.f.=3, $p>0.05$).

TABLE 7.7 : Attitudes of non-smokers on the segregation of smokers in the work-place

Count (Column%) Responses	Darwin "Build-up"	Melbourne AC	Melbourne NAC
Definitely for segregation	57 (46.0%)	54 (40.9%)	39 (31.0%)
Segregation depend--ing on density	20 (16.1%)	32 (24.2%)	43 (34.1%)
Definitely against segregation	43 (34.7%)	41 (31.1%)	40 (31.7%)
Don't know	4 (3.2%)	5 (3.8%)	4 (3.2%)

Perhaps of more direct relevance to the management of passive smoking problems than sensory irritation assessments are the responses to the following question:

> "Do you think it is necessary to segregate smokers from non-smokers in the workplace, or is it O.K. having them together?"

The question was put to all non-smokers (assuming that smokers wouldn't vote for segregation) in the Darwin "Build-up" and both Melbourne surveys. Answers were coded into four categories as listed in Table 7.7. The "segregation depending on density" category covered those respondents who felt that segregation of smokers was only necessary when level of smoking in an office was extremely heavy, but not as a general policy.

About a third of non-smokers in each survey were categorically against segregation of smokers. However, there was a statistically significant difference in the distribution of "definitely for segregation" and "segregation depending" responses across the three surveys in Table 7.6 (chi square=11.9, d.f.=2, $p<0.01$). The respondents in Melbourne's non-air-conditioned survey were the least definite about segregation, and this supports the expectations discussed earlier in relation to ventilation rates in free-running buildings.

7.4 Attitudes Toward Air Conditioning in the Workplace

7.4.1 Salience of attitudes on indoor climatic issues

Data on the relative importance of nine aspects of an office building to the occupants' overall assessment of working environmental quality are given in Table 7.8. The items in that table are listed in the same order

as they were presented to respondents. Cell entries in the table represent each survey's median rating on the four-point scale of importance for a particular aspect of the built environment, and its ranking out of all nine components of an office building (column rank).

TABLE 7.8 : Relative importance of indoor climatic issues in overall built-environmental quality *

Median (Column rank)	BRISBANE		MELBOURNE	
Component of the built environment	AC	NAC	AC	NAC
Location/access	2.8 (5th)	2.6 (6th)	2.8 (4th)	2.8 (3rd)
Privacy/quietness	2.9 (4th)	3.0 (4th)	2.8 (4th)	2.8 (4th)
Spacious	2.9 (4th)	3.2 (3rd)	2.4 (5th)	2.8 (3rd)
Temperatures	3.4 (3rd)	3.5 (2nd)	3.5 (3rd)	3.4 (2nd)
Furniture/equipment	2.7 (6th)	2.7 (5th)	2.3 (6th)	2.3 (4th)
Decor/aesthetics	2.3 (7th)	2.4 (7th)	2.4 (5th)	2.3 (4th)
Window views	2.0 (8th)	1.9 (8th)	2.0 (7th)	1.9 (5th)
Lighting	3.5 (2nd)	3.7 (1st)	3.7 (1st)	3.6 (1st)
Fresh air/ventil.	3.6 (1st)	3.7 (1st)	3.6 (2nd)	3.6 (1st)

* 1=of no importance; 2=of some importance; 3=of great importance; 4=of very great importance

Views from windows were considered in all four surveys to be of least importance, with median ratings in the region of 2 (of some importance). Decor, followed by furnishings and equipment were next in the rankings, although the Brisbane surveys gave furniture and equipment a higher median rating (2.7) than did the Melbourne surveys (2.3). Building location, privacy/quietness, and spaciousness all received middle rankings with median ratings around 3 (of great importance). Temperature of the workplace received a third ranking (or second in the case of a tied first position) in all four surveys, with median ratings

about midway (3.5) between "of great importance" and "of very great importance". Lighting and ventilation were ranked as being the most important of the nine elements of the built environment, with median ratings at about 3.6.

While there was some shuffling among the middle rankings between the four surveys, there seemed to be good agreement between cities, and also between AC and NAC surveys, about which environmental factors were the least or most important in Table 7.8. The ranking of ventilation and fresh air as the most important determinant of environmental quality tends to reinforce the volume of concern expressed in other parts of the attitude questionnaire about the adverse health effects of air conditioning. There seems to be unanimous agreement between the six samples that the atmospheric, along with the luminous environments are the key factors in overall building quality.

7.4.2 Thurstone successive-interval scale of affect toward air conditioning

While this attitude scale was designed to yield real-number data, the results have been grouped into intervals of 0.5 units to allow presentation as a frequency distribution for each survey in Figure 7.3. Accompanying each histogram is the survey's mean and standard deviation for the Thurstone scale. At the foot of Figure 7.3 are four attitude statements selected from the full battery used in the scale (as derived in Appendix G) to illustrate the meaning of scale values on the horizontal axis.

The affect scale means in all six surveys were positive, ranging from +0.35 in Brisbane's non-air-conditioned survey through to +1.23 in the Darwin "Build-up". In the development of the scale in Appendix G, the zero-point was assumed to coincide with the scale value for this attitude item:

"I don't strongly like or dislike air conditioning in the office."

The validity of this scaling assumption was checked by inspecting the mean affective scale values of those respondents who stated a preference for working in non-air-conditioned buildings against the mean for those who preferred air conditioning. The expectation was for the former group's mean to be negative and equally displaced from zero as the latter group's mean, which was expected to be positive. While there was a statistically significant t test at better than 0.01 probability, in each of the five surveys (the question of preference was not asked in the Darwin "Dry" survey), the mean scale values for respondents preferring non-air-conditioned buildings were only slightly negative (ranging from -0.40 to +0.05 in the Melbourne and Darwin "Build-up" air-conditioned surveys respectively), in comparison to the strongly positive mean scale values for respondents preferring air conditioning (ranging from +1.17 through to +1.42 in Brisbane's non-air-conditioned and Darwin's "Build-up" surveys respectively).

From these results it would seem reasonable to conclude that the "true" zero-point for the Thurstone successive-interval scale of affect was somewhere to the right of the zero depicted on the horizontal axes of Figure 7.3. However, despite this scaling problem, the attitude continuum appears to be validated by the highly significant differences

between the mean Thurstone scale values of the two preference groups (in Darwin "Build-up" $t=8.16$, $d.f.=186$, $p<0.01$; Brisbane AC $t=12.70$, $d.f.=196$, $p<0.01$; Brisbane NAC $t=13.12$, $d.f.=192$, $p<0.01$; Melbourne AC $t=10.08$, $d.f.=175$, $p<0.01$; Melbourne NAC $t=11.03$, $d.f.=181$, $p<0.01$).

The mean scale values and also the shapes of the histograms for the six surveys in Figure 7.3 clearly highlight the respondents of the Darwin "Build-up" survey as being the most favourably disposed to air conditioning in their offices during the season surveyed. The mean of +1.23 and also the negative skew in the distribution suggest that the scale values were approaching the positive extremity of the continuum. The Darwin "Dry" and Brisbane non-air-conditioned survey means were the least favourably disposed to air conditioning at about +0.35. The shape of these two surveys' histograms in Figure 7.3 appear to most closely approximate that of the normal frequency distribution. The histograms for the Brisbane and Melbourne air-conditioned surveys, and particularly the Melbourne non-air-conditioned survey, have a bimodal shape. Of the numerous explanations that might be advanced to account for these features, perhaps the most plausible is the difference between affective scale values of respondents who preferred working in air conditioning in comparison to those preferring a non-air-conditioned building, as discussed earlier. The scale distances between these two groups' means would be sufficiently large to span the peak-to-peak distances depicted in Figure 7.3.

Other between-group differences in affective scale values investigated were; 1) age (greater than or less than 34 years old), 2) length of residence in the tropics (Darwin), and 3) sex. Using two-tailed t tests between age groups' means, no significant differences

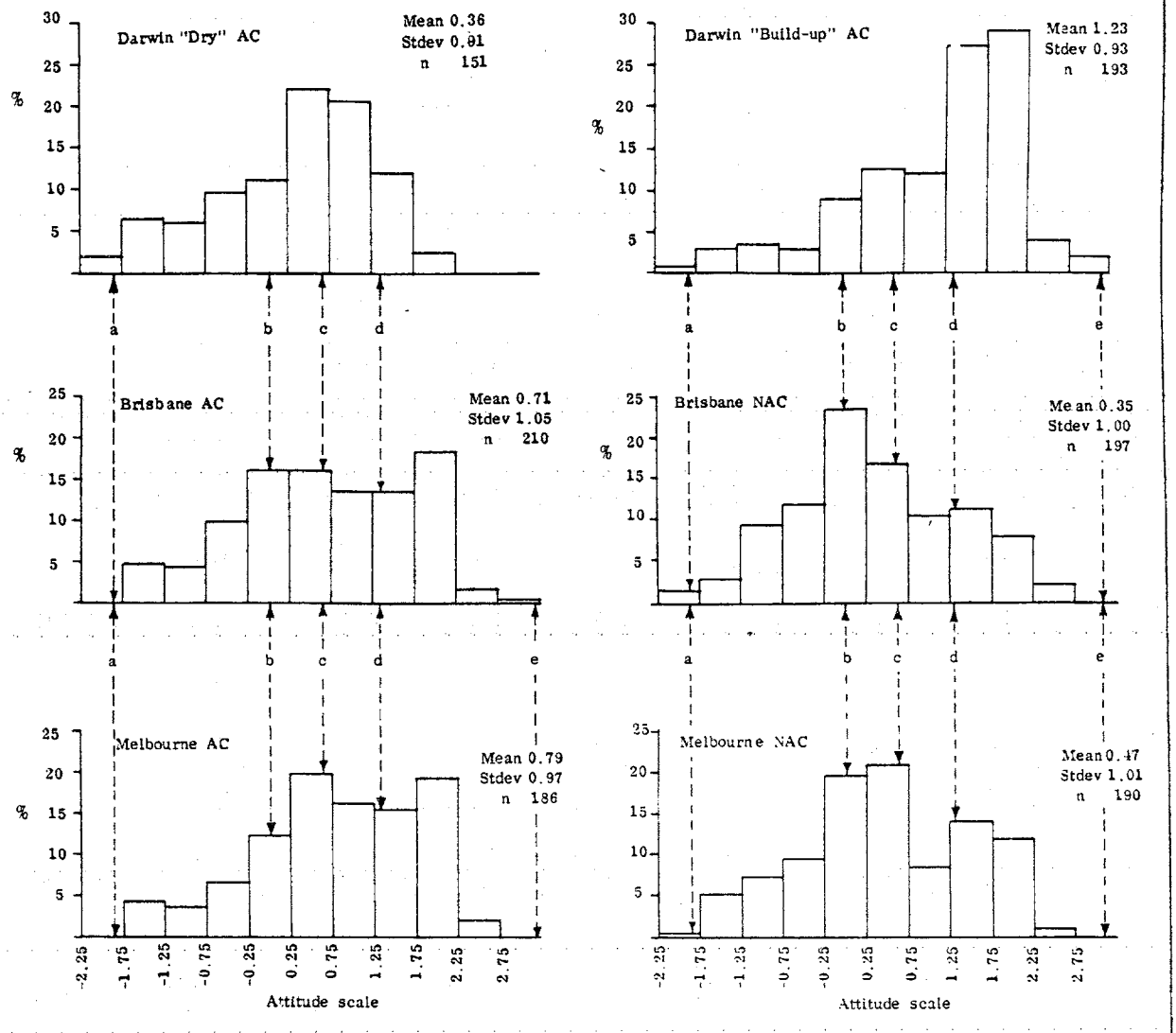


FIGURE 7.3 : Frequency distribution of the Thurstone successive-interval scale of affect toward air conditioning

were found in the two Melbourne surveys nor in the Darwin Dry survey. However, in the Brisbane non-air-conditioned survey, the older respondents were less favourably disposed toward air conditioning than

the young ($t=2.53$, $d.f.=195$, $p<0.05$), while the opposite was observed in the Brisbane and Darwin "Build-up" air-conditioned surveys ($t=2.12$, $d.f.=203$, $p<0.05$ in Brisbane, and $t=2.16$, $d.f.=191$, $p<0.05$ in Darwin). The inconsistency of the relationship between age and affect would suggest that it was spurious, with possibly a third variable providing a causal explanation.

Darwin respondents who had lived there for less than two years had their mean Thurstone score compared with that of respondents who had lived in Darwin for more than 20 years. In the "Dry" survey the long term residents' mean was 0.214 units less than the new arrivals' ($t=0.89$, $d.f.=56$, $p>0.05$), indicating that there was no real difference between the two groups' favourability towards air conditioning in the "Dry" season. However, there was a significant difference between the Thurstone means of these two groups in the "Build-up" survey, with the short-term residents being 0.62 units higher in this season than the long-term residents ($t=2.87$, $d.f.=51$, $p<0.01$). Possibly there was some form of long-term acclimatisation that progressively reduced Darwin residents' dependence on air conditioning during the "Build-up" and "Wet" seasons.

Each survey's affective scale values were disaggregated according to sex, and the resulting means were also tested for significant differences with a two-tailed t test. The males in each of the four Brisbane and Melbourne surveys were more favourable toward air conditioning than were the women (Brisbane A.C. $t=2.78$, $d.f.=207$, $p<0.05$; Brisbane N.A.C. $t=2.64$, $d.f.=194$, $p<0.01$; Melbourne A.C. $t=2.91$, $d.f.=184$, $p<0.05$; Melbourne N.A.C. $t=2.07$, $d.f.=189$, $p<0.05$). However, no significant differences were observed between the sexes in the two Darwin surveys,

suggesting that each survey's affect scores became more homogenous as the overall mean shifted towards either the favourable or unfavourable end of the attitude continuum.

In view of the prominence of health issues in attitudes toward air conditioning, as discussed earlier, statistical relationships between the scale of affect and belief in the adverse effects of air conditioning were sought in the Melbourne and Brisbane air-conditioned surveys. Given that three grades of belief in the connection between air conditioning and health were recorded, two separate hypotheses were tested in each survey:

1. Respondents who believed there was no adverse effect of air conditioning on health were expected to be more favourably disposed to the climate control than respondents believing there was a <u>possible</u> causal nexus (one-tailed test used). In Brisbane, the "disbelievers" mean affective scale value of +1.46 was significantly higher than the +0.87 mean for those respondents conceding a possible causal relationship ($t=2.57$, $d.f.=98$, $p<0.01$).

2. Respondents who believed there was <u>definitely</u> an adverse health effect of air conditioning were expected to be less favourable toward air conditioning than those who thought the causal connection was possible (again a one-tailed test being used). In both the Brisbane and the Melbourne air-conditioned surveys, the differences between these two groups' mean affective scale values were in the predicted direction and statistically significant (in Brisbane

t=4.13, d.f.=153, p<0.01; Melbourne t=3.93, d.f.=124, p<0.01).

Clearly, on the basis of these data it can be concluded that the cognitive issues relating to health in air conditioning interact with the affective disposition of building occupants to such climate controls.

7.4.3 Stated preferences for air-conditioned or free-running buildings

The attitude questionnaires used in each of the six surveys included questions on what type of workplaces were considered preferable; air-conditioned versus non-air-conditioned. To the extent that these stated preferences imply some form of behavioural response, they have been regarded as indicators of the effective component of attitude towards air conditioning. The four Brisbane and Melbourne questionnaires used the same format for the question and the breakdown of responses is presented in Table 7.9. Because the Darwin surveys were treated differently, their results will be presented separately. Table 7.9 is arranged so that each survey is represented as the row variable, and is broken down according to whether or not the respondents had experience of working in both air-conditioned and non-air-conditioned office buildings. For example, 67 people or 72% of Brisbane's air-conditioned sample who had at some stage earlier worked in non-air-conditioned offices, stated a preference for air conditioning in summer.

Before an interpretation of the table could be made, it was considered desirable to clarify the way in which respondents understood the question:

"If given a choice, which would you prefer in summer...

TABLE 7.9 : Preferences for air-conditioned or free-running buildings
Brisbane and Melbourne

Count Row%		STATED PREFERENCES			
		air-cond.	non-air-cond.	D K*	row total
Brisbane air-conditioned survey	respondents with NAC experience	67 72.0%	24 25.8%	2 2.2%	93 100%
	respondents without NAC experience	69 59.4%	39 33.6%	8 6.9%	116 100%
Brisbane non-air-cond. survey	respondents with AC experience	32 42.7%	42 56.0%	1 1.3%	75 100%
	respondents without AC experience	49 40.5%	70 57.9%	2 1.7%	121 100%
Melbourne air-conditioned survey	respondents with NAC experience	72 64.9%	36 32.4%	3 2.7%	111 100%
	respondents without NAC experience	40 53.3%	29 38.7%	6 8.0%	75 100%
Melbourne non-air-cond.	respondents with AC experience	51 39.2%	77 59.2%	2 1.5%	130 100%
	respondents without AC experience	23 36.5%	36 57.1%	4 6.3%	63 100%

* D K = Don't Know

1. Working in an office that had air conditioning? OR

2. Working in an office that didn't have air conditioning?"

In particular, it was unclear whether the question was being used as a means for respondents to protest about the particular building in which they were being interviewed, or as a general statement of preferences. Two non-air-conditioned buildings in Melbourne provided an opportunity to check this validity issue. The building at 2 Treasury Place (number 1 in Figure 5.6 and Table 5.3) was generally treated very favourably by its

occupants who found thermal conditions quite acceptable during summer. By contrast, the Commonwealth Centre Block 1 (number 2 in Figure 5.6 and Table 5.3) was designed as if air conditioning was to be installed but was withheld at the last minute. This impression was reinforced by comparison with Block 2 of the Centre, of exactly the same design and built several years after Block 1, but with air-conditioning. Block 1 was also the subject of an industrial campaign at the time of survey. Logically therefore, if the preference question was being used for a "protest vote", the respondents of Block 1 at the Commonwealth Centre should have a greater preference for air conditioning than the occupants of 2 Treasury Place. Forty-three percent of the Commonwealth Centre respondents were in favour of air conditioning as opposed to only 22.2% in 2 Treasury Place (chi square=6.4, d.f.=1, $p<0.05$), thereby indicating that the question was partially influenced by the particulars of each survey building. However, that a majority of Commonwealth Centre Block 1 respondents (56.6%) were still in favour of non-air-conditioned buildings also suggests that the stated preferences were not overwhelmed by peculiarities of the buildings in which the surveys were conducted.

The first general feature of Table 7.9 is that respondents without experience of working in both air-conditioned and non-air-conditioned buildings were slightly more reticent about committing themselves than respondents with such experience. For example, in the Brisbane air-conditioned survey, 6.9% of respondents without experience of NAC buildings cast "Don't know" responses, as opposed to 2.2% of those with such experience. Presumably the non-committed respondents were "keeping an open mind" about the ability of architects to implement passive design features, or HVAC engineers to successfully control indoor climates.

The second noteworthy aspect of Table 7.9 is the comparison of air-conditioned surveys with their non-air-conditioned counterparts. Disregarding the "Don't knows", and collapsing those with and those without NAC experience together, there was a clear majority (65.1%) of Brisbane's air-conditioned respondents stating a preference for working in air conditioning in summer. The opposite was true of the Brisbane non-air-conditioned survey, where 58.7% of respondents were in favour of working in non-air-conditioned buildings. There was a statistically significant difference in the distribution of preferences between the two Brisbane surveys (chi square=30.1, d.f.=1, $p<0.01$). The same comparison of preferences expressed in Melbourne's air-conditioned and non-air-conditioned surveys yielded the same result; those currently in air conditioning preferred it that way, while those currently in free-running buildings preferred not having air conditioning at work (chi square=20.5, d.f.=1, $p<0.01$). The implication of these data is that respondent's expectations of indoor climate and their preferred mode of climate control are generally determined by their recent experiences. An inherent conservatism appears to have led the majority of respondents to prefer the type of building that they were most familiar with.

The issue of experience influencing stated preferences was further explored in Table 7.9 by comparing the responses of people who had worked in both air-conditioned and free-running buildings with those of people without such experience. In the Brisbane air-conditioned survey, people without experience of NAC buildings seemed more favourably disposed to such buildings (33.6%) than were respondents who had previously worked in NAC buildings (25.8%). However, the distributions of preferences for these two groups were not significantly different (chi square=2.2,

d.f.=1, p>0.05). The breakdown for the Brisbane non-air-conditioned survey in Table 7.9 clearly indicates that preferences for air conditioning were unrelated to whether or not the respondent had previously experienced working in air conditioning (chi square=0.1, d.f.=1, p>0.05). Similarly, while the breakdown of responses in Melbourne's air-conditioned survey in Table 7.9 indicates a slightly higher preference for air conditioning among respondents with experience of the alternative (64.9%) than among those without (53.3%), the difference was statistically insignificant (chi square=0.9, d.f.=1, p>0.05). Finally, the distribution of preferences in Melbourne's non-air-conditioned survey was also unrelated to the respondents' having experience of air-conditioning at work (chi square=0.01, d.f.=1, p>0.05). Thus, while the presence of air conditioning in the survey buildings was related to the preferences of their occupants, exposure of the respondents to the alternative mode of climate control at some earlier stage had no effect on their preference for air-conditioned or free-running buildings.

The final aspect of Table 7.9 worth comment is the comparison between Brisbane and Melbourne preferences (excluding the "Don't knows"). Looking at the two air-conditioned surveys first, there was a slightly higher preference for air conditioning in Brisbane (65.1%) than in Melbourne (60.2%), but this failed to meet statistical significance (chi square=1.1, d.f.=1, p>0.05). Similarly, there was no statistically significant difference in the distribution of preferences between the two non-air-conditioned surveys (chi square=0.1, d.f.=1, p>0.05). Despite the lower average temperatures and humidities, higher diurnal temperature ranges, and the improved viability of passive architectural principles in

Melbourne's climate, there was not a decreased preference for active air conditioning in Brisbane as might have been expected.

The effective, or behavioural component of air conditioning attitude (preference) was shown earlier to be closely associated with the scale of affect. Not surprisingly, respondents who scored highly on the latter scale were also more likely to prefer air conditioning in the workplace than were respondents with negative affective scale scores. The preferences of Brisbane and Melbournes' air-conditioned survey respondents were also strongly related to their belief in the adverse health effect of air conditioning. Respondents who held such beliefs were more likely to prefer non-air-conditioned buildings in summer than were those people who believed there was only a possible, or even no causal connection between air conditioning and health (Brisbane AC chi square=21.1, d.f.=2, $p<0.01$; Melbourne AC chi square=32.9, d.f.=2, $p<0.01$).

The question of preferred method of climate control in Darwin was only put to 194 respondents in the "Build-up" air-conditioned survey on the grounds that the milder "Dry" season might have biased responses towards an underestimation of favourability towards air conditioning. The result in the "Build-up" season was 87.1% in favour of air conditioning on all year round, leaving only 10.3% in favour of no air conditioning at all (and 2.6% of "Don't knows"). Comparison with the Melbourne and Brisbane air-conditioned surveys indicates the Darwin respondents to be clearly the most favourable to air conditioning, with the difference between these three surveys' preference distributions being highly significant (chi square=39.0, d.f.=2, $p<0.01$).

While only 44 people in the Darwin "Build-up" survey had previously worked in a non-air-conditioned office, this lack of experience with passive climate control appears not to have been responsible for the overwhelming preference for air conditioning, because the 44 respondents with such experience had their preferences distributed almost identically to those without (chi square=0.2, d.f.=1, $p>0.05$). Presumably it was the widespread recognition by Darwin respondents of the architectural difficulties in dealing with high humidities and low diurnal temperature ranges that caused them to strongly prefer the active climate controls of air conditioning.

Since the cooling cycle of air conditioning was in operation all year round in the Darwin buildings surveyed, the respondents of both surveys were asked for a month-by-month breakdown of their preferences for air conditioning in the workplace. There seemed to be no visible difference between each of the surveys' monthly breakdown, so they have been aggregated into a single diagram (Figure 7.4).

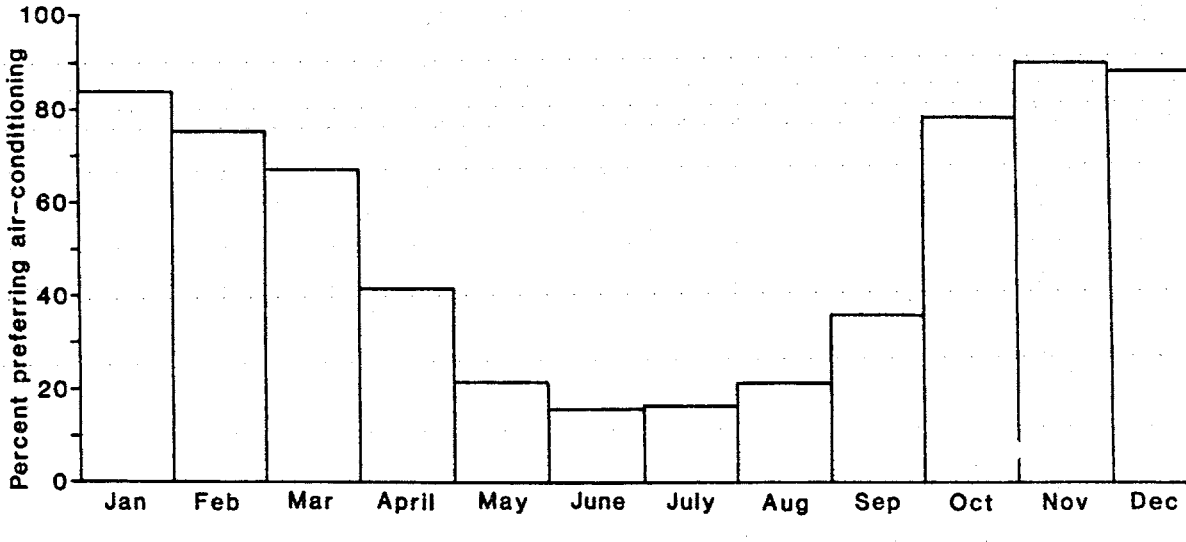


Figure 7.4 Monthly breakdown of Darwin respondents' preferences for air-conditioning in the workplace.

The salient feature of Figure 7.4 is that the six months from April through September had a majority of the 371 respondents preferring to work in non-air-conditioned buildings. Only 15% of respondents stated a preference for air conditioning in June. However, the preference for air conditioning peaked at 89% in the "Build-up" month of November. Despite comparable levels of thermal stress in the "shoulder" months of November and April, as measured by the frequency of occurrence of Relative Strain Index values greater than 3.1 (Desplace and Drosdowsky, 1981), the preference for air conditioning dropped by 22% between these two months. This finding is broadly consistent with the hypothesis that acclimatisation and habituation in the intervening "Wet" season mitigated physiological and psychological strain.

7.5 Perceived Control of Microclimatic Conditions

Respondents' perceptions of the degree of their participation in the regulation of indoor climatic conditions were assessed in all but the Darwin "Dry" surveys, and the answers coded into; 1) "Yes, I think I have sufficient control over conditions of warmth or coolness in my workplace during summer", 2) "I usually have sufficient control", 3) "No, I don't have enough control" and, 4) "Don't know". The percentages of determinate responses (codes 1-3) falling into the "no control" category for each of the five surveys are listed in Table 7.10.

The level of dissatisfaction with microclimatic control ranged between 70% in the Melbourne non-air-conditioned survey to 81% in Brisbane's air-conditioned buildings. As was expected, the occupants of Brisbane's air-conditioned buildings more frequently claimed to have no

TABLE 7.10 : Percentages of respondents claiming to have no control over microclimatic conditions in the work-place

	Darwin AC "Build-up"	Brisbane AC	Brisbane NAC	Melbourne AC	Melbourne NAC
% claiming no control	71.0%	81.2%	72.4%	76.0%	70.4%

control over their microclimatic conditions than their non-air-conditioned counterparts (chi square=4.52, d.f.=1, $p<0.05$). Surprisingly there was no statistically significant difference between the two Melbourne surveys' answers to the question (chi square=1.80, d.f.=1, $p>0.05$). However, this finding possibly reflects the strong undercurrent of dissatisfaction in the non-air-conditioned Block 1 of Melbourne's Commonwealth Centre, where 80.3% of respondents claimed they had no control over microclimatic conditions. By way of contrast, only 41.3% of the occupants of Melbourne's non-air-conditioned building at 2 Treasury Place felt they had no control (chi square=25.3, d.f.=1, $p<0.01$).

By breaking the Brisbane and Melbourne surveys down into two sets of buildings; air-conditioned and non-air-conditioned, and weighting each building by the number of respondents drawn from its occupants, it was possible to correlate the perceived microclimatic control percentages with thermal environmental variables in each building. This was achieved by using the "case weight" facility in the SPSS regression subroutine (Nie et al., 1975), which simply treated each building as a cluster of data points sharing the same values. The number of data points in each

cluster was simply the number of respondents in each building. The main draw back of this approach was the estimation of significance, because the degrees of freedom were set to the number of people rather than the number of buildings. Nevertheless, the actual correlation and regression coefficients can still be treated as approximate indications of "true values" for the current purposes.

In the non-air-conditioned buildings, the percentage of respondents claiming they had no control over thermal conditions had a simple correlation coefficient of +0.26 with the mean air temperature recorded in each building; as mean temperature increased, the perceived level of control slightly decreased. By using the standard deviation of indoor air temperatures recorded in each building as an indication of the degree of microclimatic variability, and using this, along with mean building air temperature as independent variables, the multiple correlation coefficient with the perceived microclimatic control variable jumped to 0.71. This indicates that about 50% of the perceived control variance between non-air-conditioned buildings was accounted for by mean warmth and temperature variability.

The same sequence of correlations for the air-conditioned buildings' perceived control variable yielded a higher coefficient of +0.54 for mean indoor air temperature, that was increased to +0.63 with the inclusion temperature standard deviation in the independent variable list. Thus, while mean warmth was more important in determining the level of perceived control in air-conditioned buildings, it was temperature variability that was most closely associated with this variable in non-air-conditioned buildings.

Apart from being asked whether or not they felt they had sufficient control over their workplace microclimate, respondents in all six surveys were asked to enumerate the specific microclimatic adjustments that they made. While clothing garment adjustment was a popular response in all six surveys, several less likely answers were given in certain buildings. For example, in the Darwin "Dry" survey in which all buildings had their air-cooling plant in operation, one building (Minerals House) was overcooled to such an extent that 7 of the 29 respondents actually had small 1000W radiator heaters under their desks, some of which were turned on at the time of interview.

Another surprising finding in Darwin's air-conditioned buildings was the number of respondents who claimed they made adjustments to the vents delivering conditioned air when ambient warmth was unsuitable (20.9% in the "Build-up survey). While most of these people were referring to adjustable ceiling diffusers such as in the Palmerstone Building, or terminal units with adjustable vents, several respondents in Darwin, and the other cities also, pointed to strips of plastic or cardboard that they had taped across vents. Also in Darwin, the relatively large number of respondents in the Community College buildings who felt they had sufficient control over microclimatic conditions (68.8%) was probably related to the fact that the air conditioning was mainly by window-mounted units. Hence, 68.8% of respondents claimed to adjust thermostats, 43.8% adjusted the air conditioner vents, and 56.3% opened windows whenever thermal conditions were unsatisfactory. By far the most frequently mentioned form of thermoregulatory behaviour for the Darwin "Build-up" respondents was to complain to the persor who was responsible for their building's air conditioning system (70.6% of respondents gave

this response).

In the Brisbane air-conditioned survey, the Commonwealth Centre's relatively high percentage of satisfaction with microclimatic control (37%) was reflected in the low number of people who admitted to complaining about the air conditioning when it didn't suit them (32.4% as opposed to 68.6% in the other four air-conditioned buildings in Brisbane). The Commonwealth Courts building in Brisbane had an unusually high number of respondents who claimed to personally adjust thermostats in their HVAC zone despite repeated admonition from the building services engineer (18.4% as opposed to 6.3% in the rest of Brisbane's air-conditioned buildings).

This same building, along with Statistics House, was identified in Section 7.2 as a possible "sick building", yet neither seemed to have a response on the perceived control variable (77.8% and 84.0% claiming no control) that was markedly different from the 79.9% recorded in the remaining three air-conditioned buildings in Brisbane. However, both the Commonwealth Courts building and Statistics House had a percentage of respondents who complained about the air conditioning whenever they felt thermal conditions to be unsatisfactory (71.1% and 69.2% respectively) that was higher than the 49.8% recorded in other Brisbane buildings with air conditioning (chi square=7.62, d.f.=2, $p<0.05$). This finding underscores the relationship between cognitive and behavioural aspects of people's relationship with air conditioning.

Respondents in Melbourne's air-conditioned buildings were slightly less prone to complaining about the air-conditioning system than were the Brisbane respondents (47.1% as opposed to 56.0% in Brisbane). The

building at 33 St Andrews Place that had air conditioning retrofitted still had its original windows, and an unusually large percentage of respondents claimed they used these windows whenever their thermal environment was unsatisfactory (64.9% as opposed to 2.1% in the remaining air-conditioned buildings surveyed in Melbourne). Melbourne's air-conditioned respondents made extensive use of solar blinds in double-glazed windows and other awning devices to regulate solar ingressions (51.3% of respondents gave this answer).

The respondents in Brisbane's non-air-conditioned survey made extensive use of fans of various types to maintain acceptable thermal conditions, with 52.6% using desk-top personal fans, 24.1% using floor-standing pedestal fans, and 51.3% making use of ceiling fans. As was expected in Brisbane's sub-tropical summer, windows were used by a large percentage of respondents (88.8%) to regulate microclimatic conditions. These observations explain why the Brisbane non-air-conditioned survey had the highest indoor air velocity in Table 6.2, with a mean of 0.31m/s. Awnings and solar blinds were also used in these non-air-conditioned buildings by 32.1% of respondents.

Melbourne's non-air-conditioned survey buildings also provided their respondents (89.3%) with windows that were used for behavioural thermoregulation. Awnings were used by 64% of respondents while 57.7% of respondents used desk-top fans to enhance air motion in their workplace. Larger pedestal and ceiling fans were less in evidence in Melbourne's survey buildings than they were in Brisbane. Thus, while the mean air velocity in these buildings at 0.17m/s was higher than in their air conditioned counterparts' mean of 0.11m/s ($t=4.13$, $p<0.01$), it was significantly less than the mean of 0.31m/s recorded in Brisbane's

non-air-conditioned survey ($t=7.53$, $p<0.01$).

In summary, while the occupants of all survey buildings, including air-conditioned offices, employed a variety of behavioural thermoregulatory strategies, ranging from clothing adjustments through to the use of fans and windows, only in three of the 31 survey buildings was there a majority of respondents who felt they had sufficient microclimatic control. One was Safety House in Darwin, that had terminal units from which occupants could control the volume of conditioned air being supplied. The second was also in Darwin, at the Community College, where room air conditioners permitted a degree of occupant regulation and the number of occupants in any one area was sufficiently small to allow group decision-making to be successful. The third building was Melbourne's non-air-conditioned 2 Treasury Place, which was constructed along traditional passive design principles, relying on large thermal mass to filter the occasional hot spells that characterise Melbourne's summer. While complaining about the air conditioning system to the building services engineer or industrial officer seemed generally to be one of the most frequent forms of regulatory behaviour, it was particularly prominent among occupants who had an unusually high level of concern over the adverse health effects of air conditioning.

7.6 Overall Impressions of Indoor Warmth and Satisfaction

Apart from being asked to give instantaneous assessments on the seven-point scales of warmth of the thermal conditions prevailing at the time of each interview, respondents were also asked to integrate their recent experiences into an overall impression of the warmth or coolness

in their workplace during the season in which the survey was being conducted. These overall impressions were recorded on the familiar ASHRAE scale, and their summary statistics are presented in Table 7.11 for each of the six surveys.

TABLE 7.11 :Summary statistics for overall indoor warmth assessments on the ASHRAE scale

	Darwin		Brisbane		Melbourne	
	"The Dry"	"Build-up"	AC	NAC	AC	NAC
Mean	-1.09	-0.59	0.90	0.60	0.13	1.19
Stdev	0.97	1.17	1.23	1.31	1.17	1.43
Sterror	0.07	0.08	0.09	0.09	0.09	0.10
n	172	195	209	198	184	192

As with the instantaneous ASHRAE scale votes in Table 6.8, the overall impressions of indoor warmth in the Darwin "Dry" survey were the coolest, with a mean of -1.09. This mean was significantly different from the -0.59 mean recorded in the next coolest survey, Darwin "Build-up" ($t=4.70$, $p<0.01$). A surprising result in Table 7.11 for the Brisbane surveys was that the non-air-conditioned respondents had a mean overall impression of their buildings' indoor climate during summer (+0.60) that was cooler than their air-conditioned counterparts' mean of +0.90 ($t=2.38$, $p<0.01$). This was despite the fact that the mean values for the microclimatic indices recorded in the non-air-conditioned Brisbane buildings were clearly the warmest of all six surveys (see Tables 6.2 and 6.7). Furthermore, despite the similarity of mean indoor warmth recorded in the two Melbourne surveys (mean PMV scores 0.2 units apart), the mean overall impression of warmth in the non-air-conditioned

survey of +1.19 was over one full scale unit warmer than the air-conditioned mean of +0.13 ($t=7.85$, $p<0.01$). These data strongly suggest that thermal impressions of building occupants are not solely determined by the typical thermal conditions prevailing in their building.

A possible explanation for this seeming dissociation of overall warmth assessments from the instantaneous measurements of thermal environments made in the Brisbane and Melbourne surveys could be that the thermal questionnaires were administered on an unrepresentative sample of days. Although the actual scheduling of interviews was not randomly designed, the average survey length of eight weeks was considered long enough to represent summer conditions in the two cities, so this explanation seems unlikely.

On the expectation that overall impressions of warmth would be more influenced by the peculiarities of individual buildings than the broader characteristics of the six surveys, the data in Table 7.11 were disaggregated to the building level, yielding 31 units for analysis. By weighting each building with the number of respondents it accommodated, a correlation analysis of mean overall warmth assessments in each building was conducted using the mean instantaneous ASHRAE votes for each building as the independent variable. The caveat raised earlier regarding the SPSS "case weight" facility applies to this analysis as well, so the statistics can only be regarded as rough approximations. Fifty percent of the variance in the overall warmth means was explained ($r=+0.71$) and the scattergram of the buildings in this relationship is given in Figure 7.5. The plot reveals the Brisbane air-conditioned buildings and one Melbourne non-air-conditioned building to be the outliers from the

general trend. The latter building was Block 1 of the Commonwealth Centre, where a "protest vote" was expected for reasons discussed earlier in Section 7.4.3.

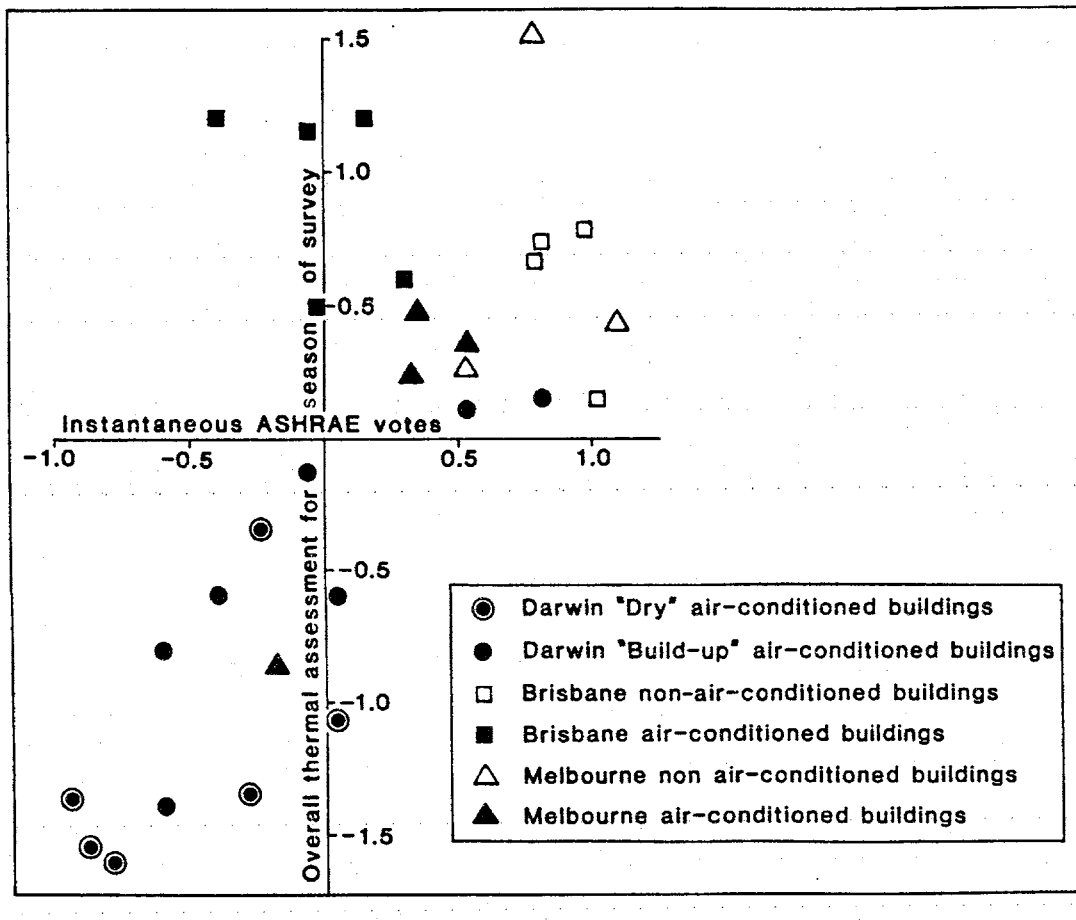


Figure 7.5 Mean overall thermal assessments of each building for the season of survey plotted against their mean instantaneous ASHRAE scale votes.

The hypothesis that overall impressions of a building's warmth would be biased by microclimatic extremes was investigated by using both mean and standard deviation of the buildings' indoor air temperature as independent variables in a correlation analysis. Using a stepwise procedure to establish which would have the largest squared partial correlation, standard deviation of building temperature entered the

equation first, accounting for 19.3% of the variance in overall warmth, while mean air temperature contributed a further 18% (multiple R=0.61). Thus, to the extent that the standard deviation of temperatures recorded in a building represents the occurrence of extreme conditions, the hypothesis appears to be supported by these data.

Along with overall thermal assessments of the workplace microclimate in the season of the surveys, respondents in the Brisbane and Melbourne surveys were asked to give an assessment of how satisfactory they found the typical summer thermal conditions in their workplace. The responses to this question were recorded on a linear format five-point scale that ranged from 1="satisfactory" through to 5="intolerable" (see Appendix F). The non-air-conditioned Brisbane survey mean of 1.81 (stdev=0.83; n=198) was virtually identical to that city's air-conditioned survey (mean=1.86; stdev=0.82; n=209), at just better than "slightly unsatisfactory".

Melbourne's air-condioned survey had a mean level of satisfaction (mean=1.98; stdev=0.94; n=184) broadly comparable to the two Brisbane surveys, but the non-air-conditioned Melbourne respondents were definitely less satisfied (mean=2.83; stdev=1.16; n=192) with their overall thermal assessments than were their air-conditioned counterparts ($t=7.82$; $p<0.01$).

These broad comparisons of survey satisfaction means seems to closely parallel the earlier differences between their mean overall warmth assessments. Namely, that actual microclimatic differences between the Brisbane surveys were largely irrelevant to overall seasonal assessments, while in Melbourne, the relatively minor differences between the mean levels of environmental warmth prevailing in the surveys was

greatly amplified in the overall subjective assessments by respondents.

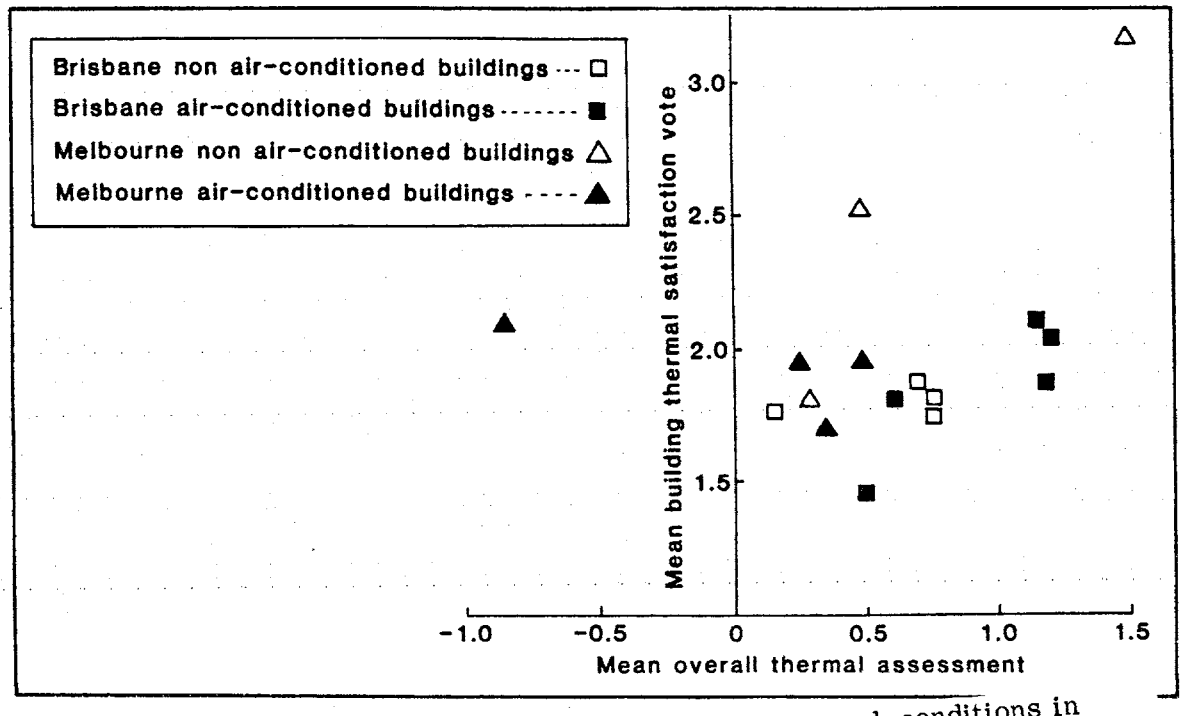


Figure 7.6 Plot of mean satisfaction w summer thermal conditions in Brisbane and Melbourne bu ngs against mean overall thermal assessments of those buildi s.

To further investigate these overall thermal satisfaction scores, the four Brisbane and Melbourne surveys were disaggregated to the building level, yielding 16 units of analysis that were weighted by the number of respondents drawn from each. There were 786 respondents in these buildings. The first analysis related satisfaction to mean warmth, as depicted in Figure 7.6. Because the scale did not differentiate cold or warmth dissatisfaction, actual thermal indices could not b used as independent variables in regression models because of the expectation of a "U"-shaped function, which is partly evident in the scattergram of

Figure 7.6. Consequently, the absolute value of mean overall warmth impression was used, and found to explain 62.6% of the variance in building thermal satisfaction means (r=+0.79).

Apart from overall warmth impressions, other variables investigated for their relationships with mean thermal dissatisfaction included; the standard deviation of air temperatures recorded in each building, the gradient between mean outdoor and indoor temperatures during each building's survey period, and the percentage of each building's respondents who felt they had no control over their immediate thermal environment. The degree of variability of temperature in a building appeared to be as closely associated with the mean level of satisfaction (r=+0.81; R =65%) as the overall thermal impression was. These simple relationships and the interaction of the thermal gradient and perceived microclimatic control variables in determining overall satisfaction with thermal conditions in the Brisbane and Melbourne buildings are presented as a zero-order correlation matrix in Table 7.12.

Overall thermal dissatisfaction decreases as the mean temperature inside a building gets cooler than mean outdoor temperature (gradient increases). Also, while the perceived microclimatic control variable had a direct correlation of +0.24 with thermal satisfaction, it was more strongly related to the overall thermal impression variable, accounting for 14% of its variance (r=+0.38). This variable in turn correlated strongly with the thermal satisfaction variable (r=+0.79). Thus, perceived control appeared to contribute directly and indirectly to the level of thermal dissatisfaction expressed in buildings.

TABLE 7.12 : Zero-order correlation matrix of thermal dissatisfactioion with other microclimatic and perceptual variables

	Gradient between mean survey outdoor and indoor temps. (outdoor minus indoor)	Standard deviation of indoor air temperatures	% of occupants claiming to have no microclimatic control	Absolute value of overall warmth assessment mean	Mean overall thermal dissatisfaction score
Gradient between mean survey outdoor and indoor temps. (outdoor minus indoor)	1.00				
Standard deviation of indoor air temperatures	-0.20	1.00			
% of occupants claiming to have no microclimatic control	0.09	-0.02	1.00		
Absolute value of overall warmth assessment mean	0.14	0.50	0.38	1.00	
Mean overall thermal dissatisfaction score	-0.29	0.81	0.24	0.79	1.00

Before actually submitting these independent variables into a stepwise multiple correlation analysis of overall thermal dissatisfaction, the buildings were sorted according to the presence or absence of air conditioning, and the analysis was conducted separately on each group. Starting with the non-air-conditioned buildings' analysis in Table 7.13, it is evident that satisfaction was best predicted by the mean overall warmth assessment given in each building, with 85% of the variance accounted for. Variability of indoor temperatures (standard deviations) added a further 12% to the explained variance in mean dissatisfaction scores, while the addition of the perceived control variable maximised explained variance at a surprisingly high 99.5% (For reasons discussed earlier, this figure is probably an overestimation of actual correlation).

TABLE 7.13 : Stepwise multiple correlation analysis of thermal satisfaction building means as the dependent variable *

Type of building (Bris. & Melb.)	Independent vars. in order of entry	Change in R squared	Total model R squared
Non-air-condit--ioned buildings	Abs. val. of mean overall warmth	0.85	
	Stdev of indoor air temperatures	0.12	
	Perceived micro--climatic control	0.03	
	Outdoor-indoor mean temp. gradient	0.00	
			0.995
Air-conditioned buildings	Absol. val. of mean overall warmth	0.12	
	Outdoor-indoor mean temp. gradient	0.49	
	Stdev of indoor air temperatures	0.00	
	Perceived micro--climatic control	0.00	
			0.609

* The forward inclusion stepwise selection criterion was used the largest squared partial correlation with dependent variable

While overall warmth assessment was also the first variable to enter the air-conditioned building satisfaction correlation analysis in Table 7.13, it accounted for only 12% of variance as opposed to the 85% in non-air-conditioned buildings. The second variable to enter the analysis for air-conditioned buildings was the gradient between mean outdoor and mean indoor temperatures during the survey, adding a further 49% to explained variance; thermal satisfaction in an air-conditioned building was greater when the indoor temperature was much cooler than mean outdoor temperature. However, this is not to suggest that making building occupants cooler than neutral would enhance their thermal satisfaction, because, as indicated by one of Melbourne's air-conditioned buildings in the plot of Figure 7.6, thermal dissatisfaction was associated with a mean overall thermal impression approaching "slightly cool".

In summary, whereas most of the variance between non-air-conditioned buildings' mean thermal satisfaction scores could be accounted for by the independent variables in Table 7.13, only 61% of the variance in satisfaction in air-conditioned buildings was explained by the same set of variables. Presumably, non-thermal factors were influencing the degree of thermal dissatisfaction expressed in the air-conditioned buildings.

7.7 Interactions Between Subjective Response to Microclimate and Non-Thermal Factors

The two derived variables of DISCR and DISPO provided a method of classifying either thermal questionnaire responses (in the case of DISCR), or individual respondents (DISPO), according to the discrepancy

TABLE 7.14 : t tests between the mean DISCR scores of various sub-samples *

Hypothesis tested		Darwin		Brisbane		Melbourne	
		"The Dry"	"Build-up"	AC	NAC	AC	NAC
Male v female (2 tail)	Diff	-0.11	+0.04	-0.05	-0.14	-0.27	-0.15
	t	0.79	0.33	0.45	1.28	1.93	1.50
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Respondents who own home air-condit. v those who don't	Diff	+0.18	+0.23	-0.26	+0.17	-0.13	+0.12
	t	1.68	2.47	1.62	1.38	0.95	1.09
	Sig	0.05	0.01	N.S.	N.S.	N.S.	N.S.
Respondents who bought home AC v those who didn't but still had AC	Diff	+0.27	+0.09	+0.13	-0.01	+0.04	+0.02
	t	1.48	0.56	0.42	0.06	0.23	0.14
	Sig	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Respondents who believed they had enough control over workplace micro--climate v those who didn't	Diff		-0.17	-0.08	-0.59	-0.33	+0.11
	t	N.A.	1.83	0.60	4.50	2.08	0.59
	Sig		0.05	N.S.	0.01	0.05	N.S.
Respondents who preferred work in AC v those who prefd. NAC	Diff		-0.52	-0.20	-0.32	+0.03	-0.16
	t	N.A.	2.99	1.80	2.96	0.25	1.78
	Sig		0.01	0.05	0.01	N.S.	0.05
Respondents who believed AC had adverse health effect v those who didn't	Diff			0.00		-0.08	
	t	N.A.	N.A.	0.00	N.A.	0.62	N.A.
	Sig			N.S.		N.S.	

Notes:
* The DISCR score is a signed discrepancy between instantaneous ASHRAE scale v ..e and PMV.
Diff= difference between group means; t= t test; Sig= statistical significance (1 tailed tests).
N.S. indicates Not Significant at .05; N.A. indicates data Not Available in questionnaire.

between expressed subjective warmth (instantaneous ASHRAE scale votes) and the level of subjective warmth that was predicted on the basis of heat-balance calculations (PMV). The current section reports some statistical associations between DISCR (or DISPO) and various non-thermal variables and attitudes recorded in the questionnaires.

The differences between various sub-samples' mean DISCR scores were examined for statistical significance using Student's t in Table 7.14. While mens' DISCR scores were larger (more positive) than womens' in five of the six surveys, there was no statistical significance in this difference using a two-tailed test. Consequently, it would seem likely that the popular belief that women are subjectively cooler than men, if true at all, is attributable to clothing differences between the sexes (see Section 6.1.3).

The hypothesis that exposure to air conditioning in the home environment would diminish the efficacy of seasonal adaptation to heat was investigated by classifying respondents of each survey according to whether or not there was any form of refrigerated air conditioning in their house. Seventy-one and 75 respondents had air conditioning in the Darwin "Dry" and "Build-up" surveys (40.1% and 38.1% respectively). In both surveys, the owners of home air conditioning had, as expected, mean DISCR scores that were warmer than those of respondents without air conditioning in their house. That is, after the effects of all heat-balance variables had been taken into account, people who owned air conditioning in their homes felt warmer in their air-conditioned workplaces than did those respondents without air conditioning at home when exposed to the same office microclimatic conditions. While the difference was small, amounting to about one fifth of a unit on a

seven-point scale, it was statistically significant using a one-tailed test ($t=1.68$, $p<0.05$ in the "Dry"; $t=2.47$, $p<0.01$ in the "Build-up").

A convenient check on the direction of causality in the above statistical association was possible by further subdividing the owners of home air conditioning in Darwin according to whether they bought the air conditioning or whether it was installed in their home before they moved in. A plausible alternative explanation for the difference between DISCR means of owners and non-owners was that the former group were innately more sensitive to moderate heat stress and that it was this characteristic that motivated them to install air conditioning in their homes. According to this line of reasoning, respondents who had air conditioning at home, but didn't buy it themselves, should have been less susceptible to moderate heat stress and their DISCR mean should consequently be lower. The third row of Table 7.14 indicates this not to be the case, with the one-tailed t tests between these groups' DISCR means being insignificant. This null result therefore corroborates the earlier hypothesis that exposure to cooled environments in the home hampered the processes of adaptation to moderate thermal stress.

There were too few owners of home air conditioning among the Brisbane respondents (11 in AC survey; 8 in NAC) to observe any significant differences between their mean DISCR scores and those of the non-owners ($t=1.62$, $p>0.05$; $t=1.38$, $p>0.05$ respectively). However, 47 of Melbourne's air conditioned survey respondents (25.3%) and 38 of the non-air-conditioned survey respondents (19.6%) owned refrigerated air conditioning in their homes. As indicated in the second row of figures of Table 7.14, there were no significant differences between these groups' mean DISCR scores and those of the non-owners of air conditioning

($t=0.95$, $p>0.05$; $t=1.09$, $p>0.05$ in the AC and NAC Melbourne surveys respectively).

Comparing this null result with the significant differences observed in Darwin suggests that the mean thermal experiences of Melbourne's air conditioning owners at home were not greatly different from those of the non-owners, because the air conditioning was only being turned on during intermittent hot spells. Perhaps the reason for such a high level of air conditioning ownership in Melbourne in comparison to the low level in sub-tropical Brisbane was that the machines popular in Melbourne acted as an economical form of heating in their reversed cycle mode during winter. Alternatively, given that the mean summer outdoor temperatures in Melbourne were mild by comparison with Brisbane (see Table 6.1), when the hot spells arrived in Melbourne, residents were neither physiologically nor psychologically adapted. Consequently, these occasional hot spells may have elicited greater strain than did the persistently warm-humid summer of Brisbane. Indeed, the mean overall thermal assessments of the two non-air-conditioned surveys in Table 7.11 tend to support this explanation.

The respondents of Darwin's "Build up" survey, and all four Brisbane and Melbourne surveys were classified according to whether or not they believed they had sufficient control over thermal conditions at their workplace. It was expected that those who complained of having insufficient control would have larger, positive discrepancies between expressed and predicted subjective warmth than those who fe't they had enough microclimatic control. The results of this hypothesis test are presented in the fourth row of Table 7.14, where it was supported in three of the five surveys; Darwin "Build-up", Brisbane

non-air-conditioned and Melbourne air-conditioned. In those three surveys, respondents who felt they were excluded from the regulation of their microclimate experienced warmer thermal sensations than did those who felt they had sufficient microclimatic control when both groups were exposed to similar thermal loads. There were no obvious explanations for the failure of this hypothesis in Brisbane's air-conditioned survey, except that this survey also recorded the highest percentage (81.2%) of respondents who felt they had insufficient microclimatic control, thus leaving too small a group (18.8%) for comparisons. The failure of the Melbourne non-air-conditioned survey data to support the hypothesis could possibly be attributed to the extremely high mean DISCR score of +0.93 that may have masked any within-survey differences.

The data contained in the fifth row of Table 7.14 generally support the hypothesis that people who prefer non-air-conditioned workplaces during summer are less sensitive to moderate heat stress than are those who prefer air conditioning. In four of the five surveys where this hypothesis was tested, there were significant differences in mean DISCR scores in the predicted direction. These ranged from about one sixth of a unit on the seven-point scale in Melbourne's non-air-conditioned survey, up to about half a unit in Darwin's "Build-up". That the latter survey recorded the largest mean difference is understandable given the strong agreement about the undesirability of Darwin's climate for at least six months of the year (for example, see Figure 7.4). Thus, while cognitive factors relating to air quality and the health effects of air conditioning were demonstrated to interact with respondents' favourability towards such climate controls in Sections 6.4.2 and 6.4.3, so too did respondents' subjective susceptibility to moderate thermal

stress appear related to their preferences for air conditioning in the workplace.

The last row of Table 7.14 indicates that there were no significant differences between the mean DISCR scores of respondents who believed that air conditioning had an adverse health effect, and those who didn't hold such a belief. Hence in Brisbane's air-conditioned survey, the two buildings that were possibly "sick buildings" had a mean DISCR score (+0.53) that was identical with that recorded in the remaining buildings fo that survey. Therefore, while the cognitive and thermal comfort factors were independent, both seemed to exert an influence on peoples' attitudes and preferences for air conditioning in the workplace.

TABLE 7.15 : Bivariate correlation and regression of the DISPO variable with length of residence * in the survey cities

		Darwin		Brisbane		Melbourne	
		"The Dry"	"Build-up"	AC	NAC	AC	NAC
Correlation with length of residence (yrs)	r	-0.20	-0.17	-0.13	-0.02	-0.06	+0.01
	Sig	0.05	0.05	N.S.	N.S.	N.S.	N.S.
Regression on length of residence (yrs)	b	-0.022	-0.016	-0.008	-0.001	-0.004	0.000
	se(b)	0.008	0.007	0.004	0.005	0.005	0.000
	Sig	0.05	0.05	N.S.	N.S.	N.S.	N.S.

* DISPO is the mean of each respondent's three DISCR score
N.S. indicates Not Significant at .05 level

The DISPO variable has been used to quantify individual respondents according to their average thermal disposition (their mean DISCR), and bivariate correlations of this variable with length of residence in the survey city are presented for each of the six surveys in Table 7.15. Of

particular interest are the statistically significant, albeit weak, inverse correlation coefficients in Darwin ($r=-0.20$ in "the Dry", and -0.17 in the "Build-up"). Compared with the many respondents in Darwin who were relatively new arrivals (there was a mean length of residence in Table 5.4 of between 9 and 10 years), the longer-term residents appeared to be less sensitive to moderate thermal stress. While the questionnaires recorded where each respondent lived before Darwin, the classification of these origins on a thermal basis proved to be too cumbersome. Nevertheless, Darwin's status as one of the largest settlements in the climatically stressed far north of Australia would logically make the simple length of residence variable a reasonable quantification of respondents' long-term thermal history. According to the regression line gradients associated with these inverse correlations in Table 7.15, a respondent who had lived in Darwin for somewhere between 45 and 63 years would, on average, have a thermal sensation that was one full unit cooler on a seven-point scale than would a new arrival to Darwin who was exposed to the same thermal load. Thus, while exposure to the seasonal extremes, unmitigated by home air conditioning, enhanced Darwin residents' tolerance of moderate heat stress, the data in Table 7.15 suggest that this benefit is also cumulative from year-to-year.

CHAPTER EIGHT

SUMMARY, APPLICATIONS AND CONCLUSIONS

As well as summing up and concluding the study, this chapter also indicates various practical applications of the results. Further, throughout the chapter are acknowledgements of the limitations in the research methodology, as well as suggestions of where the research might usefully be extended. The chapter is structured so that the first four sections correspond with the four sections of research questions outlined in Chapter 4. However, the contents within each of these sections have not been sequentially numbered as in Chapter 4, so as not to inhibit synthesis. Certain key words in the text have been underlined to

facilitate cross referencing.

8.1 Thermal Comfort Surveys

While the number of air conditioned buildings surveyed in Melbourne and Brisbane was too small to allow any strong generalisations, the surveys in Darwin, represent a reasonable cross-section of air conditioning practices in that city. The Carrier company's Australian design manual (undated) appears to have been fairly strictly implemented in the four air-conditioned building surveys, with observed mean air temperatures at about 23.5degC, relative humidities between 40 and 60%, and relative air velocities less than 0.15m/s. Hence, Darwin's air-conditioning engineers appeared to be following the same guidelines as their Melbourne and Brisbane counterparts, regardless of the differences in climates and building occupants between these three locations.

While the aforementioned design manual was undated, it is known to predate the two modern indoor climate standards that were reviewed in Section 1.3.3 (ISO 7730 and ASHRAE 55-81). Because these two standards have been based on heat-balance and thermoregulatory principles as outlined in Chapter 2 and Section 3.2, they incorporate concessions at least for seasonal and regional differences in building occupants' clothing behaviour. Hence their recommended design conditions for the current study's buildings vary considerably between surveys in anticipation of these human differences. About 25degC appears to be the optimum air temperature in the four air-conditioned surveys according to the ISO 7730 and ASHRAE 55-81 standards, holding all other heat-balance

variables constant. Compared to the mean air temperature observed in the air-conditioned surveys, these recommendations indicate that buildings were being overcooled by about 1.5K in all four surveys. Reducing the temperature gradient between indoor and outdoors by this amount would no doubt effect substantial economies in energy consumption.

In Darwin, energy conservation will inevitably become a larger public issue than it currently is if and when the Commonwealth ceases the current practice of funding the difference between oil-fired electricity generation costs and the consumer electricity tariff (NTEC, 1982). Consequently, there would be a convincing argument for recommending a design temperature that was towards the upper limit of the comfort envelope as described in the ISO 7730 and ASHRAE 55-81 standards. Indoor air temperature could be lifted as high as 26.5degC in that city and conditions would still be within the 10% PPD criterion of the ISO 7730 standard, as long as all other variables such as relative humidity, air velocity, clothing and metabolic rates were held at their present levels. Allowing for perhaps even further reductions in clothing insulation that would result from these guidelines being implemented, and also possibly higher air velocities, 27.0degC (3.5K higher than current practices) could well be an appropriate design temperature for Darwin's air-conditioned buildings.

A comparison of microclimatic conditions in the Brisbane air-conditioned and free-running building surveys indicates that the main result of mechanical climate controls was to reduce mean ambient temperatures by about 4K as well as dehumidify the ambient air by about 9mmHg. The microclimatic homogeneity in these two surveys was approximatedly equal, although the humidity levels in the

non-air-conditioned survey were more varied.

The mean indoor temperature recorded in the Melbourne air-conditioned survey were barely 1K cooler than the means recorded in the free-running buildings in the same city. Clearly, the intention of air conditioning in that type of climate is not simply to reduce ambient temperatures but rather, to dampen down any temperature perturbations. The success of this intention was observed in the air-conditioned survey's temperature standard deviations, which were half the size of their non-air-conditioned counterparts. A surprising finding in the Melbourne surveys was that in one building at least, this indoor climatic homogeneity necessitated heating as well as cooling during the summer months. This is probably one aspect of HVAC operations that bears closer attention with a view to energy conservation. The viability of such a strategy would partially depend on the willingness of occupants to increase their clothing insulation during temperature excursions below the average ambient condition in summer.

The role of clothing behaviour as a link between indoor and outdoor atmospheric environments was confirmed in the current study. Empirical support was particularly strong in the Melbourne non-air-conditioned survey where outdoor air temperature exerted both a direct influence on clothing insulation levels, and also an indirect influence by virtue of its strong relationship with indoor operative temperature, which in turn accounted for some residual variation in clothing insulation.

The lower limit of building occupants' clothing insulation in Australian clerical settings appears to be about 0.43clo, although women's values were observed to be lower by as much as 0.13clo on average

in some surveys. This finding suggests that women's clothing is more amenable to thermoregulatory behaviour than men's. There is also a suggestion arising from the current investigations into clothing behaviour that this variable would be worthy of close attention if an energy conservation plan was implemented. The latest clothing research that is emerging from ASHRAE's Technical Committee 2.1 at present (McCullough et al., 1985) will greatly facilitate future field studies of thermal comfort, HVAC load estimation and also HVAC energy management programmes.

While the mean thermal conditions prevailing in the four air-conditioned surveys were relatively fixed, the mean instantaneous assessments in each of those surveys varied considerably. Mean ASHRAE and Bedford scale responses ranged from a low of -0.4 in Darwin to a high of about +0.3 in Melbourne's air-conditioned surveys. The air temperature neutralities that were observed in the Darwin and Brisbane air-conditioned surveys were all about 24degC, whereas the Melbourne air-conditioned neutrality was 22.5degC.

The Darwin and Brisbane air-conditioned surveys go some way towards filling the gap in comfort surveys with mean monthly temperatures above 23degC. However, there still remains a need for further climate-controlled building studies where monthly means are between 25 and 29degC. Addition of all six current surveys to the data set used by Auliciems (1983) lifted the number of free-running building studies to 24, the number of climate-controlled building studies to 35 and the total of these two combined to 59. Regeneration of the adaptation Equation (3.10) with the inclusion of these six new cases had a negligible effect on the size of the regression coefficients, and the

amount of variance in survey neutralities explained by the model was a high 88%:

$$T_{\psi iv} = 0.441\ T_i + 0.136\ T_{\overline{m}} + 10.16 \qquad (8.1)$$

where T_i is mean indoor temperature

$T_{\overline{m}}$ is mean monthly temperature outdoors

Application of either Equations (8.1) or (3.10) to the task of predicting design temperatures for HVAC in future buildings is hampered by the requirement to input mean indoor temperature. One solution to this circular problem would be to use Fanger's comfort equation (1970) to derive an initial estimate of mean indoor temperature (Dedear and Auliciems, 1985). As attractive as this reconciliation between the "constancy" and "adaptation" hypotheses seems, there still remains the difficulty of having an estimate of mean clothing insulation input to the Fanger model. Another solution, with greater emphasis on human adaptation, would be to use the predictive equations that require only mean monthly outdoor temperature as input. While not actually included in the independent variables, clothing and other human adaptations are implicitly acknowledged in such an approach.

Apart from these practical issues, several methodological research questions were raised in Section 4.1. Firstly, there seems to be prima facie case in the bivariate analyses of Chapter 6 for concluding that simple indices of environmental warmth, such as air- or operative-temperature, are related more closely with assessments of subjective warmth than are the sophisticated heat-balance indices such as PMV and SET. This counterintuitive finding was further elaborated by the

stepwise multiple regression models of seven-point scale of warmth responses. Operative temperature was always the first variable entered, and not one of the remaining heat-balance variables entered on subsequent steps was capable of incrementing explained variance by any more than 2.8%.

The ASHRAE scale of subjective warmth has been traditionally regarded as dealing with thermal sensations only, while the terms on the Bedford seven-point scale suggest that it relates to thermal affect, or comfort. Since both these scales were used in the current study, it is possible to conclude that their differing semantics had virtually no effect on the way either was used in field studies. Their neutralities and correlations with various thermal indices were very similar. Thus, while various researchers have been able to experimentally disentangle sensation and comfort in climate laboratories, the difference would seem to be negligible in field settings such as those used in the current study. Therefore, in the interests of simplicity, the separate paths of sensation and comfort in Figure 4.1 could be amalgamated into one comfort channel.

While the sensation and comfort responses appeared to be very similar in field settings, an effective scale of temperature preference (PREFV) behaved quite differently in some cases. The effective scale seemed to correlate just as closely with environmental warmth as did the comfort and sensation scales. However, the effective scale's neutrality was 1K different from the other scales' in at least one of the six surveys.

More pronounced differences between the three scales were noticed in the analysis of the sensitivity of subjective warmth to changes of environmental warmth. While the sensation and comfort scales were again very similar, the effective scale was less sensitive to thermal changes. This was indicated both by the gradients obtained by simple linear regression analysis, and also the temperature width of the central category, as derived by probit analysis. Thus, the adjectival labels attached to seven-point scales of warmth have an effect on the way field-study respondents use them, even though these differences were not noticeable between the sensation and comfort scales. Another finding in the analysis of subjective sensitivity was that field study respondents were about one third less sensitive to changes in warmth, all else being equal, than climate chamber subjects. This observation emphasises the limitations of chamber studies' external validity.

8.2 Thermal Constancy Versus the Adaptation Hypothesis

The most fundamental question addressed in this study was the issue of systematic group differences in thermal perception once the six key heat-balance variables of air- and radiant-temperatures, air velocity, humidity, clothing insulation and metabolism had been accounted for. Relating the question to the conceptual scheme depicted in Figure 4.1, the research attempted to hold constant the middle line of causal links connecting the climatic, physiological and psychological sub-systems. By doing so, the intention was to attribute any of the residual between-group differences in thermal perception to the processes of set-point adjustment depicted on the left-hand side of Figure 4.1.

The central methodological problem in achieving this objective has been holding constant, or at least taking into account, all six heat-balance variables in architecturally and climatically diverse settings. The heat-balance indices of environmental warmth were used to this end as they translate complex actual environments back into standardised scales, such as SET or thermal load in PMV. However, as pointed out in the preceding section, these standardised indices were relatively poorly correlated with assessments of subjective warmth. These lower degrees of association in turn made the detection of systematic group differences more difficult than would otherwise have been the case, because the variance associated with any estimates of population parameters were wider by comparison with those obtained from simpler indices of environmental warmth.

Notwithstanding these problems, significant differences were observed in the six current field studies, with about 2.5degC range in SET neutralities using all three scales of subjective warmth. The warmest neutralities were observed in the warmest location of Darwin (and free-running Brisbane buildings), while the coolest neutrality was observed in Melbourne. That the range in SET neutralities (2.5K) was considerably smaller than the dry bulb temperature neutrality range (about 4K) would tend to suggest that a good proportion of the neutrality range observed in the last 50 years of field studies (Humphreys, 1975, 1976; Auliciems, 1983) was indeed attributable to variations in other heat-balance variables. Clothing has been previously singled out as a key variable in this context, but the current data indicate that air velocity, which is often left unmeasured in field studies, contributed significantly to the explanation of between-group differences in

neutrality.

While the "constancy" hypothesis of thermal comfort was originally applied only to thermal neutrality, it has in recent times been extrapolated to cover human response to sub-optimal thermal conditions as well. This is the clear implication of comfort standards that prescribe outer limits of the comfort envelope. Significant between-survey differences were observed in the rates of change of subjective warmth estimates in response to standardised changes in environmental warmth. Building occupants who were exposed to a very tightly regulated indoor climate were generally more sensitive to minor temperature variations than were the occupants of buildings in which thermal conditions varied considerably.

Homogeneous indoor climatic conditions were also hypothesised in Chapter 4 to induce within-group consistency of subjective response to thermal stimuli. That is, the variance in sensation and comfort assessment of a group who were exposed to their neutral temperature was expected to be low for the occupants of buildings in which there was a homogeneous indoor climate. By using the SET index to standardise thermal data, no support for this hypothesis was obtained. Therefore, within-group-variability in subjective response appears to be unrelated to thermal experience.

The six samples of the current study were also examined for group differences in thermal acceptability. The SET temperatures that induced 20% of each sample to vote outside the central three 'acceptable" categories on the comfort scale were noted to have a range of about 2.5K. The highest values were obtained in the survey that had the warmest

indoor conditions. These data fail to support the "constancy" hypothesis, which predicted that 20% unacceptability would be reached by all groups at the same standardised thermal load, regardless of their thermal histories.

Returning the discussion back to the neutralities observed in the six surveys, they provided a means of evaluating the relative merits of the "constancy" and "adaptation" hypotheses. In the four air-conditioned surveys, the best predictor of observed neutralities was an "adaptation" equation that required inputs for mean indoor and outdoor warmth. It would seem that when air conditioning is used to provide indoor climates independent of prevailing outdoor conditions, people' responses to those conditions are still partly determined by the outdoor meteorological environment.

That all four group neutralities observed in the air-conditioned surveys were cooler than the Fanger comfort equation predictions suggests that respondents were becoming adapted (or habituated in Figure 4.1) to indoor conditions that were cooler than theoretical neutrality. It should be pointed out that the Fanger technique still made reasonably accurate predictions in the Darwin studies, but the discrepancy between these predictions and observed neutralities increased to about 1K in the Brisbane AC survey, and 2K in the Melbourne AC survey.

The neutralities observed in the two free-running building surveys were also most accurately predicted by an "adaptation" equation. However, the equation in question required only one input, mean monthly outdoor temperature, to arrive at these results. This probably indicates the strong dependence of indoor climatic conditions on the outdoor

situation in such buildings. Again it should be noted that the "constancy" hypothesis yielded a reasonably accurate prediction in the Brisbane survey, but the error in Melbourne was over 3K.

Since some of the reaction against the "constancy" hypothesis in the comfort literature has been stimulated by the requirement for energy conserving indoor climates (Cooper, 1982a, 1982b; Auliciems, 1983; Auliciems and Dedear, 1984a, 1984b), it becomes interesting to compare the comfort hypotheses for their conservation potential in the current four air-conditioned surveys. Initially, it appears as though Fanger's comfort model offers greater scope for thermostat "set forwards" than any of the adaptation models. However, this conclusion was based on the low indoor mean temperatures that characterise current air conditioning practices. If the earlier suggestion of seeding the $T_{\psi iv}$ adaptation Equation (3.10) with a mean indoor temperature derived from one of the outdoor mean monthly temperature regression equations was followed, the neutralities predicted by the adaptation hypothesis would conserve more energy than those of the constancy hypothesis.

The above discussion of energy conservation and thermal comfort models has focused on neutrality as the appropriate criterion for HVAC set points. However, as pointed out earlier in the current section, a higher temperature with lower levels of occupant satisfaction may, in some expensive energy contexts, be more appropriate. However, an alternative strategy might be to use predicted neutrality as the set point, but to allow passive temperature drifts within a broad deadband range of, for example, $\pm$2K. The data presented in the current study would offer considerable support for this strategy, as the sensitivity of subjective warmth was shown to be inversely related to the variability of

indoor climatic conditions.

The final research question in Section 4.2 concerned the ability of the "semantic set" hypothesis to reconcile the adaptation and constancy hypotheses. While the neutrality observed on the temperature preference scale (PREFV) did in one study depart significantly from the sensation (ASHRAE) and comfort (Bedford) scales' neutralities, these data seem inconsistent with the notion of local climate interfering in the semantic relationship between the thermal state people describe as comfortable/neutral and their preferred thermal state.

Another semantic issue relates to the validity of some of the earlier conclusions concerning group differences in thermal sensitivity. It could be argued that the thermal states that a group of people associate with the various adjectives on seven-point scales of warmth depends on their range of recent thermal experiences. This criticism, the "range effect", relates not just to the current study, but indeed to most comfort research, as the rating scale is the most important method devised to date. The preferred temperature method in climate chambers has its attractions for this reason, but it is not useful in determining subjective reactions to sub-optimal thermal environments. Other psychophysical methods such as relative magnitude estimation are also susceptible to unwanted range effects. However, the current study provided some evidence against this suggestion that building occupants were simply using the rating scale to subdivide the range of their recent thermal experiences into seven intervals; the adjectives on these scales were shown to have distinct thermal-state referents because the seven-point thermal preference scale (PREFV) was less sensitive to thermal changes and its categories spanned wider temperature bands than

either the seven-point sensation or comfort scales.

8.3 Attitudes on Indoor Climatic Issues

In the schematic presentation of the man-climate system in Figure 4.1, the higher-order responses of the psychological and behavioural subsystems become increasingly more complex compared with the physiological and instantaneous sensory reactions. Obviously this increased complexity presents new difficulties of measurement and research in general. Notwithstanding these problems, several broad answers may be given to the research questions raised in Section 4.3 regarding attitudes on indoor climatic issues.

The significance of indoor climatic issues for building occupants was demonstrated by the samples' ranking of indoor temperature and ventilation issues along with lighting as the most important determinants of built environmental quality. This finding on its own provides a sound justification for the considerable research effort that has been, and should continue to be spent on indoor climate and air quality problems.

Beginning with cognitive aspects of attitudes, the study indicated that most consumers of air conditioning believe that there are deleterious health effects of this climate control. When pressed for specific ailments that they attributed to it, a wide variety of responses were elicited in all buildings surveyed. This suggests that the "sick building" phenomenon is possibly only an exaggerated case of a general malaise that exists in all air-conditioned buildings, regardless of the engineering or operational peculiarities of their air conditioning

systems. Colds, "sniffles" and other respiratory problems were the most common ailments attributed to air conditioning, reflecting a widespread belief in the dangers of recirculated air. Several other symptoms were blamed on the thermal features of indoor climate; particularly the large thermal gradients between indoors and outdoors during the cooling season.

These beliefs have a direct bearing on the occupant acceptance of energy conservation programmes, in that a temperature "set forward" could reduce the thermal gradient as well as the degree of occupant concern over the effects of low temperatures and "thermal shocks" on health. Alternatively, the energy savings that would result from higher set-points and wider deadbands could be spent increasing ventilation rates and thereby minimising the risks from indoor air pollution. However, this assumes that "sick building" symptoms have environmental causes, which is a point open to question. For example, the current study failed to detect any differences between the health status self-ratings of air-conditioned and non-air-conditioned building occupant samples that were reasonably well matched in the usual biographical variables. Also, the observation of a certain degree of "background" complaint about health issues in every air-conditioned building surveyed lends support to the notion that such complaints may have no validity in drawing the causal connection between microclimate and health. It is possible that these grievances are manifestations of some other form of discontent, perhaps with the lack of occupant control over microenvironmental conditions.

Regardless of the causality or otherwise between indoor climatic conditions, ventilation rates (above current standards at least) and building occupants' health, any energy management programme that

attempted to lift summer temperatures in order to allow an increase in ventilation would have to be accompanied by a well implemented innformation package for building occupants, if an overreaction to the "technical fix" was to be avoided.

Apart from health concerns, another widely held belief among the current samples of building occupants was that any departure of indoor temperatures away from their comfort optimum would result in immediate productivity decrements in the workplace. Despite the considerable body of evidence that places temperature (between the limits of heat and cold stress at least) as only of minor significance to performance, the popular belief on the matter would inevitably become a barrier to the smooth implementation of energy conservation strategies. Here again, as with health factors, information intelligible to the building occupants would be a desirable accompaniment to any energy management programme involving higher and more varied temperatures during summer.

An overwhelming majority of occupants of almost all the air conditioned buildings surveyed felt they had insufficient control over their immediate microclimatic conditions. This issue appeared in several areas of the questionnaire, including the open-ended beliefs on the disadvantages of summer air conditioning. In response to that question, one of the most frequently given answers mentioned both spatial and temporal variability of indoor temperatures in air-conditioned buildings. This finding adds further support to the conclusions drawn earlier concerning the inverse relationship between indoor microclimatic variability and the sensitivity of subjective warmth to changes in environmental warmth. On the basis of the current data, one can anticipate initial resistance from the occupants of air-conditioned

buildings in response to temperature drifts, ramps, "thermobile" (Auliciems, 1984) and deadband strategies of HVAC control. However, in time, microclimatic uniformity and constancy should become less entrenched in building occupants' expectations of air conditioning, and consequently, occupant acceptance of energy conservation should be enhanced.

The current practice of excluding occupants from participation in the processes of microclimatic control appears to be something of a stumbling block in the context of the preceding discussions. It is acknowledged to be among the most poorly operationalised constructs in the current research and is certainly deserving of more intensive investigation by future researchers. The call from Hawkes (1982) for selective rather than exclusive, control of environments acknowledges the importance of this variable, and the current study lends a certain degree of support to the idea. In Darwin there was a majority of air-conditioned building occupants who felt that their central climate controls could be turned off completely for at least six months of the year, thus allowing occupants to partially regain control over their working environment.

As crudely measured as the perceived microclimatic control construct was in the current study, a few broad conclusions can be drawn. Firstly, denying building occupants any semblance of control over their environment elicits several behavioural responses that are often deleterious to the efficient and effective operation of HVAC systems. For example, thermostats were tampered with, air conditioning vents were sealed off, and whenever possible, windows and fire-escape doors were left open by dissatisfied occupants. In an extreme case, personal

radiators were turned on during the hottest season in a monsoonal climate! Secondly, the single most commmon form of thermoregulatory behaviour in the air-conditioned survey buildings was complaining to whoever was responsible for the HVAC. Finally, the volume of complaints being registered about thermal conditions in air conditioned buildings was highest in the buildings that were identified as possible "sick buildings". This last observation lends some support to the nexus between microclimatic control and health complaints as discussed earlier.

Whereas passive smoking in the workplace seems to have become a contentious public issue in recent years, there was only a minority of respondents in the current surveys who found it adversely affected them in terms of sensory irritation. Nevertheless, there was a considerable volume of support, if not a majority, for the segregation of smokers from non-smokers in the workplace. This support was strongest in the air-conditioned buildings, with the free-running structures' natural ventilation making passive smoking less contentious.

The current study indicated the strong interrelationships between the affective, cognitive and behavioural components of air conditioning attitudes. In particular, belief in the deleterious health effect of air conditioning was associated with a greater preference for non-air-conditioned buildings in summer. The affective component of attitude towards air conditioning in the workplace was also associated with the belief in adverse health effects. As the strength of building occupants' belief in the health effect increased, their overall favourability towards air conditioning decreased.

There seemed to be very little effect of outdoor climate on occupant's affective disposition towards air conditioning between Brisbane and Melbourne, despite the former's persistently warmer and more humid summers. It would appear as though the occasional hot spells in Melbourne's summer had as much subjective impact in this regard as the subtropical summer had in Brisbane. However, there was a much more noticeable impact of climate on AC affective scores in Darwin, with the "Build-up" season yielding the highest values, and the "Dry" season the lowest.

These broad climatic influences on the affective aspect of AC attitudes were paralleled in the "behavioural" responses in which respondents stated their preference for either air-conditioned or free-running workplaces. Melbourne and Brisbane respondents were broadly comparable in their preferences, while Darwin's sample (in the "Build-up" at least) was much stronger in its preference for air conditioning for at least four months of the year. However, the degree of preference for air conditioning in Darwin was not a simple function of climatic stress prevailing in each month. Two months that had approximately equal thermal conditions (one at the beginning and the other at the end of the "Wet" season) did not elicit the same degree of preference for air conditioning. There was a lower level of AC preference in the "post-Wet" month, suggesting that some degree of adaptation to hot-humid atmospheres had taken place in the interim. A further suggestion of adaptational processes diminishing tropical residents' "dependence" on air conditioning was in evidence in the comparison of recent arrivals to Darwin with the long-term residents. The former group was more favourably disposed towards the climate control than was the group of

people who had lived in Darwin for longer than 20 years.

The preferences in Brisbane and Melbourne were noted to be closely associated with the type of building in which the survey was conducted. In both cities, a majority of the non-air-conditioned survey respondents stated a preference for free-running buildings, while the opposite was the case for the occupants of the air conditioned survey buildings. This finding possibly reflects the importance of expectations and experience in man-environment systems, and recognition of these factors had been made in Figure 4.1 by way of the processes of set-point adjustment in the psychological and behavioural subsystems. It was also noted however, that the influence of experience on preference did not extend back beyond the buildings currently occupied by the respondents. That is, prior experience of an air-conditioned building did not cause respondents currently in non-air-conditioned buildings to have preferences any less favourable towards them. These data therefore give support to the practitioners of passive architecture in the sub-tropical and temperate climatic regions of Figure 5.1 at least.

By asking respondents to abstract from their recent experiences in the survey buildings an overall thermal impression, and also an assessment of the degree of thermal satisfaction they attached to those overall experiences, it was possible to examine some of the hypotheses expressed in the "behavioural" subsystem of Figure 4.1. The first noteworthy point, and perhaps one of the most striking conclusions of the study, was that overall thermal impressions and satisfaction were largely dissociated from the mean instantaneous assessments and actual microclimatic measurements taken in the same buildings. The overall assessments in Brisbane's non-air-conditioned buildings were on average,

closer to neutral and at least as satisfactory as those in the city's air-conditioned survey, despite the considerable differences in thermal conditions between the two surveys. The length of the survey periods, and also the similarity of outdoor meteorological conditions recorded in those periods to the long-term seasonal averages, would tend to discount the sampling-error explanation of these findings. Consequently, the role of building occupants' seasonal expectations in adjusting the behavioural subsystem's set point in Figure 4.1 is generally consistent with these data.

This expectation construct is also useful in interpreting the overall thermal impressions and thermal dissatisfaction scores recorded in the two Melbourne surveys. Mean thermal conditions were broadly equivalent in both the air-conditioned and free-running surveys, yet the subjective impressions at this level of integration were very much warmer in the free-running survey with accompanying increases in thermal dissatisfaction. Part of the explanation for these observations could be in the substantially increased variability of indoor temperatures in the non-air-conditioned buildings, with the occasional temperature excursions into the low 30s having a disproportionate subjective impact on a population that was neither physiologically nor psychologically adapted to such conditions. This interpretation was further supported by the stepwise correlation of overall thermal satisfaction means recorded in non-air-conditioned buildings, where the standard deviation of indoor temperatures accounted for 12% of the between-building variance.

8.4 Interaction Between Instantaneous Thermal Assessments and Non-Thermal Factors

The battery of research questions in Section 4.4 dealt with the possibility of factors exogenous to the psychological subsystem and the body/environment heat balance having an effect on instantaneous evaluations of microclimatic conditions. Section 8.2 has already discussed the impacts of long-term adaptational processes on thermal neutrality, subjective warmth sensitivity and instantaneous thermal acceptability, but the study investigated several other factors in this respect.

First, occupants' sex was shown to have no effect on their evaluations of immediate thermal environments once all of the heat-balance factors had been taken into account. However, women were noted to be dressed lighter than men and this factor probably accounts for the frequent observation that women are more sensitive to cold and draughts than men.

The possibility of thermal exposures in one setting influencing instantaneous thermal perceptions in another place was followed up by comparing Darwin's respondents who owned home air conditioning with those who didn't. From this comparison, it was concluded that the former group were less habituated/acclimatised to tropical warmth, and as a result, felt warmer and less comfortable in a given thermal environment that did respondents who didn't have air conditioning at home.

Furthermore, length of residence in a tropical climate was found to correlate with instantaneous thermal perceptions. Long-term residents of Darwin found standardised conditions in the workplace cooler and more

comfortable than did the new arrivals. Therefore, the benefits of adaptational processes in thermal perception, as depicted on the left-hand side of Figure 4.1, would appear to be cumulative through time.

Interactions were observed between the instantaneous thermal perceptions of building occupants and various attitudinal factors. It was noted that in a majority of surveys, respondents who felt they had sufficient control over their microclimatic environment in the workplace felt cooler and more comfortable in standard environments than did those who felt they had no control. While there is no evidence in the current study about the direction of causality in this association, the flow line connecting these two factors in Figure 4.1 could be analogous to the "origin-pawn" dimension of personality as discussed by Carlton-Foss and Rohles (1982). In that research, personality was noted to affect thermal acceptability and comfort, and an extension of that observation to the general model of Figure 4.1 would have personality adjusting the psychological and behavioural subsystems' set points.

Finally, there was a clear association between building occupants' preferences for either air-conditioned or free-running workplaces and their instantaneous thermal perceptions. Those preferring air conditioning in summer were noted to feel warmer and less comfortable in standardised environments than those who preferred non-air-conditioned workplaces in summer. Again, the direction of causality is unclear in this association. However, since there was no relationship between the cognitive factor of belief in adverse health effects of air conditioning and instantaneous thermal perceptions, it would seem most probable that the respondent's comfort set point affected preference rather than vice versa. This is due to the observed relationship between cognitive

factors and preferences (via affective component of attitude). Thus, belief is interpreted as a cause of affect, which in turn was a cause of preferences for air conditioning, while thermal comfort set points are seen as another, independent determinant of preferences. This complexity is indicated in Figure 4.1 by the mutually causal connection between the comfort perceptual and behavioural set points.

8.5 General Conclusions

The notion of climatic optima, advanced intially by the climatic determinists and subsequently taken up by the HVAC industry, appears to have been closely adhered to in Australian air conditioning practice. While the determinists' hypothesis focused on a temperature-performance relationship, the HVAC industry has shifted attention towards thermal comfort. However, the use of mechanical cooling to reduce thermal discomfort indoors tends to reduce the comfort set point of building occupants. Furthermore, the maintenance of constant indoor climates appears to heighten subjective sensitivity to minor fluctuations in ambient warmth while reducing acceptability of any departures from the occupants' expected temperatures. These conclusions fit well into the theory of adaptation level discussed in other areas of environmental psychology, and the processes of acclimatisation and habituation represent plausible explanations for the shifting adaptation levels.

There is considerable scope for energy conservation in current air conditioning practices in Australia. The comfort options can be sorted into three levels of energy saving:

1. Shifting ambient temperatures towards the temperatures that were observed in the current study to induce optimal comfort,

2. Shifting ambient temperatures towards the comfort optimum predicted by the "constancy hypothesis" (ISO 7730 or ASHRAE 55-81), or

3. Adopting the recommendations of the "adaptation hypothesis" by basing HVAC set temperatures on a combination of mean indoor and outdoor temperatures.

The last of these represents the preferred option from the theoretical perspective embodied in the preceding paragraph.

Whereas air conditioning has traditionally carried with it prestigious connotations, recent events such as Legionnaires Disease outbreaks sensationalised in the mass media, along with a growing suspicion of the general health effects of HVAC have tarnished this product image. There appears to be a majority of occupants in all air-conditioned buildings, regardless of ventilation rates and HVAC system quality, who feel that air conditioning is responsible for various health problems. The "sick building" syndrome represents an exaggerated form of this general phenomena.

While specific health problems have been traced to air quality factors such as formaldehyde and radon that can be mitigated by increased ventilation rates and appropriate building material selection, the "sick building" syndrome appears in the literature to be unrelated to indoor pollutants. A growing volume of evidence indicates the "perceived control" construct to be implicated in this regard. This issue lends

support to the passive, or at least selectively active strategies of climate control. Either way, the "zoo keeper" approach, which has hitherto been regarded as essential to efficient energy management in environmental control, appears to be due for critical reappraisal.

These conclusions were further supported by the preferenes of building occupants for either air-conditioned or passively controlled workplaces. A majority of people currently in air-conditioned buildings felt they would prefer that option during summer, indicating a dependence on active climate controls. However, a majority of people currently in passive buildings, including those who had previously worked in air conditioning, stated a preference for free-running buildings. Presumably, as one progresses up the hierarchy of human responses from immediate physiological processes, through sensation and comfort, to behavioural factors such as preference, the influence of the immediate environment gradually diminishes. This was most strikingly illustrated by the dissociation of occupants' overall thermal impressions and thermal dissatisfaction from the microclimatic conditions actually observed in their workplaces.

The most obvious suggestions for future research that have emerged out of the current study are:

1. The "perceived control" construct in the microclimatic context needs to be more thoroughly understood.

2. Further comfort studies using standardised microclimatic measurement procedures need to be performed in air conditioned buildings in climates with mean monthly temperatures between 25 and 29degC.

3. Following on from the preceding point, there is a need for monitoring the occupant acceptance of buildings in which the various energy conservation strategies discussed in the current study have been implemented. These should be either longitudinal and spanning at least one full cycle of seasons after implementation, or cross-sectional and timed at least one year post-implementation. Before-and-after energy audits would be a desirable accompaniment to such a study.

APPENDIX A

The Contribution of Psychologists to Thermal Comfort Research

A.1 Introduction

The reasons for the relatively minor input from psychology to the study of thermal perception are difficult to discern from the literature. Whether it is due simply to a preoccupation with more easily investigated sensory modes (McIntyre, 1978c), or rather an over-reaction to the excesses of climatic determinism in the social sciences earlier this century (Auliciems, 1981c) remains unclear at this stage. A notable exception to this paucity of psychologists actively engaged in comfort research is F. Rholes Jr. of Kansas State University. Also, while researchers in the area of psychophysics have only occasionally studied the thermal sense (e.g. Stevens and Stevens, 1960; 1963; Stevens et al., 1969; Stevens and Marks, 1970), the general methodology of that subdiscipline seems to be very relevant to the chamber studies of comfort discussed in Section 3.1. Another connection between psychology and the approaches to comfort research reviewed in the current thesis is via Adaptation Level theory, which received its initial expression in the field of psychophysics (Michels and Corso, 1949; Helson, 1947; Helson, 1964; Corso, 1971). There were more recent developments in the 1960's and 70's, when ecological issues were receiving considerable attention in the West, environmental psychology emerged as a clearly identifiable subdiscipline. Again, the methodological tenets of this branch of psychology seem to have been closely practised in certain strains of comfort research; particularly the field studies (see Section 3.3).

The notion of individual differences in comfort responses have been acknowledged in the work of Fanger (1970), where it has been claimed that it was impossible to satisfy any more than 95% of a sample of people with any one thermal environment. Corroborating this conclusion was

McIntyre's (1978c) finding that the standard deviation of a group of laboratory subjects' thermal comfort assessments on a seven-point scale when exposed to a constant thermal environment amounts to about 0.8 scale units. Nevertheless, only a handful of researchers appear to have made any attempt to explain these individual differences. One such attempt was that by Howell and Stramler (1981) who investigated the contribution of cognitive variables to the explanation of variance in thermal comfort assessments collected in field studies. The main "cognitive" variable under investigation was the respondents' numerical estimate of the temperature at the time of interview. It was found that the "cognitive" variable contributed much more to the explained variance in comfort assessments than did the usual microclimatic independent variables. However, this conclusion seems unsatisfactory for two reasons; 1) the authors didn't measure air velocity at the time of interview , and this could account for a good proportion of the variance in subjective warmth estimates unexplained by the microclimatic variables in their model, and 2) the so-called cognitive variable seems to be little different from a normal rating scale except that it has more points on it. The research design was no better than using Bedford scale votes to predict ASHRAE votes.

Carlton-Foss and Rohles (1982) produced a more compelling case for the role of psychological factors in accounting for individual differences in comfort and acceptability. They used the thematic apperception test to classify respondents as "origin types" and "pawn types" of personalities for their independent variable, and the Rohles semantic differential comfort index as the dependent variable. A significant correlation was observed with "origins" being much better at coping with sub-optimal thermal conditions than "pawns".

Other studies by Rohles and associates have indicated that non-thermal aspects of environment can influence human thermal assessments. The "plushness" of a climate chamber was shown to influence comfort votes (Rohles and Wells, 1977). Twenty three degC was found to be cooler in a chamber that looked stark than it was in a pleasantly decorated and carpeted environment, even though all other thermal variables were held constant. In another study, Rohles (1980) found that misinforming samples about the room temperature influenced the way in which they assessed their thermal environment. Furthermore, Rohles, Bennett and Milliken (1981) found that the type of lighting in an environment influenced subjective thermal assessments in cooler than neutral environments.

A.2 Psychophysics

The subdiscipline which defines itself as studying "...the manner in which the apparent magnitude of sensation depends on the physical magnitude of stimulation" is psychophysics (Stevens and Marks, 1970, p.110). The traditional method is essentially reductionist insofar as it strips away all of the confounding influences in the objective-subjective relationship and treats sensation as the fundamental unit of perception (Gescheider, 1976).

The magnitude of the physical stimulus has been much easier to measure than the apparent magnitude of sensations. For the latter, cross-modal matching has sometimes been used, but the most common measurement technique is known as magnitude estimation. The procedure consists of getting each subject to nominate an arbitrary number to represent a reference level of stimulus intensity (modulus) and then

assign ratio estimates of various intensities proportional to their original modulus number. The main alternative to magnitude estimation is the use of rating scales for sensation magnitude. These typically have the form of a continuum, with sensory anchor terms at either end and a neutral or indifferent point somewhere in the middle (Helson, 1964).

Various mathematical models have been proposed in psychophysics to relate the objective and subjective variables. One of the earliest attempts was Fechner's logarithmic function that had sensation growing arithmetically while the stimulus grew geometrically. The logarithmic psychophysical law received support from Adaptation Level (AL) theorists (Michels and Helson, 1949). Their psychophysical function was formally similar to that of Fechner's function but it incorporated a variable describing the prior sensory experiences of the subject; namely the level of stimulation to which they had become adapted. The AL is that value of the stimulus that evokes the neutral, zero or indifferent response category of a rating scale (Helson, 1964, p.126). This "frame of reference" approach to psychophysics came under criticism on the grounds of its use of category rating scales and the Fechnerian logarithmic function (Stevens, 1958). Due to the psychological inequality of successive rating scale categories, the plot of judgement categories on psychological magnitude is concave downwards which explains why the Adaptation Level reformulation of Fechner's logarithmic function can predict this type of experimental sensory data (Stevens, 1958, p.641).

Apart from the problems with the inequality of successive intervals on common rating scales and end-of-scale truncation (Stevens and Galanter, 1957; Stevens, 1958), Stevens further criticised Adaptation

Level psychophysics, claiming that its use of categorical rating scales confounded the notion of shifts in adaptation level with "semantic set". Long term exposure to a level of stimulation that was originally described as slightly warm was claimed to cause that stimulus to become reclassified as the norm, or neutral. However, this change of description is one of semantic adjustment, uninvolved with changes in the sensory character of the stimulus according to Stevens (1958, p.633). This semantic artifact or change-of-modulus argument as it became known, was subsequently challenged by Helson and Kozaki (1968) in an experiment involving numerical estimates of dots within frames.

Another widely supported psychophysical function is known as the Power Law which holds that the apparent magnitude of sensation was an exponential function of stimulus magnitude (Stevens and Stevens, 1963, p.239). Numerous studies have been published on empirically fitted exponents for various modes of sensory stimulation (e.g. Stevens and Stevens, 1960; Stevens and Marks, 1970; Stevens et al,. 1969; Gonzalez and Gagge, 1973), and it is now generally conceded that Steven's Power Law is more appropriate for experimental psychophysical data than the Adaptation Level weighted log mean (Corso, 1971, pp.28-29). However, the two approaches are not entirely incompatible. By using the method of magnitude estimation with the thermal sense, Stevens and Stevens (1960) were unable to fit a power function to their data until a threshold correction was introduced; 32.5 degC skin temperature which elicited a neutral thermal sensation (1960, p.186). Those authors circuitously defined the correction as the constant value, that when subtracted from the stimulus values, succeeded in rectifying the log-log plot of the power function. Conceptually though, the correction for neutrality parallels the notion of Adaptation Level in psychophysics.

A.3 Environmental Psychology

Environmental Psychology emerged in the 1960's with the recognition by architects, human geographers and town-planners, of the valuable contribution that psychology could make to their endeavours. Consequently, the thrust of environmental psychology has been problem-oriented (Proshansky, 1972; Patterson, 1977). A formal definition of the interdisciplinary area is difficult to dfromcern in the literature, but most commentators seem agreed that environmental psychology studies the reciprocal relationships between behaviour and the built or natural environment (Heimstra and McFarling, 1974; Proshansky et al., 1976; Russell and Ward, 1982; Proshansky and O'Hanlon, 1977).

Since the process of perception lies at the very interface of the man-environment system, it is to be expected that environmental psychologists should pay considerable attention to it. Three very general conclusions about perceptual processes can be gleaned (Helson, 1971; Ittelson, 1973):

1. Perception is no longer considered to be strictly determined by environmental stimulus (or the physiological strain induced by the stimulus).

2. The process is no longer considered as being a discrete psychological process but rather as being indistinguishable from memory, cognition and other psychological functions.

3. Perception is relevant to, and appropriate for, the environmental context in which it occurs.

Quite clearly then, environmental psychology looks at perception in a

much more holistic manner than does the reductionist methodology of psychophysics.

The interdisciplinary area of environmental psychology has several other distinguishing methodological traits that are relevant to the current research topic. First among these is the treatment of the man-environment system as an integral unit. Behaviour is influenced by the environment, but it is also recognised that behaviour has an effect on environment. A concrete example of the reciprocal relationship between person and thermal environment is contained in the act of opening a window; environment causes discomfort which in turn motivates behavioural modification of environment (Nicol and Humphreys, 1973). In contrast, the climate chamber approach to thermal comfort research emphasises the unidirectional causality in the relationship between environments and people.

Also following from an emphasis on the unity and mutual causality of the man-environment system is the characteristic use of field settings for much research in environmental psychology. This represents a reaction against the highly contrived laboratory experimental methodology which "peels" and "cleans up" real-life issues in order to make them researchable. The cost of this laboratory simplification process is that the experimental results barely hold any applicable relevance to the real world processes they supposedly represent (Stokols, 1977; Proshansky and O'Hanlon, 1977; Ellingstad and Heimstra, 1974). By investigating phenomena within their naturally occuring context, the environmental psychologist is able to maximise the "phenomenal integrity (Stokols, 1977, p.31) of the environment as a real-life experience for the individual. This concept has been given the name "experiential realism"

by Patterson (1977, pp.332-333) and is a criterion on which the external validity of a research design is assessed.

Clearly then, the field studies of thermal comfort discussed in Section 3.3 fall within the definition of environmental psychology, even though very few of them were conducted by self-identified psychologists. Indeed, most comfort surveys would have been published before the term "environmental psychology" had ever been coined.

APPENDIX B

Ping-Pong Globe Thermometers for Mean Radiant Temperature

B.1 Introduction : Radiant Fields and Globe Thermometers

Air conditioning engineers, thermophysiologists and comfort researchers have long been aware of radiant heat exchanges between the body and its thermal environment (Vernon, 1932; Missenard, 1935). More recently, the heat-balance "comfort equation" by Fanger (1967) and the new ASHRAE effective temperature ET* (Nishi and Gagge, 1977) both include inputs of radiant measurements. The mean radiant temperature T_{mrt} is the most useful variable describing the radiant field in this context, and is defined as the uniform surface temperature of an imaginary black enclosure with which a person (assumed to be a black body) exchanges the same heat by radiation as in the actual environment. Usually it has been measured with a 150mm diameter blackened copper ball with a mercury-in-glass thermometer inserted to the centre of the sphere (Bedford and Warner, 1934). It has been suggested that a smaller globe of 40mm could be used quite successfully as a unitary index of human warmth (Humphreys, 1977). The current appendix briefly compares the performance of such "home-made" miniature globe thermometers with the traditional 150mm model in the estimation of mean radiant temperatures.

The theory of globe thermometers has been explained thoroughly by Kuehn et al., (1970). Put simply, the globe reaches thermal equilibrium with its surroundings when radiant gains (or losses) are balanced by convective losses (or gains). This balance may be expressed algebraically:

$$\sigma \varepsilon (T_g^4 - T_{mrt}^4) = h_c (T_g - T_a) \qquad (B.1)$$

where σ is Stefan Boltzmann constant
ε is the emissivity of the black globe (near unity)
T_g is temperature of globe (K)
T_a is ambient air temperature (K)

T_{mrt} is mean radiant temperature (K)

h_c is convective heat transfer coefficient (W/m^2 degC)

In effect, the globe temperature represents a weighted average of radiant and ambient temperatures. Therefore, the practical problem of assessing mean radiant temperature requires an estimation of these weights, which will subsequently be referred to as the coefficient of radiant heat transfer h_r and the coefficient of convective heat transfer h_c. The advantage of using a large 150mm diameter globe is that it increases the weight of h_r at the expense of h_c, thereby improving the accuracy of mean radiant temperature estimates.

In discussing the performance of different sized globes, Humphreys (1977) made use of the notion of radiant response ratio $g=h_r/(h_r+h_c)$. If g equals .5, the globe gives equal weighting to changes in air and mean radiant temperatures. By extending Hey's (1968) expression of the dependence of the convective coefficient upon air velocity and globe diameter, McIntyre (1980) gave the following equation for radiant response ratio:

$$g=1/(1 + 1.13v^{0.6}\,d^{-0.4}) \qquad (B.2)$$

where v is air velocity (m/s)
d is globe diameter (m)

Logically, the convective response ratio is g subtracted from unity. Thus a linear approximation for the equilibrium temperature of a globe thermometer can be given as:

$$T_g = T_a \frac{h_c}{h_r+h_c} + T_{mrt} \frac{h_r}{h_r+h_c} \qquad (B.3)$$

In summarising physiological experiments on heat transfer from the human body, Humphreys (1977) found the average value of 0.46 for radiant response ratio. At relative air velocities less than 0.15m/s it was demonstrated that a globe diameter of 40mm best simulated this radiant response ratio of the body. On the basis of these findings, Humphreys (1977) recommended the use of 40mm ping pong globes, painted matt black with fast-response mercury-in-glass thermometers inserted in them, for assessing the warmth of a room for human comfort when air velocity is less that 0.15m/s. As well as being cheaper and easier to construct, these miniature globe thermometers were reported to be substantially faster in reaching equilibrium temperature than the traditional 150mm Vernon globes constructed out of copper. However, Humphreys stopped short of recommending the miniature globes for deriving mean radiant temperature, pointing out the greater weight given to the radiant term in the larger globe's thermal exchanges with the environment.

By substituting Equation (B.2) above into Equation (B.3), and solving for mean radiant temperature:

$$T_{mrt} = \frac{T_g - T_a \left(1 - \left(\frac{1}{1+1.13v^{0.6}d^{-0.4}}\right)\right)}{\left(\frac{1}{1+1.13v^{0.6}d^{-0.4}}\right)} \qquad (B.4)$$

a simple means of estimating the most important parameter of the radiant field was obtained. By measuring air velocity, ambient air temperature and both 40mm and 150mm globe temperatures in a variety of thermal environments, Equation (B.4) provided a method for assessing the inaccuracies that a field-researcher could expect when using a smaller globe for mean radiant temperatures.

B.2 Method and Results

The two types of globe thermometer were tested by suspending them side-by-side in a variety of thermal environments. Readings were taken at the end of 20 minutes exposure. The test chamber consisted of a small office with two variable-speed ceiling fans, and a 2.3kW refrigerated air conditioner. The radiant field was controlled by a 1kW radiator placed at varying distances from the globes. Air velocity was measured with a Kurz hot-wire anemometer and ambient air temperature with a Cassella aspirated psychrometer (see Section 5.2). The globe thermometers were;

1. 150mm diameter copper shell painted matt black with a Cassella mercury-in-glass thermometer,

2. 40mm diameter ping-pong ball, painted matt black and with a Zeal whirling psychrometer replacement thermometer sealed into a central position.

The performance of the two globe thermometers in 12 different thermal environments is summarised in Table B.1. The 12 environments were considered to give adequate coverage of situations likely to be encountered in a field survey of summer indoor climates in which the mean radiant temperature is warmer than ambient air. The last column of Table B.1 shows the discrepancy between the two globes' estimates of mean radiant temperatures and in all but Environment 2, the error was less than one degree. In the case of Environment 2, the air velocity (1.60m/s) was much greater than is likely to be encountered i: a normal indoor setting. Even with that extreme case included, the average of the absolute values of the discrepancy was 0.33K, which for most indoor comfort surveys would fall within acceptable limits of error.

TABLE B.1 : Comparison of T_{mrt} derived from 150mm and 40mm globe thermometers

Test Environment Description	T_a degC	Air vel m/s	Globe temperature globe diam	T_g	T_{mrt} EqB.4	Error 150mm T_{mrt} -40mm T_{mrt}
1.Radiator on;fans at high speed	22.5	1.20	150mm	23.3	25.5	
			40mm	23.0	25.3	+0.2
2.Radiator close to globes;	22.6	1.60	150mm	24.6	31.0	
			40mm	24.1	32.2	-1.2
3.Radiator at distance; fan on at low speed	22.5	0.18	150mm	23.7	24.7	
			40mm	23.4	24.7	0
4.Radiator close to globes; fans on at low speed	22.6	0.20	150mm	26.6	30.3	
			40mm	25.6	30.3	0
5.No radiator; no fans	21.2	0.02	150mm	20.6	20.5	
			40mm	20.6	20.4	+0.1
6.Radiator on; fans on medium speed	33.7	0.30	150mm	35.5	37.7	
			40mm	35.0	37.6	0
7.No radiator; fan on medium speed	32.5	0.30	150mm	32.9	33.4	
			40mm	32.7	33.1	+0.3
8.No radiator; fan on low speed	31.7	0.20	150mm	31.9	32.1	
			40mm	31.6	31.5	+0.6
9.No fan; no radiator	30.3	0.03	150mm	30.9	31.1	
			40mm	32.8	30.9	+0.2
10.Radiator close to globe; refrig air con on	28.4	0.15	150mm	34.1	38.5	
			40mm	32.8	38.6	-0.1
11.Radiator at distance; refrig air con on	27.4	0.15	150mm	30.0	32.0	
			40mm	29.2	31.6	-0.4
12.Radiator on; refrig air con on; fans at low speed	27.1	0.22	150mm	27.9	28.7	
			40mm	27.4	27.9	+0.8
					Mean absol. value	0.33K

Figure B.1 shows the response time taken for both thermometers to reach thermal equilibrium in four of the test environments. The larger radiant response ratio of the 150mm globe ensured that it gave a warmer temperature reading in each of the radiant fields, but the time taken for both thermometers to reach equilibrium seemed to be approximately the same.

B.3 Discussion

It would appear from the data presented that miniature globes can quite successfully be used to estimate mean radiant temperature in circumstances where the relative air velocity is less than 1 m/s and the radiant field is equal to or warmer than ambient air temperature. It seems reasonable to assume that the same conclusion would hold for environments where the ambient temperature was warmer than the radiant temperature, but there was insufficient evidence in the current study to be confident on this assessment.

The conclusion reached by Humphreys (1977) that the miniature globes reached thermal equilibrium much quicker than the 150mm globes appears not to be supported by the current data (Figure B.1). Perhaps Humphreys' results were more a function of the type of mercury-in-glass thermometer that was used than the size of the globe. In the current experiments, readings from both sized globes would have been significantly different from the final equilibrium temperature if taken before 20 minutes of exposure. However, in more natural settings where mean radiant temperature departs from ambient air temperature by only a few degrees (less than 4K), equilibrium temperatures should be approximated by the miniature globes after 10 minutes of exposure.

Finally, in field settings where thermal comfort researchers or air-conditioning engineers require a readily available method for estimating mean radiant temperature, the ping-pong globe thermometers described above provide a solution which is cheap enough to allow more than one instrument to be used for a room assessment.

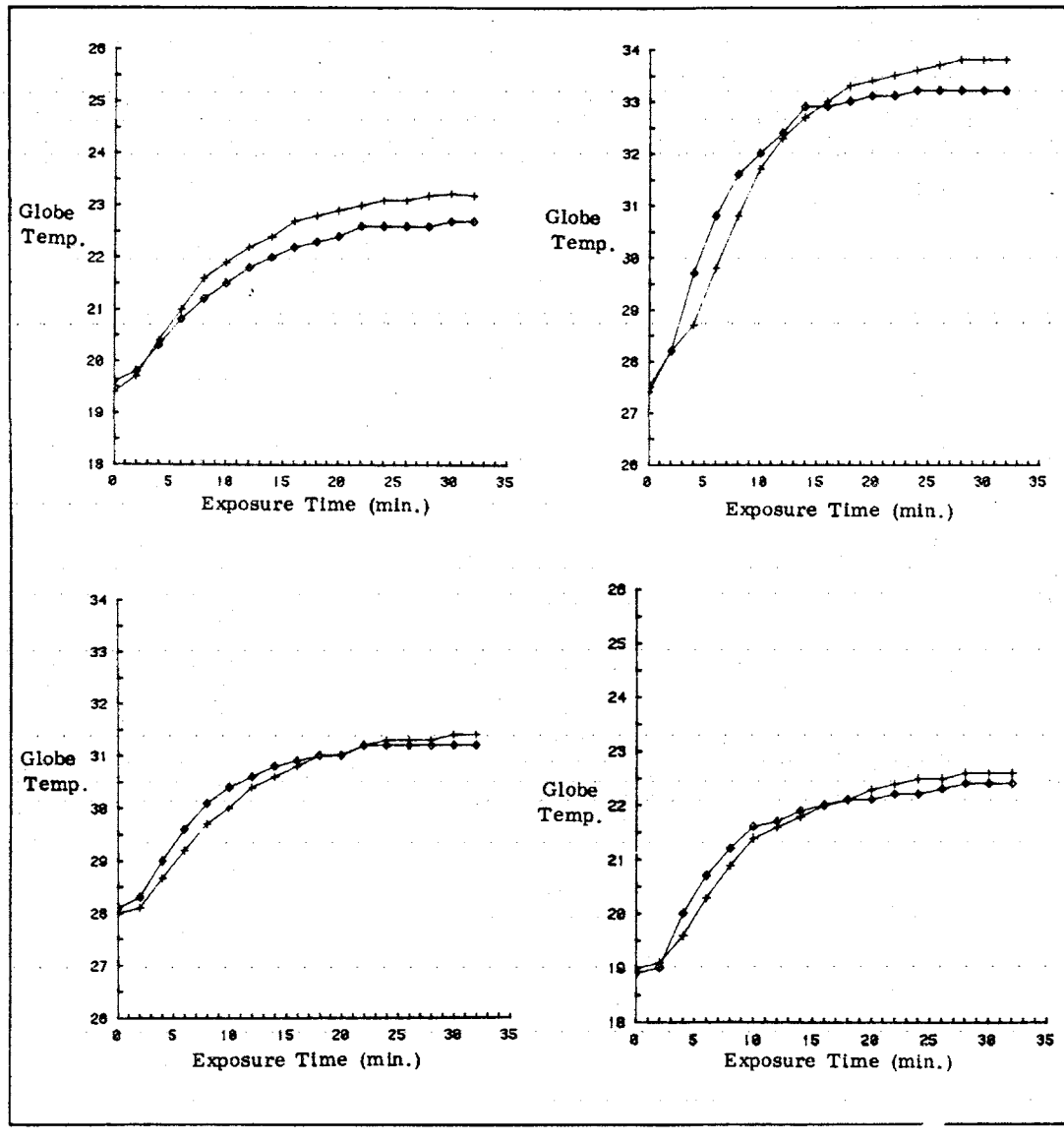


FIGURE B.1 : Response curves for 40mm(◇) and 150mm(+) diameter globe thermometers

APPENDIX C

Fortran IV and BASIC Programs for PMV, PPD and SET Indices

```
C
C
C THIS FORTRAN IV PROGRAM CALCULATES FANGER'S P.M.V.
      REAL ICL,MA,MRT
      OPEN (UNIT = 21 , FILE = 'BNCTMP.DM2')
      OPEN (UNIT = 22 , FILE = 'BNCPMV.OUT')
C THERE WERE 603 CASES IN BNCPMV.DMI THEREFORE INDEX MAXIMUM OF I = 603
      DO 100 I=1,603
C  SECTION 1: DATA INPUT
      READ(21,16)I1,I2,I3,I4,A1,A2,A3,I5,A4,A5,A6,A7,A8,I6,I7,I8,I9,A9,A
     110,A11,I10,A12,PIN
   16 FORMAT(I4,X,3I2,X,3(F4.1,X),I1,X,3(F4.1,X),2F4.2,X,4I3,X,3(F4.1,X)
     1,I2,X,F4.2,X,I3)
C
C SECTION 1A:MISSING VALUE PROCEDURE
C             IF EITHER DRY OR WET BULB TEMP. IS MISSING ,THE CASE IS
C             DELETED FROM THE ANALYSIS. IF ANY OTHER VARIABLES ARE
C             MISSING ,THE AVERAGE FOR THE SAMPLE IS SUBSTITUTED AND
C             THE ANALYSIS CONTINUED.
      IF (A9.EQ.99.9)GO TO 48
      IF (A10.EQ.99.9)GO TO 48
      IF (A11.EQ.99.9)A11=A9
      IF (A12.EQ.9.99)A12=0.11
      IF (A7.EQ.9.99)A7=0.55
      IF (A8.EQ.9.99)A8=1.08
      IF (I6.EQ.999)I6=066
      IF (I7.EQ.999)I7=068
      IF (I8.EQ.999)I8=069
      IF (I9.EQ.999)I9=071
C
C
C SECTION 2:INPUT VARIABLE DERIVATION AND TRANSFORMATION
      TDB=A9
      TWB=A10
      TG=A11
      V=A12
      DIAM=0.001*38.
C     VAPOUR PRESSURE  MMHG
      PSWB=EXP(18.956-4030.18/(TWB+235.))
      PA=(PSWB-0.667*(TDB-TWB))*0.75
C     MEAN RADIANT TEMPERATURE BY MCINTYRE'S (1980) METHOD
      RRR=1./(1.+1.13*V**0.6*DIAM**-0.4)
      CRR=1.-RRR
      MRT=(TG-TDB*CRR)/RRR
C     CLOTHING (CLO) AND METABOLISM (CONVERTS W/SQ M INTO KCAL/HR/SQ M)
      ICL=A7
      FCL=A8
C                  EXTERNAL MECHANICAL EFFICIENCY ASSUMED ZERO
C                  THEREFORE MA(1-EME)=MA
C                  METABOLISM IS ASSUMED TO BE THE AVERAGE OF THE
C                  FOUR TIME PERIODS
      MA=(FLOAT(I6)+FLOAT(I7)+FLOAT(I8)+FLOAT(I9))/4.
C     CONVERT WATTS/SQ M   TO KCAL/HR/SQ M      (METABOLISM)
      MA=MA/1.163
C
C SECTION 3:SOLUTION OF FOURTH DEGREE POLYNOMIAL IN TCL
```

```
C
C      INITIAL ASSUMPTION FOR CONVECTION COEFFICIENT (HC)
       HC=10.4*SQRT(V)
       ALPHA=MA-0.35*(43.-0.061*MA-PA)-0.42*(MA-50.)-0.0023*MA*(44.-PA)-0
      1.0476*MA
       A=0.612E-8*ICL*FCL
C      INITIAL GUESS OF TCL
       TCL=20.0
       ITN=0
   20  B=0.18*ICL*FCL*HC+1
       C=-0.18*ICL*FCL*(HC*TDB+3.4E-8*(MRT+273.)**4)-35.7+0.032*MA
       F=A*(TCL+273.)**4+B*TCL+C
       FDASH=4.*A*(TCL+273.)**3+B
       TNEW=TCL-F/FDASH
       IF (ABS(TCL-TNEW).LE.0.01)GO TO 50
       ITN=ITN+1
       TCL=TNEW
       IF (ITN.EQ.15)GO TO 50
       X=2.05*(TCL-TDB)**0.25
       Y=10.4*SQRT(V)
       IF (X.GT.Y)GO TO 30
       HC=Y
       GO TO 20
   30  HC=X
       GO TO 20
C
C SECTION 4: CALCULATION OF P.M.V.
       GO TO 50
C MISSING VALUE
   48  PMV=9.999
       IF(PMV.EQ.9.999) MRT =99.99
       IF(MRT.EQ.99.99) MA =999.9
       IF(MA.EQ.999.9) PA =99.99
       GO TO 55
   50  PMV=(0.352*EXP(-0.042*MA)+0.032)*(ALPHA+0.0014*MA*TDB-3.4E-8*FCL*(
      1(TNEW+273.)**4-(MRT+273.)**4)-FCL*HC*(TNEW-TDB))
C
C SECTION 5: OUTPUT OF RESULTS
C                          CONVERTING METABOLISM BACK TO W.SQ.M.
       MA=MA*1.163
   55  WRITE(22,6)I1,I2,I3,I4,A1,A2,A3,I5,A4,A5,A6,A7,A8,I6,I7,I8,I9,A9,A
      110,A11,I10,A12,PIN,PMV,MRT,MA,PA
    6  FORMAT(I4,X,3I2,X,3(F4.1,X),I1,X,3(F4.1,X),2F4.2,X,4I3,X,3(F4.1,X)
      1,I2,X,F4.2,16X,I3,X,F6.3,X,F6.3,X,F5.1,X,F5.2,20X)
  100  CONTINUE
       STOP
       END
```

```
00100 REM   A BASIC version of Fanger's (1970) PMV method of
00110 REM assessing indoor thermal environments.
00120 REM This implementation  requests
00130 REM keyboard input of 4 micro-climatic parameters and
00140 REM 2 behavioural variables. It then solves iteratively
00150 REM for clothing temperature and convective heat transfer
00160 REM coefficient by the Newton-Raphson method. These are
00170 REM input to the final PMV equation. The answer output
00180 REM is a predicted thermal environment assessment on the
00190 REM ASHRAE 7 point sensation scale of a group of adults.
00200 INPUT "P.M.V. : Do you want paper print-out (yes/no)? ";M4$
00230 IF M4$="NO" OR M4$="no" THEN GOTO 250
00240 OUT 1 ON   :   REM   turns printer port on
00250 PRINT : PRINT
00260 PRINT "**************      FANGER'S PMV     ***************"
00270 PRINT
00280 PRINT
00290 INPUT "       ENTER DRY BULB AIR TEMPERATURE (degC)......." ; A1
00300 INPUT "       ENTER WET BULB TEMPERATURE (degC)..........." ; B1
00310 INPUT "       ENTER RELATIVE AIR VELOCITY (m/s)..........." ; V1
00320 INPUT "       ENTER METABOLIC RATE (W/sq.m.)............." ; D1
00330 INPUT "       ENTER CLOTHING INSULATION (intrinsic clo)..." ; E1
00340 INPUT "       MEAN RADIANT TEMP = DRY BULB ? (YES/NO)....."; A2$
00350 GOSUB [A1,B1] 790      :REM   CALCULATE VAPOUR PRESSURE
00360 IF A2$="NO" OR A2$="no" THEN GOSUB 710: REM  CALC MEAN RAD TEMP
00370 F1=0.15*E1+1.  :  D1=D1/1.163  :   H1=10.4*SQR(V1)
00380 G1=D1-0.35*(43.-0.061*D1-P1)
00390 I1=-0.42*(D1-50.)-0.0023*D1*(44.-P1)-0.0476*D1   :  J1=G1+I1
00400 N1=0.612E-8*F1*E1
00410 U1=20. :  M=0 : IF A2$="YES" OR A2$="yes" THEN LET C1=A1
00420 O1=0.18*E1*F1*H1+1.0
00430 Q1=-0.18*E1*F1*(H1*A1+3.4E-8*(C1+273.)**4)-35.7+.032*D1
00440 R1=N1*(U1+273.)**4+O1*U1+Q1  :  T1=4*N1*(U1+273.)**3+O1
00450 Y1=U1-R1/T1   :  IF ABS(U1-Y1) <= 0.01 THEN GOTO 530
00460 M=M+1   :   IF M=15 THEN GOTO 530
00470 LET Y3=SGN(U1-A1)
00480 U1=Y1  : X1=Y3*(2.05*ABS(U1-A1)**0.25) :   W1=10.4*SQR(V1)
00490 IF X1 < W1 THEN GOTO 510
00500 H1=X1   :   GOTO 520
00510 H1=W1
00520 GOTO 420
00530 A3=(0.352*EXP(-0.042*D1)+0.032)
00540 A4=(Y1+273.0)**4-(C1+273.0)**4
00550 A5=A3*(J1+0.0014*D1*A1-3.4E-8*F1*A4-F1*H1*(Y1-A1))
00560 P6=100.0-(95.0*EXP(-0.03353*(A5*A5*A5*A5)-0.2179*(A5*A5)))
00570 PRINT
00580 PRINT "     ***************************************************"
00590 PRINT "                  PREDICTED MEAN VOTE = ",[F6.2 A5]
00600 PRINT "     PREDICTED PERCENT DISSATISFIED  = ",[F6.2 P6]
00610 PRINT "     ***************************************************"
00620 PRINT
00630 PRINT "      -3       -2        -1          0          1          2         3"
00640 PRINT "       ---------------------------------------------------------------"
00650 PRINT "       :        :         :          :          :          :         :"
00660 PRINT  "     COLD     COOL    SLIGHTLY    NEUTRAL   SLIGHTLY     WARM      HOT"
00670 PRINT  "                        COOL                  WARM"
```

```
00680 OUT 1 OFF   :   REM   Turn printer port off
00690 END
00700 REM
00710 REM    Mean Radiant Temperature Subroutine
00720 INPUT "       ENTER GLOBE TEMPERATURE (degC)....." ; A6
00730 INPUT "       ENTER GLOBE THERMOMETER DIAMETER (mm)..... " ; A7
00740 Z3=1./(1.+1.13*V1**.6*(.001*A7)**-.4)
00750 C1=(A6-(A1*(1.-Z3)))/Z3
00760 RETURN
00770 REM
00780 REM Subroutine for Antoine psychrometric equation
00790 VAR (A1,B1)
00800 S1=EXP(18.956-4030.18/(B1+235.))
00810 P1=(S1-0.667*(A1-B1))*0.75
00820 RETURN
```

```
C
C  Fortran IV Program for Standard Effective Temperature and the
C  Pierce Laboratory Two-Node Model (Adapted from Nishi and Gagge,1977)
C  TABULATION OF INITIAL CONDITIONS
C
       INTEGER PIN
       REAL MA,MRT
C   THIS SECTION CONTROLS RAW DATA INPUT AND PROCESSED DATA OUTPUT.
      OPEN (UNIT = 22 , FILE = 'MACTMP.DMI' )
      OPEN (UNIT = 23 , FILE = 'MACTMP.DM2' )
C
C
      DO 2606 J=1,558
C
C
154   READ(22,1795)I1,I2,I3,I4,F1,F2,F3,I5,F4,F5,F6,F8,F9,I6,I7,I8,I9,F1
     10,F11,F12,I10,F13,PIN,PMV,MRT,MA
 1795 FORMAT(I4,X,3I2,X,3(F4.1,X),I1,X,3(F4.1,X),2F4.2,X,4I3,3(F4.1,X),I
     12,X,F4.2,16X,I3,X,F6.3,X,F6.3,X,F5.1)
C    MISSING VALUES PROCEDURE
       IF(F10.EQ.99.9)GO TO 2687
       IF(F11.EQ.99.9)GO TO 2687
       IF(F12.EQ.99.9)F12=F10
       IF(F8.EQ.9.99)F8=0.48
       IF(F13.EQ.9.99)F13=0.31
       IF(MA.EQ.999.9)MA=68.0
       TA=F10
       TWET=F11
       GLOBT=F12
       VEL=F13
       CLO=F8
C  METABOLIC RATE IN WATTS
       ACT=MA
       DIAM=0.001*38.0
C  CALL TO MEAN RADIANT TEMPERATURE FUNCTION
       TR=TMRT(TA,GLOBT,VEL,DIAM)
C  CALL TO SAT VAP PRESS FUNCTION FOR CALCULATION OF PA
       PA=SVP(TWET)-0.5*(TA-TWET)
       RH=PA/SVP(TA)
C  PRESETTING SOME OF THE BASIC HEAT BALANCE CONSTANTS
       TIME=1.0
       TTSK=34.0
       TTCR=36.6
       ALPHA=0.1
C  MECHANICAL EFFICIENCY IS SET TO 0 FOR INDOORS
       WK=0.0
       WE=0.0
       TTBM=ALPHA*TTSK+(1.-ALPHA)*TTCR
       CSW=200.
       CSTR=0.5
       CDIL=150.
C
C
C
C THE INITIAL CONDITIONS ARE NOW ESTABLISHED BY THE FOLLOWING STATEMENTS
C
```

```
   26 CONTINUE
C  ACTIVITY LEVEL( ACT IN MET UNIT),AIR MOVEMENT (VEL IN M/SEC),
C  STEADY STATE CHARACTERISTICS OF MODEL THERMAL NEUTRALITY
C  INITIAL CONDITION - PHYSIOLOGICAL THERMAL NEUTRALITY
C
      TSK=TTSK
      TCR=TTCR
      TBM=ALPHA*TSK+(1.-ALPHA)*TCR
      SKBFN=6.3
      SKBF=SKBFN
       EV=0.1*ACT
C  CLOTHING AND ENVIRONMENTAL HEAT TRANSFER FACTORS AT SEA LEVEL-INITIAL
      CHR=4.7
C  CHCA CORRESPONDS TO TREADMILL WALKING IN STILL AIR
      CHCA=5.66*(ACT/58.2-0.85)**0.39
C  CHCV FOR ROOM AIR MOVEMENT
      CHCV=8.6*(VEL)**0.53
      IF(CHCV-CHCA) 5,5,6
 5    CHC=CHCA
      GO TO 3
    6 CHC=CHCV
    3 CONTINUE
C  CHC VALUE FOR STILL AIR =3.0 AT SEA LEVEL
    7 IF(CHC-3.0)8,9,9
    8 CHC=3.0
    9 CONTINUE
C  FACL IS RATIO OF CLOTHED BODY SURFACE TO NUDE SURFACE
      FACL=1.+0.15*CLO
      CTC=CHC+CHR
      CLOE=CLO-(FACL-1.)/(0.155*FACL*CTC)
      FCLE=1./(1.+0.155*CLOE)
      FPCL=1./(1.+0.143*CHC*CLOE)
C  INITIAL ESTIMATE OF TR AND EFF. RADIANT FIELD (ERF)
      TR=TMRT(TA,GLOBT,VEL,DIAM)
      TO=(CHR*TR+CHC*TA)/CTC
      TIM=0.
C  AT THIS STAGE ALL INITIAL CONDITIONS AND ENVIRONMENTAL HEAT TRANSFER
C  COEFFICIENTS HAVE BEEN FULLY ESTABLISHED FOR THE SELECTED PARAMETERS
C  AT THE START OF THE SIMULATION OF THE BODY
C  IS ASSUMED TO BE RESTING AND IN PHYSIOLOGICAL THERMAL NEUTRALITY.
C
C
C  SIMULATION OF BODY TEMPERATURE REGULATION - START OF REG.LOOP
 100  CONTINUE
      CLOE=CLO-(FACL-1.)/(0.155*FACL*CTC)
       FCLE=1./(1.+0.155*CTC*CLOE)
       TCL=TO+FCLE*(TSK-TO)
       CHR=4.*5.67E-8* (((TCL+TR)/2.+273.2)**3)*0.72
       CTC=CHR+CHC
       TO=(CHC*TA+CHR*TR)/CTC
       ERES=0.0023*ACT *(44.-RH*SVP(TA))
       CRES=0.0014*ACT *(34.-TA)
C  HEAT FLOW EQUATION AT SKIN SURFACE
       DRY=FCLE*CTC*(TSK-TO)
       ESK=EV-ERES
       HFSK=(TCR-TSK)*(5.28+1.163*SKBF)-DRY-ESK
```

```
      HFCR=ACT -(TCR-TSK)*(5.28+1.163*SKBF)-CRES-ERES-WK
C AVERAGE PERSON 70KG,1.8 SQ.METER
      TCSK=0.97*ALPHA*70.
      TCCR=0.97*(1.-ALPHA)*70.
      DTSK=(HFSK*1.8)/TCSK
      DTCR=(HFCR*1.8)/TCCR
      DTIM=1./60.
      DTBM=ALPHA*DTSK+(1.-ALPHA)*DTCR
      TIM=TIM+DTIM
      TSK=TSK+DTSK*DTIM
      TCR=TCR+DTCR*DTIM
C  DEFINITION OF VASCULAR CONTROL SIGNALS
      SKSIG=TSK-TTSK
      IF(SKSIG) 10,10,15
  10  COLDS=-SKSIG
      WARMS=0.
      GO TO 20
  15  COLDS=0.
      WARMS=SKSIG
  20   CRSIG=TCR-TTCR
      IF(CRSIG) 30,30,35
  30  COLDC=-CRSIG
      WARMC=0.
      GO TO 40
  35  WARMC=CRSIG
      COLDC=0.
  40  CONTINUE
C  CONTROL SKIN BLOOD FLOW
      STRIC=CSTR*COLDS
      DILAT=CDIL*WARMC
      SKBF=(SKBFN+DILAT)/(1.+STRIC)
C   RELATIVE WT. OF SKIN SHELL TO CORE CHANGES WITH SKBF
      ALPHA=0.04415+0.351/(SKBF-0.014)
C  DEFINITION OF CONTROL SIGNALS FOR SWEATING
      TBM=ALPHA*TSK+(1.0-ALPHA)*TCR
      BYSIG=TBM-TTBM
      IF(BYSIG) 50,50,55
  50  COLDB=-BYSIG
      WARMB=0.
      GO TO 60
  55  WARMB=BYSIG
      COLDB=0.
  60  CONTINUE
C  CONTROL OF REGULATORY SWEATING
      REGSW=CSW*WARMB*EXP(WARMS/10.7)
      ERSW=0.68*REGSW
      EMAX=2.2*CHC*(SVP(TSK)-RH*SVP(TA))*FPCL
      PRSW=ERSW/EMAX
      PWET=0.06+0.94*PRSW
      EDIF=PWET*EMAX-ERSW
      EV=ERES+ERSW+EDIF
      IF(EMAX-ERSW)70,70,75
  70  EV=ERES+EMAX
      ERSW=EMAX
      EDIF=0.
      PWET=1.
```

```
      PRSW=1.
   75 CONTINUE
      IF(TIM-TIME) 100,110,110
  110 CONTINUE
C  END OF REGULATORY LOOP
C  NOW THE FINAL VALUES OF RM (METABOLIC ENERGY),TSK,TCR,TBM,REGSW
C  (REGULATORY SWEATING IN GM-2H-1),AND SKBF (SKIN BLOOD FLOW IN LITRES
C  M-2H-1) HAVE BEEN DETERMINED AFTER "TIME" HR OF EXPOSURE. IN ADDITION
C  THE FINAL VALUES FOR ERES,EDIF,ERSW,DRY,AND SWDRIP ARE DETERMINED.
C  THE NEXT SECTION EVALUATES STORE,FROM THE BODY HEAT BALANCE EQUATION;
C  STO (STANDARD OPERATIVE TEMPERATURE);THE EFFECTIVE TEMPERATURES SET
C  AND SETBM; AND THE DISCOMFORT SENSATIONS DISC AND DISCB.
C
C  CALCULATION OF HEAT STORAGE
      STORE=ACT-WK-CRES-DRY-EV
C  CALCULATION OF SKIN HEAT LOSS( HSK)
      HSK=ACT-ERES-CRES-WK-STORE
C  CALCULATION OF ASHRAE STANDARD EFFECTIVE TEMPERATURE - SET
C  DEFINITION OF ASHRAE STANDARD ENVIRONMENT
      CHRS=CHR
C  CHCS IS CHCA VALUE AT SEA LEVEL FOR ACT SELECTED
      CHCS=CHCA
      CLOS=.6
      FACLS=1.09
      CTCS=CHRS+CHCS
      CLOES=CLOS-(FACLS-1.)/(0.155*FACLS*CTCS)
      FCLES=1./(1.+0.155*CTCS*CLOES)
      FPCLS=1./(1.+0.143*CHCS*CLOES)
C STANDARD ACTIVITY POINT
      TACTS=TSK-HSK/(CTCS*FCLES)
C AT START OF ITERATION
      SET=TACTS
C DEFINITION OF SET IS SOLUTION OF THE THIS HEAT-BAL. EQ.(ERROR =0)
  200 ERROR=HSK-CTCS*FCLES*(TSK-SET)-PWET*2.2*CHCS*FPCLS*(SVP(TSK)
     X-0.5*SVP(SET))
      IF(ERROR) 210,220,220
  210 SET=SET+0.1
      GO TO 200
  220 CONTINUE
C   MISSING VALUES PROCEDURE
      GO TO 2605
 2687 SET=99.99
 2605 WRITE(23,4002)I1,I2,I3,I4,F1,F2,F3,I5,F4,F5,F6,F8,F9,I6,I7,I8,I9,F
     110,F11,F12,I10,F13,PIN,PMV,MRT,MA,PA,SET
 4002 FORMAT(I4,X,3I2,X,3(F4.1,X),I1,X,3(F4.1,X),2F4.2,X,4I3,3(F4.1,X),I
     12,X,F4.2,16X,I3,X,F6.3,X,F6.3,X,F5.1,X,F5.2,X,F5.2)
 2606 CONTINUE
      STOP
      END
      FUNCTION SVP(TEMP)
      SVP=EXP(18.6686-4030.183/(TEMP+235.0))
      RETURN
      END
      FUNCTION TMRT(TA,GLOBT,VEL,DIAM)
      RRR=1./(1.+1.13*VEL**0.6*DIAM**-0.4)
      CRR=1.-RRR
```

```
      TMRT=(GLOBT-TA*CRR)/RRR
      RETURN
      END
```

```
00100 CLS   :   REM  Clears screen
00110 REM   A BASIC implementation of Standard Effective Temperature.
00120 REM  This version used for calculating tables of the
00130 REM  effect of variations in one of the SET input variables.
00140 REM  It loops through the routine 15 times and to
00150 REM  select the variable to be investigated, edit line 1760
00160 PRINT "Pierce Laboratory S.E.T."
00170 INPUT "Do you want paper printout (yes/no)? ";C5$
00180 REM
00190 REM
00200 INPUT "Enter the DRY-BULB temperature (degC)_____";Z1
00210 INPUT "Enter the WET-BULB temperature (degC)_____";Z2
00220 INPUT "Enter the VELOCITY (m/s)__ _____";Z3
00230 INPUT "Enter GLOBE TEMP.(with 38mm. diam. thermom.)___";Z4
00240 INPUT "Enter METABOLIC RATE (W/Sq.m)_____";Z5
00250 INPUT "Enter clothing ensemble's CLO _____";Z6
00270 IF C5$"YES" OR C5$="yes" THEN OUT 1 ON ELSE OUT 1 OFF
00280 PRINT"*******  PIERCE LAB. STANDARD EFFECTIVE TEMPERATURE *******"
00290 PRINT
00300 PRINT
00310 PRINT
00320 PRINT "     TA   TWET  GLBT  TMRT   VEL   CLO  MET  RH%  WET%  TCORE TSKIN  S.E.T. "
00330 PRINT "    ____ _____ _____ _____ _____ ____ ____ ____ _____ _____ _____"
00340 FOR K=1 TO 15 : REM Tabulate 15 rows of data output
00350 Y1 = 0.1: REM Initially set skin/core ratio of mass at 1 to 9
00360 GOSUB [Z1,Z4,Z3] 1800    :   REM  Call to MRT subroutine
00370 Y3=0. : REM Assume mechanical efficiency of activity = zero
00380 Y5=34.0 : REM assumed set point for skin signal
00390 Y6=36.6 : REM assumed set point for core signal
00400 Y7=0. : REM no external work is accomplished
00410 REM Function for saturated vapour pressure
00420 FN1 =EXP(18.6686-4030.18/( +235.))
00430 X0=(FN1(Z2)-0.5*(Z1-Z2))
00440 X1=X0/FN1(Z1)
00450 X4=X3
00460 X6 =1.0 : REM total exposure duration is one hour
00470 W0=Y1*Y5+(1. - Y1)*Y6
00480 W1=200. : REM sweating's sensitivity to mean body temp signal
00490 W2=0.5 : REM vaso constrictor sensitivity to core temp
00500 W3=150. : REM vaso dilation sensitivity to core temp
00510 REM  :  THE NEXT SECTION ESTIMATES THE STEADY STATE
00520 REM  :  CHARACTERISTICS OF THE MODEL IN PHYSIOLOGICAL
00530 REM  :  NEUTRALITY (the assumed initial condition of body)
00540 W4=Y5 : REM mean skin temperature
00550 W5=Y6 : REM mean core temperature
00560 W6=Y1*W4+(1. - Y1)*W5 : REM mean body temperature
00570 W7=6.3 : REM normal skin blood flow rate
00580 V0=W7: REM actual skin blood flow rate
00590 V1=0.1*Z5 : REM total evaporative loss from skin
00600 V2=4.7  :REM  linear radiant heat transfer coefficient
00610 REM selecting convective heat transfer coefficient
00620 V3=5.66*(Z5/58.2-0.85)**0.39
00630 V4=8.6*(Z3**0.53)
00640 IF V4-V3>0.0 THEN GOTO 670
00650 V5=V3
00660 GOTO 680
```

```
00670 V5=V4
00680 IF V5 < 3.0 THEN LET V5=3.0
00690 V6=2.2 : REM Lewis relationship at sea level
00700 V7=1.0+0.15*Z6 : REM clothing area factor
00710 U0=V5+V2 : REM combined dry heat transfer coefficient
00720 U1=Z6-(V7-1.)/(0.115*V7*U0)
00730 U2=1./(1.+1.155*U0*U1)
00740 U3=1./(1.+0.143*V5*U1)
00750 X6=1.0
00760 S1=0.0 : REM time reached in exposure duration
00770 REM ------------------------------------------------------
00780 REM All initial conditions have been set and the
00790 REM program now attempts to simulate the thermo-
00800 REM -physiological processes by looping through this next
00810 REM section for each minute of the total exposure period
00820 REM in the stated thermal environment.
00830 U1 = Z6 -(V7-1.)/(0.155*V7*U0)
00840 U2 = 1./(1.+0.155*U0*U1)
00850 U4 = U5+U2*(W4-U5)
00860 V2 = 4.0*5.67E-8*(((U4+X4)/2.+273.)**3)*0.725
00870 U0=V2+V5
00880 U5=(V2*X4+V5*Z1)/U0
00890 U6=0.0023*Z5 *(44.-X1*FN1(Z1))
00900 U7=0.0014*Z5 *(34.-Z1)
00910 REM HEAT FLOW EQUATION AT SKIN SURFACE
00920 T0=U2*U0*(W4-U5)
00930 G5=V1-U6
00940 T1=(W5-W4)*(5.28+1.163*V0)-T0-G5
00950 T2=Z5 -(W5-W4)*(5.28+1.16*V0)-U7-U6-Y7
00960 REM AVERAGE MAN 70KG,1.8 SQ.METRE
00970 T3=0.97*Y1*70
00980 T4=0.97*(1.-Y1)*70
00990 T5=(T1*1.8)/T3
01000 T6=(T2*1.8)/T4
01010 T7=5./60.
01020 S0=Y1*T5+(1.-Y1)*T6
01030 S1=S1+T7
01040 W4=W4+T5*T7
01050 W5=W5+T6*T7
01060 REM DEFINITION OF VASCULAR CONTROL SIGNALS
01070 S2=W4-Y5
01080 IF S2>0.0 THEN GOTO 1110
01090 S4=-S2 :S5=0.0
01100 GOTO 1120
01110 S4=0.0 : S5=S2
01120 S3=W5-Y6
01130 IF S3>0.0 THEN 1160
01140 S6=-S3 : S7=0.0
01150 GOTO 1170
01160 S7=S3 : S6=0.0
01170 REM CONTROL SKIN BLOOD FLOW
01180 R0=W2*S4
01190 R1=W3*S7
01200 V0=(W7+R1)/(1.+R0)
01210 REM RATIO OF SKIN-CORE MASSES CHANGES WITH SKBF
01220 REM DEFINING A NEW WEIGHTING COEFF (Y1) FOR AVE BODY TEMPERATURE
```

```
01230 Y1=0.04415+0.351/(V0-0.014)
01240 REM DEFINITION OF CONTROL SIGNALS FOR SWEATING
01250 W6=Y1*W4+(1.-Y1)*W5
01260 R2=W6-W0
01270 IF R2>0.0 THEN GOTO 1300
01280 R3=-R2 : R4=0.0
01290 GOTO 1310
01300 R4=R2 : R3=0.0
01310 REM CONTROL OF REGULATORY SWEATING
01320 R5=W1*R4*EXP(S5/10.7)
01330 R6=0.68*R5
01340 R7=2.2*V5*(FN1(W4)-X1*FN1(Z1))*U3
01350 Q0=R6/R7
01360 Q1=0.06+0.94*Q0
01370 Q3=Q1*R7-R6
01380 V1=U6+R6+Q3
01390 IF R7-R6 > 0.0 THEN GOTO 1450
01400 V1=U6+R7
01410 Q3 = 0.0
01420 Q0=1.
01430 R6=R7
01440 Q1=1.0
01450 REM
01460 IF S1-X6 <0.0 THEN GOTO 830
01470 REM END OF REGULATORY LOOP
01480 REM NEXT SECTION EVALUATES STORE FROM BODY HEAT-BAL. EQ.,
01490 REM STANDARD OPERATIVE TEMP. AND STANDARD EFFECTIVE TEMP.
01510 REM CALCULATION OF HEAT STORAGE
01520 Q5=Z5 -Y7-U7-T0-V1
01530 REM CALCULATION OF SKIN HEAT LOSS( Q6)
01540 Q6=Z5-U6-U7-Y7-Q5
01550 REM CALCULATION OF STANDARD EFFECTIVE TEMPERATURE - SET
01560 REM DEFINITION OF ASHRAE STANDARD ENVIRONMENT
01570 Q7=V2
01590 P1=V3
01600 P2=0.6
01610 P3=1.09
01620 P4=Q7+P1
01630 P5=P2-(P3-1.0)/(0.155*P3*P4)
01640 P6=1.0/(1.0+0.155*P4*P5)
01650 P7=1.0/(1.0+0.143*P1*P5)
01660 REM    STANDARD ACTIVITY POINT
01670 O0=W4-Q6/(P4*P6)
01680 REM    AT START OF ITERATION
01690 O1=O0
01700 REM S.E.T. IS SOLUTION OF HEAT BAL. EQ. WHEN O2=0
01710 O2=Q6-P4*P6*(W4-O1)-Q1*2.2*P1*P7*(FN1(W4)-0.5*FN1(O1))
01720 IF O2<0.0 THEN LET O1=O1+0.1 ELSE GOTO 1740
01730 GOTO 1710
01740 REM   SOLUTION OF SET IS COMPLETE
01750 PRINT "   " ; [F5.1 Z1][F6.1 Z2][F6.1 Z4][F6.1 X3][F6.2 Z3][F6.2
Z6];" ";INT(Z5);[F6.1 X1*100.][F6.1 100*Q1][F6.1 W5][F6.1 W4][F8.2 O1]
01760 Z6=Z6+.05:REM Z1=TA,Z2=TWET,Z3=VEL,Z4=GLBT,Z5=METAB  AND Z6=CLO.
01770 NEXT K : REM write the next row in the matrix of results
01780 OUT 1 OFF : REM turn printer off
01790 END
```

```
01800 VAR (Z1,Z4,Z3) : REM Subroutine to calculate MRT
01810 M5=1./(1.+1.13*Z3**0.6*.038**-0.4)
01820 M6=1.-M5
01830 X3=(Z4-Z1*M6)/M5
01840 RETURN
```

APPENDIX D

The Thermal Questionnaire

TELEPHONE 377-1111
EXTENSION 2060

University of Queensland

ST. LUCIA, QUEENSLAND, AUSTRALIA. 4067

Office Use Only

B. THERMAL QUESTIONNAIRE

TIME.....
DATE.....

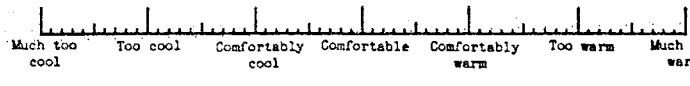
1 2 3 4
6 7 8 9 10 11

The next couple of pages are concerned with how you feel about the air in this room at the moment and the various factors that affect those feelings.

---

1) Are you feeling any warmth or cold discomfort at the moment? Mark this line where it will describe exactly how you feel at present;

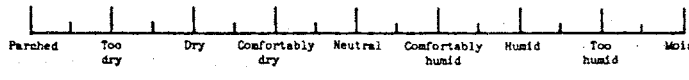
13 14 15 16



---

2) How would you describe the humidity or dryness of the air in this room at present? Mark this line for your answer;

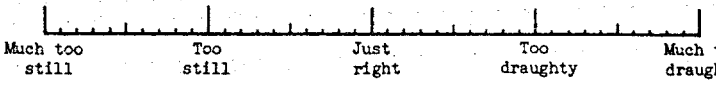
18 19 20 21



---

3) With this room's temperature as it is, how do you feel about the present rate of air movement in here? Mark this line for your answer;

23 24 25 26



---

4) If the air movement rate was not "JUST RIGHT", why is this? Tick one box only;

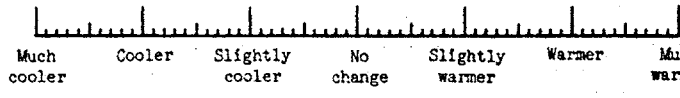
[ ] It is too warm for this still air 1
[ ] It is too cold for this much draught 2
[ ] It is too dry for this much draught 3
[ ] This much air movement creates a nuisance 4
[ ] Stuffiness/odours/lack of fresh air 5
[ ] Don't know
[ ] Another reason, please explain;..... 7

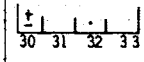
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.....

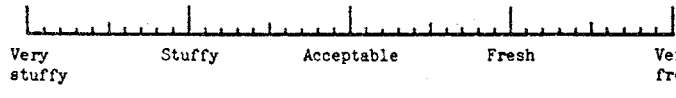
For Office Use Only

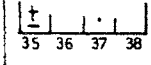
5) Dressed as you are now, would you prefer the temperature of this room to be different from what it is at present? Mark this line for your preferred temperature;



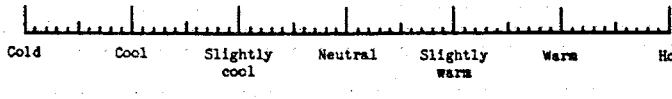


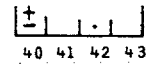
6) How would you rate the STUFFINESS/FRESHNESS in here at the moment? Mark this line for your answer;





7) Show how you feel at this moment by putting a mark somewhere on this line;





Office Use Only

I want you now to look at one of these lists (men, the left hand side and women, the right hand side) and circle those words that best describe the clothes you are wearing at the moment. The reason for asking you to do this is simply that the amount and type of clothing a person wears greatly affects the temperature that they need to be comfortable.

If you come to a clothing item in the list and you are not sure about which word to circle, please ask the interviewer to help you decide.

MEN	WOMEN
Undershirt: singlet, "T" shirt	Slip: full, half
Shirt: light, medium, heavy, short sleeve, long-sleeve, tie or turtleneck, "T" shirt	Dress: light, medium, heavy, long sleeve, short-sleeve, sleeveless, above the knee, knee-length, below the knee.
Vest: light, medium, heavy	Blouse: light, medium, heavy, sleeveless, short-sleeve, long sleeve
Trousers: shorts, light, medium, heavy	Skirt: light, medium, heavy, above the knee, knee-length, below the knee
Jumper: light, medium, heavy, long sleeve, short-sleeve, sleeveless	Slacks: shorts, light, medium, heavy
Jacket: light, medium, heavy	Jacket: light, medium, heavy
Socks: ankle length, knee-high	Jumper: light, medium, heavy, sleeveless, short sleeve, long sleeve
Footwear: sandals, shoes, boots	Stockings: socks, long stockings, pantyhose
OTHER ITEMS: please describe below.	Footwear: sandals, shoes, boots
_____	OTHER ITEMS: please describe below:
_____	_____
_____	_____
_____	_____

METABOLIC AND METEOROLOGIC DATA SHEET *(for office use only)*

(slip it between the pages of the completed thermal questionnaire)

The type and the amount of physical activity that a person performs has an effect on the temperature they require for comfort. If we divide the last half hour into 3 ten minute periods, what activities were you doing in each?

sitting quietly [58], *sitting at desk (reading/writing)* [62], *sitting/typing (electric) word processing* [66], *standing still* [70], *general office duties - on feet - moderately active* [79], *draughting* [70], *driving a car* [87], *strolling* [104], *walking normal pace outdoors* [116]

a) beginning with the last ten (10) minutes?

_____ 54 55 56

_____

_____

b) the ten (10) minute period before the last 10 minutes?

_____ 57 58 59

_____

_____

c) the ten (10) minute period before the last 20 minutes?

_____ 60 61 62

_____

_____

d) Finally, what activities were you doing in the half hour immediately before the last half hour?

_____ 63 64 65

_____ carriage return

Dry bulb temperature (°c one decimal place) 1 2 . 3 4

Wet bulb temperature (°c one decimal place) 6 7 . 8 9

Globe temperature (°c one decimal place) 11 12 . 13 14

Globe diameter (38mm or 15cm) 16 17

Relative air velocity ($m.sec^{-1}$) [i] _____ average

[ii] _____ . .

[iii] _____ 19 20 . 21 22

OTHER OBSERVATIONS:

APPENDIX E

Analysis of Seven-Point Scales of Warmth

E.1 Introduction

Seven-point scales of warmth have been typically presented to respondents as simply a choice of seven adjectives. Therefore, these data possess ordinal qualities and analytical techniques should be selected from the non-parametric group. However, numerous researchers have ignored this restriction and have used the scales as dependent variables in various regression models, with some measure of temperature or warmth index as the independent variable. Humphrey's (1976) authoritative review of such studies identified two main approaches to this modelling problem; 1) simply use each individual vote as a unit of analysis and regress all votes on their respective temperature (or thermal index value), or 2) grouping the data into temperature ranges, for example 1K, averaging both the votes and the temperatures recorded in each temperature range, and then regressing these averages.

Both of the above regression methods have their advantages but both transgress the same data assumptions of the simple linear regression technique. Of these assumptions, the most important would be that of equal-interval data. There is no empirical basis to the assumption that the psychological distance between the sensations of "slightly cool" and "neutral" is the same as that between "warm" and "hot". Indeed, since there are no "very hot" or "extremely hot" options in the seven-point scales, it would seem logical for the end categories to be infinitely wide on the psychological continuum.

In the current surveys these problems of the scales' have been partially mitigated by the choice of a continuous answer format on the thermal questionnaires (see Appendix D). The adjectives of the scales were attached to a line with gradations similar to a ruler's, thereby

going some way towards encouraging respondents to use the scales in an equal-interval manner. Although the end-category problem would still exist, it would not be severe because very few field survey respondents would be expected to use the extreme categories.

E.2 Probit Analysis

Another analytic method that makes no equal-interval assumption about the scales and is unaffected by restricted ranges in the independent variable is probit regression. In fact, the method assumes that the data are only quantal (yes/no). The method has been applied to such scales by Chrenko (1955), Webb (1959), and Ballantyne et al.(1977), but for a complete explanation, the reader is directed to Finney (1971). Finney developed the technique in the context of biological assay where batches of organisms are given various doses of a pharmacological agent and the proportion of the batch that responds (usually meaning dies), is the result of the experiment. Probit analysis attempts to fit a linear model with the observed percentage of batch responding as the ordinate and dose as the abscissa. Finney (1971) observed that the typical pattern of responses in such experiments conformed to a sigmoidal curve. As Chrenko (1955, p.290) pointed out, "...it [probit analysis] is only a convenient trick for representing a sigmoidal curve by a straight line", and it achieves this by transforming the observed percentage response rates on the ordinate into normal expected deviates, or PROBability unITS (probits). That is, the method of probit analysis treats the percentage response rates as areas under the unit normal curve, and then by taking the Z values corresponding to these areas, the ordinate is stretched near the upper and lower extremities while being compressed in the middle. The goodness of fit for a probit model is assessed using the chi square

statistic. Chi square represents the sum of squares of the residuals weighted by the number of observations at each level of dose.

In applying probit analysis to thermal assessment scales, the "dose" is environmental warmth, measured as simple dry bulb temperature or more complex indices such as the standard effective temperature. The temperatures are grouped into discrete classes of a width sufficiently large so that each category will contain a reasonable number of observations. One Kelvin was used as the class width in the current study and this is quite comparable to the 1.1K used by Ballantyne et al. (1977). According to Finney (1971), the dose should be transformed into a metameter by taking its natural logarithm. However, neither Ballantyne et al. (1977) nor Woolard (1980) transformed their temperatures when applying probit analysis to thermal comfort data. In an attempt to decide this issue for the current study, a preliminary test was conducted on the results of the Darwin "build-up" survey using both the "logged" and the "unlogged" dry bulb temperatures as the abscissa. Probits of responses on the ASHRAE, Bedford and PREFV scales were each modelled on both types of dose and the chi square results are presented in Table E.1. In all three test cases, the untransformed dry bulb temperature yielded a better fit although the difference in chi square values was marginal. The difficulties of using and interpreting the transformed dose makes the choice of "unlogged" predictor variables much clearer.

The response variable being modelled was subjective assessment of environmental warmth on the seven-point scales discussed earlier. In reducing these interval/ordinal data back to a quantal level of measurement required for probit analysis, the thermal assessments by respondents were simply dichotomised into groups less than or greater

TABLE E.1 : Goodness of fit (χ^2) using transformed and untransformed temperatures *

Independent variables	Dependent variables		
	ASHRAE	Bedford	PREFV
$Log_e (T_a)$	5.945	5.540	6.424
T_a	4.219	5.014	5.868

* Tests done on ED50 model (d.f.=7)

than the scale value of interest. Since the result of most interest in the analysis of seven-point scales of warmth was neutrality, the assessments were classified into less than or greater than zero. Those assessments that fell directly on zero were divided evenly into each side of the dichotomy.

Providing there were sufficient numbers of assessments recorded away from the middle of the seven-point scale, it was possible to use probit analysis to derive ED50 (Effective Dose for 50% response rate) for other points of the scale. Of particular interest were the temperatures that characterised boundaries between assessment categories. Ballantyne et al. (1977) referred to non-neutral ED50s as "transition temperatures" because they represented that level of environmental warmth that caused the maximum number of people to change their assessment from, for example, "neutral" to "slightly warm" (using the ASHRAE scale). Assuming that the dividing point between successive categories on the psychological continuum is exactly midway, it is theoretically possible to obtain six transition temperatures corresponding to scale values of -2.5, -1.5, -0.5, +0.5, +1.5 and +2.5. In field surveys however, it is highly improbable that -2.5 and +2.5 transition temperature will be capable of being estimated with any precision, because to do so would

require that at some point in the survey, the environmental warmth was so extreme (in either direction) that half of the repondents were casting subjective assessments greater than +2.5 or less than -2.5. Field survey respondents invariably do something to modify their thermal environment before it gets so extreme. Therefore only the -1.5, -0.5, +0.5 and +1.5 transition temperatures were amenable to probit analysis.

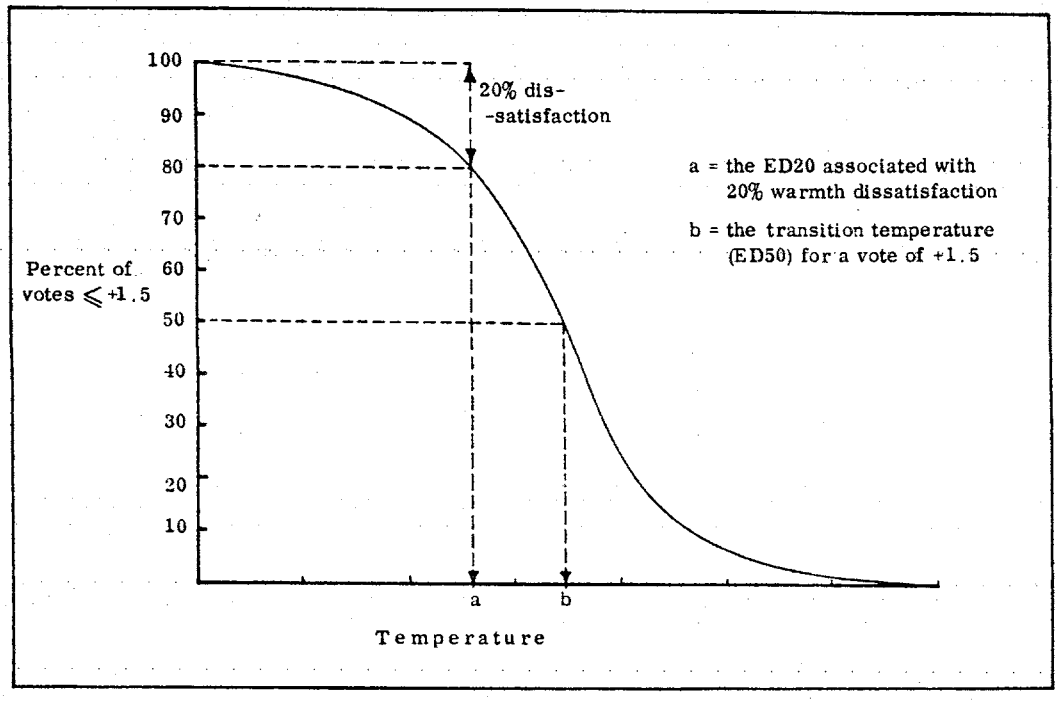


FIGURE E.1 : The hypothetical relationship between ED20 and transition temperature ED50

As well as calculating the ED50 for various points along the scales, probit analysis was also used to dichotomise votes on an 80/20 basis. Assuming that a vote within the central three categories of the seven-point scales is acceptable, the ED20 calculated for a scale value of +1.5 should represent the temperature at which 20% warmth dissatisfaction occurs. Figure E.1 illustrates the concept of ED20 and

its relationship with the transition temperature (ED50) for the same category boundary. It is clear from that diagram that comparisons of different groups' ED20s will be influenced by the relative position of their transition temperatures, and also the gradients of the probit models used to derive those ED50s. Because the ED20 for +1.5 is inevitably closer to the scale midpoint, the precision of its estimation should be superior to that of the transition temperature. Therefore, the ED20s provide better data for drawing between-survey comparisons.

The final type of information that probit analysis was used to derive in the current study related to the degree of concensus prevailing within each sample of respondents concerning their neutrality. This information was provided by the gradient of the neutrality probit model: a very steep model indicating the respondents were close to being unanimous about which temperature constituted neutrality, while a shallow model gradient indicates divergence among respondents. Using the terminology of Humphreys (1975), the reciprocal of neutrality model gradient shall be referred to as its standard deviation.

E.3 Computer Solution of Probit Analysis

The Royal Statistical Society's GLIM 3.10 package (Nelder and Baker, 1978) as implemented on the University of Queensland's Digital PDP1090 computer was used to perform the probit analysis, employing a maximum likelihood algorith in which the residuals were distributed according to binomial probability. The number of observations in each temperature band was used as the numerator for the binomial probability calculations.

The GLIM 3.10 package can read information from secondary input channels and this facility was used for accessing macros (blocks of repeatedly used directives). In the current study, two macros were written which executed a complete probit analysis. With these macros stored in a disk file FOR20.DAT and the input data stored as FOR21.DAT, it was possible to perform the analysis with a simple one-line sentence of directives to GLIM:

```
$UNIT n$INPUT 20$USE PROBIT$USE INT$
```

where n represents the number of rows in the data matrix.

The secondary input channel's file (FOR20.DAT) which actually contained the two macros is listed below:

---------- FOR20.DAT ----------

```
Note :  the text following "!" is commentary, not part of the macros
$DATA TEMP C1 C2 N$ ! DEFINE STRUCTURE OF DATA; C1=N<0;C2=N>0;N=TOTAL
$DINPUT 21$         !INPUT DATA FILE FROM FOR21.DAT
$YVAR C1$           !DEFINE DEPENDENT VARIABLE AS THE NUMBER OF CASES <0
                    !THE NEXT LINE BEGINS THE PROBIT MODEL MACRO
$MACRO PROBIT $ERROR B N$LINK P$LOOK TEMP C1 C2 N$
$FIT TEMP$DISP E V$
$CALC FIT =(%FV/N)*100$CALC D1=(C1/N)*100$PLOT FIT D1 TEMP$
$ENDMAC$
$MACRO INT
$EXTRACT %PE %VC
$CALC %A=%PE(1) $CALC %B=%PE(2)
$CALC %L=50         ! OR CALC %L=80 IN ORDER TO DERIVE ED20
$CALC %C=95
$CALC %D=(%ND(%L/100)-%A)/%B
$CALC %H=%SQR(%VC(1)+2*%D*%VC(2)+%D*%D*%VC(3))/%B
$CALC %H=%ND(0.5+%C/200)*%H
$CALC %F=%D-%H
$CALC %G=%D+%H
$PRINT '  '
$PRINT '  '
$PRINT '  '
$PRINT 'THE TRANSITION TEMPERATURE  = ' %D
$PRINT 'THE LOWER AND UPPER 95% CONFIDENCE LIMITS ARE '  %G  %F
$ENDMAC$
$RETURN$
```

APPENDIX F

The Six Surveys' Attitudinal, Cognitive and Behavioural Questionnaires

TELEPHONE: (07) 377-1111
EXTENSION: 2060



University of Queensland

DEPARTMENT OF GEOGRAPHY
ST. LUCIA, QUEENSLAND, AUSTRALIA. 4067

Dear Sir/Madam,

The University of Queensland is undertaking a survey on the atmospheric conditions in various types of building, and their effects on people. The survey is being conducted in various Australian cities and the results will supplement those gained from similar studies overseas.

You have been selected through a scientific sampling procedure, and we hope you will agree to participate so as to ensure that we get a true cross-section. The information you give will be strictly confidential, and only statistical totals will be used in the study.

Thank you very much for your co-operation.

Yours faithfully,

MELBOURNE AIR-CONDITIONED

MELBAC.DAT

1 2 3 4 5 6

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

1) What do you <u>like most</u> about the <u>building</u> where you work? *(prompt for 2 answers)*

i)_____ 8 9

ii)_____ 10 11

2) What do you <u>dislike most</u> about this <u>building</u>? *(prompt for 2 answers)*

i)_____ 13 14

ii)_____ 15 16

3) Suppose that you were helping an architect design a new office building; of course the design is constrained by a fixed budget, so we have to decide how important each of the factors which go together to make up an office environment, are. How important would the following 9 factors be in your advice to the architect? (mark one box for each factor)

Show card A

	4 OF VERY GREAT IMPORTANCE	3 OF GREAT IMPORTANCE	2 OF SOME IMPORTANCE	1 OF NO IMPORTANCE	
1 Convenience of the building's location.					18
2 Privacy/quietness for the occupants....					19
3 Plenty of space in the building.....					20
4 Ideal temperatures in the work place...					21
5 Having high quality equipment/furniture					22
6 Pleasant aesthetics/decor in the office					23
7 Interesting views from the windows.....					24
8 Adequate and pleasant lighting.....					25
9 Plenty of fresh air in the work place..					26

The next questions are mainly concerned with <u>REFRIGERATED</u> AIR CONDITIONING IN <u>MELBOURNE</u> DURING <u>SUMMER</u>. I must stress that this does <u>not</u> include EVAPORATIVE COOLING.

4) What are the <u>disadvantages</u> in your opinion, of summer air conditioning in the work place? *(prompt for 3 answers)*

P.T.O

Q. 4 continued.

i) _____ 28 29

ii) _____ 30 31

iii) _____ 32 33

5) What are the advantages in your opinion, of summer air conditioning in the work place? *(prompt for 3 answers)*

i) _____ 35 36

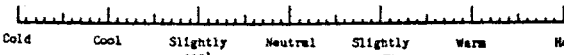
ii) _____ 37 38

iii) _____ 39 40

6) Have you ever worked in an unair conditioned building during a Melbourne summer before? (sedentary occupation)

NO / YES N.A.
(0) (1) (8) 42

7) (If answered YES to question 6) How did you find the summer temperatures in that building? N.A. (8.8) D.K. (7.7)



( ) D.K. 44 45 46

8) If given a choice, which would you prefer in summer;

a) working in an office that had air conditioning? OR ( ) 1
b) working in an office that didn't have air conditioning? (natural ventilation, fans etc.) ( ) 2

COMMENTS: *(transcribe verbatim)* don't know ( ) 7 48

_____ 49

_____

9) Do you believe that working in refrigerated air conditioned buildings is bad for your health, or that there is no connection between health and air conditioning?

7 ( ) don't know
0 ( ) no connection
1 ( ) possibly some causal connection
2 ( ) definite causal connection 51

10) What are some of the symptoms resulting from working in air conditioning during summer? *(prompt for 3 answers)* (N.A.=88, M.V.=99, D.K. =77)

i) _____ 53 54

ii) _____ 55 56

iii) _____ 57 58

11) Do you smoke cigarettes or tobacco at work? (YES / NO) 1 0 60

(if YES, finish section 1 here; if NO, continue to question 12)

12) Is there USUALLY cigarette or tobacco smoke in the air at your workplace? (YES / NO)

0 (if NO, go to question 15)

13) How heavy is this smoke USUALLY? light (1), moderate (2) heavy (3), very heavy (4), N.A. (8) 61

14) How would you rate the OVERALL IRRITATION (if any) resulting from exposure to this smoke in the air at work? *(prompt into one of these 6)* unnoticeable (1), acceptable (2), slightly irritating (3), irritating (4), very objectionable (5), intolerable (6) 62

P.T.O.

15) Do you think that it is necessary to segregate smokers from non-smokers in the workplace,or is it O.K. having them together? 64

categorically "segregated" (2), segregated, but qualified by considerations of density (1), categorically mixed (0), D.K. (7), N.A. (8), M.V. (9)

DO THERMAL QUESTIONNAIRE NOW.

SECTION 3: General Questionnaire *(interviewer administered)*

This section deals with general background issues relating to you and your household. The researchers would like this information simply to find out what sort of people answered the earlier questions in different ways.

1) Would you mind telling me which of these broad age-groups you fall into? *(show list)*

1 20 and under
2 21 - 27
3 28 - 34
4 35 - 41
5 42 - 48 66
6 49 - 55
7 56 - 62
8 63 and over

(do not ask : circle)
male / female
(1) (2) 68

2) How long have you lived in MELBOURNE for? [ ][ ].[ ][ ] years.
70 71 72 73

3) Where did you live BEFORE Melbourne? _____Place_____State

(if N.A. skip to question 5)

4) How long did you live there for? _____years.

5) Do you spend most of your working day in this building or do you usually go outside at least twice a day?

0 ( ) indoors
1 ( ) out about twice per day
2 ( ) out up to 5 times a day 75
7 ( ) D.K.

6) How would you rate your general level of health .... at present?

1 ( ) poor
2 ( ) fair
3 ( ) good 77
4 ( ) excellent
7 ( ) D.K.

7) Which of these 7 options best describes your current home?

1 ( ) Separate house
Flat or home unit
2 ( ) up to 3 storeys high
3 ( ) above 3 storeys high 79
4 ( ) Mobile dwelling one
5 ( ) House/flat attached to shop/office space
6 ( ) Improvised home then
7 ( ) Other (terrace) no <cr>

8) Is the ceiling of your current home INSULATED? *(only if home is separate house)*

5 ( ) whole ceiling
4 ( ) part of ceiling
3 ( ) no insulation 1
7 ( ) D.K.
8 ( ) N.A. (other than separate house)

P.T.O.

9) What are the OUTER WALLS of your current house made of?

5 ( ) solid stone
4 ( ) cavity brick, brick and stone
3 ( ) concrete block, brick veneer
2 ( ) timber, fibro cement (uninsulated)
7 ( ) D.K.

3

10) Do you have REFRIGERATED AIR CONDITIONING at home?
(if no, go to question 11)

NO / YES
(0) (1)

5

(i) What parts of your home are air conditioned?

1 ( ) Bedroom only (*respondent's*)
2 ( ) Living area only
3 ( ) About ½ the dwelling
4 ( ) Full home air conditioning
5 ( ) Other
8 ( ) N.A.
9 ( ) M.V.

6

(ii) In a typical week at this time of year, in what fraction of the time <u>that YOU spend at home</u>, do you have the air conditioner on?

1 ( ) Zero
( ) 1/4
about half (sleep with it on?)
2 ( ) YES
3 ( ) NO
4 ( ) <u>All</u> of the time I am home
8 ( ) N.A.

7

(iii) Did you (or any usual member of your household) buy the air conditioner, or was it there before you moved in?

1 ( ) Bought it
2 ( ) Was there already
8 ( ) N.A.

8

11) Have any of your <u>previous</u> dwellings ever had refrigerated air conditioning?

YES / NO
(1) (0)

10

12) What other COOLING DEVICES do you have at home?

(write in the frequency of each device, e.g. 3 port. fans)

( ) Evaporative cooler 12
( ) portable fans (approx 30cm) 13
( ) pedestal fans 14
( ) overhead fans 15
( ) inlet &/or outlet fans (e.g. Cardiffair) 16
( ) OTHER 1 _____ 17
2 _____ 18
3 _____ 19

SECTION 4. ATTITUDE SCALES Name:

This final section continues with your attitudes to "indoor climates" both in the work place and at home. It is designed so that you can complete it in your own time if you wish, but most people elect to finish it here on the spot, seeing that it requires no more than 5 minutes.

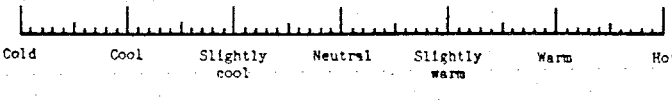
1) When the temperatures of the work place do not suit us, there is usually a variety of ways by which we can restore comfort; Which of the following 10 adjustments do you make in your work place? Tick any of the adjustments that apply during summer;

( ) Adjust thermostats on air conditioning
( ) Open and close windows
( ) Adjust awnings, curtains, blinds (incl. venetians)
( ) Turn on/off personal fans (about 30cm diam)
( ) Turn on/off larger pedestal fans (industrial type)
( ) Turn on/off overhead fans
( ) Adjust air vents of air conditioning (incl. blocking them over)
( ) Complain to whoever is responsible for air conditioning
( ) Move to another part of the building
( ) OTHERS (please specify up to 3 others not already mentioned) _____

_____

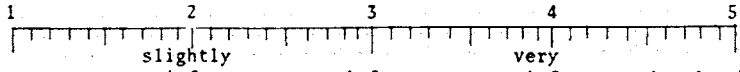
_____

2) What is your OVERALL IMPRESSION of your home's warmth or coolness at the present time of year?



( ) don't know

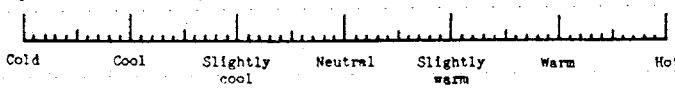
3) How SATISFACTORY are the summer conditions of warmth or coolness at home?



satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

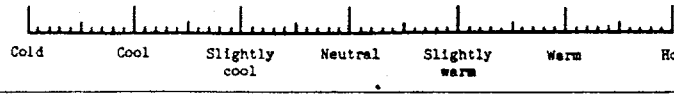
4) Mark the next line for your PREFERRED or IDEAL temperature in the home at the present time of year;



( ) don't know

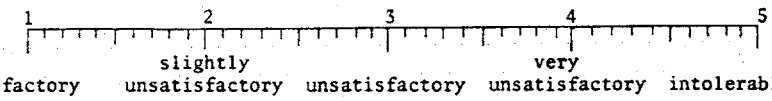
P.T.O.

5) Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this work place at the present time of year. (How would you describe the workplace temperatures to someone at home if they asked you?)



( ) don't know

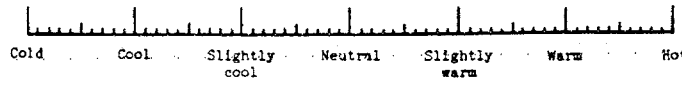
6) How SATISFACTORY are the summer conditions of warmth or coolness in this work place? Mark this line;



satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

7) Mark the next line for your PREFERRED or IDEAL temperature in the work place at this time of year;



( ) don't know

8) The following list of items is designed to further explore your attitudes toward refrigerated air conditioning in the office; all I want you to do is read each item carefully and tick (✓) those statements that you FULLY AGREE WITH.

	YOUR TICKS (✓)
Office air conditioning creates more problems than it solves	
Office air conditioning keeps you feeling fresh	
Air conditioning is absolutely necessary in offices	
Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it	
We would be a lot better off without office air conditioning	
I don't strongly like or dislike office air conditioning	
The disadvantages of office air conditioning greatly outweigh the advantages	
The disadvantages of office air conditioning slightly outweigh the advantages	
Office air conditioning is no longer a luxury but an essential part of modern living	
I'd prefer to work without air conditioning but if it's there I don't complain	
I am neither pro nor con office air conditioning	
The advantages of office air conditioning greatly outweigh the disadvantages	
The advantages of office air conditioning slightly outweigh its disadvantages	
Life before the invention of office air conditioning was primitive	
There are plenty of things about office air conditioning that annoy me	
Occasionally I appreciate the benefits of air conditioning in the office, but most of the time, I would prefer to be without it	
I hate spending more time than is absolutely necessary in air conditioned buildings	
There are a few disagreeable aspects to having air conditioning at work, but I am still in favour of it	

MELBOURNE NON-AIR-CONDITIONED

MELNAC DAT.

1	2	3	4	5	6

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

1) What do you like most about the building where you work? *(prompt for 2 answers)*

i)_____ 8 9

ii)_____ 10 11

2) What do you dislike most about this building? *(prompt for 2 answers)*

i)_____ 13 14

ii)_____ 15 16

3) Suppose that you were helping an architect design a new office building; of course the design is constrained by a fixed budget, so we have to decide how important each of the factors which go together to make up an office environment, are. How important would the following 9 factors be in your advice to the architect? (mark one box for each factor)

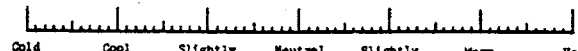
	4 OF VERY GREAT IMPORTANCE	3 OF GREAT IMPORTANCE	2 OF SOME IMPORTANCE	1 OF NO IMPORTANCE	
1 Convenience of the building's location.					18
2 Privacy/quietness for the occupants....					19
3 Plenty of space in the building.....					20
4 Ideal temperatures in the work place...					21
5 Having high quality equipment/furniture					22
6 Pleasant aesthetics/decor in the office					23
7 Interesting views from the windows.....					24
8 Adequate and pleasant lighting.....					25
9 Plenty of fresh air in the work place..					26

4) Have you ever worked in an air conditioned building during a Melbourne summer before? (By air conditioned I mean refrigerated air conditioning which doesn't include evaporative cooling.)

NO / YES N.A.
(0) (1) (8) 28

5) How did you find the summer temperatures in that building?
N.A. = 8.8; D.K. = 7.7

30 31 32



( ) Don't know

6) What are the disadvantages in your opinion, of summer air conditioning in the workplace? *(prompt for 3 answers)*

i) _____ 34 35
ii) _____ 36 37
iii) _____ 38 39

7) What are the advantages in your opinion, of summer air conditioning in the workplace? *(prompt for 3 answers)*

i) _____ 41 42
ii) _____ 43 44
iii) _____ 45 46

8) If given a choice, which would you prefer in summer;

a) working in an office that had air conditioning? OR ( ) 1
b) working in an office that didn't have air conditioning? (natural ventilation, fans etc.) ( ) 2 48

COMMENTS: *(transcribe verbatim)* don't know ( ) 7

_____ 49
_____

9) Do you smoke cigarettes or tobacco at work? (YES / NO)
1 0 51

(if YES, finish section 1 here; if NO, continue to question 10)

10) Is there USUALLY cigarette or tobacco smoke in the air at your workplace?
(NO / YES)
(0)
(if NO, go to question 13)

11) How heavy is this smoke USUALLY? light (1), moderate (2) heavy (3), very heavy (4), N.A. (8) 52

12) How would you rate the OVERALL IRRITATION (if any) resulting from exposure to this smoke in the air at work? *(prompt into one of these 6)* unnoticeable (1), acceptable (2), slightly irritating (3), irritating (4), very objectionable (5), intolerable (6) 53

13) Do you think that it is necessary to segregate smokers from non-smokers in the work place, or is it O.K. having them together?

categorically "segregated" (2); segregated, but qualified by considerations of density (1); categorically mixed (0); D.K. (7); N.A. (8); M.V. (9) 54

DO THERMAL QUESTIONNAIRE NOW

SECTION 3: General Questionnaire *(interviewer administered)*

This section deals with general background issues relating to you and your household. The researchers would like this information simply to find out what sort of people answered the earlier questions in different ways.

1) Would you mind telling me which of these broad age-groups you fall into? *(show list)*

1 20 and under
2 21 - 27
3 28 - 34
4 35 - 41
5 42 - 48
6 49 - 55
7 56 - 62
8 63 and over

56

(do not ask : circle)
male / female
(1) (2)

58

2) How long have you lived in MELBOURNE for? | | | . | | years.
70 71 72 73

3) Where did you live BEFORE Melbourne? _____ Place _____ State

(if N.A. skip to question 5)

4) How long did you live there for? _____ years.

5) Do you spend most of your working day in this building or do you usually go outside at least twice a day?

0 ( ) indoors
1 ( ) out about twice per day
2 ( ) out up to 5 times a day
7 ( ) D.K.

65

6) How would you rate your general level of health ..... at present?

1 ( ) poor
2 ( ) fair
3 ( ) good
4 ( ) excellent
7 ( ) D.K.

67

7) Which of these 7 options best describes your current home?

1 ( ) Separate house
Flat or home unit
2 ( ) up to 3 storeys high
3 ( ) above 3 storeys high
4 ( ) Mobile dwelling
5 ( ) House/flat attached to shop/office
6 ( ) Improvised home
7 ( ) Other (terrace)

69

8) Is the ceiling of your current home INSULATED? *(only if home is separate house)*

5 ( ) whole ceiling
4 ( ) part of ceiling
3 ( ) no insulation
7 ( ) D.K.
8 ( ) N.A. (other than separate house)

71

9) What are the OUTER WALLS of your current house made of?

5 ( ) solid stone
4 ( ) cavity brick, brick and stone
3 ( ) concrete block, brick veneer
2 ( ) timber, fibro cement (uninsulated)
7 ( ) D.K.

73

10) Do you have REFRIGERATED AIR CONDITIONING at home?
(if no, go to question 11) NO / YES (0) (1)

75

(i) What parts of your home are air conditioned?

1 ( ) Bedroom only (*respondent's*)
2 ( ) Living area only
3 ( ) About ½ the dwelling
4 ( ) Full home air conditioning
5 ( ) Other
8 ( ) N.A.
9 ( ) M.V.

76

(ii) In a typical week at this time of year, in what fraction of the time <u>that YOU spend at home</u>, do you have the air conditioner on?

1 ( ) Zero
( ) 1/4
about half (sleep with it on?)
2 ( ) YES
3 ( ) NO
4 ( ) <u>All</u> of the time I am home
8 ( ) <u>N.A.</u>

77

(iii) Did you (or any usual member of your household) buy the air conditioner, or was it there before you moved in?

1 ( ) Bought it
2 ( ) Was there already
8 ( ) N.A.

78

11) Have any of your <u>previous</u> dwellings ever had refrigerated air conditioning?
YES / NO (1) (0)

80
no <cr> then 1 space

12) What other COOLING DEVICES do you have at home?

(write in the frequency of each device, e.g. 3 port. fans)

( ) Evaporative cooler
( ) portable fans (approx 30cm)
( ) pedestal fans
( ) overhead fans
( ) inlet &/or outlet fans (e.g. Cardiffair)
( ) OTHER 1 _____
2 _____
3 _____

2
3
4
5
6
7
8
9

MELNAC.DAT

SECTION 4. ATTITUDE SCALES Name:

This final section continues with your attitudes to "indoor climates" both in the work place and at home. It is designed so that you can complete it in your own time if you wish, but most people elect to finish it here on the spot, seeing that it requires no more than 5 minutes.

1) Do you think you have enough CONTROL over conditions of warmth or coolness in your work place during summer? Tick one box only.

2 ( ) YES
1 ( ) USUALLY
0 ( ) NO
7 ( ) DON'T KNOW

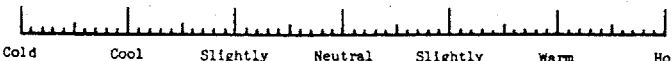
2) When the temperatures of the work place do not suit us, there is usually a variety of ways by which we can restore comfort; Which of the following 10 adjustments do you make in your work place? Tick any of the adjustments that apply during summer;

1 ( ) Adjust thermostats on air conditioning
2 ( ) Open and close windows
3 ( ) Adjust awnings, curtains, blinds (incl. venetians)
4 ( ) Turn on/off personal fans (about 30cm diam)
5 ( ) Turn on/off larger pedestal fans (industrial type)
6 ( ) Turn on/off overhead fans
7 ( ) Adjust air vents of air conditioning (incl. blocking them over)
8 ( ) Complain to whoever is responsible for air conditioning
9 ( ) Move to another part of the building
10 ( ) OTHERS (please specify up to 3 others not already mentioned) _____

_____

_____

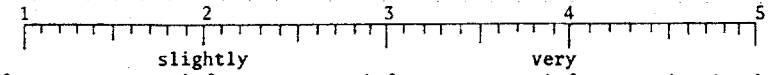
3) Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this work place at the present time of year. (How would you describe the workplace temperatures to someone at home if they asked you?)



( ) don't know

---

4) How SATISFACTORY are the summer conditions of warmth or coolness in this work place? Mark this line;

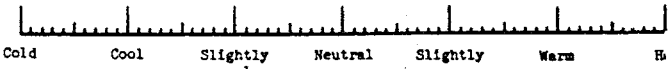


satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

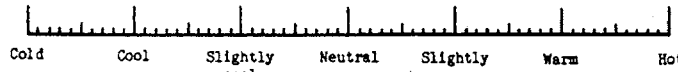
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5) Mark the next line for your PREFERRED or IDEAL temperature in the work place at this time of year;



( ) don't know

6) What is your OVERALL IMPRESSION of your home's warmth or coolness a the present time of year?

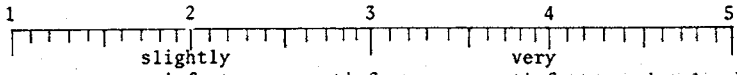


Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot

( ) don't know

---

7) How SATISFACTORY are the summer conditions of warmth or coolness at home?

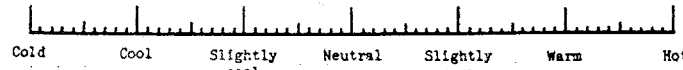


satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

---

8) Mark the next line for your PREFERRED or IDEAL temperature in the home at the present time of year;



Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot

( ) don't know

The following list of items is designed to further explore your attitudes toward refrigerated air conditioning in the office; all I want you to do is read each item carefully and tick (✓) those statements that you FULLY AGREE WITH.

	YOUR TICKS (✓)
Office air conditioning creates more problems than it solves	
Office air conditioning keeps you feeling fresh	
Air conditioning is absolutely necessary in offices	
Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it	
We would be a lot better off without office air conditioning	
I don't strongly like or dislike office air conditioning	
The disadvantages of office air conditioning greatly outweigh the advantages	
The disadvantages of office air conditioning slightly outweigh the advantages	
Office air conditioning is no longer a luxury but an essential part of modern living	
I'd prefer to work without air conditioning but if it's there I don't complain	
I am neither pro nor con office air conditioning	
The advantages of office air conditioning greatly outweigh the disadvantages	
The advantages of office air conditioning slightly outweigh its disadvantages	
Life before the invention of office air conditioning was primitive	
There are plenty of things about office air conditioning that annoy me	
Occasionally I appreciate the benefits of air conditioning in the office, but most of the time, I would prefer to be without it	
I hate spending more time than is absolutely necessary in air conditioned buildings	
There are a few disagreeable aspects to having air conditioning at work, but I am still in favour of it	

BRISBANE AIR-CONDITIONED

BRISAC.DAT

1 2 3 4 5 6

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

1) When architects design office buildings, their final plan represents a compromise between various competing factors. Decisions have to be made about the relative importance of each aspect of an office environment. How important do you feel the following 9 factors are in relation to each other? (Tick one box for each of the factors on the left).

	4 OF VERY GREAT IMPORTANCE	3 OF GREAT IMPORTANCE	2 OF SOME IMPORTANCE	1 OF NO IMPORTANCE	
1 Convenience of the building's location.					8
2 Privacy/quietness for the occupants....					9
3 Plenty of space in the building.....					10
4 Ideal temperatures in the work place...					11
5 Having high quality equipment/furniture					12
6 Pleasant aesthetics/decor in the office					13
7 Interesting views from the windows.....					14
8 Adequate and pleasant lighting.....					15
9 Plenty of fresh air in the work place..					16

The next questions are mainly concerned with REFRIGERATED AIR CONDITIONING IN Brisbane DURING SUMMER. I must stress that this does not include EVAPORATIVE COOLING.

2) What are the disadvantages in your opinion, of summer air conditioning in the work place? *(prompt for 3 answers)*

i)_____ 18 19

ii)_____ 20 21

iii)_____ 22 23

3) What are the advantages in your opinion, of summer air conditioning in the work place? *(prompt for 3 answers)*

i)_____ 25 26

ii)_____ 27 28

iii)_____ 29 30

4) If given a choice, which would you prefer in summer;

a) working in an office that had air conditioning? OR (1)
b) working in an office that didn't have air conditioning? (natural ventilation, fans etc.) (2)

COMMENTS: (*transcribe verbatim*) don't know (7)

32

33

5) Have you ever worked in an unair conditioned building during a Brisbane summer before? (sedentary occupation)

NO / YES N.A.
(0) (1) (8)

35

6) (If answered YES to question 5) How did you find the summer temperatures in that building? N.A. (8.8) D.K. (7.7)

Cold Cool Slightly cool Neutral Slightly warm Warm Hot ( ) Don't know

36 37 38 39

7) Do you believe that working in refrigerated air conditioned buildings is bad for your health, or that there is no connection between health and air conditioning?

7 ( ) don't know
0 ( ) no connection
1 ( ) possibly some causal connection
2 ( ) definite causal connection

41

What are some of the symptoms resulting from working in air conditioning during summer? *(prompt for 3 answers)* (N.A.=88, M.V.=99, D.K. =77)

i) 43 44

ii) 45 46

iii) 47 48

8) Do you think you have enough CONTROL over conditions of warmth or coolness in your work place during summer? Tick one box only.

2 ( ) YES
1 ( ) USUALLY
0 ( ) NO
7 ( ) DON'T KNOW

50

GO TO THERMAL QUESTIONNAIRE

SECTION 3: General Questionnaire *(interviewer administered)* BRISAC.DAT

This section deals with general background issues relating to you and your household. The researchers would like this information simply to find out what sort of people answered the earlier questions in different ways.

1) Would you mind telling me which of these broad age-groups you fall into? *(show list)*

1 20 and under
2 21 - 27
3 28 - 34
4 35 - 41
5 42 - 48
6 49 - 55
7 56 - 62
8 63 and over

52

(do not ask : circle)
male / female
(1) (2)

54

2) How long have you lived in BRISBANE for? | | | . | | years.

56 57 58 59

3) Where did you live BEFORE Brisbane ? _____ Place _____ State

(if N.A. skip to question 5)

4) How long did you live there for? _____ years.

5) Do you spend most of your working day in this building or do you usually go outside at least twice a day?

0 ( ) indoors
1 ( ) out about twice per day
2 ( ) out up to 5 times a day
7 ( ) D.K.

61

6) How would you rate your general level of health ... at present?

1 ( ) poor
2 ( ) fair
3 ( ) good
4 ( ) excellent
7 ( ) D.K.

63

7) Which of these 7 options best describes your current home?

1 ( ) Separate house
Flat or home unit
2 ( ) up to 3 storeys high
3 ( ) above 3 storeys high
4 ( ) Mobile dwelling
5 ( ) House/flat attached to shop/office
6 ( ) Improvised home
7 ( ) Other

65

(i) Is the ceiling of your current home INSULATED? *(only if home is separate house)*

5 ( ) whole ceiling
4 ( ) part of ceiling
3 ( ) no insulation
7 ( ) D.K.
8 ( ) N.A. (other than separate house)

66

(ii) Is your current home HI-SET (1m above ground)?

1( ) Hi-set
2( ) Low-set
3( ) Split-level/multi-level
4( ) Not applicable
5( ) Missing value (missed all Section 3)

67

8) What are the OUTER WALLS of your current house made of?

5 ( ) solid stone
4 ( ) cavity brick, brick and stone
3 ( ) concrete block, brick veneer
2 ( ) timber, fibro cement (uninsulated) 69
7 ( ) D.K.

9) Do you have REFRIGERATED AIR CONDITIONING at home?
(if no, go to question 11)
NO / YES
(0) (1) 71

(i) What parts of your home are air conditioned?

1 ( ) Bedroom only (*respondent's*)
2 ( ) Living area only 72
3 ( ) About ½ the dwelling
4 ( ) Full home air conditioning
5 ( ) Other
8 ( ) N.A.
9 ( ) M.V.

(ii) Did you (or any usual member of your household) buy the air conditioner, or was it there before you moved in?

1 ( ) Bought it 73
2 ( ) Was there already
8 ( ) N.A.

10) Have any of your <u>previous</u> dwellings ever had refrigerated air conditioning?
YES / NO
(1) (0) 75

11) What other COOLING TECHNIQUES do you have at home?

( ) evaporative cooler..... 77
( ) portable fans (approx. 30 cm)..... 78
( ) pedastal fans..... 79
( ) overhead fans..... 80
( ) cardiffair..... 1(81)
( ) verandahs & outdoor living areas..... 2(82)
( ) shady garden..... 3(83)
( ) external awnings..... 4(84)
( ) OTHER 1..... 5(85)
( ) OTHER 2..... 6(86)
( ) OTHER 3..... 7(87)

SECTION 4. ATTITUDE SCALES Name:

This final section continues with your attitudes to "indoor climates" both in the work place and at home. It is designed so that you can complete it in your own time if you wish, but most people elect to finish it here on the spot, seeing that it requires no more than 5 minutes.

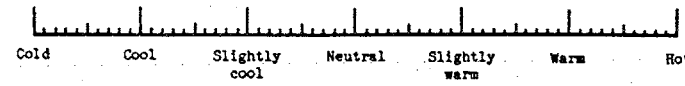
1) When the temperatures of the work place do not suit us, there is usually a variety of ways by which we can restore comfort; Which of the following 10 adjustments do you make in your work place? Tick any of the adjustments that apply during summer;

( ) Adjust thermostats on air conditioning
( ) Open and close windows
( ) Adjust awnings, curtains, blinds (incl. venetians)
( ) Turn on/off personal fans (about 30cm diam)
( ) Turn on/off larger pedestal fans (industrial type)
( ) Turn on/off overhead fans
( ) Adjust air vents of air conditioning (incl. blocking them over)
( ) Complain to whoever is responsible for air conditioning
( ) Move to another part of the building
( ) OTHERS (please specify up to 3 others not already mentioned) _____

_____

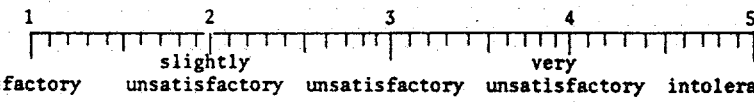
_____

2) What is your OVERALL IMPRESSION of your home's warmth or coolness at the present time of year?



( ) don't know

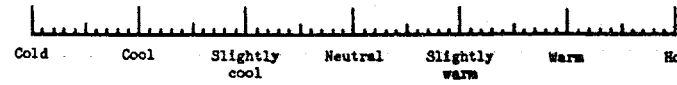
3) How SATISFACTORY are the summer conditions of warmth or coolness at home?



satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

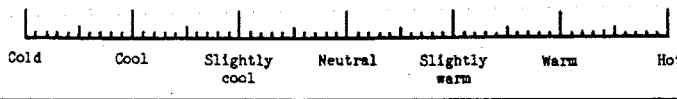
4) Mark the next line for your PREFERRED or IDEAL temperature in the home at the present time of year;



( ) don't know

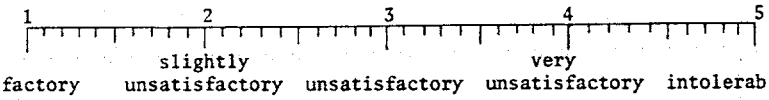
P.T.O.

5) Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this work place at the present time of year. (How would you describe the workplace temperatures to someone at home if they asked you?)



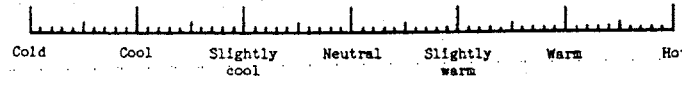
( ) don't know

6) How SATISFACTORY are the summer conditions of warmth or coolness in this work place? Mark this line;



( ) don't know

7) Mark the next line for your PREFERRED or IDEAL temperature in the work place at this time of year;



( ) don't know

8) The following list of items is designed to further explore your attitudes toward refrigerated air conditioning in the office; all I want you to do is read each item carefully and tick (✓) those statements that you FULLY AGREE WITH.

	YOUR TICKS (✓)
Office air conditioning creates more problems than it solves	
Office air conditioning keeps you feeling fresh	
Air conditioning is absolutely necessary in offices	
Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it	
We would be a lot better off without office air conditioning	
I don't strongly like or dislike office air conditioning	
The disadvantages of office air conditioning greatly outweigh the advantages	
The disadvantages of office air conditioning slightly outweigh the advantages	
Office air conditioning is no longer a luxury but an essential part of modern living	
I'd prefer to work without air conditioning but if it's there I don't complain	
I am neither pro nor con office air conditioning	
The advantages of office air conditioning greatly outweigh the disadvantages	
The advantages of office air conditioning slightly outweigh its disadvantages	
Life before the invention of office air conditioning was primitive	
There are plenty of things about office air conditioning that annoy me	
Occasionally I appreciate the benefits of air conditioning in the office, but most of the time, I would prefer to be without it	
I hate spending more time than is absolutely necessary in air conditioned buildings	
There are a few disagreeable aspects to having air conditioning at work, but I am still in favour of it	

BRISBANE NON-AIR-CONDITIONED

BRINAC.DAT

1 2 3 4 5 6

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

1) When architects design office buildings, their final plan represents a compromise between various competing factors. Decisions have to be made about the relative importance of each aspect of an office environment. How important do you feel the following 9 factors are in relation to each other? (Tick one box for each of the factors on the left).

	4 OF VERY GREAT IMPORTANCE	3 OF GREAT IMPORTANCE	2 OF SOME IMPORTANCE	1 OF NO IMPORTANCE	
1 Convenience of the building's location.					8
2 Privacy/quietness for the occupants....					9
3 Plenty of space in the building.....					10
4 Ideal temperatures in the work place...					11
5 Having high quality equipment/furniture					12
6 Pleasant aesthetics/decor in the office					13
7 Interesting views from the windows.....					14
8 Adequate and pleasant lighting.....					15
9 Plenty of fresh air in the work place..					16

The next questions are mainly concerned with REFRIGERATED AIR CONDITIONING IN Brisbane DURING SUMMER. I must stress that this does not include EVAPORATIVE COOLING.

2) If given a choice, which would you prefer in summer;

a) working in an office that had air conditioning? OR (1)
b) working in an office that didn't have air conditioning? (natural ventilation, fans etc.) (2) 18

COMMENTS: (*transcribe verbatim*) don't know (7)

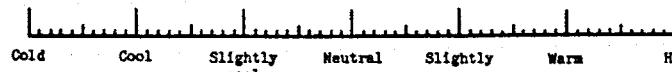
_____

_____ 19

3) Have you ever worked in an air conditioned building during a Brisbane summer before? (sedentary occupation)

NO / YES N.A.
(0) (1) (8) 21

4) (If answered YES to question 3) How did you find the summer temperatures in that building? N.A. (8.8) D.K. (7.7)



( ) Don't know

+/- | | . | | 23242526

5) What are the disadvantages in your opinion, of summer air conditioning in the workplace? *(prompt for 3 answers)*

i) _____ 28 29
ii) _____ 30 31
iii) _____ 32 33

6) What are the advantages in your opinion, of summer air conditioning in the workplace? *(prompt for 3 answers)*

i) _____ 35 36
ii) _____ 37 38
iii) _____ 39 40

7) Do you believe that working in refrigerated air conditioned buildings is bad for your health, or that there is no connection between health and air conditioning?

7 ( ) don't know
0 ( ) no connection 42
1 ( ) possibly some causal connection
2 ( ) definite causal connection

8) What are some of the symptoms resulting from working in air conditioning during summer? *(prompt for 3 answers)* (N.A.=88, M.V.=99, D.K. =77)

i) _____ 44 45
ii) _____ 46 47
iii) _____ 48 49

9) Do you think you have enough CONTROL over conditions of warmth or coolness in your work place during summer? Tick one box only.

2 ( ) YES
1 ( ) USUALLY 51
0 ( ) NO
7 ( ) DON'T KNOW

GO TO THERMAL QUESTIONNAIRE

SECTION 3: General Questionnaire *(interviewer administered)*

This section deals with general background issues relating to you and your household. The researchers would like this information simply to find out what sort of people answered the earlier questions in different ways.

1) Would you mind telling me which of these broad age-groups you fall into? *(show list)*

1 20 and under
2 21 - 27
3 28 - 34
4 35 - 41
5 42 - 48
6 49 - 55
7 56 - 62
8 63 and over

53

(do not ask : circle)
male / female
(1) (2)

55

2) How long have you lived in BRISBANE for? | | | . | | years.
57 58 59 60

3) Where did you live BEFORE Brisbane ? _____Place_____State

(if N.A. skip to question 5)

4) How long did you live there for? _____years.

5) Do you spend most of your working day in this building or do you usually go outside at least twice a day?

0 ( ) indoors
1 ( ) out about twice per day
2 ( ) out up to 5 times a day
7 ( ) D.K.

62

6) How would you rate your general level of health at present?

1 ( ) poor
2 ( ) fair
3 ( ) good
4 ( ) excellent
7 ( ) D.K.

64

7) Which of these 7 options best describes your current home?

1 ( ) Separate house
Flat or home unit
2 ( ) up to 3 storeys high
3 ( ) above 3 storeys high
4 ( ) Mobile dwelling
5 ( ) House/flat attached to shop/office
6 ( ) Improvised home
7 ( ) Other

66

(i) Is the ceiling of your current home INSULATED? *(only if home is separate house)*

5 ( ) whole ceiling
4 ( ) part of ceiling
3 ( ) no insulation
7 ( ) D.K.
8 ( ) N.A. (other than separate house)

67

(ii) Is your current home HI-SET (1m above ground)?

1( ) Hi-set
2( ) Low-set
3( ) Split-level/multi-level
4( ) Not applicable
5( ) Missing value (missed all Section 3)

68

8) What are the OUTER WALLS of your current house made of?

5 ( ) solid stone
4 ( ) cavity brick, brick and stone
3 ( ) concrete block, brick veneer
2 ( ) timber, fibro cement (uninsulated)
7 ( ) D.K.

70

9) Do you have REFRIGERATED AIR CONDITIONING at home?
(if no, go to question 11)

NO / YES
(0) (1)

72

(i) What parts of your home are air conditioned?

1 ( ) Bedroom only (*respondent's*)
2 ( ) Living area only
3 ( ) About ½ the dwelling
4 ( ) Full home air conditioning
5 ( ) Other
8 ( ) N.A.
9 ( ) M.V.

73

(ii) Did you (or any usual member of your household) buy the air conditioner, or was it there before you moved in?

1 ( ) Bought it
2 ( ) Was there already
8 ( ) N.A.

74

10) Have any of your <u>previous</u> dwellings ever had refrigerated air conditioning?

YES / NO
(1) (0)

76

11) What other COOLING TECHNIQUES do you have at home?

( ) evaporative cooler..... 78
( ) portable fans (approx. 30 cm)..... 79
( ) pedastal fans..... 80
( ) overhead fans..... 1(81)
( ) cardiffair..... 2(82)
( ) verandahs & outdoor living areas..... 3(83)
( ) shady garden..... 4(84)
( ) external awnings..... 5(85)
( ) OTHER 1..... 6(86)
( ) OTHER 2..... 7(87)
( ) OTHER 3..... 8(88)

GO TO SECTION 4: ATTITUDES

SECTION 4. ATTITUDE SCALES Name:

This final section continues with your attitudes to "indoor climates" both in the work place and at home. It is designed so that you can complete it in your own time if you wish, but most people elect to finish it here on the spot, seeing that it requires no more than 5 minutes.

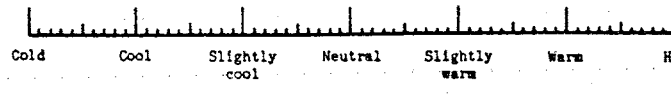
1) When the temperatures of the work place do not suit us, there is usually a variety of ways by which we can restore comfort; Which of the following 10 adjustments do you make in your work place? Tick any of the adjustments that apply during summer;

( ) Adjust thermostats on air conditioning
( ) Open and close windows
( ) Adjust awnings, curtains, blinds (incl. venetians)
( ) Turn on/off personal fans (about 30cm diam)
( ) Turn on/off larger pedestal fans (industrial type)
( ) Turn on/off overhead fans
( ) Adjust air vents of air conditioning (incl. blocking them over)
( ) Complain to whoever is responsible for air conditioning
( ) Move to another part of the building
( ) OTHERS (please specify up to 3 others not already mentioned) _____

_____

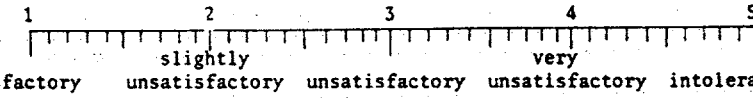
_____

2) What is your OVERALL IMPRESSION of your home's warmth or coolness at the present time of year?



( ) don't know

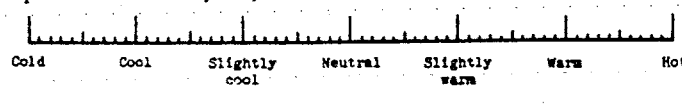
3) How SATISFACTORY are the summer conditions of warmth or coolness at home?



satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

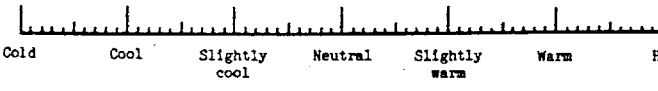
4) Mark the next line for your PREFERRED or IDEAL temperature in the home at the present time of year;



( ) don't know

P.T.O.

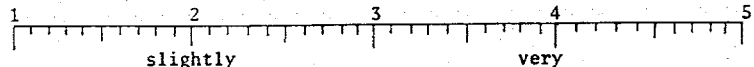
5) Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this work place at the present time of year. (How would you describe the workplace temperatures to someone at home if they asked you?)



( ) don't know

---

6) How SATISFACTORY are the summer conditions of warmth or coolness in this work place? Mark this line;

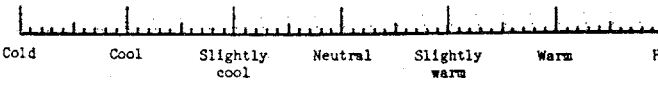


satisfactory | slightly unsatisfactory | unsatisfactory | very unsatisfactory | intolerable

( ) don't know

---

7) Mark the next line for your PREFERRED or IDEAL temperature in the work place at this time of year;



( ) don't know

---

8) The following list of items is designed to further explore your attitudes toward refrigerated air conditioning in the office; all I want you to do is read each item carefully and tick (✓) those statements that you FULLY AGREE WITH.

	YOUR TICKS (✓)
Office air conditioning creates more problems than it solves	
Office air conditioning keeps you feeling fresh	
Air conditioning is absolutely necessary in offices	
Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it	
We would be a lot better off without office air conditioning	
I don't strongly like or dislike office air conditioning	
The disadvantages of office air conditioning greatly outweigh the advantages	
The disadvantages of office air conditioning slightly outweigh the advantages	
Office air conditioning is no longer a luxury but an essential part of modern living	
I'd prefer to work without air conditioning but if it's there I don't complain	
I am neither pro nor con office air conditioning	
The advantages of office air conditioning greatly outweigh the disadvantages	
The advantages of office air conditioning slightly outweigh its disadvantages	
Life before the invention of office air conditioning was primitive	
There are plenty of things about office air conditioning that annoy me	
Occasionally I appreciate the benefits of air conditioning in the office, but most of the time, I would prefer to be without it	
I hate spending more time than is absolutely necessary in air conditioned buildings	
There are a few disagreeable aspects to having air conditioning at work, but I am still in favour of it	

DARWIN "DRY"

DARWIN "DRY"

1	2	3	4	5	6	

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

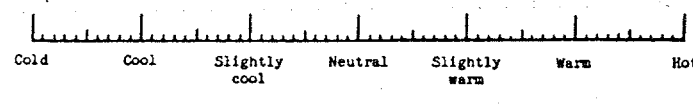
1. What are the disadvantages, in your opinion, of air conditioning in your workplace? *(prompt for three answers)*

2. What are the advantages, in your opinion, of air conditioning in your workplace? *(prompt for three answers)*

3. What are the disadvantages, in your opinion, of air conditioning in the home? *(prompt for three answers)*

4. What are the advantages, in your opinion, of air conditioning in the home? *(prompt for three answers)*

5. Mark this line for your PREFERRED or IDEAL temperarure in a room where you have to spend a lot of time



6. In what ways do you adjust the conditions of warmth or coolness in this building? (Discuss this one with the interviewer)

_____

_____

_____

_____

_____

7. Are you a smoker? (Anyone who regularly smokes as much as one cigarette a day or 10 grammes (1/5 of a pouch) of tobacco per week)

_____

(Yes/No)

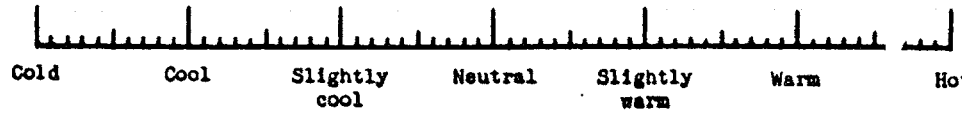
8. Is there cigarette or tobacco smoke in the air at your work-place?

(No/Yes)

9. How would you rate the overall irritation (if any) resulting from this exposure to smoke in the atmosphere at work?

unnoticeable [1], acceptable [2],
slightly irritating [3], irritating [4],
very objectionable [5], intolerable [6].

10. What is your OVERALL IMPRESSION of your home's warmth or coolness at the present time of year?



The next couple of questions are mainly concerned with AIR-CONDITIONING at work and at home. By air-conditioning I mean the refrigeration process which controls the temperature, humidity and circulation speed of the air in a room. This does not include evaporative "air conditioning".

11. Are there any months in the Darwin year in which you would prefer to live in an air-conditioned home rather than an un-air-conditioned one? Circle the months in which you prefer air-conditioning.

JAN	FEB	MAR
APR	MAY	JUN
JUL	AUG	SEP
OCT	NOV	DEC

12. **Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this work place at the present time of year. (How would you describe the workplace temperatures to someone at home if they asked you?)**



Cold **Cool** **Slightly cool** **Neutral** **Slightly warm** **Warm** **Hot**

13. Are ther any months in the Darwin year in which you would prefer to work in an air-conditioned building rather than an un-air--conditioned one? Circle the months in which you prefer air-conditioning.

JAN	FEB	MAR
APR	MAY	JUN
JUL	AUG	SEP
OCT	NOV	DEC

GO TO THERMAL QUESTIONNAIRE NOW

Section 3: General Questionnaire (interviewer administered)
This section deals with general background issues relating to you and your household. The researchers would like this information simply to find out what sort of people answered the earlier questions in different ways.

OFFICE USE ONLY

1. Would you mind telling me which of these age groups you fall into?

   24 and under
   25-34
   35-44
   45-54
   55-64
   65 and over

   (Male/Female)

2. How long have you lived in Darwin?

   _____ years

3. Where did you live before Darwin?

   _____ place
   _____ state
   Not Applicable (skip to Question 5)

4. (If previous question was applicable)
   How long did you live there?

   _____ years

5. How many years have you been working in this present building?

   _____ years

6. Was the building that you worked in before the present one, air conditioned? By "air conditioning" I mean the refrigeration process which controls the temperature, humidity and circulation speed of air inside a building.

   (YES/NO)
   Not applicable

7. Which of these types of structure best describes your dwelling?

   ( ) Separate house?
   Flat or home unit,
   ( ) Up to three storeys high?
   ( ) Above three storeys high?
   ( ) Mobile dwelling?
   ( ) House or flat attached to a shop, office, etc.
   ( ) Improvised home
   ( ) Other

OFFICE USE ONLY

8. Is your dwelling owned (or being purchased) by you or any usual member of your household?

( ) Owner/purchaser
( ) Tenant (renting from housing authority)
( ) Tenant (renting privately)
( ) OTHER

9. Which of the following materials are the outer-walls of your present dwelling made of?

( ) Brick, brick veneer
( ) Concrete, concrete block
( ) Stone
( ) Timber, weatherboard
( ) Fibro, Asbestos
( ) OTHER

10. Is your present dwelling air conditioned?

(Yes/No)

(i) What type of air conditioner have you got at home?

( ) R.A.C. (window mounted)
( ) Split system
( ) Ducted and zoned system
( ) Fully ducted system
( ) OTHER (please specify)

_____

(ii) Estimate the fraction of your dwelling's total floor area which is air conditioned. (Do not include garages and outdoor living areas).

( ) ¼ or less
( ) ½
( ) 3/4
( ) Full dwelling

(iii) Did you (or any usual member of the household) buy the air conditioner or was it there before you moved in?

( ) Bought it
( ) Was there already

11. Have any of your <u>previous</u> dwellings in Darwin ever had air conditioning?

(Yes/No)
Not applicable

12. What are the <u>design features or modifications</u> to your present dwelling that make it comfortable in Darwin's climate?

_____

_____

_____

Section 4 Attitude Scales

The following list of items is designed to explore some of your feelings and opinions about office air conditioning in Darwin at the present time of year. The list is not a test of your knowledge and there are no right and wrong answers. Please read each item carefully and circle the number opposite each item that you fully AGREE with. Thank you.

Office air conditioning creates more problems than it solves.....-1.46

Office air conditioning keeps you feeling fresh..... 1.59

Air conditioning is absolutely necessary in offices..... 3.1

Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it..... .9

We would be a lot better off without office air conditioning.....-1.85

I don't strongly like or dislike office air conditioning..... .01

The advantages of office air conditioning slightly outweigh its disadvantages..... .48

There are plenty of things about office air conditioning that annoy me.....-1.17

You can't maintain a reasonable standard of living without the widespread use of air conditioning..... 1.93

The disadvantages of office air conditioning slightly outweigh the advantages.....-0.45

The advantages of office air conditioning greatly outweigh the disadvantages..... 2.06

Life before the invention of office air conditioning was primitive..... 2.44

Air conditioning is a loathesome invention of engineers who use it in all sorts of buildings without consulting us, the occupants who have to live with it.....-2.51

The disadvantages of office air conditioning greatly outweigh its advantages.....-1.98

Office air conditioning is no longer a luxury but an essential part of modern living..... 2.54

I'd prefer to work without air conditioning but if it's there,I don't complain.....-0.29

I am neither pro nor con office air conditioning..... 0

Office Use Only

$\Sigma/n=$ ± | | . | | |

76 77 78 79 80

NO carriage return

This next list of items is concerned with your opinions about air conditioning in the home in Darwin. This ranges from simple window mounted units through to full home air conditioning.
The method of showing which statements you AGREE with remains the same; simply circle their numbers at the right of the page.

Home air conditioning is no longer a luxury but an essential part of modern living..... 2.54

The disadvantages of air conditioning greatly outweigh the advantages.....-1.98

I'd prefer to live without air conditioning but if it was there, I wouldn't complain.....-0.29

I am neither pro nor con air conditioning in the home..... 0

There are a few disagreeable aspects to having air conditioning at home, but I am still in favour of it..... 0.58

I'd rather spend time in houses with plenty of open windows and perhaps ceiling fans instead of full air conditioning.....-1.49

Air conditioning is absolutely necessary in Darwin homes..... 3.1

I'm looking forward to the day when they can put big bubbles over cities and then air condition the whole atmosphere..... 3.38

I wouldn't have air conditioning in the home even if you paid me.....-2.82

We would be a lot better off without air conditioning in our houses.....-1.85

I don't strongly like or dislike air conditioning in houses.....-0.01

The advantages of air conditioning in the home slightly outweigh its disadvantages..... 0.48

There are plenty of things about home air conditioning that annoy me.....-1.17

Occasionally I would appreciate the benefits of an air conditioner in the home, but most of the time, I would prefer to be without it.....-0.45

The advantages of air conditioning greatly outweigh the disadvantages..... 2.06

Life before the invention of air conditioning was primitive..... 2.44

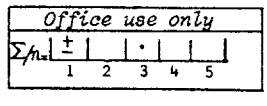
An air conditioner in the home keeps you feeling fresh..... 1.59

I hate spending more time than is absolutely necessary in air conditioned houses.....-2.21

You can't maintain a reasonable standard of living without the widespread use of air conditioning in houses..... 1.93

Home air conditioning may not be perfect but it satisfies most of the people most of the time they are in it..... 0.9

An air conditioner in the home creates more problems than it solves.....-1.46



DARWIN "BUILD_UP"

DARWIN BUILD-UP

1	2	3	4	5	6

University of Queensland

This questionnaire is divided into 4 sections, the first of which consists of some simple questions about your thoughts on various aspects of office buildings. However, before we get started, I wonder if you would mind telling me your name so that we can keep track of who we interview during our survey? (We call back on everyone twice in the next 2-3 weeks.) You can rest assured though, that all names will be omitted from the final report.

NAME:.....

BUILDING:.....EMPLOYER/DEPT.....

RESPONDENT'S LOCATION.....

INTERVIEWER'S INITIALS.....

OTHER COMMENTS.....

.....

SECTION 1 *(interviewer administered)*

(Define Air-conditioning now)

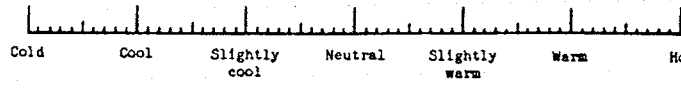
1. What are the disadvantages ,in your opinion,of air conditioning in your workplace? *(prompt for three answers)*

2. What are the advantages, in your opinion, of air conditioning in your workplace? *(prompt for three answers)*

3. What are the disadvantages, in your opinion, of air conditioning in the home? *(prompt for three answers)*

4. What are the advantages, in your opinion, of air conditioning in the home? *(prompt for three answers)*

5. Mark this line for your PREFERRED or IDEAL temperarure in a room where you have to spend a lot of time



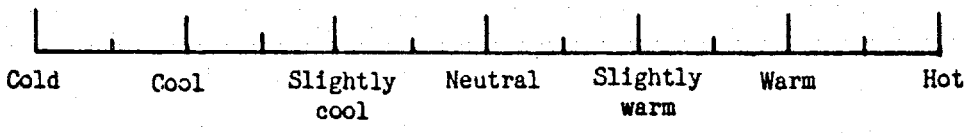
6. If you had to choose between...
   a) working in an office that had air conditioning on all-year-round, OR ( )
   b) working in an office that had no air conditioning at all, ( )

   which would you prefer? (Tick one box only)

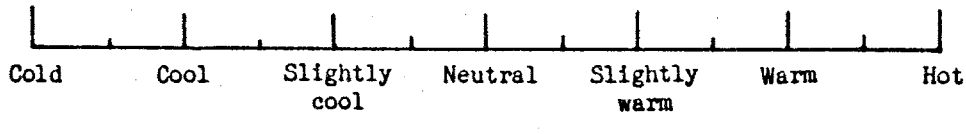
7. Supposing that it was possible to design office buildings in between the two extremes outlined above, circle the months (if any) in which you would prefer having air conditioning at work.

   JAN FEB MAR
   APR MAY JUN
   JUL AUG SEP
   OCT NOV DEC

8. Place a mark on this line where it will describe your OVERALL IMPRESSION of the warmth or coolness of this building at the present time of year.



9. What is your OVERALL IMPRESSION of your home's warmth or coolness at the present time of year? Mark this line for your answer.



10. When the atmosphere and/or temperature of a room does not suit us, there is usually a variety of ways by which we can restore comfort; which of the following adjustments do you make in this room? Circle either YES or NO next to each adjustment.

    1 Adjust thermostats on air conditioning.....YES/NO
    2 Turn on small heating appliances (such as radiators)...YES/NO
    3 Open and close windows.....YES/NO
    4 Adjust awnings,curtains and blinds (incl. venetians)...YES/NO
    5 Turn on (small) fans.....YES/NO
    6 Adjust air vents of air conditioning (incl. blocking them over).....YES/NO
    7 Complain to whoever is responsible for the air conditioning.....YES/NO
    8 OTHER (PLEASE SPECIFY)
    .....
    .....
    .....

11. Do you find that you have enough CONTROL over conditions of warmth or coolness in your workplace? Circle your answer... YES/NO

12. Are you a SMOKER? (anyone who regularly smokes as much as one cigarette a day or 10 grammes of tobacco ($\frac{1}{5}$ of a pouch) per week).
(YES/NO)

13. (*for non smokers and ex smokers only*)
Is there USUALLY cigarette or tobacco smoke in the air at your workplace? (YES/NO)

-How heavy is this smoke usually? light [1], moderate [2], heavy [3], very heavy [4]
-How would you rate the IRRITATION (if any) resulting from this exposure to smoke in the atmosphere at work? *(prompt into one of these 6)*
unnoticeable [1], acceptable [2], slightly irritating [3], irritating [4], very objectionable [5], intolerable [6].

14. Do you think it is necessary to segregate smokers from non-smokers in the workplace, or is it O.K. having them together?

Segregated	[1]
Mixed	[0]

GO TO THERMAL QUESTIONNAIRE NOW

Section 3

General Questionnaire *(Interviewer administered)*

This section deals with general background issues relating to you and your household. The researchers need to know these details simply to enable them to find out what sort of people responded to the earlier questions in different ways.

1. Would you mind telling me which of these broad age-groups you fall into?
(show the list)

1	20 and under
2	21 - 27
3	28 - 34
4	35 - 41
5	42 - 48
6	49 - 55
7	56 - 62
8	63 and over

(do not ask : circle)
male/female
1 2

2. How long have you lived in Darwin for? |__|__|.|__| years.
78 79 80 1

3. Where did you live BEFORE Darwin? _____ Place _____ State

4. How long did you live there for? _____ years.

5. Have you ever worked in an unairconditioned building in Darwin before?
(in sedentary type occupation)

YES/NO N.A.
(1) (0) (8)

6. Which of these 7 options best describes your current home? *(show the list)*

1 ( ) Separate house
Flat or home unit,
2 ( ) Up to three storeys high
3 ( ) Above three storeys high
4 ( ) Mobile dwelling
5 ( ) House or flat attached to a shop, office
6 ( ) Improvised home
7 ( ) Other

7. Is your dwelling owned (or being purchased) by you or any usual member of your household?

1 ( ) Owner/purchaser
2 ( ) Tenant (renting from housing authority)
3 ( ) Tenant (renting privately)
4 ( ) Other

8. Is your current home HI-SET (above the ground 1m)

1 ( ) Hi-set
2 ( ) Low-set
3 ( ) Split-level
4 ( ) Other

9. Do you have air conditioning at home? YES/NO *(if no, go to* →

(i) What parts of your home are air conditioned?

1 ( ) Bedroom only *(respondent's)*
2 ( ) Living area only
3 ( ) About ½ the dwelling
4 ( ) Full home air conditioning
5 ( ) Other
8 ( ) N.A.
9 ( ) M.V.

(ii) In a typical week at this time of year, in what fraction of the time <u>that YOU spend at home</u>, do you have the air conditioner on?

1 ( ) ¼
about half (sleep with it on?)
2 ( ) YES
3 ( ) NO
4 ( ) <u>All</u> of the time I am home
8 ( ) N.A.

(iii) Did you (or any usual member of your household) buy the air conditioner, or was it there before you moved in?

1 ( ) Bought it
2 ( ) Was there already
8 ( ) N.A.

10. Have any of your <u>previous</u> dwellings ever had air conditioning?

YES/NO
1 2

11. What are the OUTER WALLS of your current home made of? *(show the list)*

1 ( ) brick/brick veneer
2 ( ) concrete/concrete block
3 ( ) timber/weatherboard
4 ( ) fibro/asbestos
5 ( ) metal cladding
7 ( ) OTHER/DON'T KNOW

12. In the last 5 working days, how many LUNCH BREAKS have you spent in air conditioned spaces? ( )

Section 4 Attitude Scales

The following list of items is designed to explore some of your feelings and opinions about office air conditioning in Darwin at the present time of year. The list is not a test of your knowledge and there are no right and wrong answers. Please read each item carefully and circle the number opposite each item that you fully AGREE with. Thank you.

Office air conditioning creates more problems than it solves.....-1.46

Office air conditioning keeps you feeling fresh..... 1.59

Air conditioning is absolutely necessary in offices..... 3.1

Office air conditioning may not be perfect but it satisfies most of the people most of the time they are in it..... .9

We would be a lot better off without office air conditioning.....-1.85

I don't strongly like or dislike office air conditioning..... .01

The advantages of office air conditioning slightly outweigh its disadvantages..... .48

There are plenty of things about office air conditioning that annoy me.....-1.17

You can't maintain a reasonable standard of living without the widespread use of air conditioning..... 1.93

The disadvantages of office air conditioning slightly outweigh the advantages.....-0.45

The advantages of office air conditioning greatly outweigh the disadvantages..... 2.06

Life before the invention of office air conditioning was primitive..... 2.44

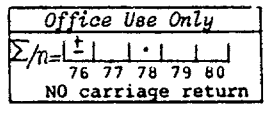
Air conditioning is a loathesome invention of engineers who use it in all sorts of buildings without consulting us, the occupants who have to live with it.....-2.51

The disadvantages of office air conditioning greatly outweigh its advantages.....-1.98

Office air conditioning is no longer a luxury but an essential part of modern living..... 2.54

I'd prefer to work without air conditioning but if it's there,I don't complain.....-0.29

I am neither pro nor con office air conditioning..... 0



This next list of items is concerned with your opinions about air conditioning in the home in Darwin. This ranges from simple window mounted units through to full home air conditioning.
The method of showing which statements you AGREE with remains the same; simply circle their numbers at the right of the page.

Home air conditioning is no longer a luxury but an essential part of modern living..... 2.54

The disadvantages of air conditioning greatly outweigh the advantages.....-1.98

I'd prefer to live without air conditioning but if it was there, I wouldn't complain.....-0.29

I am neither pro nor con air conditioning in the home..... 0

There are a few disagreeable aspects to having air conditioning at home, but I am still in favour of it..... 0.58

I'd rather spend time in houses with plenty of open windows and perhaps ceiling fans instead of full air conditioning.....-1.49

Air conditioning is absolutely necessary in Darwin homes..... 3.1

I'm looking forward to the day when they can put big bubbles over cities and then air condition the whole atmosphere..... 3.38

I wouldn't have air conditioning in the home even if you paid me.....-2.82

We would be a lot better off without air conditioning in our houses.....-1.85

I don't strongly like or dislike air conditioning in houses.....-0.01

The advantages of air conditioning in the home slightly outweigh its disadvantages..... 0.48

There are plenty of things about home air conditioning that annoy me.....-1.17

Occasionally I would appreciate the benefits of an air conditioner in the home, but most of the time, I would prefer to be without it.....-0.45

The advantages of air conditioning greatly outweigh the disadvantages..... 2.06

Life before the invention of air conditioning was primitive..... 2.44

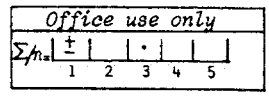
An air conditioner in the home keeps you feeling fresh..... 1.59

I hate spending more time than is absolutely necessary in air conditioned houses.....-2.21

You can't maintain a reasonable standard of living without the widespread use of air conditioning in houses..... 1.93

Home air conditioning may not be perfect but it satisfies most of the people most of the time they are in it..... 0.9

An air conditioner in the home creates more problems than it solves.....-1.46



APPENDIX G

Thurstone and Successive-Interval Attitude Scales

Having decided on an interval level of attitude measurement, the techniques outlined by Thurstone and enhanced by Guilford (Guildford, 1954; Edwards, 1957; Green, 1974) were applied to the development of a scale of affect towards air conditioning.

While the method to be outlined in this appendix is applied to attitude statements, it is part of a more generalised phsychometric tool. At its core is the recognition that the same stimulus will not always elicit the same response on different occasions or from different people. Furthermore, this variability of response, called a discriminal dispersion by Thurstone, is often normally distributed around what might be called the modal or "true" response. While there are ample studies supporting the assumption of normality (Guilford, 1954), it is one of the criticised elements in Thurstone's psychometric hypothesis. Nevertheless, the scaling data used in the current research conformed reasonably well to the assumption.

Essentially, the Thurstone method of scaling involves using a panel of judges to place each of a battery of attitude items into one of a limited number (usually eleven) categories on a continuum of stimulus intensity. That is, the judges are asked to evaluate the intensity of attitude expressed in each of the attitude statements. The eleven-point continuum has a scale value of six as the neutral mid-point. Judges assign those attitude statements that they consider to be neither favourable nor unfavourable towards air conditioning, into the sixth category. Category one is for the most extremely unfavourable attitude statements, while category eleven is for the extremely favourable. All the other categories are left undefined. At no stage in the process do the feelings or attitudes of the judges on the matter of air conditioning

enter their assessments.

The next stage in Thurstone's scaling technique is to examine the responses of the judges to each attitude statement. The median and interquartile range of each statement's discriminal dispersion are calculated from cumulative frequency ogives, and these two statistics serve as the criteria for construction of the final attitude scale. The final scale should be comprised of the 20 to 25 (Helmstadter, 1964; Shaw and Wright, 1967) items whose median or mean judgements on their discriminal dispersions give good coverage of all sections of the eleven-point continuum. It is these medians or means that become the scale values for the items. Secondly, the final 20 to 25 items selected for the scale should each have small interquartile ranges for their discriminal dispersions. That is, only those items that the total group of judges perceived to have a fairly unequivocal position on the continuum should be in the final attitude scale.

Described above is the basic Thurstone scaling technique. The final instrument is presented to the survey respondents (not judges) with the instructions that they are to indicate which of the 20 or so items best reflect their own attitude on the topic. If they have a consistent attitude on the matter and the instrument is reliable, valid and unidimensional, the respondents should be able to select only a couple of attitude items and their scale values should all fall in one region of the attitude continuum. The respondent's score on the instrument is simply the arithmetic mean of the scale values of the items they selected.

Remmers (1954) claimed that the scale resulting from the above process should possess equal interval properties if the judges were instructed to sort the battery of attitude items into the eleven categories of the continuum in such a way that the psychological distances between categories are equal. It is doubtful whether judges are truly capable of such fine discrimination with so many attitude items, so more sophisticated approaches to the problem of equal psychological intervals have been developed. The most commonly used technique is called the method of successive intervals (or categories) and is most thorougly explained in Guilford (1954), Edwards (1974) and Torgerson (1958).

The current attitude scale on air conditioning began with 49 attitude statements (Table G.1). A total of 66 second-year Geography students at the University of Queensland during May 1982 were asked to judge the attitude intensities of the 49 attitude statements using an eleven-category scale. No assumption was made concerning the psychological equality of the category intervals. The frequency with which each attitude item was placed in each category was calculated. These frequencies were then transformed into cumulative proportions as shown in Table G.2 along with their interquartile ranges. The critical assumption underlying the method of successive intervals is that the distributions of judgements on each of the 49 attitude items are all normal on the psychological continuum. Any skewing in the response distributions simply indicates the psychological inequality of the eleven response category intervals.

TABLE G.1: The original 49 item attitude statement pool

1. Air conditioning creates more problems than it solves
2. Air conditioning can't satisfy all of the people all of the time
3. I have no strong preference for air-conditioned or un-air-conditioned buildings but if I am forced to express an opinion, I would go for air conditioned ones
4. Air conditioning keeps you feeling fresh
5. I hate spending more time than is absolutely necessary in air-conditioned spaces
6. Air conditioning may not be perfect but it is the closest we have come to making summers comfortable
7. I'd rather spend time in buildings with plenty of open windows and perhaps ceiling fans instead of full air conditioning
8. Air conditioning is absolutely necessary in buildings
9. I have no strong preference for air-conditioned or un-air-conditioned buildings but if I am forced to express an opinion, I'd go for the un-air conditioned ones
10. Air conditioning may not be perfect but it satisfies most of the people most of the time they are in it
11. Air conditioning is a necessary evil
12. I'm looking forward to the day when they can put big bubbles over cities and then air condition the whole atmosphere
13. I wouldn't have air conditioning in the home even if you paid me
14. Air conditioning is a basic requirement for civilized life
15. We would be a lot better off without air conditioning
16. I don't strongly like or dislike air conditioning
17. The advantages of air conditioning slightly outweigh its disadvantages
18. There are plenty of things about air conditioning that annoy me
19. There is no need to air condition buildings
20. You can't maintain a reasonable standard of living without the widespread use of air conditioning
21. The disadvantages of air conditioning slightly outweigh the advantages
22. Occasionally I appreciate the benefits of air conditioning but most of the time I would prefer to be without it
23. The advantages of air conditioning greatly outweigh the disadvantages
24. Life before the invention of air conditioning was primitive

cont.

TABLE G.1 : cont.

25. Air conditioning is a loathesome invention of engineers who use it in all sorts of buildings without consulting us, the occupants who have to live with it

26. The disadvantages of air conditioning greatly outweigh its advantages

27. It is great to be able to get away from the heat into air-conditioned buildings

28. Air conditioning in a hot place lets people get on with leading a normal life

29. Air conditioning is no longer a luxury but an essential part of modern living

30. The disadvantages of air conditioning greatly outweigh the advantages

31. I'd prefer to live without air conditioning but if it's there, I don't complain

32. I am neither pro nor con air conditioning

33. There are a few disagreeable aspects to air conditioning but I am still in favour of it

34. People who complain about air conditioning are the types who are never satisfied

35. Air conditioning causes disharmony between indoors and outdoors

36. Air conditioning doesn't really harm anyone

37. Air conditioning improves the morale and the general efficiency of employees

38. I hate having to breathe the "canned air" provided by air conditioning

39. Air conditioning in the workplace reduces absenteeism amongst the staff

40. I think I am drowsier in un air-conditioned rooms

41. Air conditioning makes the air too dry

42. Air conditioning keeps interiors cleaner than would normally be the case

43. air-conditioned rooms seem to have an unpleasant odor

44. air-conditioned buildings seem like draughty places

45. Air conditioning technology is continually improving

46. I find the constant temperature in air-conditioned rooms boring

47. Air conditioning creates too big a difference between indoor and outdoor temperatures

48. Air conditioning increases risks of catching colds

49. Air conditioning hampers a person's acclimatisation

TABLE G.2 : Cumulative proportions for judgements of 49 attitude statements in 11 successive categories (Pij)

Attitude Statement	Successive Intervals (j)											Inter-quartl. range
(i)	1	2	3	4	5	6	7	8	9	10	11	
1	.045	.288	.636	.848	.924	.985	.985	1.00				1.65
2	.015	.045	.152	.333	.439	.742	.896	.955	1.00			2.55
3		.015	.015	.03	.076	.136	.848	.970	.985	1.00		0.70
4				.03	.045	.076	.167	.424	.742	.924	1.00	1.75
5	.136	.379	.652	.833	.924	.970	1.00					2.05
6				.015	.015	.061	.136	.50	.864	1.00		1.35
7	.106	.379	.621	.864	.97	.985	.985	.985	.985	1.00		1.95
8	.015	.015	.061	.076	.091	.106	.121	.182	.273	.470	1.00	1.75
9	.015	.045	.061	.158	.924	.939	.985	1.00				0.70
10			.015	.045	.061	.197	.439	.727	.924	1.00		1.85
11	.045	.167	.167	.212	.333	.561	.864	.939	.985	1.00		2.30
12	.045	.076	.091	.091	.091	.091	.106	.152	.152	.242	1.00	0.70
13	.697	.879	.939	.970	.970	.970	.985	1.00				0.95
14	.015	.030	.030	.061	.076	.091	.136	.288	.455	.697	1.00	2.35
15	.121	.545	.894	.939	.939	.970	1.00					0.50
16			.015	.030	.045	.985	1.00					0.45
17			.015	.030	.030	.076	.924	.985	1.00			0.60
18		.121	.470	.818	.970	.985	1.00					1.45
19	.197	.409	.621	.848	.909	.955	.970	1.00				2.32
20			.061	.091	.091	.106	.106	.212	.591	.879	1.00	1.45
21			.015	.061	.924	.970	1.00					0.60
22			.091	.242	.742	.864	.985	1.00				1.05
23		.015	.015	.015	.030	.076	.106	.136	.515	.955	1.00	1.25
24		.045	.045	.061	.076	.106	.121	.197	.394	.652	1.00	2.00
25	.530	.848	.939	.939	.955	.970	1.00					1.20
26	.091	.652	.924	.985	.985	1.00						1.00
27			.015	.030	.045	.045	.076	.333	.591	.879	1.00	1.90
28							.045	.242	.591	.909	1.00	1.45
29				.015	.030	.061	.121	.167	.379	.652	1.00	1.90
30	.076	.561	.803	.879	.909	.970	.970	.970	1.00			1.40
31			.015	.061	.591	.864	.970	1.00				1.20
32				.015	.015	1.00						0.50
33					.045	.152	.667	.955	.985	1.00		1.10
34			.028	.028	.056	.111	.222	.50	.694	1.00		2.10
35	.028	.222	.500	.889	.972	.972	.972	.972	1.00			1.55
36						.250	.556	.806	.944	1.00		1.80
37							.056	.389	.556	.861	1.00	2.10
38	.222	.639	.889	.972	1.00							1.35
39			.028	.028	.028	.028	.028	.389	.667	.917	1.00	1.70
40		.028	.028	.194	.333	.333	.556	.861	.944	1.00		3.20
41	.028	.083	.278	.722	.889	.889	.917	.972	1.00			1.25
42			.028	.028	.028	.028	.389	.778	.861	1.00		1.25
43	.028	.056	.278	.667	.889	.917	1.00					1.50
44	.028	.083	.306	.667	.889	.917	.944	1.00				1.70
45					.056	.306	.583	.750	.972	1.00		2.25
46		.111	.278	.500	.917	.972	1.00					1.70
47	.028	.222	.583	.806	.972	1.00						1.60
48	.028	.111	.500	.833	.944	.944	.972	1.00				1.45
49	.056	.250	.528	.778	.861	.972	.972	1.00				1.90

The next step of scaling the category limits was to make the response histograms conform to the normal distribution by compression and expansion of the horizontal axis where necessary. To achieve this, the cumulative proportions in Table G.2 were taken to be areas under the unit normal curve below the upper limits of the respective category intervals. Table G.3 contains the distance of the upper limit of each category from the mean response in each discriminal dispersion. Matrix entries were obtained by looking up the normal deviate corresponding to each cumulative proportion in a set of statistical tables. The data in Table G.3 were then used to estimate the width of the eleven categories for each of the 49 response dispersions. The results are contained in Table G.4. In that table it will be noticed that the lower limit of the first category and the upper limit of category 11 were indeterminate due to their cumulative proportions being zero and one respectively. A solution to this end category problem will be given later. From the 49 separate estimates of each of the eleven category widths, an average set of widths was derived simply by summing each of Table G.4's columns and dividing by the number of non-zero entries in the corresponding columns of Table G.2. The resulting average estimates of category widths are given in the bottom row of Table G.4.

Cumulating these average interval widths yielded the 10 category upper limit scale values as shown in Figure G.1. It will be noted that the scale has an arbitrary zero point that is the boundary between categories 1 and 2. In the present scaling exercise, the attitude in question is a simple bipolar construct, with the mid-point of the original sixth category being the neutral point on the eleven-category scale as used by the 66 judges. This original mid-point was the logical choice for the new neutral and all subsequent scale values were

TABLE G.3 : Normal deviates for the upper limits of successive intervals (Zij)

Attitude Statement	Successive Intervals (j)									
(i)	1	2	3	4	5	6	7	8	9	10
1	-1.695	-0.559	0.348	1.028	1.433	2.17	2.1			
2	-2.17	-1.695	-1.028	-.432	-.154	.650	1.259	1.695		
3		-2.17	-2.17	-1.881	-1.433	-1.098	1.028	1.881	2.17	
4				-1.881	-1.695	-1.433	-.966	-.192	.650	1.433
5	-1.098	-.308	.391	.966	1.433	1.881				
6				-2.17	-2.17	-1.546	-1.098	.000	1.098	
7	-1.248	-.308	.308	1.098	1.881	2.17	2.17	2.17	2.17	
8	-2.17	-2.17	-1.546	-1.433	-1.335	-1.248	-1.170	-.908	-.604	-.075
9	-2.17	-1.695	-1.546	-.650	1.433	1.546	2.17			
10			-2.17	-1.695	-1.546	-.852	-.154	.604	1.433	
11	-1.695	-.966	-.966	-.80	-.432	.154	1.098	1.546	2.17	
12	-1.695	-1.433	-1.335	-1.335	-1.335	-1.335	-1.248	-1.028	-1.028	
13	.516	1.170	1.546	1.881	1.881	1.881	2.17			
14	-2.17	-1.881	-1.881	-1.546	-1.433	-1.335	-1.098	-0.559	-.113	.516
15	-1.170	.113	1.248	1.546	1.546	1.881				
16			-2.17	-1.881	-1.695	2.17				
17			-2.17	-1.881	-1.881	-1.433	1.433	2.17		
18		-1.170	-.075	.908	1.881	2.17				
19	-.852	-.230	.308	1.028	1.335	1.695	1.881			
20			-1.546	-1.335	-1.335	-1.248	-1.248	-.800	.230	1.170
21			-2.17	-1.546	1.433	1.881				
22			-1.335	-.700	.650	1.098	2.17			
23		-2.17	-2.17	-2.17	-1.881	-1.433	-1.248	-1.098	.038	1.695
24		-1.695	-1.695	-1.546	-1.433	-1.248	-1.170	-.852	-.269	.391
25	.075	1.028	1.546	1.546	1.695	1.881				
26	-1.335	.391	1.433	2.17	2.17					
27			-2.17	-1.881	-1.695	-1.695	-1.433	-.432	.230	1.17
28							-1.695	-.70	.230	1.335
29				-2.17	-1.881	-1.546	-1.170	-.966	-.308	.391
30	-1.433	.134	.852	1.170	1.335	1.881	1.881	1.881		
31			-2.17	-1.546	.230	1.098	1.881			
32				-2.17	-2.17					
33					-1.695	-1.028	.432	1.695	2.17	
34			-1.911	-1.911	-1.589	-1.221	-.765	0.0	.507	
35	-1.911	-.765	0.0	1.221	1.911	1.911	1.911	1.911		
36						-.674	.141	.860	1.589	
37							-1.589	-.282	.141	1.085
38	-.765	.356	1.221	1.911						
39			-1.911	-1.911	-1.911	-1.911	-1.911	-.282	.432	1.385
40		-1.911	-1.911	-.863	-.432	-.432	.138	1.085	1.589	
41	-1.911	-1.385	-.589	.589	1.221	1.221	1.385	1.911		
42			-1.911	-1.911	-1.911	-1.911	-.282	.765	1.085	
43	-1.911	-1.589	-.589	.432	1.221	1.385				
44	-1.911	-1.385	-.507	.432	1.221	1.385	1.589			
45					-1.589	-.507	.210	.674	1.91.	
46		-1.221	-.589	0	1.385	1.911				
47	-1.911	-.765	.210	.863	1.911					
48	-1.911	-1.221	0	.966	1.589	1.589	1.911			
49	-1.589	-.674	.070	.765	1.085	1.911	1.911			

TABLE G.4 : Successive interval widths (Wij)

Attitude Statement	Successive Intervals (j)								
(i)	2	3	4	5	6	7	8	9	10
1	1.136	.907	.68	.405	.737	0			
2	.475	.667	.596	.278	.804	.609	.436		
3		0	.289	.448	.335	2.126	.853	.289	
4				.186	.262	.467	.774	.842	.783
5	.79	.699	.575	.467	.448				
6					.624	.448	1.098	1.098	
7	.940	0	.79	.783	.289	0	0	0	
8	0	.624	.113	.098	.087	.078	.262	.304	.529
9	.475	.148	.896	2.083	.113	.624			
10			.473	.149	.694	.698	.758	.829	
11	.729	0	.166	.368	.586	.944	.448	.624	
12	.262	.098	0	0	0	.087			
13	.654	.376	.335	0	0	.289			
14	.289	0	.335	.103	.098	.237	.539	.446	.629
15	1.283	1.135	.298	0	.335				
16			.289	.186	2.865				
17			.289	0	.448	2.866	.737		
18		1.095	.983	.973	.289				
19	.622	.538	.72	.307	.36	.186			
20			.211	0	.087	0	.448	1.030	.94
21			.624	2.979	.448				
22			.635	1.35	.448	1.072			
23		0	0	.289	.448	.185	.015	1.136	1.657
24		0	.149	.113	.185	.078	.318	.585	.66
25	.953	.518	0	.149	.186				
26	1.726	1.042	.737	0					
27			.289	.186	0	.262	1.001	.662	.94
28							.995	.930	1.565
29				.289	.335	.376	.204	.658	.699
30	1.587	.698	.318	.165	.546	0	0		
31			.624	1.776	.868	.783			
32				0					
33					.667	1.46	1.263	.475	
34			0	.322	.368	.456	.765	.507	
35	1.146	.765	1.221	.69					
36						.815	.719	.729	
37							1.307	.423	.944
38	1.121	.865	.69						
39			0	0	0	0	1.629	.714	.953
40		0	1.048	.431	0	.57	.947	.504	
41	.526	.796	1.178	.632	0	.164	.525		
42			0	0	0	1.629	1.047	.32	
43	.322	1.0	1.021	.789	.164				
44	.526	.878	.939	.789	.164	.204			
45					1.082	.717	.464	1.237	
46		.632	.589	1.385	.526				
47	1.146	.975	.653	1.048					
48	.69	1.221	.966	.623	0	.322			
49	.915	.744	.695	.32	.826	0			
sum	18.31	15.82	20.43	21.16	16.72	18.75	17.55	14.34	10.30
n	22	29	40	42	41	34	26	22	11
$\overline{Wij}$	.7962	.5456	.5100	.5038	.4079	.5515	.6751	.6519	.9636
cum.$\overline{Wij}$	.7962	1.3418	1.8518	2.3556	2.7635	3.3150	3.9901	4.6420	5.6056

transformed onto this zero-calibrated scale simply by subtraction of the scale value of the mid-point of the 6th category in Figure G.1 (2.5596).

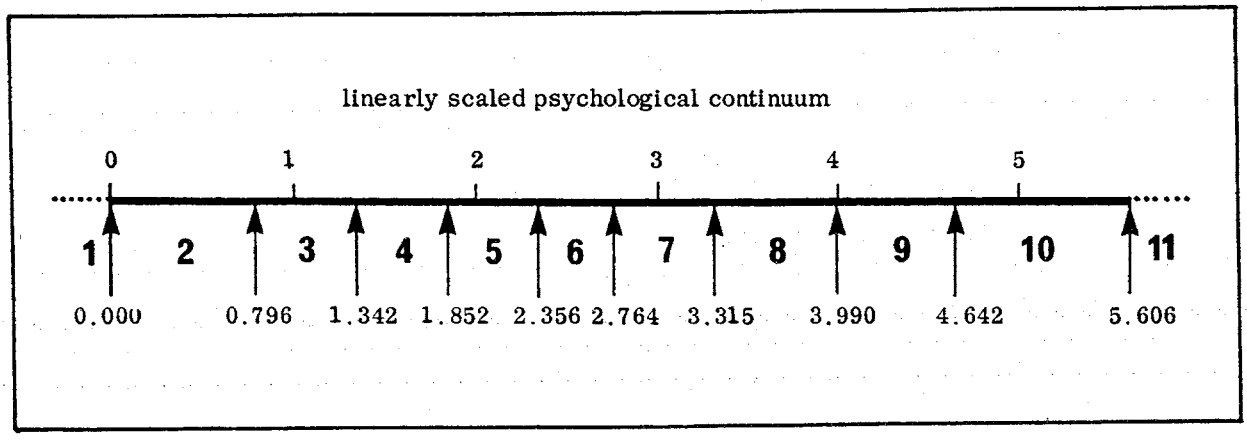


FIGURE G.1 : Common psychological continuum upon which scale values of all attitude statements were measured

As can be seen in Figure G.1, the overall result that emerged from the scaling exercise was that the scale intervals near neutrality were compressed whereas the intervals towards either end of the continuum were expanded. This probably reflects the reluctance of judges to use the extremes of the rating scale. This phenomena has been well documented in other psychological studies in which ratings are given on a linear scale (Rholes, 1974; McIntyre, 1978c). This result seems to justify the use of the successive interval technique in preference to the simpler Thurstone scaling approach.

The next stage of the scaling exercise was to attach the final scale values to the 49 attitude statements. This was accomplished by projecting each of the cumulative proportions onto the common psychological continuum (Figure G.1). The scale values of the statements

were taken as the medians of the corresponding cumulative proportion distributions on this continuum. Edwards (1957, p.129) expressed this process in the following formula:

$$Si = L + \frac{0.5 - E\,pb}{pw}\ \overline{W}ij$$

where Si is the scale value of the ith stimulus

L is the lower limit of th interval on the psychological continuum in which the ith median falls

Epb is the sum of the proportions below the interval in which the median falls

pw is the proportion within the interval in which the median falls

$\overline{W}ij$ is the width of the interval on the psychological continuum.

The application of this equation to the 49 attitude items is summarised in Table G.5. Column 7 of that table contains the final scale value for 45 of the 49 attitude items, adjusted for the zero neutrality. The remaining four items have their medians in either category 1 or 11. As discussed earlier, the width of these end categories on the psychological continuum is uncertain. Therefore, these four attitude items had their scale values derived by the alternative technique outlined in Edwards (1957, pp.131-135). The critical assumption is that taking half of the proportion of judgements falling in the end category can yield an estimate of the mid-point of that interval. To elaborate using the first category; the proportion of judges voting in that category for each statement was found, but those proportions less than 0.04 were ignored (see column 1 of Table G.2). Halving these matrix entries yielded the proportion of votes falling above the midpoint

TABLE G.5 : Scale values of attitude statements

Attitude Statement	L	+[(.5- pb)/ Pw] *	$\bar{W}ij$	unzeroed =scale val.	scale value (6)minus 2.5596
(i)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.7962	+[(.5-.288)/.348] *	.5456 =	1.123	-1.43
2	2.3556	+[(.5-.439)/.303] *	.4079 =	2.438	-0.12
3	2.7635	+[(.5-.136)/.712] *	.5515 =	3.045	0.49
4	3.9901	+[(.5-.424)/.318] *	.6519 =	4.146	1.59
5	0.0	+[(.5-.379)/.273] *	.7962 =	0.353	-2.21
6	3.315	+[(.5-.136)/.364] *	.6751 =	3.990	1.43
7	0.7962	+[(.5-.379)/.242] *	.5456 =	1.069	-1.49
8#				5.662	3.10
9	1.8518	+[(.5-.258)/.666] *	.5038 =	2.035	-0.52
10	3.3150	+[(.5-.439)/.288] *	.6751 =	3.458	0.90
11	2.3556	+[(.5-.333)/.228] *	.4079 =	2.654	0.09
12#				5.941	3.38
13#				-0.256	-2.82
14	4.6420	+[(.5-.455)/.242] *	.9636 =	4.821	2.26
15	0.0	+[(.5-.121)/.424] *	.7962 =	0.712	-1.85
16	2.3556	+[(.5-.045)/.940] *	.4079 =	2.553	-0.01
17	2.7635	+[(.5-.076)/.848] *	.5515 =	3.040	0.48
18	1.3418	+[(.5-.470)/.348] *	.5100 =	1.386	-1.17
19	0.7962	+[(.5-.409)/.212] *	.5456 =	1.030	-1.53
20	3.9901	+[(.5-.212)/.379] *	.6519 =	4.485	1.93
21	1.8518	+[(.5-.061)/.863] *	.5038 =	2.108	-0.45
22	1.8518	+[(.5-.242)/.500] *	.5038 =	2.112	-0.45
23	3.9901	+[(.5-.136)/.379] *	.6519 =	4.616	2.06
24	4.6420	+[(.5-.394)/.289] *	.9636 =	4.995	2.44
25#				-0.051	-2.51
26	0.0	+[(.5-.091)/.561] *	.7962 =	0.580	-1.98
27	3.9901	+[(.5-.333)/.258] *	.6519 =	4.412	1.85
28	3.9901	+[(.5-.242)/.349] *	.6519 =	4.472	1.91
29	4.642	+[(.5-.379)/.253] *	.9636 =	5.103	2.54
30	0.0	+[(.5-.076)/.485] *	.7962 =	0.696	-1.86
31	1.8518	+[(.5-.061)/.530] *	.5038 =	2.269	-0.29
32	2.3556	+[(.5-.015)/.985] *	.4079 =	2.556	0.0
33	2.7635	+[(.5-.152)/.515] *	.5515 =	3.136	0.58
34	3.3150	+[(.5-.222)/.278] *	.6751 =	3.990	1.43
35	0.7962	+[(.5-.222)/.278] *	.5456 =	1.342	-1.22
36	2.7635	+[(.5-.250)/.306] *	.5515 =	3.214	0.65
37	3.9901	+[(.5-.389)/.167] *	.6519 =	4.423	1.86
38	0.0	+[(.5-.222)/.417] *	.7962 =	0.531	-2.03
39	3.9901	+[(.5-.389)/.278] *	.6519 =	4.250	1.69
40	2.7635	+[(.5-.333)/.223] *	.5515 =	3.184	0.62
41	1.3418	+[(.5-.278)/.444] *	.5100 =	1.597	-0.96
42	3.315	+[(.5-.389)/.389] *	.6751 =	3.508	0.95
43	1.3418	+[(.5-.278)/.389] *	.5100 =	1.633	-0.93
44	1.3418	+[(.5-.306)/.361] *	.5100 =	1.616	-0.94
45	2.7635	+[(.5-.306)/.277] *	.5515 =	3.150	0.59
46	1.3418	+[(.5-.278)/.222] *	.5100 =	1.852	-0.71
47	0.7962	+[(.5-.222)/.361] *	.5456 =	1.216	-1.34
48	0.7962	+[(.5-.111)/.389] *	.5456 =	1.342	-1.22
49	0.7962	+[(.5-.250)/.278] *	.5456 =	1.287	-1.27

# Denotes end-category attitude items ; see TABLES G.6 and G.7

(column 3 of Table G.6). By subtracting the normal deviate of the second category's lower limit, an estimate of half the width of the first category was obtained (column 6 in Table G.6). If the average of 13 separate estimates in column 6 is 0.4519, a reasonable estimate of the full width (two halves) of category 1 is 0.904.

Attitude statements 13 and 25 had their medians in the first interval. In deriving the scale value for item 13, it was known that 0.697 of the total judgements of that item fell within the first category. The median of those judgements was obviously the scale value below which half of the judgements fell. The proportion of all category 1 votes for item 13 that fell to the right of the median was calculated by (0.697-0.5)/0.697=0.283. Multiplying the total width of the first interval on the common psychological continuum (0.904) by the proportion 0.283 yielded the psychological distance of item 13 below the lower limit of category 2. Adjusting this distance by the displacement of the neutral zero from the lower limit of category 2 gave the final scale value for attitude statement 13 as -2.304. Applying the same procedure to attitude item 25 yielded a scale value of -2.508.

In the case of statements 8 and 12 which had their medians in the 11th category, a similar procedure was applied and yielded the scale values on the common psychological continuum of 3.102 and 3.382 for items 8 and 12 respectively. The data used in deriving these last two scale values are presented in Table G.7.

Having derived the common psychological continuum and attached scale values to the entire battery of 49 attitude items, the final task of creating the attitude scale for the actual questionnaires was achieved by selecting a sub-set of the item pool that was small enough not to be too

TABLE G.6 : Derivation of the scale values for items 13 and 25
(medians in the first category)

Attitude Item (i)	proportion< upper limit (2)	proportion> mid-point (3)	normal deviate of upper limit (4)	normal deviate of mid-point (5)	(4)-(5) mid-distance (6)
1	.045	.023	-1.695	-1.995	.300
5	.136	.068	-1.098	-1.491	.393
7	.107	.053	-1.243	-1.616	.373
11	.045	.022	-1.695	-1.995	.300
12	.045	.022	-1.695	-1.995	.300
15	.121	.060	-1.170	-1.555	.385
19	.197	.099	-0.852	-1.287	.435
26	.091	.045	-1.335	-1.995	.660
30	.076	.038	-1.433	-1.774	.341
38	.222	.111	-0.765	-1.221	.456
13	.697	.348	0.516	-0.391	.907
25	.530	.265	0.075	-0.628	.703
					sum 5.875
					mean .4519

TABLE G.7 : Derivation of the scale values for items 8 and 12
(medians in the last category)

Attitude item (i)	proportion< lower limit (2)	proportion in cat. 11 (3)	proportion< mid-point (4)	normal deviate lower lim (5)	normal deviate mid-point (6)	(6)-(5) mid-distance (7)
4	.924	.076	.962	1.433	1.774	.341
8	.470	.530	.721	-.075	.586	.661
12	.242	.758	.621	-.700	.308	1.008
14	.697	.303	.847	.516	1.024	.508
20	.879	.121	.939	1.170	1.546	.376
23	.955	.045	.977	1.695	1.995	.300
24	.652	.348	.826	.391	.938	.547
27	.879	.121	.940	1.170	1.555	.385
28	.909	.091	.954	1.335	1.685	.350
29	.652	.348	.826	.391	.938	.547
36	.861	.139	.931	1.085	1.488	.398
						sum 5.421
						mean .4928

onerous for the survey respondents, but also comprehensive enough to include statements from the entire length of the common psychological continuum in Figure G.1. Most published attitude scales have about 20 items (Shaw and Wright, 1967) and these are usually selected from the larger pool on the basis of relatively small interquartile ranges in their discriminal dispersions. The interquartile ranges for the items in the attitude statement pool are listed in the last column of Table G.2.

Auliciems and Kalma (1981) estimated a market penetration factor of home air conditioning in Darwin of 55%. In view of this high level of ownership, the respondents of the two Darwin surveys were requested to complete two parallel versions of the attitude scale; one dealing with air conditioning in the workplace, and the other on home air conditioning. The Darwin pilot investigations revealed these two attitudes to be sufficiently different to justify their separate treatment in the questionnares, particularly in view of the added dimension of running costs at home. Therefore the items in the Darwin questionnaires were selected so as to reduce repetition of statements between the two implementations of the scale. Only office air conditioning affect was scaled in the Melbourne and Brisbane questionnaires. The final scale values are contained in the Darwin attitude questionnaires (see Appendix F).

APPENDIX H

Probit Neutrality Models and Scattergrams for the Three Scales of Subjective Warmth on Air Temperature and SET

The next six pages contain plots and neutrality models of the ASHRAE, Bedford and PREFV scale responses against both dry bulb temperature and the SET index.

The basic format for each model is that each 1K interval of temperatures covered by the survey's data had the associated percentage of less-than-zero responses on a seven-point scale plotted on the ordinate. The actual symbol used to represent the data points is the number of responses that were recorded within that 1K temperature interval. These numbers therefore represent the numerator that was used in calculating the models' binomial error terms.

The curve fitted through these data points represents the probit regression model, and the vertical line connecting the fitted curve and the data points is the residual, but the weight attached to each residual is a function of both the vertical discrepancy and the number of cases involved in the data point. The chi square statistics simply represent the size of the aggregated discrepancies between fitted and actual percentages, with degrees of freedom being simply the temperature range of the survey minus two. In all 36 neutrality models the chi square goodness of fit test was insignificant at 0.05, hence the models were statistically significant.

Finally, the reason for the PREFV scale's fitted curves being back-to-front in comparison with the other scales' is simply that the numerical coding for PREFV was such that a positive score indicated that the respondent wanted warmer temperatures and a negative response indicated a desire for cooler temperatures. However, this coding difference between the three scales of subjective warmth had no effect on the derivation of the neutrality temperatures.

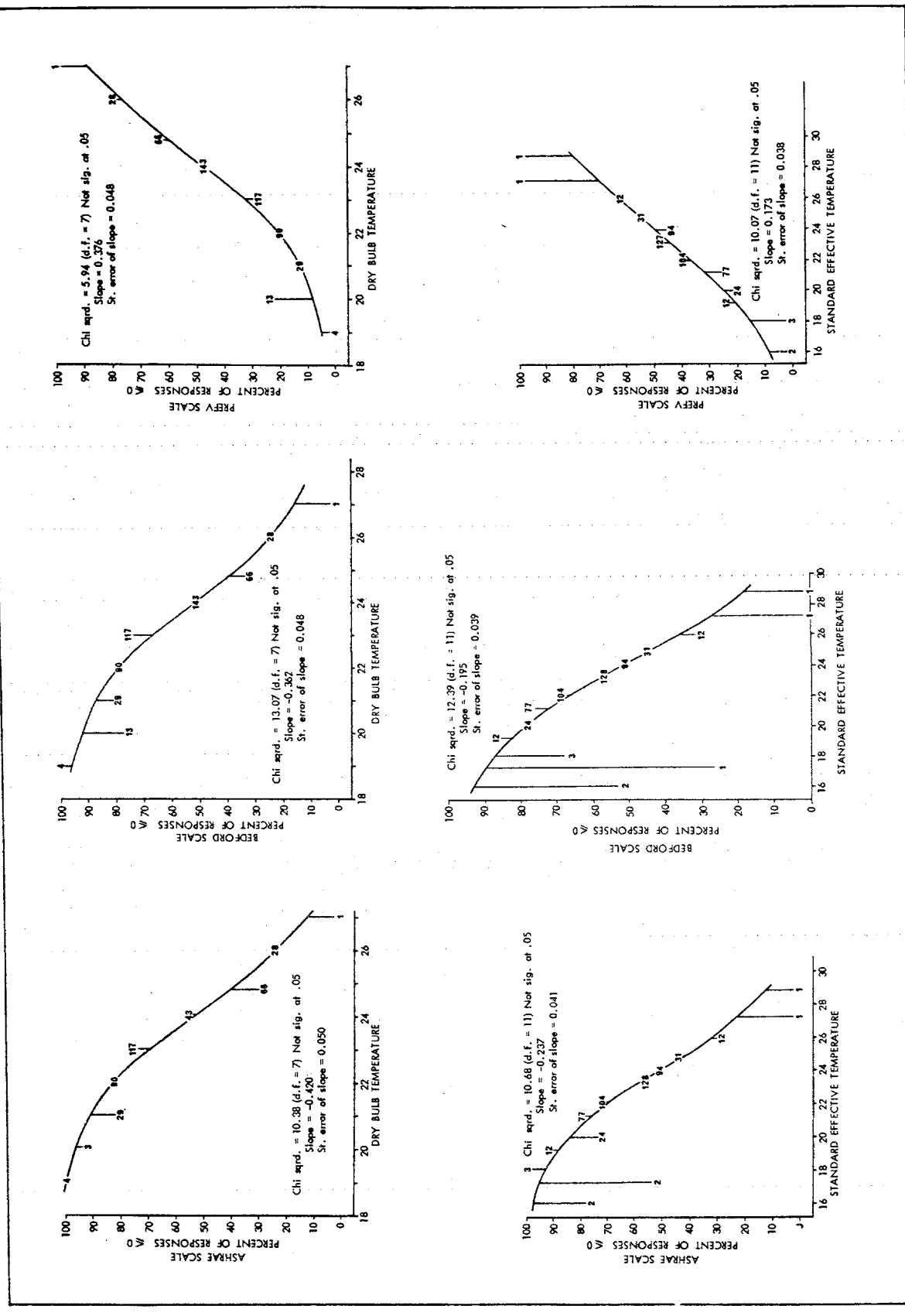


FIGURE H.1 : Probit neutrality models in the Darwin "Dry" survey (AC)

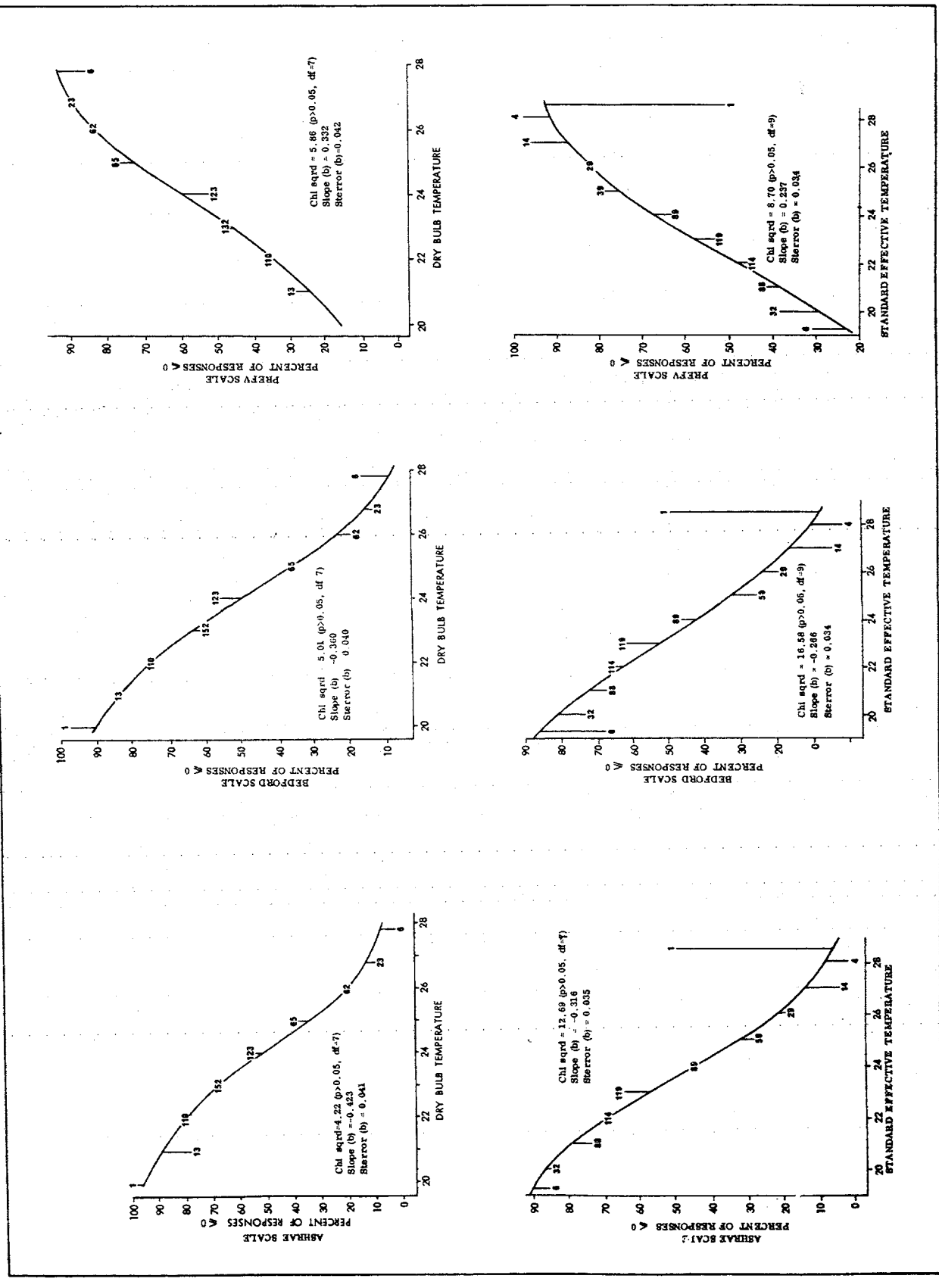


FIGURE H.2 : Probit neutrality models for the Darwin "Build-up" survey (AC)

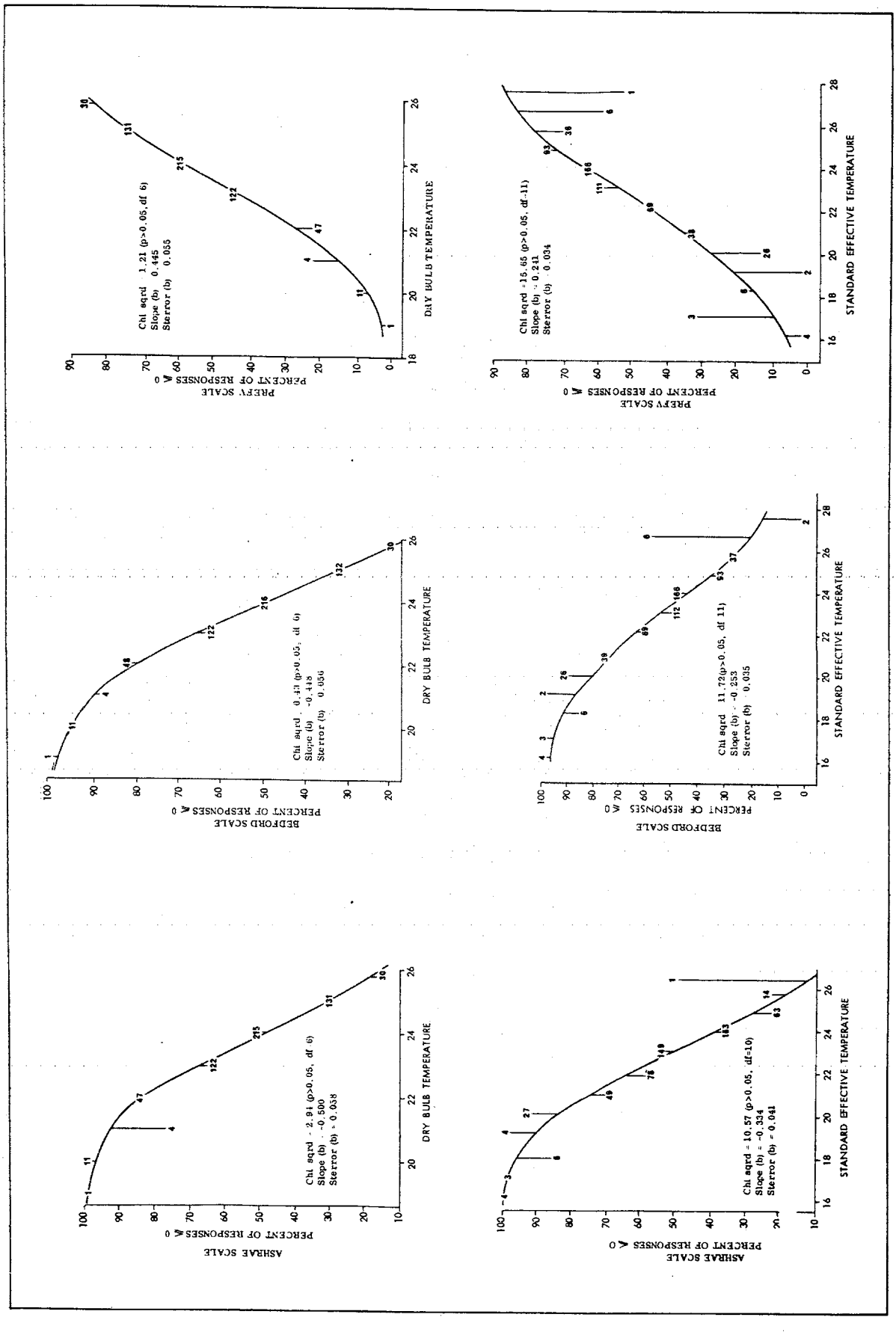


FIGURE H.3 : Probit neutrality models for the Brisbane air-conditioned survey

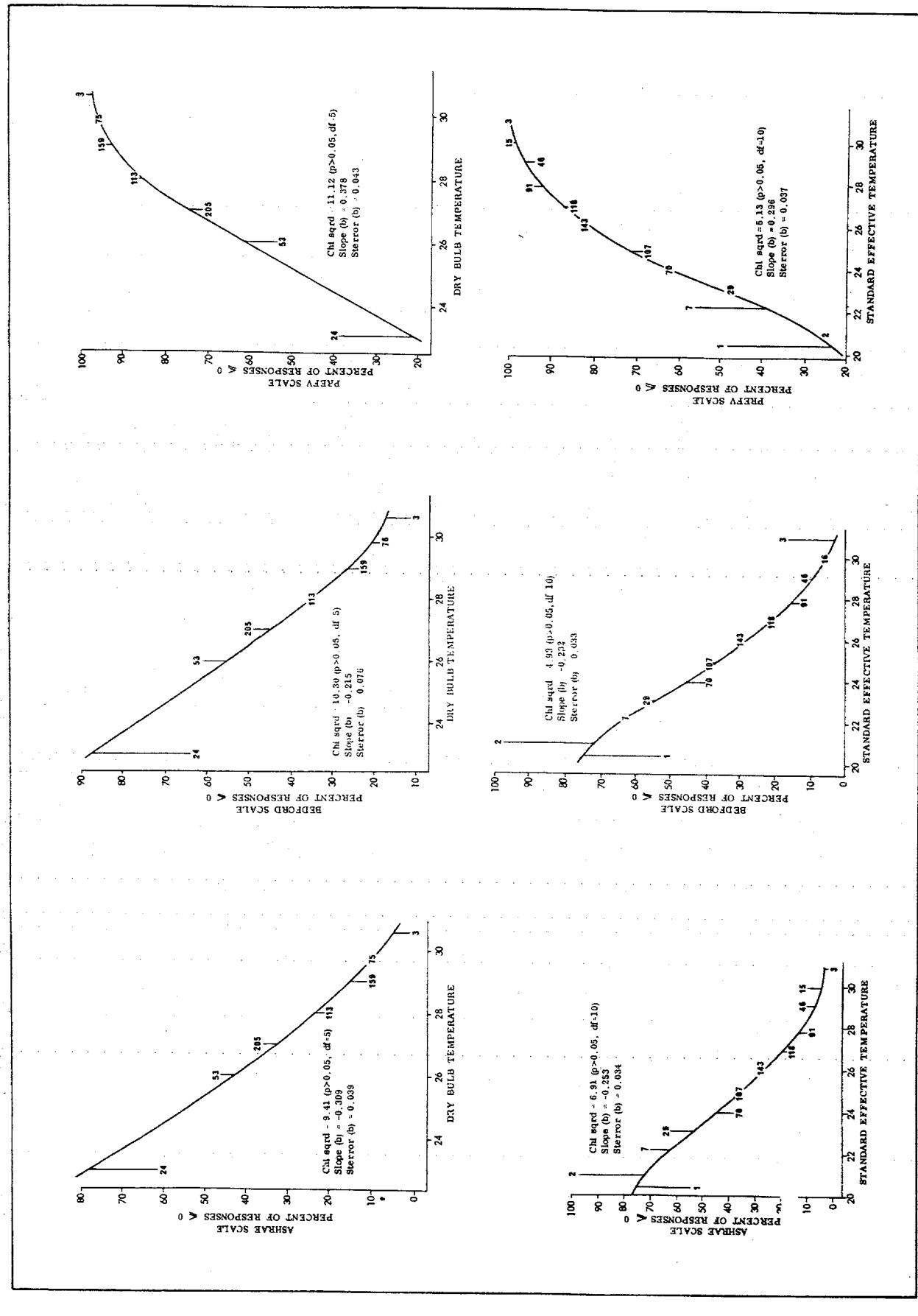


FIGURE H.4 : Probit neutrality models for the Brisbane non-air-conditioned survey

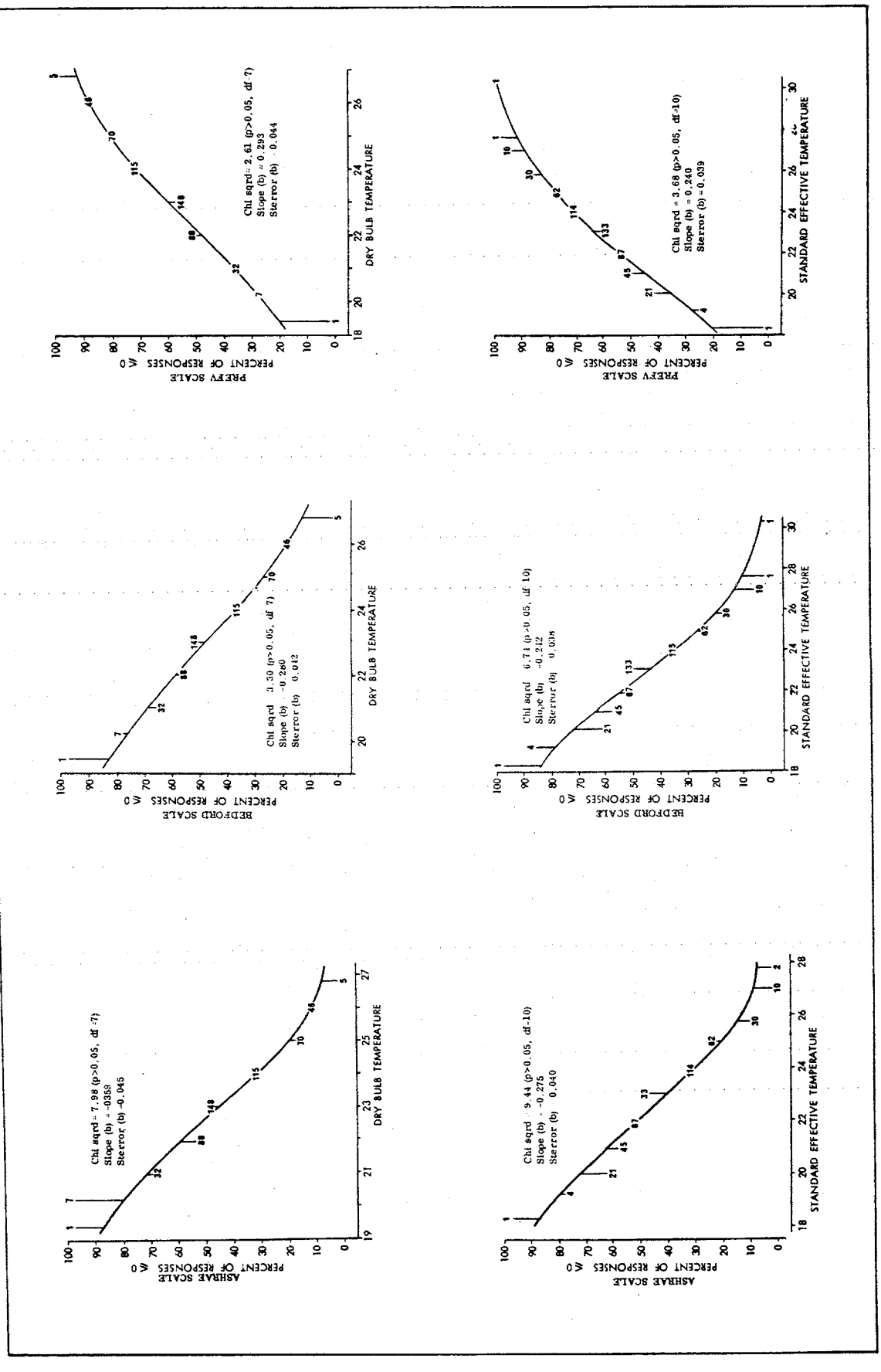


FIGURE H.5 : Probit neutrality models in the Melbourne air-conditioned survey

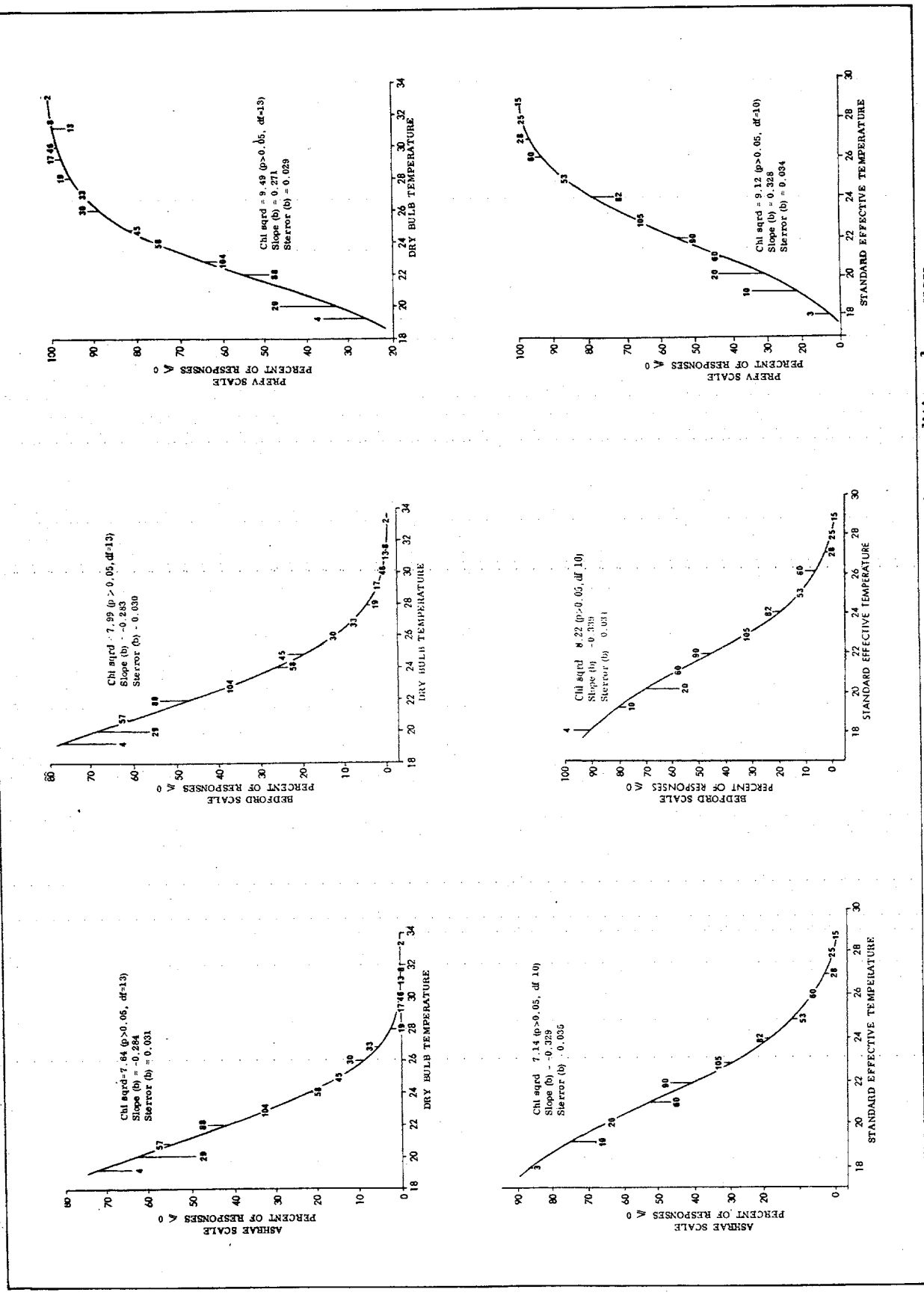


FIGURE H.6 : Probit neutrality models in the Melbourne non-air-conditioned survey

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