Seasonal Cold, Thermal Behaviour and Temperature Distributions in the Homes of Older People

Final Report to the EAGA Partnership Charitable Trust

(E-version dated 18 August 2005)

Dr James Goodwin

Steven Fenby

Professor Tracey Howe

School of Health and Social Care
University of Teesside

Statistical Consultant: Dr Kenneth Read

Contents

TABLES AND ILLUSTRATIONS

List of Tables

List of Figures

Executive Summary

Background

The hypothesis that indoor and outdoor temperatures affect activity levels in the winter, or that they affect the extent to which older people go out into the cold, does not appear to have been tested. This is an important issue because activity levels are important to health and it appears that the risk of going out into the cold ('cold excursions') is increased in older people who live in cold homes (Collins et al 1989). Preliminary work (Goodwin 1999) showed that in a small group of healthy older people, the number of outdoor excursions in a 24 h period did not change between winter and summer but this was not analysed with respect to indoor temperatures. Surprisingly, the study also showed that older people were more active in the winter (Goodwin et al 2000). There appear to be few other studies on the winter activity of older people. Therefore the aim of the study was to test the hypothesis that there is a relationship between the activity and behaviour of older people on the one hand and their winter thermal environment, domestic or outdoors, on the other.

Method

Two groups of older people took part in the study. One group of 15 older people (the 'Cold' group) did not have central heating in their homes. They were billed specifically for heating costs over and above their housing (rental) costs. By contrast, the 'Warm' group consisted of 17 older people who had unrestricted access to central heating at no additional cost to their accommodation charges. It was found necessary to divide the Warm group into 3 further categories:

a. 'true' warm (TW) – who pay a flat rate heating charge subsumed within the rent regardless of consumption (n=6);
b. 'warm*' (W*) – who pay a separate identifiable heating charge, though this is a flat rate regardless of consumption (n=4);
c. 'false' warm (FW) - who are billed for heating by consumption but *claim* their use is not restricted (n=7).

In the months January to March, each person had their daily activity levels recorded by means of a monitor worn on the thigh over a 24 hour period and their close ambient temperature ('ambulatory temperature') by means of an 'i-button' thermistor worn on the finger. Twenty-four hour Meteorological data (dry-bulb and wind-chill temperature) were also collected during the same months together with indoor room temperatures.

Statistical analysis

Waking activity data were analysed by a time series method, with the aim of summarising data in terms of the estimated parameters of a valid time series model which encapsulates the serial correlation structure of activity. More generally, the differences between the daily profiles of i) the Warm and Cold domestic temperatures and ii) the Warm and Cold bodily measurements (activity and ambulatory temperature) were assessed by analysis of variance and regression methods. Similar investigations were made of the conditioning of ambulatory temperatures by subjects' domestic and outdoor temperature environments. To make the analysis robust, consideration was given to transformations of the (activity) data, and to nonparametric significance tests as well as those based on the assumption that errors in the data would be Normally distributed.

Results

The study revealed the following:

1. During the study the older people involved experienced a particularly cold winter. Meteorological data showed that the mean 24 hour dry bulb temperature was only 5.97 °C, with a minimum of - 6.00 °C and a maximum which never exceeded 15 °C, a threshold temperature for physiological effects of cold.

2. The older people who restricted their heating on the grounds of cost were severely disadvantaged in terms of their household temperatures. Compared to the 'Warm' group, not only were there lower temperatures in all rooms but there was a much greater range *between* and *within* each of the rooms. The data showed that the mean 'Cold' living room temperature was 17.69 °C ('Warm' 22.23 °C), kitchen 16.64 °C ('Warm' 23.08 °C), bedroom 16.81 °C ('Warm' 22.16 °C) and bathroom 14.40 °C ('Warm' 23.9 °C).

3. Older people in the 'False Warm' and 'Cold' groups undertook more daily excursions into the cold than those in the 'Warm' group. For example, older people in the 'Cold' group made up to 5 excursions per day compared to 2 excursions in the 'Warm' group. The 'Cold' mean total time (hrs:min) outdoors was 3:40 compared to 2:33 in the 'Warm' group.

4. There was a strong inverse relationship between ambulatory temperature and activity in all subjects in the experiment, together with a corresponding diurnal trend in these variables. The data were suggestive of a relationship between the domestic thermal environment (as a proxy of heating charge) and the activity levels of the older people in the experiment, though statistical significance was not achieved.

5. Analysis showed that a significant contrast existed in terms of ambulatory temperature between those paying a flat rate charge for heating and those paying by use, the True Warm and Warm* groups on average being 1.6 °C warmer than the Cold and False Warm groups.

The evidence supports the hypothesis of a relationship between ambulatory temperature and activity levels; between ambulatory temperature and the *a priori* contrast of fuel payment by use ('Cold group') *vs* flat-rate charging ('Warm' group); and is suggestive of a relationship between this contrast and activity.

In summary, the behaviour of older people in the Cold and False Warm groups shows the following characteristics:

- a higher level of physical activity with clear time of day (circadian) effects
- apparent increased daily excursions into the cold
- lower ambulatory temperatures with an inverse relationship to activity
- lower domestic temperatures with steeper internal gradients and range

Discussion

Such a profile warrants the categorisation of older people in the Cold and False Warm groups as being at higher risk in the winter. In the light of the data presented here and in other studies they appear to be exposed to increased levels of risk as follows:

- probable increased cardiac work due to the effects of age, temperature, activity and interactions between these factors

- increased risk of lower core temperatures due to increased exposure to cold stress
- increased risk of raised systemic blood pressure arising from increased cold stress
- increased risk of heart attack and stroke.

Conclusions and Recommendations

The findings presented in this study add important new knowledge on the personal patterns of activity and behaviour of older people in the winter, as associated with differences in the thermal conditions of their accommodation. The main recommendations are as follows.

a. Clearly, the cold temperature conditions of those older people who restrict their heating on the grounds of cost are associated with high risk behaviour in the winter. Many of the UK's older population live in fuel poverty, notwithstanding the benefit system and in homes which lack adequate insulation (Boardman 1991; Wilkinson 2001). There appears to be a disappointing level of benefit take-up amongst many older people and many are unaware of the benefits that may be claimed, whilst at the same time it is known that benefit take-up improves the expenditure on fuel by older people (Wright 2004). Therefore there appears to be a strong case for measures which improve the benefits realised by older people. Simultaneously, policies which improve the heating, insulation and energy efficiency of homes will reduce the thermal problems which are indicated in this study.

b. The behavioural patterns associated with cold homes in the winter which have been shown in this study appear to increase greatly the risks of cold stress on older people in the winter. This is an important new finding which adds weight not only to suggestions for the reduction of indoor cold but to a programme of health promotion which identifies the importance of high risk behaviour in older people in the winter.

c. Further studies appear to be indicated from the findings in this report. In particular, a further study is required to investigate the relationship between home heating charges and activity levels; the evidence in the present report suggests a relationship but just failed to reach statistical significance. A qualitative study is also indicated, in order to establish from older people themselves the reasons for their activity levels and excursional behaviour in the winter. Further work is also recommended to establish an effective model of health promotion by which the problem of high risk behaviour may be resolved. This may involve a behavioural science based study of the social, psychological and cultural factors. There may be other studies which are necessary, eg in the area of the policy implications indicated here, but which cannot be derived strictly from the research outcomes in this study.

Acknowledgements

The authors of the report would like to make the following acknowledgements.

To the Eaga Partnership Charitable Trust who very generously provided the research grant which funded this work.

To Naomi Brown, Trust Manager, whose patience, expertise and constant advice greatly contributed to the smooth passage of the research.

To professor Paul Keane, Director of the School of Health and Social Care, University of Teesside, for his encouragement and professionalism in supporting this project.

To Alan Jackson, School Manager and his staff, for the excellent administrative support without which the project could not have been completed.

To Dr K J Collins for providing independent academic peer review of the completed text.

To the older people of Teesside, too many to name individually, without whose participation this project would not have been possible.

1. Introduction

1.1 In the UK each winter there are some 40,000 *excess* winter deaths (EWD), mainly occurring in the older population. These deaths are temperature related; that is, there is an inverse relationship with cold, with about 8,000 more deaths occurring in the UK for every degree Celsius that the winter is colder than average (Curwen, 1997). About half of these deaths are respiratory (eg bronchitis) and about half are due to arterial disease (heart attack and stroke). Few deaths are due to hypothermia. Paradoxically, though temperature related, deaths from thrombotic illness increase to a greater extent with a given fall in temperature in European regions with warm winters (Eurowinter Group 1997; Mercer 2002). This paradox raises the interesting question of the different mechanisms whereby cold may precipitate the onset of winter illness and death.

1.2 Studies have shown that the number of respiratory deaths in the winter appears to be falling and that this may be due to the increased use of central heating (Keatinge et al 1989). In contrast, the number of deaths due to thrombotic illnesses appears to show little decline. It has been suggested that one reason for this is the harmful effects of everyday excursions into the outdoor cold, with insufficient clothing protection or activity levels (Eurowinter Group 1997; Donaldson et al 1998). Analysis of the Eurowinter data revealed that high indices of mortality were related to mild winters, low indoor temperatures, low levels of clothing insulation outdoors and low levels of activity. The evidence appears to show that both indoor and outdoor cold operate independently with respect to the increased risk of winter death, though with different mechanisms. It has therefore variously been argued that respiratory illness in the winter is more sensitive to indoor temperatures and thrombotic illness to outdoor cold (Collins 1999; Keatinge 1999).

1.3 Though some authors (eg Mercer 2002) have stated that the mechanism remains unclear by which seemingly mild exposure to cold environments can increase the risk of death, there is a substantial body of evidence from which reasonable explanations may be derived. Numerous papers have shown that short term exposure to cold initiates a mild inflammatory reaction and a tendency towards hypertension and hypercoagulability, all of which increase the risk of thrombosis (Collins 1989; Stout and Crawford 1991; Woodhouse et al 1994; Keatinge et al 1984; Donaldson et al 1997). The known 'lag relationships' (2-3 days for myocardial infarction and 12 days for thrombotic stroke; Keatinge 2002) tend to support the proposed mechanisms.

1.4 It is becoming clear that it is probably the *integrated profile of exposure to cold* which brings with it the lethal consequences of winter, especially in older people. The provision of a definitive model of the integrative factors which underwrite winter mortality therefore requires data from different sources, in order to provide information not only on physiological mechanisms but also the behavioural and lifestyle factors which may be implicated. It appears that those living in cold climates take preventative measures against the cold, ie indulge in 'low risk behaviour', whereas those living in warmer countries paradoxically are exposed to more cold stress since they do not take appropriate measures ('high risk behaviour') against the cold to any great extent (Eurowinter Group 1997). These data were collected by means of large scale interview methods, which means that although impressive regression data are presented, there is little independent corroboration of the measured variables, eg the extent of outdoor physical activity. A similar method was used by Donaldson et al (1998) to investigate winter mortality and cold stress in Russia, with similar findings (and which are, therefore, subject to the same caveat as above). It was found that at temperatures down to 0°C, cold stress and excess mortality were prevented by increasing the levels of clothing protection, physical activity and indoor temperatures. These findings reveal the important role played by ‘physical or behavioural’ thermoregulation (Schonbaum and Lomax 1990). Studies in the laboratory and in the natural environment show that many species are capable of learning overt behavioural responses that alter or maintain body temperature by selecting environmental preferences with the appropriate ambient temperature (Cunningham et al 1990). In humans, evolution has elaborated complex social behaviours involving clothing, shelter and community-related activity which differ between different cultures (Grayson 1990) to the point where such deterministic behaviour is as important to thermoregulation as the physiological mechanisms, such as adjustments of the microcirculation, which though remarkably efficient are only effective over a narrow range of environmental temperatures.

1.5 At the present time, there is little information available on the personal patterns of cold exposure amongst older people. It is now fairly well established that indoor cold has a harmful effect on the health of older people (Wilkinson 2001). However, there is little information as to the health effects of uneven patterns of warmth within individual households (eg one warm room) or on the pattern of heating (thermal distribution). Information from the Eaga Partnership (Eaga 2001) reveals that up to 1,500 calls are received per day in the winter, an indication of the extent of inadequate heating or insulation experienced by people, many of them elderly. As correspondence in the BMJ testifies, the precise inter-relationship between the effects of indoor and outdoor cold has yet to be established (bmj.com dated 26 and 29 Nov, 2001). Improved practice in relation to the prevention of the large number of EWD still found in the UK would almost certainly result from clarification of these relationships. Additionally, the temperature data would enable useful, limited comparisons to be made between the two types of home envisaged in this study, particularly since the English House Conditions Survey no longer records household temperatures.

1.6 The hypothesis that indoor and outdoor temperatures affect activity levels in the winter, or that they affect the extent to which outdoor excursions are made, does not appear to have been tested. This is an important issue because activity levels are important to health and it appears that the risk of cold excursions is increased in those older people who live in low indoor temperatures (Collins et al 1985). Preliminary work (Goodwin 1999) has shown that in a small group of healthy older people, outdoor excursions do not appear to change between winter and summer but this was not analysed with respect to indoor temperatures. Surprisingly, activity levels also appeared to rise in the winter (Goodwin et al 2000) whereas in previous studies self-reported activity in older people was higher in the summer (Woodhouse et al 1993). There appear to be few other studies on the winter activity of older people. Therefore the aim of the study was to investigate the relationship between the activity and thermal behaviour of older people, the thermal environment within their homes and outside winter cold.

2. Method

2.1 Hypothesis. The null hypothesis for testing was set as follows:

There is no relationship between the activity and thermal behaviour of older people on the one hand and their winter thermal environment, domestic or outdoors, on the other.

2.2 Participants.

Ethical permission was granted by the University Ethics Committee and the investigation conformed to the University research governance procedures. The older people who participated in the investigation were assessed to be physically active and independent in their daily lives, with an acceptable level of mental competence (*vide* para 2.5). Selection to take part in the investigation was determined to a significant degree by the design requirements of the experiment in respect of their home heating. Participants were assigned to one of two groups, whose use of domestic heating was perceived as (i) 'restricted' or (ii) 'unrestricted'. These conditions are defined in para 2.3.

a. Subject numbers.

The investigation was initially carried out with 53 volunteer older people ('subjects') who gave informed consent to take part in the study. Of these subjects, 49 (20 male and 29 female) were assessed to be sufficiently active and independent to be included in the main data collection. Therefore, in total, data were collected on 49 subjects, but the series from several of these were found by the experimental investigators to be defective (missing data) and therefore unusable. An agreed set of 32 subjects (15 'Cold' and 17 'Warm') was used for the main analysis, supplemented by usable extracts from two further subjects. The 17 'Warm' subjects comprised 6 'True Warm', 4 'Warm*' and 7 'False Warm' (*vide* para 2.3). The original 49 subjects included seven couples, each of whom shared accommodation, but only one couple features in the final set of 32 subjects. This implies a single related pair of observations of domestic temperatures in the analyses of Section 4.4, but is judged overall not to be of material importance. Usually two, but up to 4, subjects were studied per day. Characteristics of the 32 subjects are given in Table 1.

b. Age Range. The age range of the overall sample was 65 – 88 years and their average age was 74.62 years. The mean age of the 'Cold' group was 73.00 (range 65 - 87); and the 'Warm' group mean was 76.24 (range 69 - 88).

c. Physical Characteristics. The mean (± sd) height of the subjects was 1.60 ± 0.09 m (range 1.42 – 1.79), body mass 70.21 ± 11.92 kg (range 48 - 93) and body mass index (BMI) 27.52 ± 4.26 kg/m^2 (range 19.90 – 38.21). Differentiation of these data by sub-group is given in Table 1 (*vide* para 3.1)

2.3 Experimental Design. The investigation was designed as a two-sample prospective study, in which continuous non-invasive measurements were taken over one 24-hour period for each subject during the winter months. Winter was defined as the inclusive period January to March, 2003. The two samples were designated as either 'restricted' or 'unrestricted' in terms of subjects' access to domestic heating. The former group, designated 'Cold' ('C') comprised those older people who did not have central heating and therefore were billed specifically for the fuel costs of their heating, over and above their housing (rental) costs. The latter 'Warm' ('W') group was defined as those participants who had unrestricted access to home (central) heating and whose heating costs were subsumed within inclusive accommodation charges, which (crucially) do not vary to reflect the costs of the fuel they individually use. The 'charging' criteria were considered necessary to render more certain those older people selected into the 'Warm' group who in fact experienced continuous warmth in the winter. However, in recruiting for the survey it was found necessary to distinguish 3 subdivisions of the 'Warm' group, namely:

a. 'true' warm (TW) – who pay a flat rate heating charge subsumed within the rent regardless of consumption;
b. 'warm*' (W*) – who pay a separate identifiable heating charge (though this is largely a flat rate because of communally shared living areas);
c. 'false' warm (FW) - who are billed for heating by consumption but *claim* their use is not restricted.

2.4 Measurements. The response variables of main interest were as follows: subject-based ambient ('ambulatory') temperature ('t_{amb}'), activity level ('act') and behavioural responses (excursional data – 'exc'). Domestic (indoor) temperature ('t_{dom}') and meteorological data – outdoor dry-bulb temperature('t_{db}') and wind-chill temperature ('t_{wc}') were also of interest. All participants provided anthropometric data (body mass and height, from which Body Mass Index (BMI) was according to the formula BMI = Body Mass x $(\text{Height})^{-2}$). Details of the methods employed to collect each of these data types are as follows.

2.4.1 Anthropometric data.

All anthropometric measures were taken by a single observer in order to eliminate inter-observer error. Height was recorded using a Holtain stadiometer (Crymmych, Wales) with the subject standing upright, head in the Frankfort Plane and light traction applied. Pre-measurement calibration was carried out, with cursor setting aligned to a standard 600mm calibration rod. Measurements were accurate to ±0.001m . Subjects were weighed in light indoor clothing, using a calibrated clinical balance (Avery, Birmingham UK) accurate to ± 0.1 kg.

2.4.2 Ambulatory temperature.

Ambulatory temperature is a prospective measure of the moment-by-moment ambient temperature experienced by an individual over 24 hours at a point close to the body. The ambient temperature of the air (dry bulb temperature) is an important indicator of the potential for heat gains and losses from the human body (Second Law of Thermodynamics) and therefore of the probable heat or cold stress to which an individual is exposed. Theoretically the value which is of importance should be representative of the temperature which determines heat exchange with the human body. The site at which sampling occurs and the frequency of sampling are therefore important issues, especially in free living conditions, where the thermal environment becomes highly variable due to individual factors and in this study, seasonal ones. The method chosen is no less important. Any instrument (including thermometry) should show stability, responsiveness, linearity, accuracy, reproducibility and robustness (ISO 7726 1985). Measurement may be made by mercury-in-glass thermometer, thermocouple, resistance thermometer or thermistor.

The chosen method was the Thermochron DS1921G 'i-Button' (Dallas Semi-conductor Corporation, USA). The i-Button comprises a 2048 byte memory platform aligned with a thermistor which stores the temperature data for subsequent download via dedicated software. It samples at one minute intervals, accurate to ± 1°C over the range -30 to 70°C. The device (*vide* Appendix One) is a small, hardened disc seated in an adjustable ring mounting so that it may be worn on a finger of either hand. The thermistor was separated at a distance of 5mm from the skin by a insulative rubberised disc. The device was calibrated *in vivo* against external air temperature and *in vitro* using a thermostatically controlled water-bath with an ascending and descending temperature protocol over the range 5°C - 40°C to obtain a hysteresis envelope between the two calibration curves (*vide* Appendix Two for data).

It should be recognised that a personally attached thermistor may not necessarily measure the 'effective' ambient temperature, given the 'boundary conditions' which may exist close to the body which are subject to moving convection currents (Parsons 1993). It is recognised that variations will occur between the usual measurements of outdoor temperature (which often fluctuate widely in field studies and in many surveys taken from the nearest meteorological station readings), indoor readings (where the climate is more controlled but nevertheless is subject to variations from space heating appliances, draughts, etc (*vide* Parsons 1993) and controlled climatic chambers (where the temperature is strictly controlled). The skin temperature will vary according to these fluctuations and with surfaces that are covered or uncovered. The microclimate that is established next to covered skin, though being relatively stable will vary with the external conditions, with the insulative value of the clothing and within the parameters of thermal comfort experienced by the individual (taking off or putting on more clothes, ie behavioural thermoregulation). These considerations clearly bear on the inferences drawn from the collected data (*vide* Discussion, Section 5).

2.4.3 Physical activity

Physical activity is a multi-dimensional behaviour and is difficult to define. Therefore there are many ways of measuring it, each method addressing one or other different dimensions. The most objective measures, such as direct observation or fitness testing have been shown to be both reliable and valid (Williams et al 1989). They are, however, difficult to apply to most practical circumstances outside of the laboratory. The most commonly used methods in field studies are physical activity diaries, questionnaires and electronic motion sensors (invariably accelerometers). None of these methods addresses all of the dimensions of activity and only motion detection provides objective data which are free of subjective bias.

Essentially what is required in the field work phase of this study (ie the data collection) is a method which provides both objective data on the extent of physical activity and also subjective data by which the former may be evaluated. The reliability and validity of electronic motion data, as tested in controlled settings, appears to be very high and such data have been found to correlate well with criterion measures (Williams et al 1989). The development of the accelerometer method is fairly advanced and many ambulatory instruments are available (eg Actigraph, Caltrac, Gaehwiler, etc). Electronic motion data were therefore collected via a single uni-axial accelerometer ('activPAL'; PAL Technologies, Strathclyde, UK) which samples at a rate of 10 Hz and converts the raw kinematic data into a calculated 'met' value (*vide* Appendix One). A 'met' (or 'Metabolic Equivalent') is a measure of oxygen consumption and 'one met' is defined as 3.5 mls of O_2/kg/min. However, objective motion data alone would be insufficient to interpret participants' responses to the thermal environment. For example, electronic motion data could not differentiate between the different locations which may influence responses, eg whether or not the subject was *inside* (possibly 'warm' in the winter) or *outside* ('cold' in the winter). In these respects, contemporaneous (as opposed to retrospective) diary data was used in order to disclose this information (excursional data). A copy of the diary is to be found at Appendix 3.

2.4.4 Domestic temperature

Separate to the collection of ambulatory temperature via the i-Button, independent assessments were made of domestic indoor temperatures so as to determine the thermal gradients within the home. Measurements were sampled via i-Button devices sited uniformly at a height of one metre in the living room, bedroom, kitchen and bathroom of participants' homes. Outdoor dry-bulb temperature data (daily minimum, maximum and average (mean) temperatures) were obtained from the local meteorological station (Teesside Airport).

2.5 <u>Procedures.</u> Subjects were visited in their own home at the start of the 24 hour period. Suitability for the study was assessed using the SF(Shortform) 36 and SM (Short Mental) questionnaires. Subjects were then weighed and measured for height. Each subject was instrumented with a ring mounted i-Button and with an activity monitor worn on the thigh, mid-way between the hip and knee such that the axis of sensitivity was in the sagittal plane. Instructions were given on how to complete the activity diary. Finally, i-Buttons were placed in the living room, kitchen, bedroom and bathroom to measure the temperature distribution in the home. At the end of the 24 hour period subjects were visited for a second time to remove the ambulatory instruments and the distributed i-buttons. The completed diaries were collected at the same time.

2.6 Statistical Analysis

2.6.1 Purpose of Analysis

The aim of the analysis was to describe in statistical terms the differences between the 'Warm' and 'Cold' groups in respect of the above data, due account being taken of the potential heterogeneity of the 'Warm' group. Of primary interest were the Warm-Cold contrasts in the bodily indicators (activity, ambulatory temperature) and any discernible relationship between these two variables. Secondly, differences between the daily profiles of the Warm and Cold domestic temperature environments were assessed. If significant differences were found in the bodily indicators, interest focused on contrasting domestic temperature environments as a possible explanation.

2.6.2 Statistical Approach

In the light of earlier work (Goodwin 1999) on similar data, time series analysis was applied to (presumed) waking activity data, with the aim of summarising data in terms of the estimated parameters of a valid time series model which encapsulates the serial correlation structure of activity. More generally, analysis of variance and regression techniques were applied to assess differences between the daily profiles of i) the Warm and Cold domestic temperature environments and ii) the Warm and Cold bodily indicators. Similar investigations were made of the conditioning of ambulatory temperatures by subjects' domestic and outdoor temperature environments. In the interests of robust analysis, consideration was given to transformations of the (activity) data, and to nonparametric significance tests as well as those based on the assumption of Normally distributed errors.

Finally, it should be noted that the subject's 'ambulatory temperature', as measured by a ring sensor worn on a finger, appeared to be a varying compromise between adjacent air temperature and some approximation to the subject's skin temperature. Although its *prima facie* meaning is thus unclear, or at least imprecise, it turned out to be highly important both as a covariate in the main analysis of activity and as a secondary response to different temperature environments. Further light was thrown upon this subject-measure of temperature by the analysis of a subsample of 5 'Cold' and 5 'Warm' subjects mentioned above and discussed in Section 5. However, as might be expected due to the relatively small numbers of subjects and their varying patterns of lagged adjustment to their surroundings (notably when asleep or outdoors), no obvious effective method was found of empirically quantifying its relationship to the subject's wider temperature environment.

3. Results

3.1 Anthropometric Data

Summary anthropometric data of the older people has been given in para 2.2 (c). Further details by sub-group are given in Table 1.

Table 1. Physical characteristics (mean ± sd) of True Warm (n=6), Warm* (n=4), False Warm (n=7) and Cold (n=15) subjects (total sample n=32)**.**

	True Warm	**Warm***	**False Warm**	**Cold**
Height (m)	1.61 ± 0.07	1.55 ± 0.04	1.61 ± 0.11	1.60 ± 0.08
Mass (kg)	66.08 ± 13.78	72.25 ± 10.11	74.29 ± 12.44	69.52 ± 11.56
BMI	25.37 ± 4.85	30.17 ± 3.09	28.51 ± 2.79	27.26 ± 4.52

BMI = Body Mass Index (*vide* para 2.4)

3.2 Ambulatory Temperature (‘t_{amb}’)

Average ambulatory (‘ring’) temperature data of the subjects, categorised by group, are given in Table 2.

Table 2. Ambulatory temperature °C (mean ± sd) of True Warm (n=6), Warm* (n=4), False Warm (n=7) and Cold (n=15) subjects (total sample n=32).

Time (hour of day)	**Ambulatory Temperature (‘t_{amb}’) °C (Mean± sd)**			
	True Warm	**Warm***	**False Warm**	**Cold**
00:00-00:59	33.02±1.45	30.99±1.42	32.12±4.44	31.53±3.56
01:00-01:59	33.58±1.48	32.85±1.38	32.00±2.93	32.22±2.34
02:00-02:59	32.69±1.43	32.91±1.75	32.53±2.68	32.19±3.15
03:00-03:59	33.20±1.44	32.82±1.78	32.75±2.47	32.39±2.66
04:00-04:59	32.84±1.28	31.79±1.85	32.56±2.03	32.65±2.73
05:00-05:59	33.18±1.42	30.66±1.65	31.88±2.52	33.23±2.43
06:00-06:59	33.36±1.70	31.19±1.79	31.75±2.46	32.94±3.13
07:00-07:59	29.62±3.54	30.87±1.83	31.09±4.89	29.70±4.92
08:00-08:59	25.89±4.88	29.46±1.61	25.13±6.07	26.34±5.57
09:00-09:59	23.61±6.30	27.66±1.97	22.78±5.61	22.20±5.23
10:00-10:59	26.51±4.09	27.95±2.19	22.44±4.03	23.14±4.14
11:00-11:59	26.72±5.02	25.00±3.78	23.69±4.17	25.30±4.47
12:00-12:59	27.91±3.39	26.78±3.42	23.19±4.49	24.87±3.86
13:00-13:59	27.47±2.67	27.46±2.56	23.59±5.18	24.49±4.00
14:00-14:59	28.33±2.61	25.73±3.83	26.19±5.46	25.83±5.34
15:00-15:59	27.90±4.04	27.65±2.75	25.64±4.61	25.18±6.58
16:00-16:59	27.04±4.34	29.16±2.71	25.46±5.39	25.72±5.95
17:00-17:59	27.73±4.26	29.34±1.84	26.50±4.91	26.65±4.16
18:00-18:59	29.42±1.98	29.15±2.23	26.11±3.59	27.94±3.60
19:00-19:59	29.06±2.88	27.99±2.26	28.99±2.67	28.88±3.16
20:00-20:59	31.28±2.41	28.73±2.42	28.58±3.59	29.81±2.88
21:00-21:59	30.43±2.03	30.40±1.56	28.92±2.94	29.01±3.41
22:00-22:59	30.35±1.73	29.66±2.71	29.13±3.96	29.62±3.07
23:00-23:59	32.34±1.96	30.09±1.69	30.82±4.36	31.45±3.26

These data are shown graphically in Figure 1 below. Examination of the data shows a stable nocturnal period where the ‘ring’ temperature on the finger varies typically from 31-32°C, followed by a steep fall of about 10°C during the early morning (0700 – 1000 h). Between the hours of 1000 and 1500, there appears to be a noticeable difference between the ambulatory temperatures of the Warm and Cold groups, with the Cold group experiencing temperatures about 3 ° C lower than the Warm group during this 5 hour period. Otherwise temperatures are remarkably similar. In summary, the general pattern consists of a convergence of temperatures in the two groups during the night (main sleep period), divergence in the middle of the day (main activity period) and a re-assertion of convergence in the late evening.

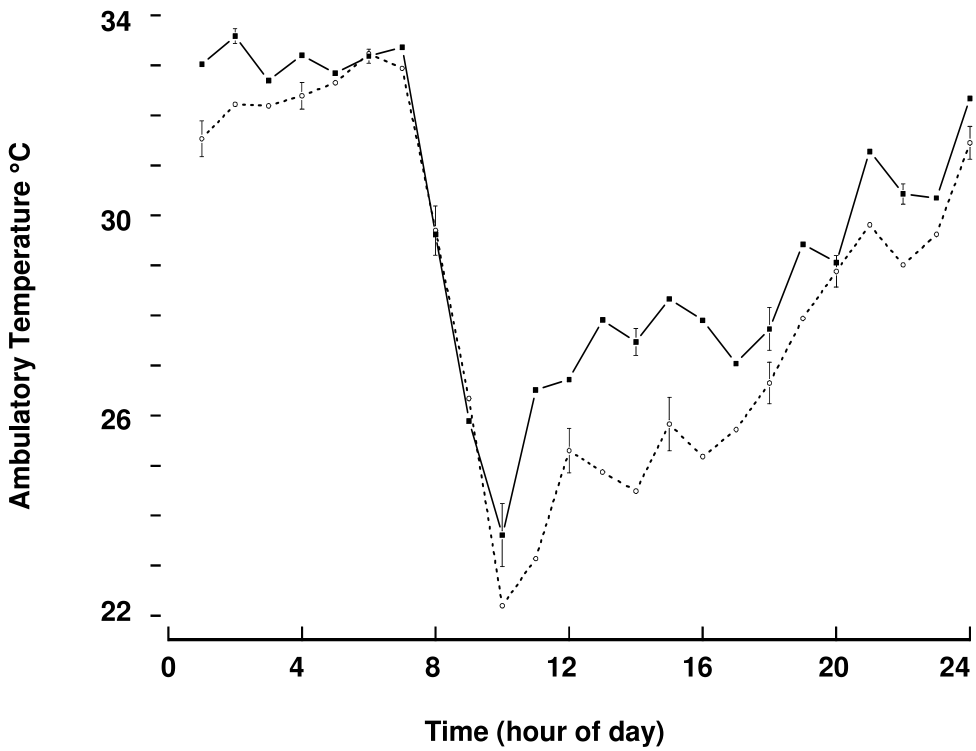


Figure 1: Ambulatory temperatures (hourly means ± sd) of True Warm (—) and Cold (···) subjects (numbers as in Table 2) over 24 hours

3.3 Activity Data ('act')

Hourly average activity data, by group, are given in Table 3 below. The sampling frequency of the instrument gave a second-by-second series of raw activity data which were entered into the statistical analysis. Readings were therefore 'met/60'. During sleep when movement was nil or minimal, the instrument resolved to a continuous minimum reading of '0.0168' units (1.008 mets). The data in Table 2 are transformed hourly activity means in mets.

Table 3. Activity data (mean ± sd) in mets of True Warm (n=6), Warm* (n=4), False Warm (n=7) and Cold (n=15) subjects (total sample n=32).

Time (hour of day)	Activity ('act') mets (mean ± sd)			
	True Warm	**Warm***	**False Warm**	**Cold**
00:00-00:59	1.01 ± 0.04	1.04 ± 0.15	1.02 ± 0.09	1.04 ± 0.15
01:00-01:59	1.02 ± 0.11	1.01± 0.00	1.01 ± 0.03	1.02 ± 0.09
02:00-02:59	1.01 ± 0.00	1.01 ± 0.04	1.02 ± 0.08	1.04 ± 0.16
03:00-03:59	1.01 ± 0.05	1.01 ± 0.03	1.01 ± 0.03	1.02 ± 0.11
04:00-04:59	1.01 ± 0.04	1.02 ±0.07	1.02 ± 0.09	1.01 ± 0.06
05:00-05:59	1.03 ± 0.10	1.03 ± 0.12	1.01 ± 0.04	1.01 ± 0.06
06:00-06:59	1.04 ± 0.13	1.03 ± 0.13	1.01 ± 0.00	1.02 ± 0.08
07:00-07:59	1.25 ± 0.36	1.07 ± 0.22	1.14 ± 0.36	1.19 ± 0.37
08:00-08:59	1.49 ± 0.52	1.23 ± 0.40	1.29 ± 0.43	1.30 ± 0.48
09:00-09:59	1.47 ± 0.57	1.40 ± 0.36	1.44 ± 0.61	1.64 ± 0.67
10:00-10:59	1.56 ± 0.66	1.70 ± 0.46	1.52 ± 0.74	1.71 ± 0.77
11:00-11:59	1.43 ± 0.74	1.46 ± 0.66	1.45 ± 0.66	1.54 ± 0.77
12:00-12:59	1.31 ± 0.52	1.30 ± 0.50	1.52 ± 0.56	1.56 ± 0.73
13:00-13:59	1.39 ± 0.48	1.64 ± 0.40	1.44 ± 0.69	1.50 ± 0.64
14:00-14:59	1.19 ± 0.39	1.37 ± 0.71	1.51 ± 0.67	1.40 ± 0.59
15:00-15:59	1.31 ± 0.46	1.18 ± 0.42	1.48 ± 0.64	1.46 ± 0.69
16:00-16:59	1.35 ± 0.67	1.14 ± 0.34	1.22 ± 0.59	1.28 ± 0.51
17:00-17:59	1.30 ± 0.66	1.15 ± 0.28	1.20 ± 0.38	1.18 ± 0.35
18:00-18:59	1.22 ± 0.33	1.25 ± 0.29	1.10 ± 0.37	1.24 ± 0.38
19:00-19:59	1.14 ± 0.33	1.09 ± 0.38	1.12 ± 0.29	1.11 ± 0.29
20:00-20:59	1.07 ± 0.20	1.09 ± 0.26	1.10 ± 0.32	1.12 ± 0.32
21:00-21:59	1.18 ± 0.37	1.10 ± 0.25	1.16 ± 0.29	1.18 ± 0.39
22:00-22:59	1.14 ± 0.30	1.09 ± 0.28	1.05 ± 0.38	1.16 ± 0.37
23:00-23:59	1.03 ± 0.13	1.70 ± 0.23	1.52 ± 0.19	1.09 ± 0.27

These data are shown graphically in Figure 2 (below). As with the ambulatory temperatures, there is a quiescent and stable nocturnal period from 0001 to 0700 h, followed by a steep rise in activity during the early morning (0700 to 1000 h). The hours between 1000 and 1500 appear to show a period of divergence between the two groups. The Cold group show an apparent higher level of activity during these hours, corresponding to a period in which their ambulatory temperatures are lower (see also Figures 3-6). This is the period of main, though falling, activity levels between the Warm and Cold groups. The general pattern of activity revealed conforms to a normative circadian rhythm, with activity rising from 0600 to 1200 and then falling in an oscillatory manner towards nocturnal quiescence.

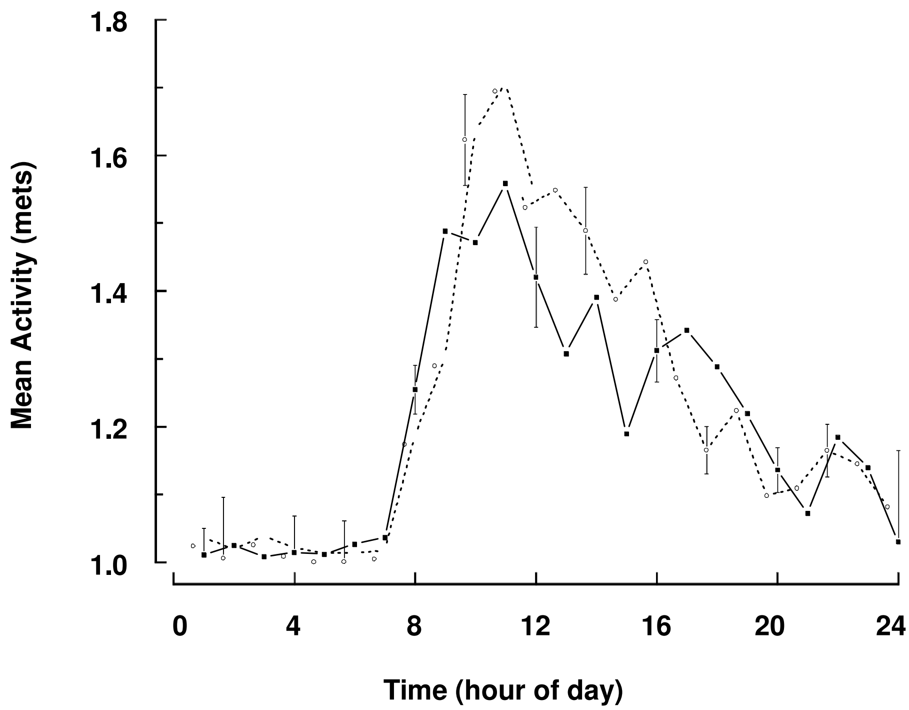


Figure Two: Activity (hourly means ± sd) of True Warm (—) and Cold (···) subjects (numbers as in Table 3) over 24 hours

3.4 Behavioural Data ('exc')

Average excursional data, defined in terms of the number of daily excursions outside the home per subject, duration of individual excursions in external temperatures and total time outdoors, are given in Table 4 below.

Table 4. Excursional data of True Warm (n=6), Warm* (n=4), False Warm (n=7) and Cold (n=10) subjects.

	True Warm	**Warm***	**False Warm**	**Cold**
No of Outdoor Excursions per day	0 (n=1) 1 (n=1) 2 (n=4)	1 (n=3) 2 (n=1)	1 (n=1) 2 (n=5) 5 (n=1)	0 (n=1) 1 (n=5) 3 (n=3) 5 (n=1)
Mean no of Excursions per person per day	1.50	1.25	2.28	1.93
Mean Duration and range (hr : min)	01 : 18 (00:45 – 02:15)	02:18 (00:45 – 04:15)	01:52 (00:20 – 06:15)	01:50 (00:40 – 04:00)
Total Time Outdoors and range (hr : min)	02:33 (01:00 – 03:30)	02:52 (01:00 – 04:15)	04:41 (00:20 – 06:15)	03:40 (01:30 – 05:50)

It appears that the number of excursions per day (mean number per person) was highest in the two colder groups, as was the total time spent outdoors. Noticeably, the longest individual outdoor excursion (at 6 hours 15 minutes) was found in the False Warm group. However, the longest mean duration was 2 hours 18 minutes in the Warm group, though there were only 4 individuals in this group.

3.5 Domestic Temperatures

The mean 24 hour data for the domestic rooms are shown in Table 5, with the 24 hour profiles of room temperatures in the various groups of subjects shown in Tables 6a and 6b. The mean 24 hour temperature varied maximally between the 'Cold' and 'True Warm' groups (Table 5) by 4.54 °C in the case of the living room, 6.44 °C in the kitchen, 5.35 °C in the bedroom and by 9.19 °C in the bathroom. The temperature distributions, however, were different in the two groups. The warmest room in the 'True Warm' group was the kitchen (23.08 °C), compared to the living room in the 'Cold' group at 17.69 °C. The coldest room in the 'True Warm' group was the bedroom at 22.16 °C, compared to the bathroom in the 'Cold' group at 14.40 °C. The maximum difference across all rooms in the 'True Warm' group only amounted to 1.43 °C whereas in the 'Cold' group the difference was some 3.3 °C. It is interesting to note that in the 'False Warm' group mean temperatures were lower than the 'Cold' group in 3 out of 4 rooms. *In conclusion therefore, not only were temperatures in the 'True Warm' group higher in all rooms but there was a much smaller range of temperatures across the rooms of the house; or, conversely, the 'Cold' household had lower temperatures in all rooms and a much greater difference between each of the rooms.* These differences are graphically illustrated over their 24 hour time course in Figures 3 -6.

The range and fluctuation of domestic temperatures were different in absolute levels and in magnitude between the various groups. For example, the range of fluctuation of living room temperatures over 24 h was greatest in the Cold group (4.18°C) which had the lowest temperature (15.51°C) between 0600 and 0700, rising to 19.69°C between 2000 and 2100. By contrast, the True Warm group had only a living room range of 2.18°C with a mean temperature 4.54°C higher than the cold group. Similarly in all the other rooms, the Cold group showed a greater fluctuation of temperatures than the other groups.

Therefore in terms of stability, mean temperatures and thermal gradients between rooms, the Cold group showed significant disadvantages to the other groups.

Table 5. Average 24 h domestic temperatures by room (mean ± sd) and range of True Warm (n=6), Warm*(n=4) False Warm (n=7) and Cold (n=15) subjects.

	Domestic Temperatures (mean ± sd) °C (range)			
Group / Room	**True Warm**	**Warm***	**False Warm**	**Cold**
Living Room (LR)	22.23 ± 2.15 (14.0 – 27.50)	19.39 ± 4.43 (9.50 – 24.00)	17.76 ± 4.25 (9.50 – 24.00)	17.69 ± 2.81 (13.00 – 28.00)
Kitchen (K)	23.08 ± 2.46 (16.00 – 27.00)	21.83 ± 1.58 (19.00 – 26.50)	14.94 ± 3.52 (6.50 – 21.00)	16.64 ± 3.92 (8.00 – 30.00)
Bedroom (BE)	22.16 ± 1.77 (17.00 – 34.00)	20.97 ± 1.36 (18.50 – 24.50)	15.00 ± 5.25 (8.00 – 25.50)	16.81 ± 2.53 (12.00 – 30.50)
Bathroom (BA)	23.59 ± 2.27 (17.00 – 26.00)	20.28 ± 1.30 (17.50 – 21.50)	13.93 ± 5.29 (8.00 – 24.00)	14.40 ± 2.94 (9.00 – 21.00)

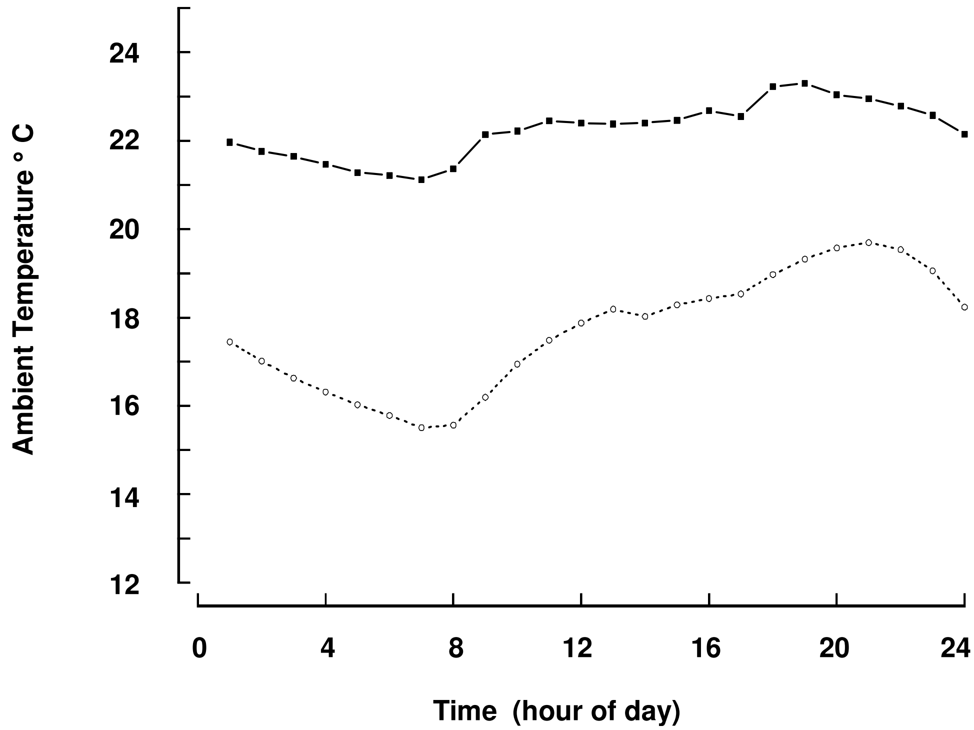


Figure 3: Living room temperatures (hourly means) of True Warm (—) and Cold (···) subjects (numbers as in Table 5) over 24 hours

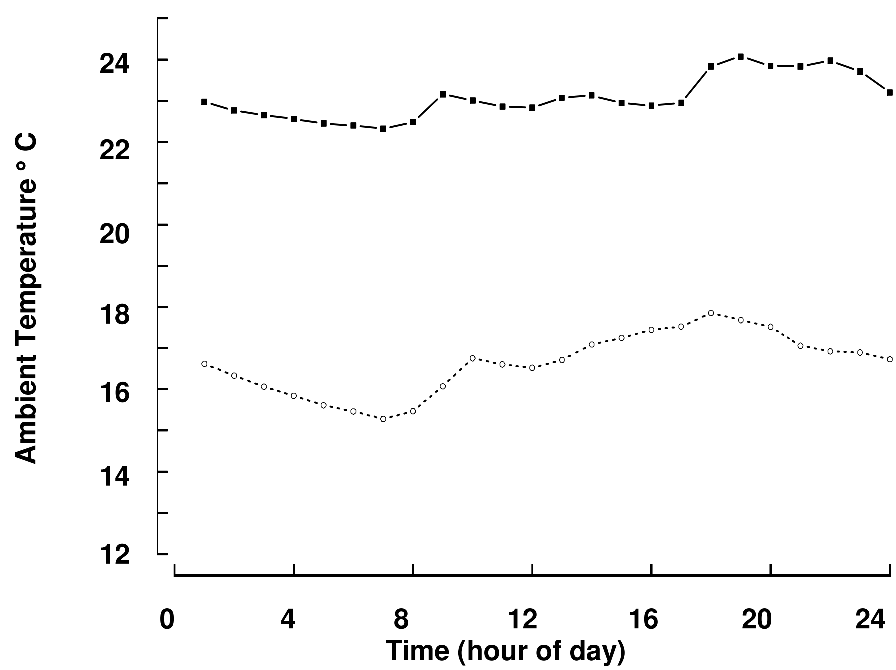


Figure 4: Kitchen temperatures (hourly means) of True Warm (—) and Cold (···) subjects (numbers as in Table 5) over 24 hours

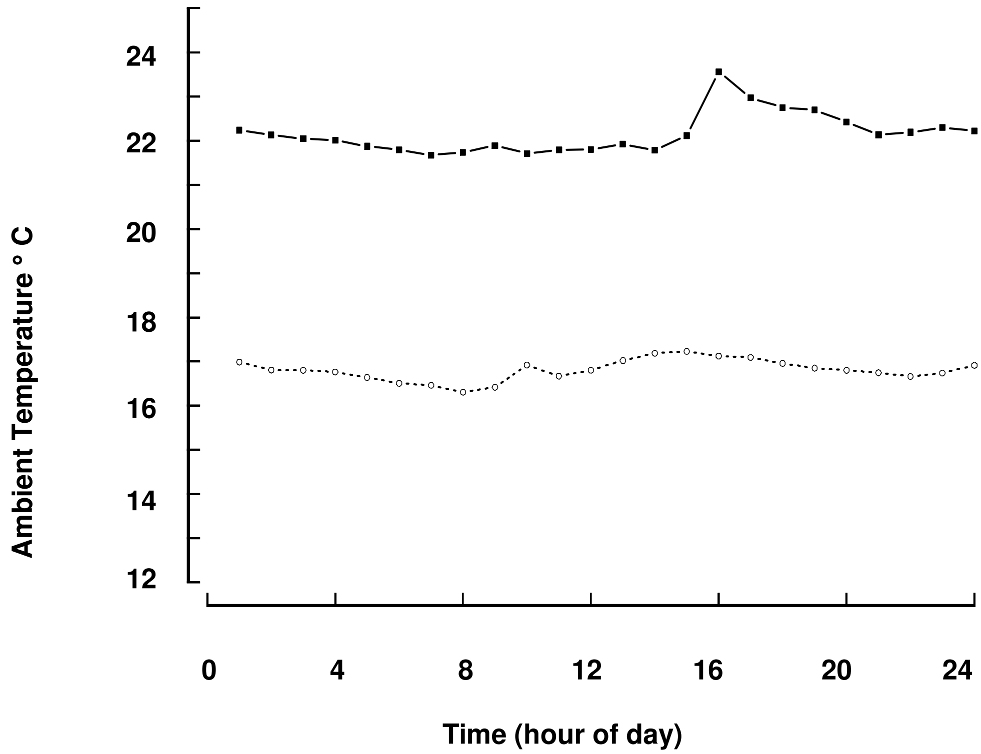


Figure 5: Bedroom temperatures (hourly means) of True Warm (—) and Cold (···) subjects (numbers as in Table 5) over 24 hours

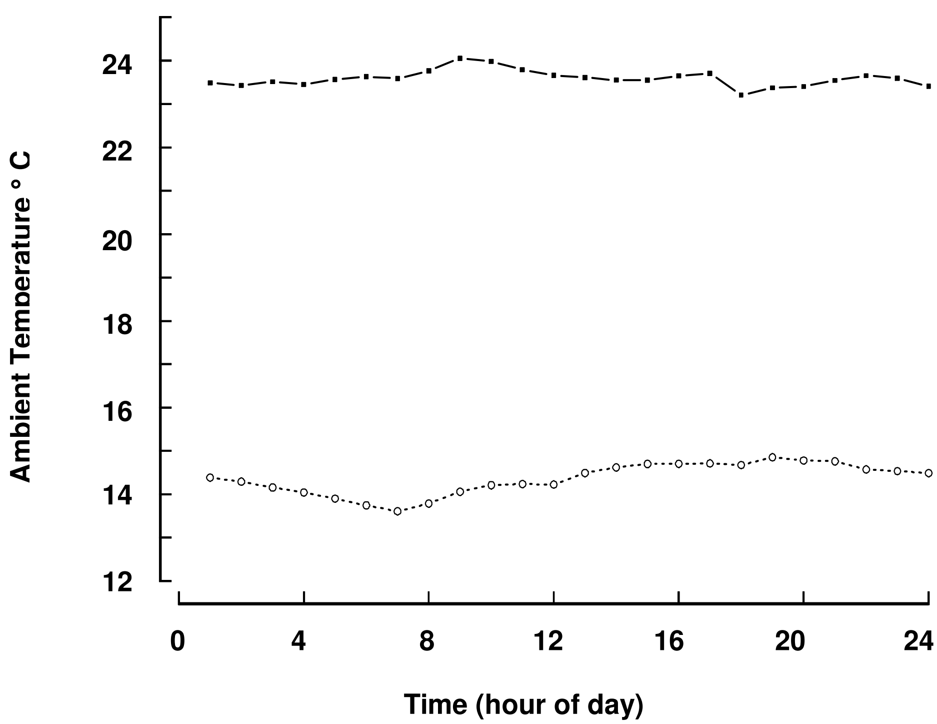


Figure 6: Bathroom temperatures (hourly means) of True Warm (—) and Cold (···) subjects (numbers as in table 5) over 24 hours

Table 6a. Average hourly temperatures by room (mean ± sd) of True Warm (n=6), Warm* (n=7) and Cold (n=15) subjects from 0001 to 1159 h.

	Living Room				Kitchen				Bedroom				Bathroom			
Time(hour of day)	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold
00:00-00:59	21.97 ±2.55	19.28 ±4.32	17.68 ±3.92	17.45 ±2.28	22.98 ±2.57	21.62 ±1.79	15.31 ±3.71	16.62 ±3.88	22.24 ±1.46	21.33 ±1.86	15.50 ±4.95	16.99 ±2.47	23.49 ±2.29	20.35 ±1.19	14.08 ±5.22	14.39 ±2.84
01:00-01:59	21.76 ±2.71	19.01 ±4.46	17.04 ±3.96	17.02 ±2.09	22.76 ±2.73	21.49 ±1.78	15.79 ±3.61	16.33 ±3.72	22.13 ±1.59	21.12 ±1.71	15.22 ±4.72	16.81 ±2.47	23.43 ±2.45	20.24 ±1.28	13.69 ±5.33	14.29 ±2.85
02:00-02:59	21.64 ±2.85	18.78 ±4.63	16.52 ±4.05	16.63 ±1.94	22.66 ±2.87	21.47 ±1.77	15.67 ±3.66	16.07 ±3.60	22.04 ±1.75	20.84 ±1.42	14.99 ±4.62	16.80 ±2.54	23.52 ±2.56	20.25 ±1.08	13.45 ±5.21	14.16 ±2.85
03:00-03:59	21.47 ±2.96	18.84 ±4.79	16.13 ±3.97	16.31 ±1.79	22.56 ±2.99	21.50 ±1.80	15.81 ±3.63	15.85 ±3.51	22.01 ±1.95	20.70 ±1.30	14.80 ±4.49	16.76 ±2.63	23.45 ±2.70	20.25 ±1.03	13.29 ±5.16	14.04 ±2.83
04:00-04:59	21.28 ±3.04	18.75 ±4.94	15.76 ±4.02	16.03 ±1.76	22.45 ±3.04	21.71 ±1.62	15.85 ±3.51	15.62 ±3.52	21.87 ±2.02	20.70 ±1.29	14.52 ±4.58	16.64 ±2.69	23.57 ±2.84	20.32 ±1.10	12.89 ±5.22	13.90 ±2.74
05:00-05:59	21.22 ±3.11	18.67 ±5.08	15.47 ±4.11	15.78 ±1.67	22.40 ±3.20	21.61 ±1.59	16.97 ±3.54	15.46 ±3.48	21.79 ±2.14	20.75 ±1.07	14.43 ±4.59	16.51 ±2.78	23.63 ±2.98	20.37 ±1.14	12.68 ±5.06	13.75 ±2.69
06:00-06:59	21.12 ±3.21	18.51 ±5.08	15.31 ±4.08	15.51 ±1.71	22.33 ±3.28	21.57 ±1.56	16.66 ±3.83	15.28 ±3.48	21.67 ±2.23	21.11 ±0.75	14.53 ±4.83	16.46 ±2.83	23.58 ±3.08	20.38 ±1.14	13.00 ±5.12	13.61 ±2.74
07:00-07:59	21.37 ±2.80	18.70 ±4.75	15.64 ±3.81	15.56 ±1.80	22.48 ±3.04	21.63 ±1.64	16.05 ±3.79	15.47 ±3.56	21.74 ±2.12	21.35 ±0.95	14.70 ±4.90	16.31 ±2.59	23.76 ±2.80	20.38 ±1.14	13.01 ±5.13	13.79 ±2.91
08:00-08:59	22.14 ±1.40	18.68 ±4.90	16.14 ±4.01	16.20 ±1.94	23.16 ±2.07	21.78 ±1.76	15.80 ±2.85	16.08 ±4.32	21.89 ±1.44	21.53 ±1.03	14.95 ±4.95	16.42 ±2.45	24.05 ±2.12	20.41 ±1.16	13.61 ±4.93	14.06 ±3.03
09:00-09:59	22.22 ±1.51	18.69 ±5.05	16.72 ±4.43	16.94 ±2.25	23.01 ±2.07	21.85 ±1.67	15.54 ±2.79	16.76 ±4.39	21.71 ±1.36	20.96 ±0.97	15.08 ±4.78	16.92 ±3.17	23.98 ±2.19	20.51 ±1.18	13.86 ±4.83	14.21 ±2.90
10:00-10:59	22.45 ±1.66	18.63 ±5.15	16.68 ±4.63	17.48 ±2.68	22.86 ±2.26	21.91 ±1.57	15.18 ±3.19	16.61 ±4.12	21.79 ±1.39	20.83 ±1.10	15.11 ±5.17	16.67 ±2.42	23.79 ±1.95	20.56 ±1.07	13.85 ±5.00	14.24 ±3.08
11:00-11:59	22.40 ±1.46	18.57 ±5.24	16.51 ±4.53	17.87 ±2.81	22.83 ±2.13	21.84 ±1.64	14.73 ±3.01	16.52 ±3.91	21.80 ±1.13	20.68 ±1.13	15.34 ±5.46	16.81 ±2.58	23.66 ±1.97	20.38 ±1.15	14.06 ±5.06	14.22 ±3.05

Table 6b. Average hourly temperatures by room (mean ± sd) of True Warm (n=6), Warm* (n=7) and Cold (n=15) subjects from 1201 to 2359 h.

	Living Room				Kitchen				Bedroom				Bathroom			
Time(hour of day)	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold	True Warm	Warm*	False Warm	Cold
12:00-12:59	22.38 ±1.07	18.64 ±5.44	17.29 ±5.02	18.19 ±2.59	23.08 ±1.77	21.76 ±1.74	15.31 ±3.13	16.72 ±3.68	21.92 ±0.88	20.74 ±1.15	16.01 ±5.98	17.02 ±2.61	23.61 ±1.98	20.24 ±1.31	14.60 ±5.41	14.49 ±2.72
13:00-13:59	22.40 ±1.04	19.41 ±4.64	18.22 ±4.35	18.02 ±2.60	23.13 ±1.92	22.12 ±1.40	15.79 ±2.87	17.09 ±3.44	21.78 ±1.03	20.89 ±1.16	16.26 ±6.01	17.19 ±2.53	23.55 ±2.12	20.22 ±1.34	14.56 ±5.64	14.62 ±2.79
14:00-14:59	22.46 ±1.26	20.30 ±2.94	19.75 ±2.91	18.28 ±2.61	22.94 ±2.15	22.03 ±1.39	15.67 ±3.17	17.25 ±3.42	22.12 ±1.42	20.85 ±1.15	16.10 ±5.54	17.23 ±2.44	23.55 ±2.02	20.14 ±1.30	14.52 ±5.50	14.70 ±2.89
15:00-15:59	22.68 ±1.66	19.73 ±4.12	19.20 ±4.22	18.43 ±2.62	22.89 ±2.13	21.97 ±1.90	15.81 ±3.43	17.44 ±3.75	23.56 ±3.57	21.06 ±1.42	16.33 ±5.71	17.13 ±2.39	23.65 ±2.09	20.19 ±1.36	14.50 ±5.52	14.70 ±2.90
16:00-16:59	22.55 ±1.77	19.34 ±4.73	18.37 ±4.60	18.53 ±3.03	22.95 ±2.25	22.27 ±2.14	15.85 ±3.72	17.52 ±3.95	22.97 ±2.72	21.18 ±1.70	16.15 ±5.55	17.10 ±2.41	23.71 ±2.21	20.22 ±1.56	14.39 ±5.50	14.71 ±2.94
17:00-17:59	23.22 ±1.55	19.85 ±3.83	18.98 ±3.87	18.97 ±3.10	23.84 ±1.98	22.10 ±1.98	16.97 ±2.73	17.85 ±4.14	22.75 ±1.14	20.86 ±1.58	16.45 ±4.83	16.96 ±2.27	23.20 ±1.71	20.09 ±1.50	14.59 ±5.24	14.68 ±2.96
18:00-18:59	23.30 ±1.29	20.23 ±3.46	19.52 ±3.46	19.32 ±3.08	24.08 ±2.08	22.14 ±1.91	16.66 ±2.90	17.68 ±4.31	22.70 ±0.88	20.99 ±1.46	16.36 ±4.89	16.85 ±2.28	23.37 ±1.90	20.14 ±1.51	14.36 ±5.44	14.85 ±3.12
19:00-19:59	23.04 ±1.22	20.87 ±2.63	20.37 ±2.55	19.57 ±3.03	23.85 ±2.07	22.05 ±1.78	16.05 ±3.12	17.52 ±4.34	22.42 ±0.94	21.08 ±1.50	16.24 ±4.99	16.80 ±2.29	23.40 ±1.98	20.15 ±1.51	14.28 ±5.45	14.78 ±3.10
20:00-20:59	22.95 ±1.12	21.02 ±2.29	20.67 ±2.25	19.69 ±2.94	23.84 ±1.94	22.02 ±1.80	15.80 ±3.36	17.06 ±3.96	22.13 ±1.04	20.99 ±1.47	16.09 ±5.02	16.75 ±2.37	23.54 ±1.88	20.13 ±1.56	14.11 ±5.57	14.76 ±3.11
21:00-21:59	22.78 ±1.05	20.83 ±2.48	20.43 ±2.30	19.54 ±2.90	23.98 ±1.82	21.93 ±1.86	15.54 ±3.47	16.93 ±3.93	22.19 ±1.14	20.88 ±1.63	16.00 ±4.95	16.66 ±2.35	23.65 ±1.80	20.23 ±1.60	14.27 ±5.33	14.57 ±3.04
22:00-22:59	22.58 ±1.49	20.25 ±3.34	19.31 ±3.19	19.06 ±2.77	23.71 ±1.95	21.79 ±1.85	15.18 ±3.61	16.90 ±3.94	22.30 ±1.46	20.87 ±1.63	15.90 ±4.93	16.74 ±2.34	23.59 ±1.87	20.26 ±1.41	14.37 ±5.27	14.54 ±2.96
23:00-23:59	22.15 ±2.23	19.72 ±4.04	18.58 ±3.91	18.24 ±2.47	23.21 ±2.32	21.66 ±1.79	14.73 ±3.72	16.73 ±3.83	22.23 ±1.42	20.97 ±1.22	15.76 ±5.07	16.92 ±2.35	23.41 ±2.15	20.39 ±1.19	14.27 ±5.20	14.49 ±2.94

3.6 Meteorological Data

Table 7. Average Daily Temperatures °C: January-March 2003 (mean and sd). 24-hour temperature data sourced from the Meteorological station at Teesside International Airport.

	Dry Bulb (t_{db})	SD	Min	Max	Wind Chill (t_{wc})	SD	Min	Max
January	6.48	3.56	-2.00	14.00	2.73	5.10	-10.00	14.00
February	3.91	3.93	-6.00	12.00	1.21	4.30	-8.00	12.00
March	7.53	3.77	-1.00	15.00	5.89	4.56	-4.00	15.00

sd = standard deviation

The weather over the testing period was very cold – at no time did dry bulb temperature rise above 15°C and the mean 24 hour dry bulb temperature over the measurement period was only 5.97°C, with minimum temperatures as low as - 6.0°C. February was the coldest month and March the warmest, though the differences are small (a maximum difference of 3.6 °C between the two months). This is further indicated by the minimum temperatures: as low as -6.0°C in February with an effective wind-chill temperature still lower at -8.0°C, rising only to a minimum of -1.0°C in March when the wind chill temperature 'rose' to -4.0°C. It is worth noting that all the mean 24 h dry-bulb and wind-chill temperatures were well below the 15 °C 'pressor' threshold, the temperature at which a temperature related systemic rise in blood pressure occurs and at which other potentially harmful haematological changes are provoked.

4. Statistical Analysis

4.1 Time Series Modelling of Waking Activity

4.1.1 Scope of Modelling

a. Human activity whilst asleep can generally be presumed to be at a consistent minimum, compared to higher and more variable levels associated with all the routines of normal daily living whilst awake. Because of the fundamental constant-variance assumption of ARIMA (**A**uto **R**egressive **1**st order **M**oving **A**verage) time series models, it was necessary to separate the typical sleeping and waking periods, and the decision was taken to focus on the description of waking activity. Throughout this section, and for all subjects, the period from midnight to 0700 h (0001 to 0700 h, minutes 1-420) was regarded as a predominant sleeping period, whilst the time from 0901 to 2200 (minutes 541-1320) was taken as essentially a waking period. It is of course recognised that the waking period will include short spells of rest or sleep for some individuals, just as the sleeping period is likely to include short spells awake, e.g. for occasional visits to the bathroom. However, as Figure 7 makes clear, the above simplification is not unreasonable and the 'flat minimum' level of activity during the hours of sleep is obvious.

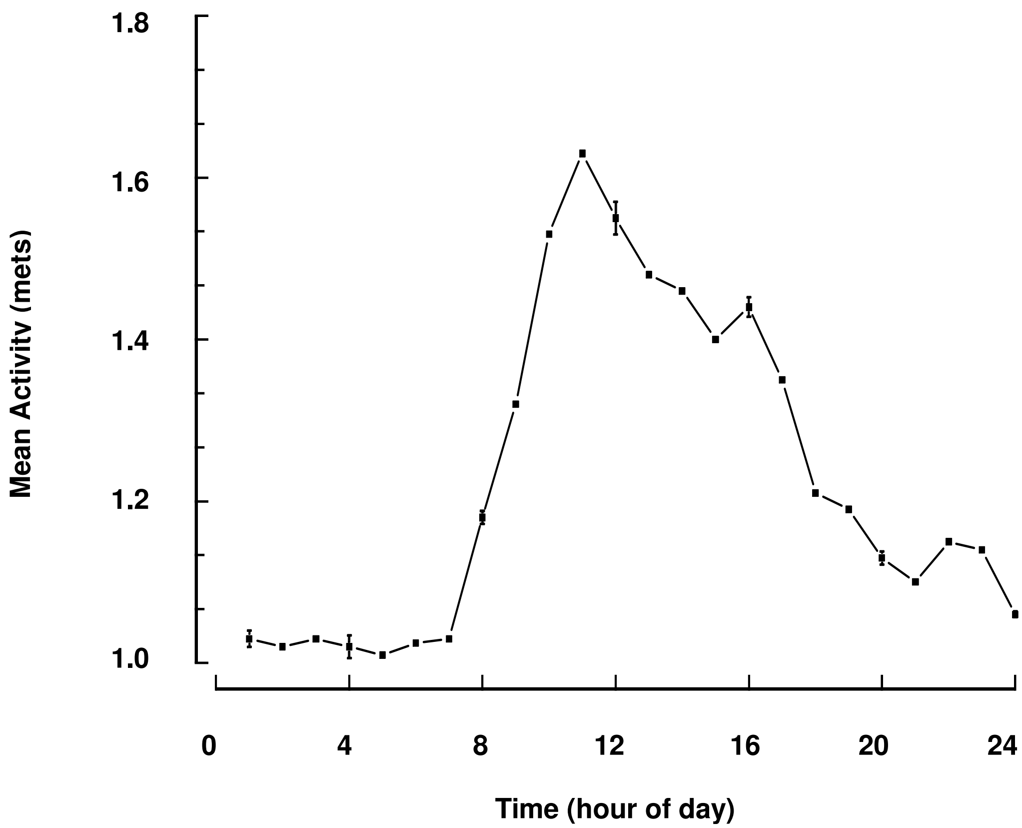


Figure 7: Activity levels (hourly means ± sd) over 24 hours (all subjects)

b. For each subject, five basic ARIMA models were fitted to the first differences of i) the raw activity series and ii) the logarithms of the raw activity values. A third log-type transformation was also used, having regard to the 'presumed instrument artefact' of an observed minimum activity reading of 0.0168 units (which is for some subjects the most commonly occurring value). Accordingly, 0.9832 was added to the data to give a minimum value of 1 before taking logs. The five models used are:

First order Autoregressive or AR(1),
First order Moving Average or MA(1),
Second order Autoregressive or AR(2),
Second order Moving Average or MA(2),
(First order) Autoregressive (First order) Moving Average or ARMA(1,1).

This choice of models follows that used in earlier work (Goodwin 1999) in which the ARMA(1,1) model was found to work well. If X_t is activity at time *t* and ε_t is the random error at time *t*, then for some constant parameters θ and φ the form of this model is

$$\log(X_t - X_{t-1}) = \phi(X_{t-1} - X_{t-2}) + \varepsilon_t - \theta\varepsilon_{t-1},$$

i.e. log(current change) = constant x (previous change) + constant x (previous error) + current error.

4.1.2 Summary Results

a. In the present analysis, time series modelling follows somewhat similar lines to the earlier work referred to above but is rather less successful. As before, fitting the ARMA(1, 1) model to first differences of the log(data) yielded the most useful results. However, in this exercise it was in several instances not possible even to estimate the model parameters and the estimated model sometimes provided a poor fit (in the sense that the standard Ljung-Box chi-square test failed for at least three of the four lags at which it was computed).

b. A brief summary of the results obtained is presented in Table 8 below, those for the best fitting **Log (Activity) model** being shown in bold type. It is seen, first, that Raw`Activity and Log (Activity + 0.9832) results are closely similar: this is not surprising, as the latter are close to the more usual Log (1 + ***x***) transformation which yields values close to the original data ***x*** if ***x*** is small compared to 1 (as is the case here). With the exception of ill-fitting models for subject 19, nearly all the estimates point consistently to a positive autoregressive parameter, typically 0.5 to 0.7 or so, and a rather larger moving average parameter, typically 0.8 to 0.9 or more. It may be conjectured that at least some of the failures of estimation arose from violation of the moving average invertibility limit of +1 during the iterative estimation procedure.

c. One-way analyses of variance for group differences related to charging for heating were carried out on the estimated AR and MA coefficients in the models for Log (Activity). As might be expected from the table, no significant differences were found.

d. It should also be noted that, for all three of the above transformations of the data, the (generally best-fitting) ARMA (1,1) model could not be estimated for 11 of the 32 subjects. In the quest for a more successful time series model, an ARMA (1,2) (first order autoregressive, second order moving average) model was applied to the log-transformed data, and modelling of second differences of the data was also tried. Neither of these performed as well as the ARMA (1,1) model.

Table 8: Summary Results of Fitting ARMA(1, 1) Model to Waking Activity Data

Subject	**Group**	**Raw Activity**		**Log(Activity)**		**Log(Activity+0.9832)**	
No.		**AR**	**MA**	**AR**	**MA**	**AR**	**MA**
3	**C**	0.728	0.944	**0.769**	**0.957**	0.728	0.944
4	**C**	x	x	**0.679**	**0.916**	x	x
27	**C**	x	x	**x**	**x**	x	x
30	**C**	0.464*	0.925*	**0.527***	**0.929***	0.466*	0.925*
39	**C**	0.547*	0.906*	**0.680***	**0.930***	0.547*	0.906*
40	**C**	0.579*	0.890*	**0.590**	**0.877**	0.579*	0.890*
41	**C**	x	x	**x**	**x**	x	x
43	**C**	0.480	0.837	**0.537**	**0.862**	0.481	0.838
44	**C**	0.625	0.923	**0.702**	**0.948**	0.624	0.921
45	**C**	0.737*	0.946*	**x**	**x**	0.742*	0.948*
49	**C**	0.513*	0.922*	**0.607**	**0.947**	0.514*	0.922*
50	**C**	0.382*	0.636*	**0.406**	**0.668**	0.377*	0.632*
51	**C**	0.639*	0.931*	**0.710**	**0.943**	0.638*	0.929*
52	**C**	x	x	**x**	**x**	x	x
53	**C**	0.505	0.864	**0.622**	**0.897**	0.505	0.862
21	**TW**	0.311	0.687	**0.377**	**0.676**	0.313	0.686
28	**TW**	0.471	0.916	**0.568**	**0.925**	0.472	0.915
32	**TW**	0.548	0.862	**0.609**	**0.890**	0.551	0.863
36	**TW**	0.643	0.844	**0.716**	**0.899**	0.645	0.846
37	**TW**	x	x	**x**	**x**	x	x
48	**TW**	x	x	**x**	**x**	x	x
9	**W***	0.583	0.964	**x**	**x**	0.583	0.964
10	**W***	x	X	**x**	**x**	x	x
13	**W***	0.676*	0.952*	**0.737**	**0.965**	0.675*	0.950*
14	**W***	0.575*	0.956*	**0.594**	**0.938**	0.572*	0.954*
6	**FW**	0.580*	0.938*	**0.589**	**0.909**	0.580*	0.938*
7	**FW**	x	X	**x**	**x**	x	x
11	**FW**	0.468	0.892	**0.557**	**0.896**	0.466	0.888
12	**FW**	x	x	**x**	**x**	x	x
17	**FW**	x	x	**0.680**	**0.965**	x	x
18	**FW**	x	x	**x**	**x**	x	x
19	**FW**	-0.617*	-0.334*	**-0.621***	**-0.437***	-0.619*	-0.339*
Adequate fit		10		**18**		10	
Poor fit		11		**3**		11	
Failed to estimate		11		**11**		11	

AR = Auto-Regression; MA = Moving Average

4.2 Two-sample Tests on Hourly Means of Activity

For each subject, hourly means of activity were stored for the 17 (predominantly waking) hourly periods from 0700 h to midnight. These were supplemented by a single (sleeping period) mean for the period midnight to 0700 h, making 18 periods in all. For each of the 18 periods, the 32 subject means were subjected to Normal t and nonparametric (Mann-Whitney) two-sample tests for differences between the Warm and Cold groups. For this purpose, the groups were dichotomised as

i) Cold versus all Warm (C vs TW + W* + FW),

ii) Cold versus True Warm (C vs TW),

iii) Cold versus True Warm and Warm* (C vs TW + W*);

further, the tests were repeated for means of Log(Activity). Tests were conducted at the 5% significance level. It was hoped that a pattern of significant differences at particular times of day would emerge, for example when subjects were most likely to go out. In the event, of the entire set of 108 t-tests only four were significant:

C vs TW for raw and log data for 12:00-1:00pm (higher mean in C, p = 0.04);

C vs TW for raw and log data for 2:00-3:00pm (higher mean in C, p = 0.04);

none of the nonparametric tests was significant. As we expect on average 5% of a large number of substantially unrelated tests at the 5% level to be significant, this is not at all strong evidence for a simple Cold-Warm contrast at any time of day.

4.3 Regression and Analysis of Variance Models

4.3.1 Relationship between Activity and Ambulatory Temperature

a. There is a highly significant inverse relationship between Activity and Ambulatory Temperature. Direct graphical evidence is found in Figures 8 and 9 following.

The trend for Log(Activity) is slightly closer to linear. Linear regression analysis of the data gives $\log_{10}(activity) = -1.200 - 0.01774 \times (ambient\ temperature)$, with the estimated standard errors of 0.005 and 0.00017 respectively.

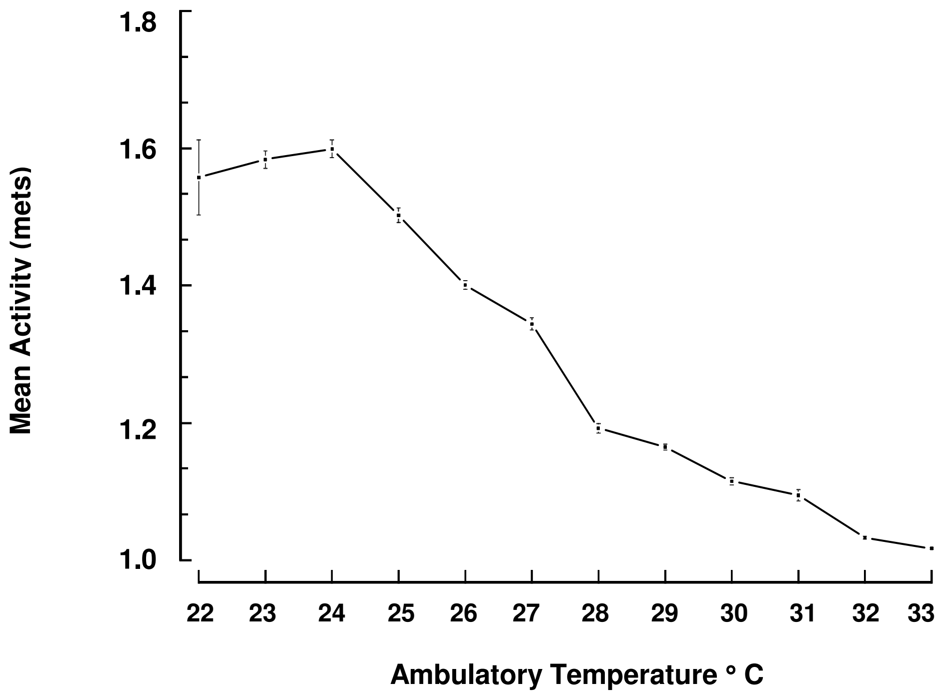


Figure 8: Activity levels (hourly means ± sd) as a function of ambulatory temperature (all subjects)

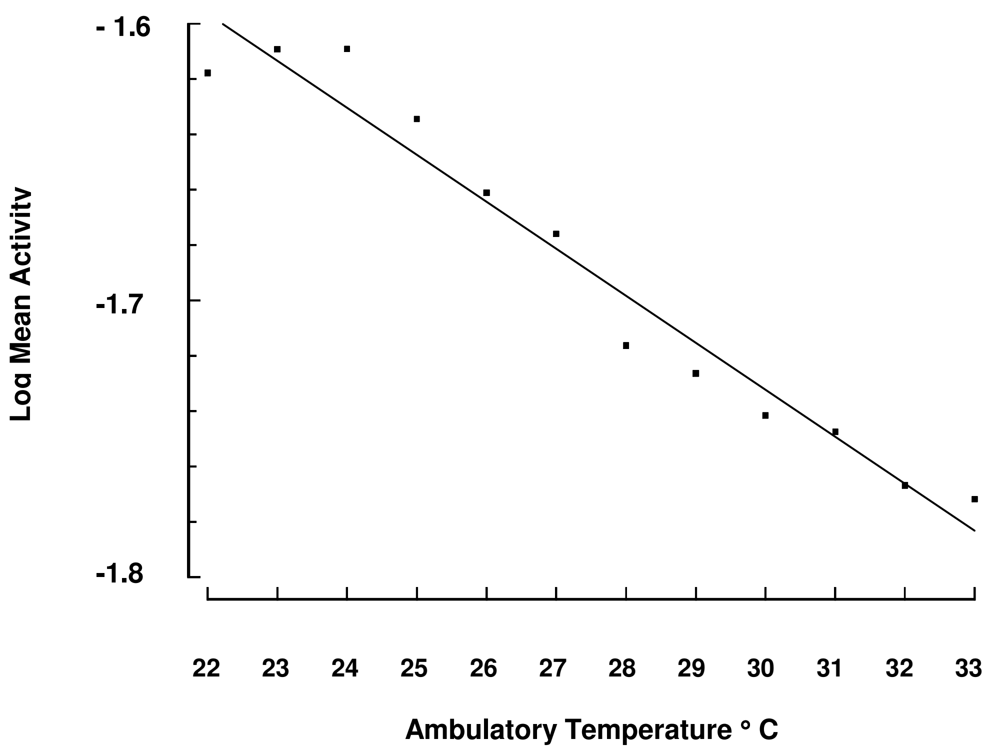


Figure 9: Mean Log (Activity) as a function of ambulatory temperature (all subjects)

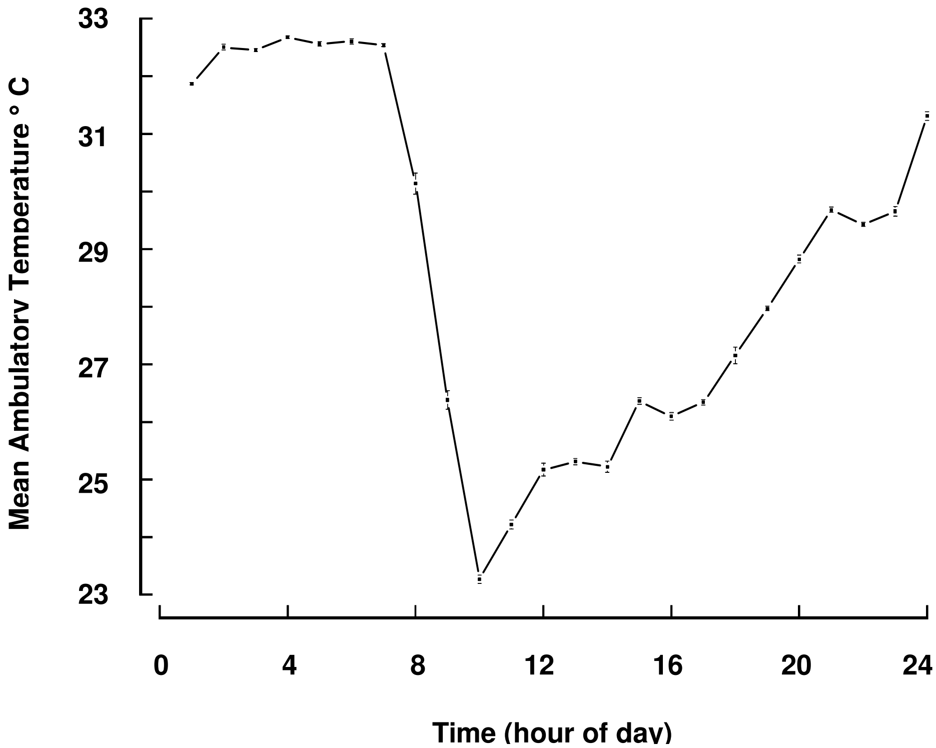


Figure 10: Ambulatory temperature (hourly means ± se) over 24 hours (all subjects)

b. The overall circadian variation of Ambulatory Temperature with time is displayed in Figure 10 above. Comparison with the corresponding graph for Activity in Figure 7 further confirms the inherent inverse relationship between these two bodily indicators. Within individual subjects, correlations between activity and ambulatory temperature range from –0.7 to –0.3 (all significant), taken over the day's observations. The case for ambulatory temperature as a covariate for the analysis of (log) activity is therefore firmly established.

4.3.2 Analysis of Covariance for Log(Activity) as Response

a. A more powerful (albeit complex) form of analysis of the activity period Means described in Section 4.2 would be to 'stack' or combine the data for all periods into a single overall response variable. This raises the possibility that experimental group contrasts, which are broadly consistent across periods but not individually significant, may by mutual reinforcement show up more clearly in the overall analysis. Models based on this underlying structure are repeated measures analyses, because 18 period Means are obtained from each subject. The Cold and Warm groups are a between-subjects factor (as each group consists of its own subjects), but the 18 Periods are 'within-subjects'. Eighteen corresponding Means of subjects' ambulatory temperatures are similarly stacked for use as a covariate, since (as we have seen) activity and ambulatory temperature are for all subjects highly negatively correlated. As suggested by Figures 8 and 9 above, Log(Activity) as response is better fitted than raw Activity, and models for this response also conform more closely to the desired assumption of constant-variance Normal errors.

b. Table 9 below shows the analysis of variance for group effects, which as formally tested are not significant. However, the *a priori* contrast (C + FW vs TW + W*), which substantially reflects the pattern of the four individual group effects, *only narrowly fails* to achieve significance at the 10% level. Residuals conform reasonably well to Normality and independence.

Table 9: Analysis of Covariance for Group and Period Effects on Log (Activity)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Amb. Temp.	2.47401	1	2.47401	716.9	$p << 0.001$
Groups (C, TW...) **[-1 1 1 –1]***	0.06200 (0.04945)	3 (1)	0.02067 (0.04945)	1.16 2.77	$p > 0.1$ $p \cong 0.1$
Subjects (within groups)	0.50018	28	0.01786		
Periods	0.24701	17	0.01453	4.21	$p < 0.001$
Error (within subjects)	1.81539	526	0.003451		
Total	5.09859	575			

Group C ‘Cold’; Group TW ‘True Warm’; etc (*vide page (v)).*

c. As was to be expected from the profile of Figure 7, period (time of day) effects are highly significant. We may now abstract from this analysis a plot of the 18 period effects against time (starting with the 7-hour sleeping period from midnight), shown in Figure 11 following. Standard errors of these effects are 0.01 approximately, so irregularities of up to this amount in the general trend should be discounted. From about 0700-0800 h there is a steep rise in activity to a sharp peak in late morning. This is followed by a decline through the afternoon, with generally low levels being reached by early evening.

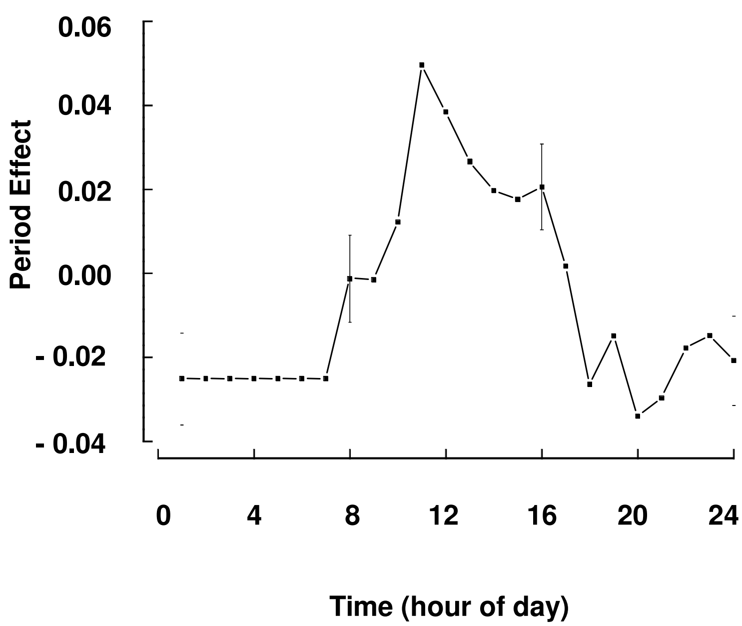


Figure 11: Diurnal trend of Period Effects (± se) on Log (Activity) – all subjects

4.3.3 Analysis of Variance for Ambulatory Temperature as Response

a. Since it is taken as understood that activity levels indicate a bodily response to ambient temperatures rather than the reverse, it seems inappropriate to use Activity or Log(Activity) as a covariate for Ambulatory Temperature. Apart from the absence of a covariate, the analysis is structured similarly to that of Section 4.2; the results are shown in Table 10 below. It is seen that all tests are more significant (or come closer to significance) than their counterparts for Log(Activity). In particular, there is reasonably strong significant support for concluding a difference between the average ambulatory temperatures of subjects according as to whether they are, or are not, billed for heating costs by use. The estimated coefficient of this contrast (which is coded as –1 for C and FW and as +1 for TW and W*) is 0.803 (±0.321). This implies that the TW and W* groups are on average 1.6 °C warmer than the C and FW groups, after allowing for the period effects. As with Activity, the Normality and independence assumptions for the residuals hold reasonably well.

Table 10: Analysis of Variance for Group and Period Effects on Ambulatory Temperature

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Groups (Cold, True Warm,..&c)	338.83	3	112.94	2.21	$p > 0.1$
[-1 1 1 –1]*	(319.51)	(1)	(319.51)	(6.25)	$0.01 < p < 0.025$
Subjects (within groups)	1432.30	28	51.15		
Periods	3558.04	17	209.30	23.11	$p << 0.001$
Error (within subjects)	4773.00	527	9.06		
Total	10102.17	575			

b. The period (time of day) effects are again extremely significant. Their pattern, shown in Figure 12, mimics the trend of mean ambulatory temperature already noted in Figure 10. Ambulatory temperature is greatest during the hours of sleep (presumably with the ring finger safely under the bedclothes) but then declines steeply to a minimum at about 1000 h. The recovery phase is steady but more gradual and protracted, and appears to continue through the afternoon and evening to bedtime. The range extends over 9 °C and the estimated standard errors are about 0.52 °C.

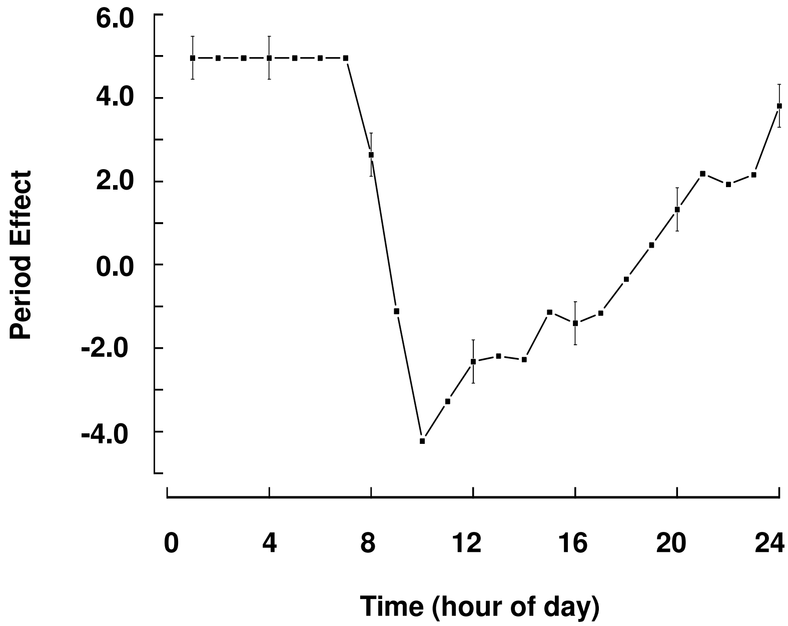


Figure 12: Diurnal trend of Period Effects (± se) on ambulatory temperature (all subjects)

4.3.4 Analysis of Variations in Domestic Heating Environment

a. A clear binary divide has now been established between the average ambulatory temperatures of subjects whose heating bills do, or do not, reflect the usage of fuel. In this section, analyses of the contemporaneous temperature records for the living-room (LR), kitchen (K), bedroom (BE) and bathroom (BA) for possible group differences and period effects are presented. Separate analyses are given for each of the 4 rooms. Because domestic room temperatures typically vary much more slowly than bodily ambulatory temperature, and to avoid unnecessarily cumbersome analysis, the day has been divided into 4 roughly equal periods rather than 18 as hitherto. These are

i) the 'night' or 'sleeping' period (0001 to 0700 or minutes 1-420, as before);

ii) 'morning' from breakfast to lunch (0701 to 1300 or minutes 421-780);

iii) 'afternoon' (1301 to 1800 or minutes 781-1080);

iv) 'evening' (1801 to 0000 or minutes 1081-1440).

Very roughly, the first period corresponds to the 'flat' portions of the generic activity and ambulatory temperature graphs in Figures 7 and 10, the second to the rise in activity / fall in ambulatory temperature; the third to the main decline in activity / rise in ambulatory temperature and the last to the low level of evening activity / final rise or recovery phase of ambulatory temperature.

Table 11: Analysis of Variance for Group and Period Effects on Domestic Temperatures

Location	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Living Room	**Groups (C, TW...)**	520.93	3	173.65	6.32	0.001 <p <0.005
	Subjects (within groups)	769.73	28	27.49		
	Periods	123.15	3	41.05	34.12	p << 0.001
	Error (within subjects)	111.88	93	1.20		
	Total	1525.69	127			
Kitchen	**Groups (C, TW...)**	1205.78	3	401.93	8.88	p < 0.001
	Subjects (within groups)	1266.77	28	45.24		
	Periods	41.28	3	13.76	19.97	p << 0.001
	Error (within subjects)	64.07	93	0.69		
	Total	2577.90	127			

Table 11 (continued)

Location	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Bedroom	**Groups (C, TW...)**	884.44	3	294.81	7.44	p < 0.001
	Subjects (within groups)	1109.58	28	39.63		
	Periods	10.50	3	3.50	3.88	0.01 < p < 0.025
	Error (within subjects)	83.93	93	0.90		
	Total	2088.46	127			
Bathroom	**Groups (C, TW...)**	1872.76	3	624.25	12.58	p << 0.001
	Subjects (within groups)	1389.43	28	49.62		
	Periods	6.30	3	2.10	7.12	p ≅ 0.001
	Error (within subjects)	27.45	93	0.30		
	Total	3295.95	127			

b. The tests for Groups in Table 11 suggest stronger effects in regard to room temperatures than have been concluded for subjects' ambulatory temperatures or (especially) activity levels, significance being established at $p = 0.005$ or better. As before, period effects also show significantly, at $p = 0.025$ or better. Residuals from the fitted models conform fairly well to the standard assumptions: those from the bedroom data are the least satisfactory with a Normal scores correlation of 0.946 and a maximum standardised value of 4.22. However, in all cases the Normal scores plots are substantially linear over the vast majority of the data range, suggesting that the above inferences are essentially valid. The next step is to examine the four sets of estimated Group and Period effects, and these are shown in Table 12.

Table 12: Estimated Group and Period Effects for Domestic Temperatures

		Living Room	Kitchen	Bedroom	Bathroom
Group	**1: Cold (C)**	-2.196	-2.468	-1.935	-3.674
	2: True Warm (TW)	2.303	3.933	3.422	5.533
	3: Warm* (W*)	1.998	2.675	2.208	2.219
	4: False Warm (FW)	-2.104	-4.140	-3.695	-4.078
Period	**1: Sleeping**	-1.186 (0.168)	-0.793 (0.127)	-0.286 (0.145)	-0.329 (0.083)
	2: Morning	-0.697 (0.168)	-0.280 (0.127)	-0.254 (0.145)	-0.075 (0.083)
	3: Afternoon	0.637 (0.168)	0.597 (0.127)	0.404 (0.145)	0.232 (0.083)
	4: Evening	1.246 (0.168)	0.476 (0.127)	0.136 (0.145)	0.171(0.083)

c. Taking the Group effects first, the main feature is that all four sets are broadly consistent with the '-1 +1 +1 –1' pattern corresponding to the contrast between (C + FW) on the one hand and (TW + W*) on the other. (Note that no standard errors are available for the estimated Group effects, but due to between-subject variation the actual standard errors are likely to be rather larger than those for the Period effects.) The results suggest that C and FW subjects keep their living rooms on average about 4.3 C° cooler than those in TW and W* homes. For the other rooms this is still the dominant pattern, but there are subsidiary contrasts of a degree or so between C and FW or between TW and W*. On the average, C and FW kitchens are relatively about 6.6 C° cooler; C and FW bedrooms about 5.6 C° cooler; and bathrooms roughly 7.8 C° degrees cooler. Regarding the Period effects, the diurnal trends are broadly consistent in all four rooms, in that mornings are cooler and afternoons and evenings warmer. Not surprisingly, all rooms are coldest at night. Kitchens and bathrooms are kept about equally warm during the afternoon and evening, whilst bedrooms are warmer in the afternoon. Living room temperatures increase steadily throughout the day, suggesting that this room is relatively little used in the morning but more popular in the evening, which accords with common experience. Typical diurnal temperature variations (from minimum to maximum) as shown by these effects are about 2.4 °C, 1.4 °C, 0.7°C and 0.6 °C for the living room, kitchen, bedroom and bathroom respectively.

4.4 Analyses of Data Extracts from 3 Temperature Environments

4.4.1 The 'Cold Outdoor Excursion' hypothesis raises the question that elderly people may be at heightened risk from suddenly leaving a warm indoor environment for the much colder outdoors. Diaries kept by subjects in the present study allow outdoor excursions to be identified, along with contrasting periods spent in specified indoor rooms or in bed. For 5 'Cold' subjects and 5 'Warm' subjects (two W* and 3 'True Warm), data were analysed for three 30-minute periods: one in bed at night, (0300 to 0329); one in the evening (0900 to 0929 pm); and an equal period outdoors (typically during late morning or early to mid afternoon). The representative outdoor sessions were selected *post hoc* so that subjects had, prior to each 30-minute extract, been outdoors for long enough for their ambulatory temperatures to have reached a roughly 'steady state' since leaving their homes. Any subjects, who at some time during the day's recording spent a continuous period of 40 minutes or so outdoors, could therefore be considered for inclusion in this purposive sub-sample. Contemporaneous bedroom and living room temperatures were included with subjects' ambulatory temperatures in the night and evening periods; and actual and wind-chill adjusted temperatures were noted for the outdoor sessions. As might be expected, it was found that for both groups wind-chill adjusted temperature correlated more closely with subjects' ambulatory temperatures than the unadjusted figures, and the wind-chill adjusted data are therefore used exclusively in this section.

4.4.2 The 30-minute average values of subjects' ambulatory temperatures constitute the 'responses' to be analysed. Corresponding 30-minute average values of the relevant environmental temperatures for each of the three periods (bedroom for night; windchill-adjusted for outdoors; living room for evening) comprise concomitant, or covariate, data for each subject. There are thus 30 responses, along with their covariate values (Environmental Temperature), corresponding to the observation of each subject in each of 3 periods, for 10 subjects equally divided between the generic 'Warm' and 'Cold' groups. The analysis of variance is given in Table 13 below. It is not surprising that environmental temperature and periods feature strongly; however, there is in this analysis no hint of a Groups contrast. Periods by Groups interactions were also tested, principally to provide for the possibility of a differential response between the groups to the sharply colder outdoor temperatures, but these were also not significant.

Table 13: Analysis of Variance of Ambulatory Temperatures in Three Environments

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Env. Temp.	1227.14	1	1227.14	125.0	p <<0.001
Groups Warm vs Cold	2.92	1	2.92	0.17	p >> 0.1
Subjects (within groups)	136.58	8	17.07		
Periods	319.81	2	159.91	16.28	p << 0.001
Periods x Groups Interactions	24.45	2	12.23	1.24	p > 0.1
Error (within subjects)	147.28	15	9.82		
Total	1858.17	29			

4.4.3 The estimated period effects are shown in Table 14 below, along with the cell mean values of subjects' ambulatory temperatures and of their environmental temperatures. First, it should be noted that the period effects are closely consistent with the variations in subjects' average ambulatory temperatures: thus night-time ambulatory temperatures are 2-2.4 C° higher than evening values and the night-time period effect exceeds the evening value by about the same amount. The outdoor effect is about 14.4 °C lower than the night value, whilst the corresponding Cold and Warm mean ambulatory temperatures differ by about 15-16 °C.

Table 14: Period Effects and Cell Mean Ambulatory and Environmental Temperatures °C

	Night (Bedroom)	Outdoors	Evening (Living Room)
Estd. Period Effect	5.58 (0.99)	-8.84 (2.19)	3.26 (1.69)
Cold Goup: Mean Amb Temp	32.92 (0.85)	16.18 (2.07)	30.54 (1.06)
Mean Env Temp	15.4 (1.32)	9.0 (1.90)	21.0 (1.75)
Warm Group: Mean Amb Temp	32.59 (0.52)	16.74 (2.39)	31.66 (0.34)
Mean Env Temp	21.0 (1.45)	4.4 (1.40)	23.5 (0.35)

Note: numbers in brackets indicate estimated standard errors.

4.4.4 Before leaving Table 14, it is necessary to draw attention to an apparent anomaly in the temperature figures. It is generally expected (and observed) that the ambulatory temperature recorded on subjects' finger rings is, as noted earlier, a varying compromise between adjacent air temperature and some approximation to the subject's body temperature. This notion is broadly illustrated in the 'Outdoors' and 'Evening' columns of the table, in which average drops in environmental temperature from 21°C to 9°C (Cold) or from 23.5°C to 4.4°C (Warm) are accompanied by a drop in ambulatory temperature from about 31°C to 16-17°C. The average night-time (bedroom) temperature of 15.4°C for the Cold group would therefore suggest an ambulatory temperature intermediate between 17°C and 31°C rather than nearly 33°C as observed. For the Warm group with a mean bedroom temperature of 21°C, the disparity is smaller but still discernible, as a drop in environmental temperature of 2.5C° is accompanied by a rise of about 1C° in ambulatory temperature.

4.5 Statistical Conclusions

4.5.1 Time series analysis of the present data is less satisfactory than had been hoped on the basis of earlier work (Goodwin 1999). This may be due to the different instrumentation used, or perhaps to the characteristics of elderly subjects. An ARMA(1, 1) model for the first differences of log(activity) is the most successful of those tried, but it fails to fit the data in nearly 50% of cases.

4.5.2 A strong inverse relationship between activity and subject-based ambulatory temperature is found, together with corresponding diurnal trends in these variables. This establishes the basis for an analysis of activity with ambulatory temperature as a covariate, in terms of diurnal time period effects and a factor for the method of charging for domestic heating. On statistical grounds, the logarithm of activity is used as the response.

4.5.3 Ambulatory temperature and time periods are found to have significant effects on activity, but the heating charge factor is not significant. However, when ambulatory temperature is analysed as the response, a significant contrast is observed between those paying a flat rate charge for heating and those paying by use, about 1.6C° in favour of the former. Analysis of living-room, kitchen, bedroom and bathroom temperatures reveals that, in the circumstances of the study, flat-rate charged subjects live in accommodation some 4-8C° warmer than do those billed by use.

4.5.4 The additional analysis (Section 4.4.2) of 30-minute night, outdoor and evening extracts of ambulatory temperature from 10 subjects in a purposive sample (carried out to throw light on the dependence of ambulatory temperature on environmental temperature and the heating charge factor) reveals significant night, outdoor and evening period effects consonant with the variations in ambulatory temperature. However, neither the full heating charge factor nor its a *priori* contrast is significant. This lack of significance may reflect the fact that the tendency of a low temperature environment to depress ambulatory temperature is largely obscured for sleeping subjects by 'insulation' of the finger-ring sensor under the bedclothes. It appears that, in the significantly cooler bedrooms of 'Cold' subjects, this insulation serves, differentially for this group, to prevent the drop in ambulatory temperature that would otherwise be expected. Unless carefully controlled, variations between subjects with regard to the wearing of gloves outdoors are also likely to have resulted in a loss of statistical power in the findings that can be deduced.

5. Discussion

5.1 All subjects demonstrated a significant inverse, approximately linear relationship between the logarithm of activity and ambulatory temperature. This is an important finding and to some extent corroborates previous work, where the daily activity levels of older people were found to be higher in cold winter temperatures than the summer (Goodwin 1999; Goodwin et al 2001) and where metabolic responses in older people were higher in colder temperatures than in warmer ones (Collins et al 1995). The importance of the finding is that we may conclude that the colder conditions of unheated homes impose an increased metabolic strain on older people in the form of a drive to increased activity levels. In purely metabolic terms this appears to be an adaptation for the purposes of heat production. This may or may not be sufficient for mitigating the effects of the cold. Lowered core temperatures in the older people were not demonstrated in this study but there is justification for inferring that they may well be lower in the Cold group compared to the Warm group (Goodwin 1999; Collins et al 1995; Keatinge et al 1986). It is known from previous work that low core temperatures, though non-hypothermic, are a central drive for raised systemic blood pressure (Collins et al 1985). Low skin temperatures are also a central drive for raised systemic blood pressure and from the evidence of the ambulatory temperatures, it may be inferred that the skin temperatures of the Cold and False Warm groups would be lower than those of the other groups. An increase in systemic blood pressure provokes mechanisms which lead to a higher risk of thrombotic incidents, such as stroke and heart attack. The met levels in this study were generally quite low (Table 3) but even at lower levels (eg at 30% of aerobic maximum) it has been shown that main effects of age, temperature and activity plus subtle interactions between age/activity and age/temperature are likely to increase cardiac strain in older people in the winter

(Goodwin 1999). At this juncture it is worth commenting on the met data recorded during sleep in this study. Met levels during sleep are well known to be below 1.08 mets (Åstrand and Rodahl 1986), the lowest continuous datum recorded here. This recording is considered to be an artefact of the instrument and represents the lowest resolvable point of its range.

5.2 In addition to the inverse temperature-activity relationship, it is worth considering the descriptive statistics in relation to excursions into the outside cold. Previous studies (Goodwin et al 2001) showed that the number of excursions in the winter is no different to those of the summer, in a group of 25 older healthy men. This may be described as an unmodified transfer of excursional behaviour from summer to winter. Such a finding is 'counter-intuitive', since many studies based on retrospective recall suggest that older people 'go out' more in the summer (eg Woodhouse et al 1993). It is therefore instructive to have data from within one winter season in which groups differing in indoor thermal conditions may be compared. The data presented in Table 4 appear to show that the older people in both the False Warm and Cold groups, with substantially cooler indoor thermal environments, undertake more daily excursions than those in the other two groups. Similarly, their total time spent outdoors appears to be considerably higher. These are new findings. There may be any number of explanations for these observations but the implication is that in warmer homes older people may be predisposed to venture out for less time, therefore protecting themselves against the risks of cold stress. There is however, a balance to be struck in relation to activity and outdoor excursions in the winter – the Eurowinter Study (1997) clearly showed an association between low indices of mortality, fewer excursions into the cold, higher activity levels outdoors, adequate clothing protection, mild winter outside temperatures and low indoor temperatures. Therefore the indication is that activity outside in the winter can be 'low risk' and there is no evidence to suggest that excursions outside in the winter, or reduced activity, should be proscribed entirely.

5.3 Both the subject-based activity and temperature measures follow broadly related diurnal (circadian) profiles. Average activity is least, and average ambulatory temperature greatest, during the night hours of rest or sleep, whilst activity is greatest (and ambulatory temperature least) around late morning to midday. The observation of a circadian rhythm of activity is to some extent to be expected – such rhythms are described in the literature (Aschoff 1970; Minors and Waterhouse 1981). However, It is interesting that there is an inverse pattern of modulation in the two rhythms. One possible explanation is that the activity rhythm, as a reflection of the endogenous rhythm of arousal, drives the daily pattern of activities which direct the individual into different thermal environments. Therefore there is a relationship between exposure to cooler temperatures and the levels of activity. Superimposed upon this relationship is the effect of ambient temperature on the degree of activity itself, as discussed in Section 5.1.

5.4 The Log (Activity) response of subjects was analysed with ambulatory temperature as a covariate, in conjunction with 'period' (time of day) effects and a 'group' factor which codes for the 4 methods of charging for heating (viz, True Warm, Warm*, False Warm and Cold). It was found that the effects of 'period' (time of day) on activity are highly significant but the heating charges factor is not significant. However, the *a priori* contrast, between subjects paying a flat rate for heating as opposed to those paying for heating by use, approaches significance at the 10% level. Strictly speaking, when α is set at 0.05 (and the power of the test is increased compared to α at 0.01) one should not draw inferences when significance is not reached. However, the results may be said to be *suggestive* of a relationship between the domestic thermal environment (as a proxy of heating charge) and the activity levels of the older people in the experiment, a position which is supported by the inverse relationship in all subjects between temperature and activity, as proven in this study.

5.5 Subject-based ambulatory temperature was analysed as the response in conjunction with ‘period’ (time of day) effects and the group factor as in *para* 5.3. The period effects were significant as expected: night time ambulatory temperatures are 2 – 2.4 °C higher than evening values and the period effect exceeds the evening value by about the same amount. The outdoor effect is about 14.4 °C lower than the night value, whilst the corresponding Cold and Warm mean ambulatory temperatures differ by about 15-16 °C. However, though the 4-level heating factor again fails to reach statistical significance, the *a priori* contrast is now significant ($p \leq 0.025$). It was estimated that the average ambulatory temperature of flat-rate charged subjects is about 1.6 °C higher than those of the ‘Cold’ subjects (all those billed by use). Such a disparity is not unexpected and it reflects the greater cooling effects of the domestic temperatures in the homes of the two groups. At this point it is worth commenting on the anomalous values of the two species of temperature measures (environmental and ambulatory). The ambulatory values appear inflated and it is suggested that this is a function of the data collection, in which a ring mounted next to the skin of the middle finger provided the site of measurement. Notwithstanding the somewhat inflated values (quantified in Table 14) the responses are consistent with changes in environmental temperature, with the exception of the night time readings. It appears reasonable to assume that the effect of the relatively cool bedroom temperature, particularly in the Cold group, was largely nullified by the insulation of bedclothes. In the context of the significantly cooler bedroom temperatures of ‘Cold’ subjects, this insulation serves, differentially for this group, to preclude the lower ambulatory temperatures that would otherwise be expected, and therefore to deflate the significance of the Cold/Warm contrast.

5.6 The results of the additional analysis of the 10 thirty-minute extracts of ambulatory temperature, carried out to throw light on the dependence of this variable on the contemporaneous environmental temperatures and the heating charge factor, deserves further comment. In contrast to the results of the analysis of domestic temperatures, neither the full heating charge factor nor the *a priori* contrast were significant. This lack of significance may reflect the fact that the tendency of a low temperature environment to depress ambulatory temperature is largely obscured for sleeping subjects by ‘insulation’ of the finger-ring sensor under the bedclothes. It appears that, in the significantly cooler bedrooms of ‘Cold’ subjects, this insulation serves, differentially for this group, to prevent the drop in ambulatory temperature that would otherwise be expected.

5.7 Similarly structured separate analyses of subjects’ domestic temperature environments were undertaken for the living room, kitchen, bedroom and bathroom. Along with time of day effects, the 4-level heating factor is consistently significant and its estimated effects are broadly consistent with the dominant operation of the *a priori* contrast noted above. On average and taken over all 4 rooms, Warm (flat-rate charged) subjects keep their accommodation some 4-8 °C warmer than that of ‘Cold’ subjects (all those billed by fuel consumption). As indicated earlier, not only were temperatures in the ‘True Warm’ group higher in all rooms but there was a much smaller range of temperatures across the rooms of the house; or, conversely, the ‘Cold’ household had lower temperatures in all rooms and a much greater difference between each of the rooms. Not only so but within each of the rooms the range and fluctuation of temperatures was also greater in the Cold than the other groups.

These temperature or thermal distributions clearly disadvantage those older people who restrict their heating on the grounds of cost. This study has shown that they result in exposure to lower domestic temperatures over 24 hours with time of day effects, a steeper thermal gradient within the house with the largest fluctuations within rooms in the four groups (with the exception of the False Warm group) and lower ambulatory temperatures. The claim of the False Warm group not to restrict their heating is shown to be largely fallacious if the environmental temperatures are examined. Table 5 shows them to have the lowest mean domestic temperatures in the kitchen, bedroom and bathroom and the lowest minimum temperatures in these rooms of all the 4 groups. Most of the minimum temperatures fall below the 15 °C 'pressor' threshold at which systemic rises in blood pressure are known to occur (Collins et al 1985) and which provokes increased co-agulability (Keatinge et al 1984). Additionally, almost all the mean domestic temperatures in the Cold and False Warm groups are below the recommended minimum living room temperature of 18 °C and below the legal working limit of 16 °C (Mitchell 2001; Parsons 1993). It therefore follows that in addition to increased exposure to outdoor cold, the routine movements of older people in the Cold and False Warm groups within their homes pose an additional risk of cold exposure. This is especially important because previous studies have shown that the 'cold body' being exposed to further cold is at an increased risk of lower core temperatures and increased blood pressure than the 'warm' body (Collins et al 1989).

6. Conclusions and Recommendations

6.1 Based on the apparent absence of previous work, the aim of this study was to test the hypothesis that there is a relationship between the activity and thermal behaviour of older people on the one hand and their winter thermal environment, domestic or outdoors, on the other.

In summary, the evidence appears to support the hypothesis of a relationship between ambulatory temperature and activity levels; between ambulatory temperature and the *a priori* contrast of fuel payment by use ('Cold group') or flat-rate charging ('Warm' group); and is suggestive of a relationship between this contrast and activity. The findings presented in this study add important new knowledge on the personal patterns of activity and behaviour of older people in the winter, as associated with differences in the thermal conditions of their accommodation. Fortuitously, by seeking to analyse effectively the arbitrarily defined distinction of 'restricted' and 'unrestricted' access to heating, additional light was thrown upon the implications of how heating is charged. In summary, in this study those older people who do not have central heating and are billed by their consumption of fuel (the 'Cold' group) or those who are billed for heating by consumption but *claim* their use is not restricted (the 'False Warm') show the following pattern of behaviour:

- a higher level of physical activity with clear time of day (circadian) effects
- apparent increased daily excursions into the cold
- lower ambulatory temperatures with an inverse relationship to activity
- lower domestic temperatures with steeper internal gradients and range

Such a profile warrants the categorisation of these older people in this study as a 'higher risk' group. These findings together with those of previous studies appear to indicate distinct disadvantages in terms of increased risk which arise from the behavioural characteristics described here. These may be summarised as follows:

- probable increased cardiac work due to the effects of age, temperature, activity and interactions between age, temperature and activity
- increased risk of lower core temperatures due to increased exposure to cold stress
- increased risk of raised systemic blood pressure arising from increased cold stress
- increased thrombotic risk (heart attack and stroke).

Increased activity levels in older people are generally thought to be advantageous in health terms. The point to be made here is not that increased activity levels are unwelcome but that they are indicative of unacceptably cold conditions. Indeed, in terms of their adaptive value, increased activity and non-shivering thermogenesis are effective mechanisms for resisting the effects of outside cold (Collins et al 1995; Eurowinter Group 1997).

6.2 There are a number of important implications to be derived from these findings. Some of these implications are presented here, though in doing so the degree to which external generalisations may be made has to be tempered by the relatively reduced size of the study population (n=32) and the degree to which it is representative of the older population at large.

a. The 'Cold' conditions comprise not only lower temperatures but steeper internal thermal gradients and fluctuations, an important finding which accentuates the need for the mitigation of thermal disadvantage. Many of the UK's older population live in fuel poverty, notwithstanding the benefit system and in homes which lack adequate insulation, particularly in the private sector (Boardman 1991; Wilkinson 2001). There appears to be a disappointing level of benefit take-up amongst many older people and many are unaware of the benefits that may be claimed, whilst at the same time it is known that benefit take-up improves the expenditure on fuel by older people (Wright 2004). Therefore there appears to be a strong case for measures which improve the benefits realised by older people. Simultaneously, policies which improve the heating, insulation and energy efficiency of homes will reduce the thermal problems which are indicated in this study. For example, such measures may include increased expenditure on programmes such as Warm Front or measures which better target such expenditure. It would also appear that the nature of the heating charges are a strong factor in the determination of adequate warmth and low risk behaviour in the older people in this study

b. The behavioural patterns associated with cold homes in the winter which have been shown in this study appear to increase greatly the risks of cold stress on older people in the winter. This is an important new finding which adds weight not only to suggestions for the reduction of indoor cold but to a programme of health promotion which identifies the importance of high risk behaviour. 'High risk behaviour' comprises a profile of frequent outdoor excursions into the cold, with inadequate clothing, low levels of activity while outdoors and low indoor temperatures – most of which factors are ascribable to the cold groups in this study. The evidence in this study supports previous work (Eurowinter Group 1997; Donaldson et al 1997; Goodwin et al 2001; Wilkinson 2001) which shows that it is the total profile of cold stress (i.e., indoor and outdoor cold) that imposes a high risk of winter illness and mortality.

c. Further studies appear to be indicated from the findings in this report. In particular, a further study is required to further investigate the relationship between home heating charges and activity levels; the evidence in the present report suggests a relationship but just failed to reach statistical significance. A qualitative study is also indicated, in order to provide more meaningful data from older people themselves in relation to their activity levels and excursional behaviour in the winter. Further work is also recommended to establish an effective model of health promotion by which the problem of high risk behaviour may be mitigated. This may involve a behavioural science based study of the social, psychological and cultural antecedents of this phenomenon. There may be other studies which are necessary, eg in the area of the policy implications indicated here, but which cannot be derived strictly from the research outcomes in this study.

References

Aschoff J (1970). Circadian rhythm of activity and body temperature (in) Physiological and behavioural temperature regulation (Eds: Hardy JD, Gagge AP, Stolwijk JAJ). Springfield, Illinois: Charles C Thomas, 909-919.

Åstrand P and Rodahl K (1986). Textbook of Work Physiology (3rd Ed). New York: McGraw-Hill.

BMJ (2001). BMJjournals.com/cgi/eletters/323/7323/1207/c dated 26 and 29 Nov 2001

Boardman B (1991). *Fuel Poverty: from cold homes to affordable warmth*. London: Belhaven Press.

Collins KJ (1999). Cold, cold housing and respiratory illnesses (in) Cutting the Cost of Cold (Eds: Rudge J and Nicol F). London: Taylor and Francis.

Collins KJ, Abdel-Rahman TA, Goodwin J and McTiffin L (1995). Circadian body temperatures and the effects of a cold stress in elderly and young subjects. Age and Ageing, 24, 485-489.

Collins KJ, Easton JC, Belfield-Smith H *et al* (1985). Effects of age on body temperature and blood pressure in cold environments. Clin Sci, 69, 465-470.

Collins KJ, Sacco P, Easton JC and Abdel-Rahman TA (1989). Cold pressor and trigeminal cardiovascular reflexes in old age. In Thermal Physiology (ed: JB Mercer) Excerpta Medica: Amsterdam pp 587-592.

Cunningham CL, Crabbe JC and Rigter H (1990). Pavlovian conditioning of drug induced changes in body temperature (in) Schönbaum E and Lomax P (Eds) Thermoregulation: International Encyclopaedia of Pharmacology and Therapeutics Section 131. New York: Pergamon.

Curwen M (1997). Excess winter mortality in England and Wales with special reference to the effects of temperature and influenza (in) The Health of Adult Britain Vol I and II (Eds Charlton J and Murphy M) Dicentennial Suppl No 12. London: The Stationery Office.

Donaldson GC, Robinson D and Allaway SL (1997) An analysis of arterial disease mortality and BUPA health screening in men, in relation to outdoor temperature. Clin Science, 92, 261-268.

Donaldson GC, Tchernjavskii VE, Ermakov SP, Bucher K, Keatinge WR (1998). Winter mortality and cold stress in Yekaterinburg, Russia: interview survey. BMJ, 316, 514-518.

Eaga Partnership, personal communication (K Thompson) 13 Dec 2001

Eurowinter Group (1997). Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease and all causes in warm and cold regions of Europe. Lancet, 349, 1341-1346.

Goodwin J (1999). Cold Stress, Circulatory Illness and the Elderly (in) Cutting the Cost of Cold (Eds: Rudge J and Nicol F). London: Taylor and Francis.

Goodwin J, Taylor RS and Pearce VR (2000) Seasonal cold, excursional behaviour, clothing protection and physical activity in young and old subjects. Int J Circ Health, 59, 4, 195-203

Goodwin J, Taylor RS, Pearce VR and Collins KJ (2001). Seasonal cold and circadian changes in blood pressure and physical activity in young and elderly subjects. Age and Ageing, 30, 311-317.

Grayson J (1990). Responses of the microcirculation to hot and cold environments (in) Schönbaum E and Lomax P (Eds) Thermoregulation: International Encyclopaedia of Pharmacology and Therapeutics Section 131. New York: Pergamon.

ISO 7726 (1985). Thermal Environments: instruments and methods for measuring physical quantities. Geneva: International Standards Organisation.

Keatinge WR (2002). Winter mortality and its causes. Int J Circ Health, 61, 292-299.

Keatinge WR, Coleshaw SRK, Cotter F, Mattock M, Murphy M, and Chelliah R (1984). Increase in platelet and red cell counts, blood viscosity and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter. BMJ, 289, 1405-1408.

Keatinge WR and Donaldson GC (1999). Cold weather, cold homes and winter mortality (in) Cutting the Cost of Cold (Eds: Rudge J and Nicol F). London: Taylor and Francis.

Keatinge WR, Coleshaw SRK and Holmes J (1989). Changes in seasonal mortalities with improvement in home heating in England and Wales from 1964 to 1984. Int J Biometeorol, 33, 71-76.

Mercer JB (2002). Cold – an underrated risk factor for health. Env Res, 92, 8-13.

Minors DS and Waterhouse JM (1981). Circadian rhythms and the human. Bristol: Wright PSG, 24-40.

Mitchell R (2001). Short days—shorter lives: studying winter mortality to get solutions. Int J Epidemiol, 30, 5, 1116.

Parsons KC (1993). Human Thermal Environments. London: Taylor & Francis.

Schönbaum E and Lomax P (Eds) (1990). Thermoregulation: International Encyclopaedia of Pharmacology and Therapeutics Section 131. New York: Pergamon.

Stout RW and Crawford V (1991). Seasonal variations fibrinogen concentrations among elderly people. Lancet 338, 9-13.

Wilkinson P (2001). Cold Comfort: The Social and Environmental Determinants of Excess Winter Deaths in England 1986-96. Abingdon: Marston Books.

Williams E, Klesges RC, Hanson CL and Eck LH (1989). A prospective study of the reliability and convergent validity of three physical activity measures in a field research trial. J Clin Epidemiol, 42, 12, 1161-1170.

Woodhouse PR, Khaw KT, Plummer M (1993). Seasonal variation of blood pressure and its relationship to ambient temperature in an elderly population. J Hypertens, 11, 1267-1274.

Wright F (2004). Older and Colder: the perceptions of older people in fuel poverty. London: Help the Aged.

Appendices

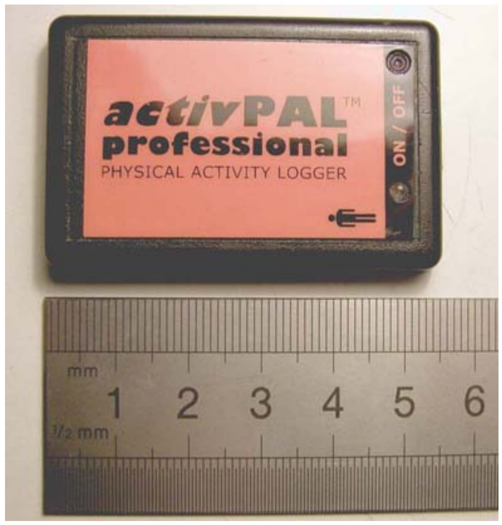
One: Ambulatory Instruments (Photographs)

Two: I-Button Calibration Data

Three: Diary Template

Appendix One: Ambulatory Instruments

'activPAL professional' **Activity Monitor**



'I Button' **Temperature data logger and ring mounted** ***'I Button'***

Appendix 2: I – Button Calibration Data

Sample No	Time	Temperature			
		Thermometer Reading	I-Button		
			2A55F	1E707	1E860
1	10:00	5.0	5	4.5	4.5
2	10:01	5.7	6	5	5
3	10:02	6.8	7	6.5	6.5
4	10:03	8.0	8	7.5	7.5
5	10:04	9.2	9.5	8.5	8.5
6	10:05	10.0	10.5	10	10
7	10:06	11.6	12	11	11
8	10:07	12.8	13	12.5	12.5
9	10:08	14.0	14.5	13.5	13.5
10	10:09	15.2	15.5	14.5	14.5
11	10:10	16.4	16.5	16	16
12	10:11	17.6	18	17	17
13	10:12	18.8	19	18	18
14	10:13	20.0	20	19.5	19.5
15	10:14	21.2	21.5	20.5	20.5
16	10:15	22.4	22.5	21.5	21.5
17	10:16	23.6	23.5	23	23
18	10:17	24.8	25	24	24
19	10:18	25.9	26	25	25
20	10:19	27.1	27	26.5	26.5
21	10:20	28.2	28.5	27.5	27.5
22	10:21	29.4	29.5	28.5	28.5
23	10:22	30.6	30.5	29.5	29.5
24	10:23	31.7	32	31	31
25	10:24	32.8	33	32	32
26	10:25	33.9	34	33	33
27	10:26	35.0	35	34	34
28	10:27	36.1	36	35.5	35.5
29	10:28	37.2	37.5	36.5	36.5
30	10:29	38.2	38.5	37.5	37.5
31	10:30	39.2	39.5	38.5	38.5
32	10:31	40.3	40.5	39.5	39.5
33	10:32	40.4	40.5	39.5	39.5
34	10:33	40.4	40.5	40	40
35	10:34	40.4	40.5	40	39.5
36	10:35	40.2	40.5	39.5	39.5
37	10:36	40.5	40.5	39.5	39.5
38	10:37	40.8	41	40	40
39	10:38	40.4	40.5	40	40
40	10:39	39.9	40	39	39.5
41	10:40	40.0	40	39.5	39.5
42	10:41	40.2	40.5	39.5	39.5

Sample No	Time	**Temperature**			
		Thermometer Reading	I-Button		
			2A55F	1E707	1E860
44	10:43	40.0	40	39.5	39.5
45	10:44	40.0	40	39.5	39.5
46	10:45	40.0	40	39.5	39.5
47	10:46	40.0	40	39.5	39.5
48	10:47	40.0	40	39.5	39.5
49	10:48	40.0	40	39.5	39.5
50	10:49	40.0	40	39.5	39.5
51	10:50	40.0	40	39.5	39.5
52	10:51	40.0	40	39.5	39.5
53	10:52	40.0	40	39.5	39.5
54	10:53	40.0	40	39.5	39.5
55	10:54	40.0	40	39.5	39.5
56	10:55	40.0	40	39.5	39.5
57	10:56	40.0	40	39.5	39.5
58	10:57	40.0	40	39.5	39.5
59	10:58	40.0	40	39.5	39.5
60	10:59	40.0	40	39.5	39.5
61	11:00	40.0	40	39.5	39.5
62	11:01	40.0	40	39.5	39.5
63	11:02	40.0	40	39.5	39.5
64	11:03	40.0	40	39.5	39.5
65	11:04	40.0	40	39.5	39.5
66	11:05	40.0	40	39.5	39.5
67	11:06	40.0	40	39.5	39.5
68	11:07	40.0	40	39.5	39.5
69	11:08	40.0	40	39.5	39.5
70	11:09	40.0	40	39.5	39.5
71	11:10	40.0	40	39.5	39.5
72	11:11	40.0	40	39.5	39.5
73	11:12	40.0	40	39.5	39.5
74	11:13	40.0	40	39.5	39.5
75	11:14	40.0	40	39.5	39.5
76	11:15	40.0	40	39.5	39.5
77	11:16	40.0	40	39.5	39.5
78	11:17	40.0	40	39.5	39.5
79	11:18	40.0	40	39.5	39.5
80	11:19	40.0	40	39.5	39.5
81	11:20	40.0	40	39.5	39.5
82	11:21	40.0	40	39.5	39.5
83	11:22	40.0	40	39.5	39.5
84	11:23	40.0	40	39.5	39.5
85	11:24	40.0	40	39.5	39.5
86	11:25	40.0	40	39.5	39.5
87	11:26	40.0	40	39.5	39.5
88	11:27	40.0	40	39.5	39.5

Sample No	Time	Temperature			
		Thermometer Reading	I-Button		
			2A55F	1E707	1E860
90	11:29	40.0	40	39.5	39.5
91	11:30	39.5	40	39	39
92	11:31	37.2	38	37	37
93	11:32	34.7	35	34	34
94	11:33	33.1	34	33	33
95	11:34	32.1	32.5	31.5	32
96	11:35	31.2	31.5	30.5	30.5
97	11:36	30.5	31	29.5	30
98	11:37	29.7	30	29	29
99	11:38	28.4	29	28	28
100	11:39	27.2	27.5	26.5	26.5
101	11:40	26.1	26.5	25.5	25.5
102	11:41	25.1	25.5	24.5	24.5
103	11:42	24.2	24.5	23.5	23.5
104	11:43	23.3	23.5	22.5	22.5
105	11:44	21.3	21.5	20.5	20.5
106	11:45	19.8	20	19.5	19
107	11:46	17.4	18	17	17
108	11:47	15.1	15.5	14.5	14.5
109	11:48	13	13.5	12.5	12.5
110	11:49	10.9	11	10.5	10
111	11:50	8.5	9	8	8
112	11:51	6.8	7	6.5	6.5
113	11:52	5	5.5	4.5	4.5
114	11:53	5	5.5	4.5	4.5

Appendix 3: Diary Template

DAY / DATE: …………………………………………… (eg Monday 23 June 2003) Subject Id: ……………………

MORNING

Tick all boxes or use codes	Mid-night - 1am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am	7-8 am	8-9 am	9-10 am	10-11 am	11-12 noon
Living Room												
Bedroom												
Bathroom												
Kitchen												
In/Out bed												
Sitting/Relaxing												
Housework												
Eating												
Trips out												
Walking												
Driving												
Shopping												
Clothing**												

AFTERNOON

Tick all boxes or use codes	12 noon – 1pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 mid-night
Living Room												
Bedroom												
Bathroom												
Kitchen												
In/Out bed												
Sitting/Relaxing												
Housework												
Eating												
Trips out												
Walking												
Driving												
Shopping												
Clothing**												

Codes

*	1	2	3	4
How Long	**15 mins or under**	**15-30 mins**	**30 mins – hour**	**1 hour +**

**	1	2	3	4
Clothing	**Light indoor clothing**	**Heavy indoor clothing**	**Heavy outdoor clothing**	**Heavy outdoor and Hat/ Gloves**

Notes