Thermal Comfort in Passive Solar Buildings

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NOTE

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EXECUTIVE SUMMARY

One of the barriers to increased adoption of passive solar heating is the concern that comfort may be compromised. Large expanses of windows can cause overheating on sunny days and radiant cooling on cold nights. The purpose of this report was to assess thermal comfort in passive solar buildings, develop a model to predict thermal comfort and validate the model against monitored data from a passive solar home. The report inclues examples of how the thermal comfort model can be used to develop guidelines for thermal comfort.

The development of a computer model to predict thermal comfort was central to this study. The ENERPASS computer program was modified to predict hourly values of Fanger's Predicted Mean Vote (PMV). Because thermal comfort modelling is not well-established, it was felt that the model had to be validated against monitored data. The thermal comfort of a passive solar home was monitored for a five day period in March, 1989.

A review of the literature found that excessive temperatures, large temperature swings and direct solar radiation incident on the occupants have the greatest potential for causing thermal discomfort in passive solar homes. Heavy-mass floors can cause discomfort if the occupants do not wear shoes.

The ENERPASS computer program predictions of thermal comfort (PMV) agreed reasonably well with the monitored data for a passive solar home. There was some discrepancy between monitored and predicted air temperatures on sunny days: this was attributed to the monitoring equipment being located close to the floor and, as such, measuring temperatures not representative of the "average" room temperature.

The passive solar home, with a 23% glass-to-floor area ratio, had air temperatures as high as 28C at 600mm above the floor. The day/night swing in the PMV of 2.0 (from slightly cool to slightly warm) is twice the recommended range. The head-to-floor temperature stratification was as high as seven Celsius degrees--greater than the recommended four-degree maximum.

Application of the ENERPASS Thermal Comfort Model developed as part of this study confirmed the 6 to 8% glass-to-floor area ratio design guideline for thermal comfort. For a person located near a window, the air temperature must be 0.8 Celsius degrees warmer if double-glazed instead of high-performance windows are used. The energy benefit of high-performance windows is 24% higher than would be calculated by a straight comparison of R-values, because of the need for a higher thermostat setting when double-glazed windows are used.

It is recommended that the thermal comfort model developed as a part of this study be used to perform a more complete analysis of the thermal comfort benefits of high-performance windows and other passive solar technologies such as phase-change drywall. The results of this analysis could be used to develop thermal comfort guidelines for passive solar homes.

RéSUMÉ

Le consommateur hésite à adopter davantage le chauffage solaire passif de peur d'avoir à faire d'importantes concesions du côté confort. Les grandes surfaces vitrées peuvent causer une surcharge de chaleur, par journée ensoleillée, et des pertes de chaleur la nuit, par temps froid. Le présent rapport a pour but d'évaluer le confort thermique dans les bâtiments à chauffage solaire, de mettre au point un modèle permettant de prédire le confort thermique, et de comparer ce modèle à des données ayant fait l'objet de contrôle à partir d'une maison solaire. Le rapport explique à l'aide d'exemples comment le modèle de confort thermique peut servir à élaborer des lignes directrices pour le confort thermique.

Le but principal de l'étude fut la mise au point d'un modèle informatisé permettant de prédire le confort thermique. On a modifié le logiciel ENERPASS afin de prédire la valeur horaire des indices PMV. Le modèle de confort thermique n'étant pas très reconnu, nous avons crû bon de le valider en le comparant à des données réelles. Le confort thermique d'une maison à chauffage solaire passif a donc fait l'objet d'une étude pendant une période de 5 jours au mois de mars 1989.

Une étude de la documentation existante a permis d'élablir que les températures excessives, les écarts de température et les effets des rayons directs de soleil sont les prinicipales causes d'inconfort pour les occupants de maisons à chauffage solaire passif. Les planchers massifs faisant office de masse thermique oblige les occupants à porter des souliers.

Les prévisions de confort obtenues grâce au logiciel ENERPASS correspondaient assez bien aux données recueillies. Cependant, les données relevées et celles qui étaient prévues ne correspondaient pas par jours ensoleillés; ce phénomène étant attribué à l'équipement de contrôle placé trop près du plancher et mesurant par conséquent des températures plus froides que la température moyenne de la pièce.

La maison à chauffage solaire passif comportant une proportion vitre-surface de 23 % présentait une température de 28 ° C à 600 mm du plancher. L'écart de température entre le jour et la nuit était de 2,0 (oscillant entre le trop froid et le trop chaud), ce qui est deux fois plus élevé que l'écart recommandé. La différence de température entre le niveau de plancher et celui de la hauteur de la tête des occupants était à 7 ° C soit plus de 4 ° C de plus que l'écart recommandé.

L'utilisation du modèle informatisé ENERPASS mis au point pour cette étude a confirmé les rapport de 6 % à 8 % entre la surface vitrée et la surface totale. Pour qu'une personne installée près d'une fenêtre soit confortable, la température de l'air doit être

0,8 ° C plus élevée, si l'on a recours aux fenêtres à double vitrage plutôt qu'aux fenêtres à haut rendement énergétique. Les avantages énergétiques découlant des fenêtres à haut rendement sont en réalité 24 % de plus que ne l'indique la simple comparaison des valeur R, en raison de la nécessité d'ajuster le thermostat à température plus chaude lorsque des fenêtres à double vitrage sont utilisées.

Il a été recommandé que le modèle de confort thermique mis au point aux fins de cette étude soit utilisé pour effectuer une analyse plus complète des avantages de confort thermique des fenêtres à haut rendement énergétique ainsi que du reste de la technologie du chauffage solaire dont le placoplâtre à changement de phase. Les résultats de la présente analyse pourraient servir à établir des lignes directrices de confort thermique pour les maisons à chauffage solaire passif.

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1. INTRODUCTION

1.1 Introduction

One of the barriers to increased adoption of passive solar heating is the concern that comfort may be compromised. Large expanses of windows can cause overheating on sunny days and radiant cooling on cold nights. The passive solar designer needs to be assured that these discomforts will not occur in his building design. Discomfort can also result from glare, lighting contrasts and increased sound levels. In most cases these non-thermal factors are of secondary importance. (In fact, for the residential sector, the increased light levels and greater view of the outdoors is one of the perceived benefits of passive solar design.) Therefore, this report will focus only on thermal comfort.

The purpose of this report is to
- assess thermal comfort in passive solar buildings,
- provide a technique for predicting thermal comfort, and
- use the model to develop some thermal comfort guidelines.

The development of a computer model to predict thermal comfort is central to this study. The many factors affecting thermal comfort and the complexity of building heat transfer necessitate the use of a computer model. Because thermal comfort modelling is not well-established, it was felt that the model had to be validated against monitored data. Those factors that affect thermal comfort were monitored in a passive solar home for a five day period.

1.2 Literature Review

1.2.1 General

Human thermal comfort has been the subject of considerable research. While some of this research deals with the environmental extremes in passive solar housing, the interest is in indoor thermal comfort in residential or commercial settings. The most rigorous and complete work in indoor thermal comfort was performed by Fanger [1], who has developed an equation for thermal comfort based on the heat transfer from the body to its environment. The equation is used to calculate the Predicted Mean Vote (PMV). The PMV is the average value of thermal discomfort, as experienced by a large population, according to the following scale:

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

It is important to note, that even if the Predicted Mean Vote is zero, there will still be some people who feel cool and some who feel warm. The percentage of people dissatisfied with the environment has been experimentally determined and is shown in Figure 1.1. At a PMV of zero, five percent of the population will be uncomfortable. As a guideline for thermal comfort, it is suggested that the Predicted Percentage Dissatisfied (PPD) should be less than 10%, which corresponds to a PMV of between -0.5 and 0.5 [2].

The equation for PMV is

$$PMV = (.303*EXP(-.036*M)+.028)*(6.937+.454*M+1.7E\text{-}5*P_a*(M+179.41)+.0014*T_a-4.29*(T_c-T_r)-1.1*H_c*(T_c-T_a))$$

where	H_c	is the convective heat transfer coefficient = maximum of $(2.38*(T_c-T_a))**.25$ or $12.1*(V_a)**0.5$
	T_c	is the clothing temperature (C)
	P_a	is the partial pressure of water in the air (Pa) = $(35.7-.028*M+.665*I_c*T_r+I_c*H_c)/(1+.665*I_c+.1705*I_c*H_c)$
	M	is the metabolic rate or activity level (= 70 W/m^2 for seated person, light activity)
	T_a	is the air temperature (C)
	T_r	is the mean radiant temperature (C)
	V_a	is the air velocity (m/s)
	I_c	is the intrinsic clothing insulation (clo), (=1.0 for medium-weight clothes)

This equation combines the effects of air temperature, mean radiant temperature, air velocity, relative humidity, clothing, and activity level to assess the degree of thermal comfort.

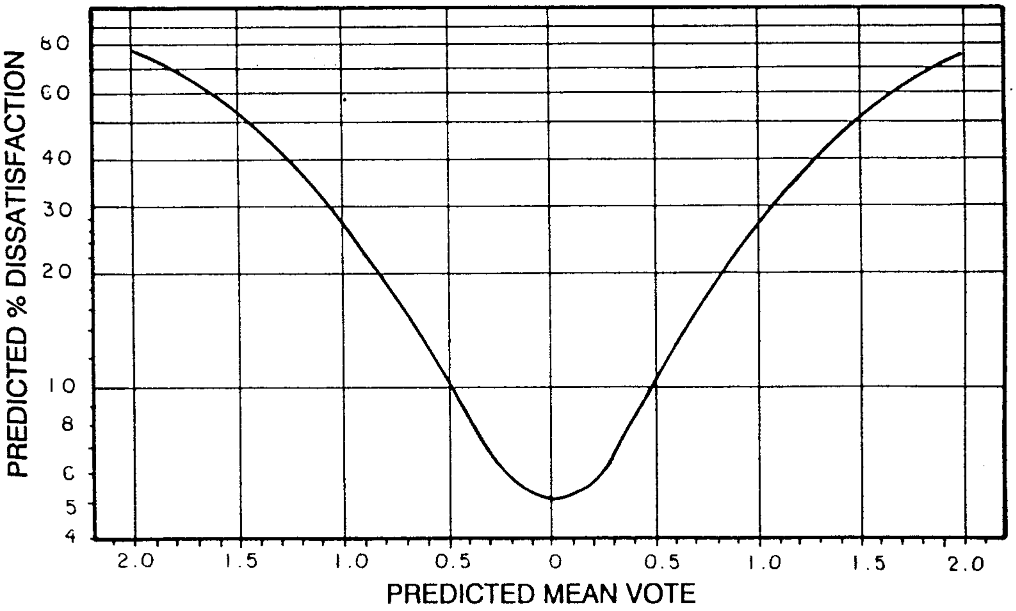


Figure 1.1 **Predicted Percentage of Dissatisfied (PPD) as a Function of Predicted Mean Vote (PMV)**

Source 1989 ASHRAE Handbook of Fundamentals.

Fanger has also studied the influence of other factors on thermal comfort. He found that the feeling of comfort is not dependent on local climate: people in hot climates wear light clothes and people in cold climates wear heavy clothes, but if dressed the same they would prefer the same conditions for comfort. Differences in age, sex, and body-build were also found not to affect the feeling of comfort under the same conditions. That is not to say that, for example, older people do not prefer warmer conditions. Because their activity level is generally lower, they require warmer conditions for comfort.

If the PMV equation is solved for +0.5 and -0.5, the range of air temperatures acceptable to 90% of the population can be established. Using this procedure, ASHRAE Standard 55-1981 defines a comfort zone for people performing sedentary activities in typical summer and winter clothing (see Figure 1.2). If there is little air movement and mean radiant temperature is equal to the air temperature, the air temperature at 50% relative humidity should be between 20 and 23.9 C in winter, and between 22.8 and 26.1 C in summer.

The previous discussion was concerned with the comfort of the body as a whole; localized heating or cooling may also cause discomfort. Local discomfort could be caused by asymmetric thermal radiation, air temperature stratification, drafts, direct contact with a hot or cold surface (e.g., floors), and high-intensity (e.g. solar) radiation . These issues are discussed in the following sections.

Asymmetric or nonuniform thermal radiation is caused by cold windows or walls, radiant heating from ceilings or floors, or from non-uniform absorption of solar radiation by interior surfaces. Fanger [3] has studied this problem and found that asymmetric radiation due to warm ceilings contributed most to discomfort, and warm walls or floors the least. If the criterion of a maximum of 10% PPD is applied, radiant temperature asymmetry should be less than 6 C degrees for warm ceilings, 12 C degrees for cool walls or windows, and 30 C degrees for warm walls. These temperatures are the difference between the mean radiant temperature that each half of the body (either left to right or bottom to top) sees. This does not imply that, for example, the temperature difference between the interior walls and window interior surface must be less than 12 C degrees: this condition would only apply if the entire plane as viewed by the body was a window.

If high-intensity radiation is striking the whole body, the mean radiant temperature can be adjusted and the use of the Fanger comfort equation is still valid.

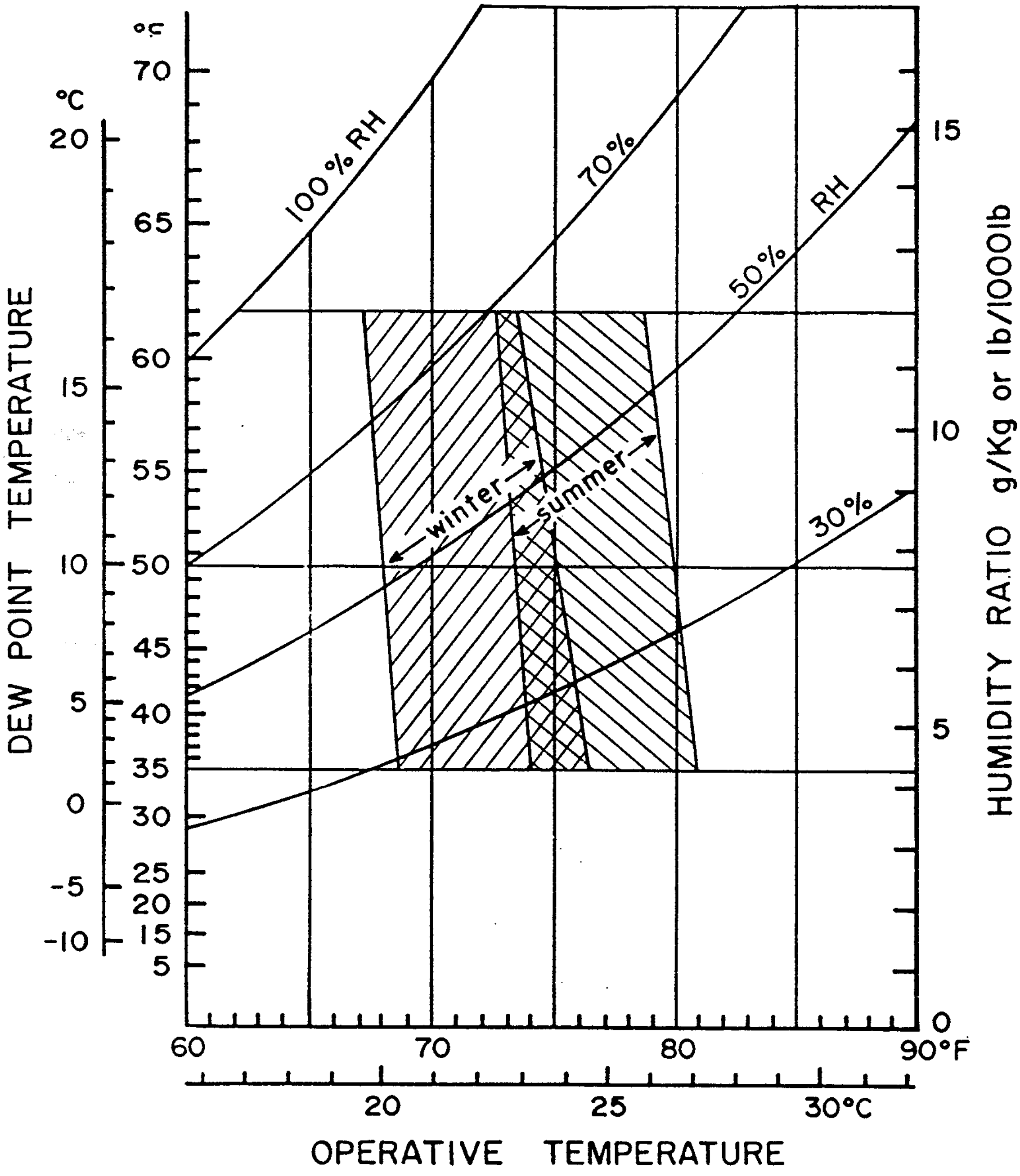


Figure 1.2 **Acceptable ranges of operative temperature and humidity for persons clothed in typical summer and winter clothing, at light, mainly sedentary, activity (≤ 1.2 met).**

Source: ASHRAE Standard 55-1981

$$T_s = \quad [T_r{*}{*}4 + (F_p{*}A{*}Q)/(E\ S)]{*}{*}0.25$$

where T_s	is the mean radiant temperature including any high-intensity radiation striking the body
Q	is the radiation intensity (W/m^2)
A	is the absorptivity of the person
F_p	is the angle factor between the source and the occupant
E	is the emissivity of the source (0.97)
S	is the Stefan-Boltzmann constant ($=5.67 \times 10^{-8}$) (W/m^2K^4)

If the radiation striking a person is not uniform, then the guidelines for comfort under asymmetric thermal radiation apply.

Air naturally tends to stratify within a space. Discomfort may occur if the head is warmer than the feet even if the body as a whole is thermally neutral. Applying the 10% PPD criterion, the results of the work by Olesen et al [4] suggest that the difference in temperature between the head and ankles should be less than 4 C degrees. The head-to-ankle distance is usually taken as 1.1 metres when seated and 1.7 metres when standing.

Drafts can cause localized cooling of the body. The work of Fanger et al [5] has shown that the discomfort associated with drafts is a function of the mean velocity, the fluctuation in the velocity, and the air temperature. To limit the percentage of people dissatisfied to under 10, constant drafts at 21 C should be kept under 0.15 m/s and the average velocity of a fluctuating draft should be under 0.1 m/s.

Because feet are often in direct contact with the floor, discomfort can occur if the floor is too hot or too cold. Olesen [6] found that the floor temperature could be between 19 and 29 C and fewer than 10% of the population would be dissatisfied with normal footwear on. The cause of this discomfort may be due to thermal radiation or drafts caused by a hot or cold floor, rather than direct contact. The acceptable temperature range narrows significantly for barefooted subjects, dependent on the thermal conductivity of the floor. For high conductivity materials like concrete, the acceptable temperature range is 26 to 28.5 C. Hardwood and linoleum floors should be between 24 and 28 C; with rugs, the range expands to 21 to 28 C.

1.2.2 Application to Passive Solar

The previous discussion can be used to provide appropriate guidelines for passive solar design. Thermal discomfort may occur in passive solar buildings because of

- high air temperature, or too large a temperature swing
- radiant cooling due to large window area
- absorption of solar radiation
- direct contact with a warm floor
- large temperature stratification
- non-uniform thermal radiation.

Each of these issues will be discussed below.

The large solar gains in passive solar buildings can cause the air temperature to rise. The ASHRAE comfort zone has a range of approximately 3.5 C degrees: this implies that if the air temperature rise is less than 3.5 C degrees, 90% of the population will be comfortable if the thermostat set-point (i.e., lowest temperature allowed) is set at the lower end of the comfort zone.

A person sitting close to a cold window may experience thermal discomfort due to radiant asymmetry. To avoid discomfort caused by radiant asymmetry due to cold windows, the following equation must be satisfied (assuming the building walls are well insulated):

$$(T_w - T_b) * F * 2 < 12 \quad \text{(C degrees radiant asymmetry)}$$

where T_w is the window temperature (C)
T_b is the building air temperature (C)
F is the occupant-to-window angle factor
In the limit of a person sitting close to a window F would be 0.5.

At the ASHRAE winter design condition of-18 C outside, the window must have an R-value of 0.4 or higher to avoid asymmetric thermal discomfort for a person sitting close to the window. It is important to note that, to maintain comfort according to the Fanger equation, the air temperature must be raised significantly to counteract the decreased mean radiant temperature.

The floor in many passive solar homes is constructed of high-thermal-capacity materials (e.g., concrete, tile) to store solar gains and limit air temperature swings. If this floor is to be used by barefooted occupants, it must be maintained at between 26 and 28.5 C to ensure thermal comfort. This presents two problems: if the floor cannot fluctuate in temperature, it will not store any heat, and 26 C is significantly above winter air temperature comfort conditions (the floor would have to be heated to maintain this temperature). Floor temperature measurements were made in a passive solar test cell at the National Bureau of Standards near Washington D.C. [7]. The test cell had a glazing-to-floor area ratio of 0.33 and was constructed with a 100mm thick concrete floor slab. The floor temperature close to the south window got as warm as 32 C on sunny fall days, and as cold as 16 C on cold winter days. If the glazing-to-floor ratio in the test cell were a more modest value, the floor temperature would likely fall within the comfort bounds for people wearing shoes. It is concluded that high-thermal-capacity floors can only be used in those parts of the building where shoes are worn.

On a sunny day, the walls in the south portion of a passive solar room will receive direct solar radiation, whereas northern portions of the room will receive only diffuse (and possibly reflected) radiation. This solar radiation imbalance will cause a radiant temperature difference between the north and south portions of a room. As discussed in the previous section, thermal discomfort will occur if the asymmetric thermal radiation is greater than 30 C. It is unlikely that this condition would occur without the air or floor temperature exceeding the comfort range.

The high solar gains in passive solar housing could result in high temperature stratification. Thermal discomfort can result if the temperature difference over a 1.7 metre height is greater than 4 C.

Olesen et al [8] examined the temperature stratification in a test chamber heated by nine different heating systems (e.g., baseboards, forced air, radiant ceiling). The largest air temperature difference between the 1.8 and 0.1 metre heights was 2.9 C degrees. Olesen's work, however, was restricted to nighttime conditions.

The larger the window opening is, the more likely it is that a person will be in direct sunlight. Using the formula in the previous section, a simple calculation can be made on the increase in mean radiant temperature due to solar radiation. Absorption of solar radiation by a person on a sunny day could increase the apparent mean radiant temperature by over 20 C, in addition to the effects caused by warmer walls. Although this condition will cause discomfort (given typical indoor air temperatures), it is not known how often this condition occurs.

In summary, excessive temperatures, large temperature swings and direct solar radiation incident on the occupants have the greatest potential for causing thermal discomfort in passive solar homes. Heavy-mass floors can cause discomfort if the occupants do not wear shoes. Air temperature stratification can also cause thermal discomfort. The remainder of this report deals with the design of passive solar buildings to ensure thermal comfort.

Design for thermal comfort requires the ability to predict thermal comfort under the expected operating conditions of the building. The ENERPASS building simulation program was modified to be able to predict thermal comfort (i.e., PMV). A passive solar home was monitored for thermal comfort, to provide data for program validation and to assess the degree to which air stratification may cause thermal discomfort.

2. MODELLING OF THERMAL COMFORT

2.1 Model Development

The ENERPASS program was used as a starting point for modelling thermal comfort. ENERPASS Version 3.0 calculates building performance on an hour-by-hour basis using hourly values of weather data. The program can handle up to seven building zones, and models many heating, cooling, and ventilation systems. The program user specifies the construction of each zone wall (i.e., the mass on the interior and exterior of the building and insulation level), azimuth direction, and what that wall is linked to (e.g., another zone or the outside). During the program simulation a heat balance is performed every timestep for each surface, and the air and wall temperatures are updated. Two temperatures are used to model the behaviour of thermally-light walls, for interior and exterior mass respectively. Thermally-heavy walls are divided into a series of nodes to better represent their transient temperature response.

The solar radiation incident on each wall is calculated using measured solar radiation on the horizontal surface and standard trigonometric relationships. A simplification is used in modelling solar radiation absorbed on interior surfaces. The amount absorbed by each surface is equal to the solar radiation entering the zone times the fraction of the absorptivity-weighted area of that surface, or

$$QSOLAR_i = QSOLAR_{total} * ABS_i * AREAi \; / \quad (ABS_i * AREA_i)$$

The solar radiation absorbed by each wall is thus assumed to be uniformly distributed over that wall. This assumption is probably reasonable where the interior surfaces are of a light colour and as such the solar radiation would be reflected around the room. The assumption would break down in those cases where the interior surfaces are a dark colour.

The program uses the Mitalis model [9] for basement heat loss and the L.B.L. model for air infiltration [10]. Indoor air relative humidity is adjusted every hour, according to the net moisture transfer with the other zones and the outside and the generation of moisture.

Evaluation of the Fanger comfort equation requires values for air temperature, relative humidity, mean radiant temperature, and air velocity. These last two factors are not calculated by ENERPASS, and the calculation of relative humidity is not rigorous: therefore, it was necessary to expand the program models.

As part of recent research project, a rigorous moisture model was developed and incorporated into a custom version of the ENERPASS program [11]. This model included moisture absorption and desorption in walls, condensation on windows, and moisture transfer through below-grade walls. This model--although well-suited for that study--required considerable computation, with a corresponding increase in execution time. If the basement is above the water table, the effect of moisture migration into basement walls is small. Similarly, if reasonably efficient windows are chosen, the quantity of moisture collecting on the window and sill is small. Thus, for most buildings, the only improvement required for the ENERPASS program was the addition of a model for wall moisture absorption/desorption. The equation, as adapted from Reference 11, for the amount of moisture transferred from the wall to the air over an hour is (in kg):

$$M = (M_w + W_a{*}M - M_{loss}) \,/\, (1 + W_s * M * 100. \,/\, C)$$

where M_w	is the moisture content of the wall (kg)
W_a	is the humidity ratio of the air (kg_w/kg_a)
M	is the zone mass (kg)
M_{loss}	is the moisture removed from the zone over the hour (kg)
W_s	is the saturated humidity ratio of the air (kg_w/kg_a)
C	is the thermal capacitance of the wall (KJ/C)

The moisture content of the air is then simply the sum of moisture transfers with the walls, the outdoors, and the other zones, and the moisture removed or added by mechanical equipment. Adding moisture storage in the walls has the effect of dampening swings in air relative humidity. The accuracy of this model is examined in Section 3.

According to Fanger [1], the mean radiant temperature is calculated for most practical cases as the sum of the surface temperature of each wall, window, floor, and ceiling, weighted by the respective angle factor. The angle factor for a surface is the fraction of the thermal radiation emitted by a person that is incident on the surface. The angle factor is a function of the orientation of the person and the size and orientation of the surface. Because of the complexity of the calculation, Fanger produced angle factor charts (e.g. Figure 2.1).

Several changes were made to the ENERPASS program to calculate the mean radiant temperature. Radiant heat exchange between surfaces was added to more closely predict the interior wall temperature. The radiant exchange to a surface in Watts, is:

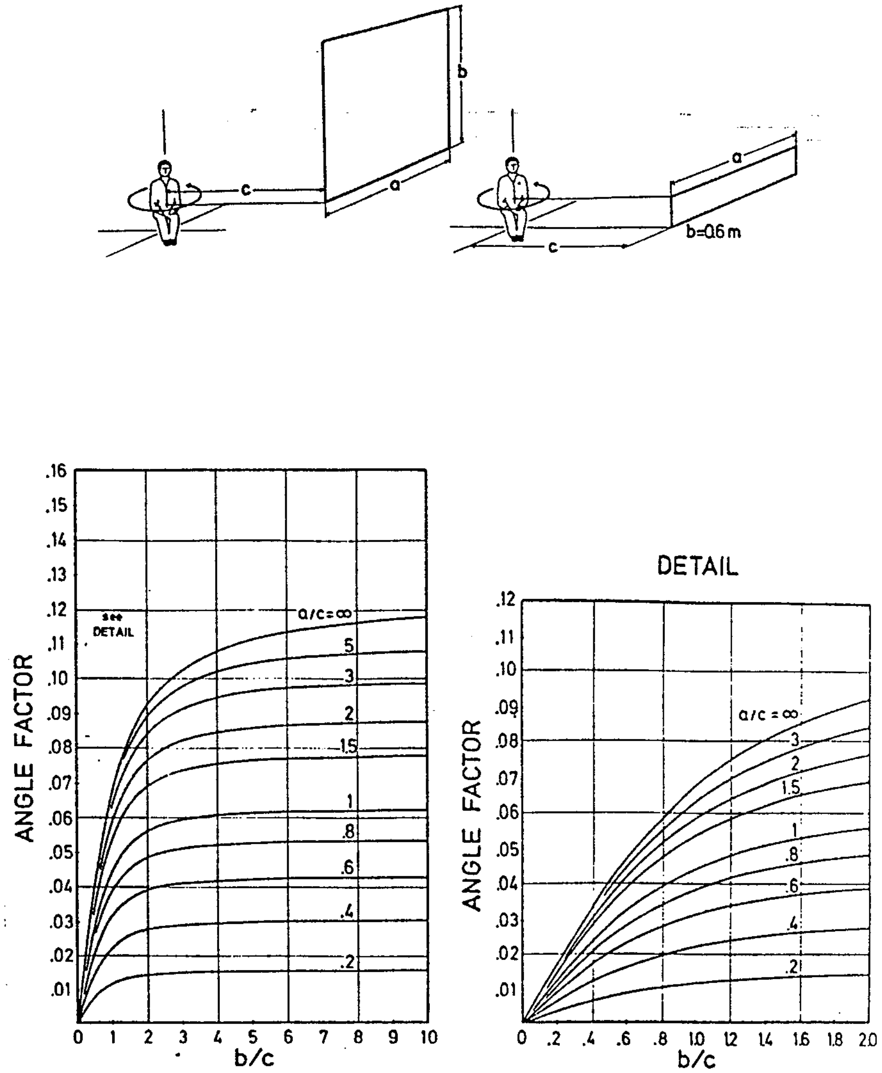


Figure 2.1 Mean value of angle factor between a seated person and a vertical rectangle (above or below his centre) when the person is rotated around a vertical axis. To be used when the location but not the orientation of the person is known.

Example: a = 4m, b = 3m, c = 5m. b/c = 0.6, a/c = 0.8: F_{P-A} = 0.029.

Source: Reference 1

$$Q_r = 4.7*A_w*(T_{wm} - T_w)$$

where T_{wm} is the mean wall temperature (T_w*A_w / A_w), in degrees C
T_w is the interior wall surface temperature, in degrees C, and
A_w is the interior wall area, in m^2

The mean radiant temperature is calculated as

$$T_{mr} = T_w * AF$$

where AF is the angle factor from the person to the wall

For the purposes of this study, the angle factor was calculated assuming that the person was seated with random orientation. A separate program was written to calculate the angle factors. This program assumes the room is a rectangle. The user locates the position of walls, windows and the person on a floor plan (see Figure 2.2). The program uses two curve-fits generated from the Fanger angle factor graphs (Figure 2.1) to calculate the angle factor for each surface. The equations used are:

$$AF = 0.05\ ATAN\ (1.206\ a/c * ATAN\ (1.32\ b/c) \quad \text{(walls and windows)}$$

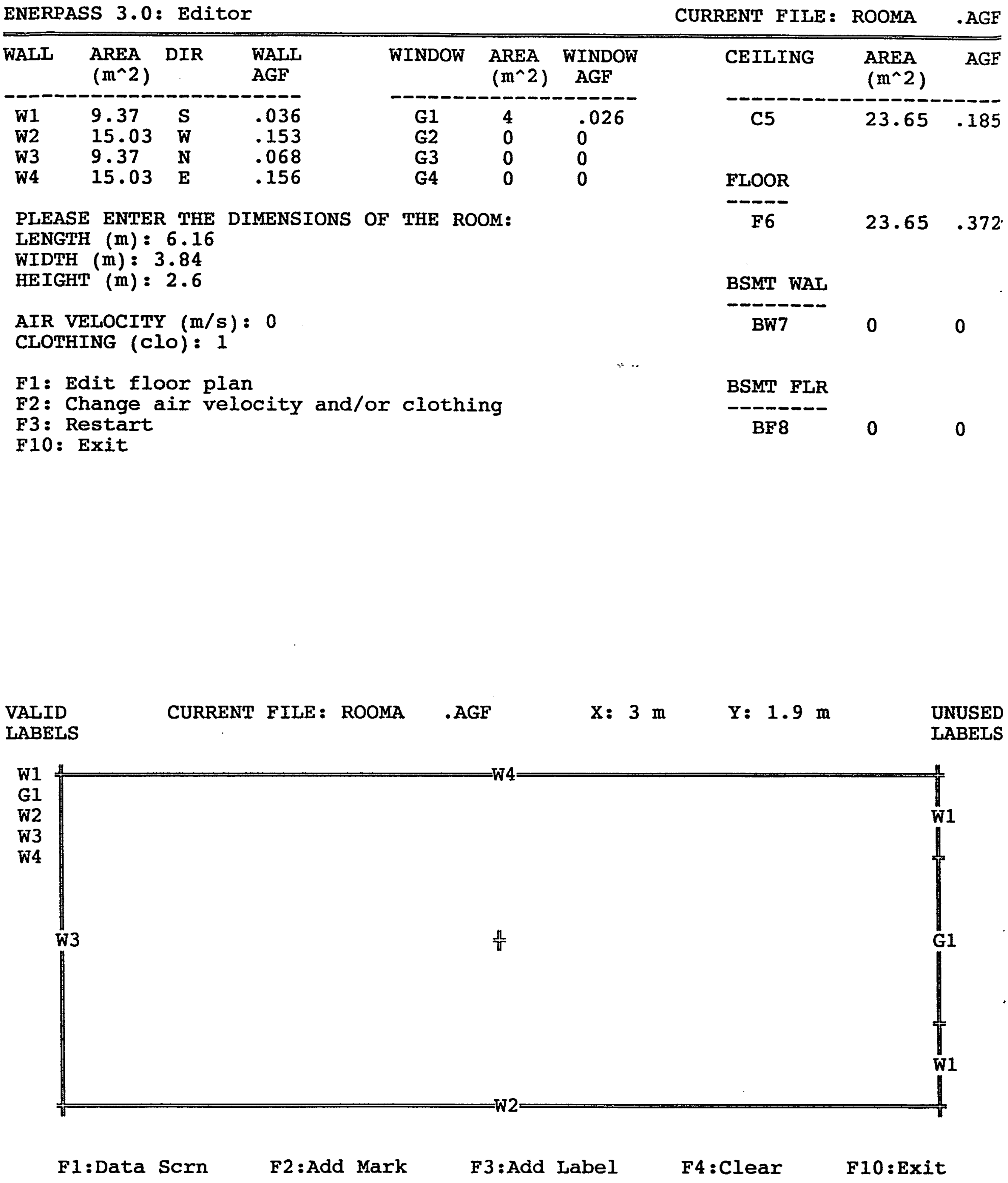
$$AF = 0.047\ ATAN\ (1.161\ a/c) * ATAN\ (1.253\ b/c) \quad \text{(floors and ceilings)}$$

where a,b and c are distances which define the room geometry (see Figure 2.1)

Air movement in a room is extremely difficult to predict. Experimental measurements made in office buildings [12] showed the average air velocity to be 0.06 m/s. Measurements made in an experimental room heated by several different heating systems gave average air velocities between 0.05 and 0.17 m/s [8]. The highest average air velocity was measured with the radiant floor heating system, but the highest instantaneous values (0.3 m/s) occurred with the forced-air (i.e., floor registers) and radiator systems. Based on this limited data, the following scale can be used with the program:

low air velocities (less than 0.05 m/s) - heating system off
average air velocities (0.05-0.15 m/s) - ceiling radiant heating, well designed radiant or forced air system
above-average air velocities (0.15 to 0.25 m/s) - radiant floor heating
- average radiant or forced air system

Figure 2.2



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       (m^2)         AGF                 (m^2)  AGF                      (m^2)
-------------------------        --------------------        ------------------------
 W1    9.37    S     .036         G1      4     .026           C5        23.65     .185
 W2    15.03   W     .153         G2      0     0
 W3    9.37    N     .068         G3      0     0
 W4    15.03   E     .156         G4      0     0              FLOOR
                                                              -----
 PLEASE ENTER THE DIMENSIONS OF THE ROOM:                      F6        23.65     .372
 LENGTH (m): 6.16
 WIDTH (m): 3.84
 HEIGHT (m): 2.6                                              BSMT WAL
                                                              --------
 AIR VELOCITY (m/s): 0                                         BW7       0         0
 CLOTHING (clo): 1

 F1: Edit floor plan                                          BSMT FLR
 F2: Change air velocity and/or clothing                      --------
 F3: Restart                                                   BF8       0         0
 F10: Exit
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VALID      CURRENT FILE: ROOMA    .AGF      X: 3 m     Y: 1.9 m          UNUSED
LABELS                                                                   LABELS

 W1
 G1
 W2
 W3
 W4

    F1:Data Scrn     F2:Add Mark     F3:Add Label     F4:Clear     F10:Exit
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unacceptably high air velocities (greater than 0.25 m/s) - poorly-designed heating system
According to Fanger, air velocities in the first two categories have little effect on thermal comfort.

The PMV is calculated at the end of each hour using the Equation presented on page 2. The occupant clothing and average air velocity are entered by the program user and the program calculates the remaining variables for the PMV equation.

Despite the improvements made to the ENERPASS program, it still has limitations in predicting thermal comfort. The ENERPASS program assumes (like almost all other building simulation programs) that the air within a zone is fully mixed. Thus, any discomfort due to temperature stratification cannot be assessed. The assumption of a fully mixed zone is likely to result in a slight under-prediction of the ceiling temperature and over-prediction of the floor temperature. The assumption of uniformly distributed solar radiation may limit the applicability of the model in some cases. On sunny days, the interior surfaces close to the windows will be warmer than those surfaces not in direct solar radiation (as documented in reference 7). Although reflection of solar radiation and infra-red radiant exchange between walls will reduce this temperature difference, the program will under-predict the mean radiant temperature for a person located near the windows, and over-predict the mean radiant temperature away from the windows. Therefore, the program is probably not suitable for examining spacial variations in thermal comfort on sunny days. (Ignoring any discomfort due to asymmetric thermal radiation, the program should provide a reasonable estimate in the centre of the room).

The program does not calculate the increase in PMV due to solar radiation incident on the occupant. It has been assumed that, if the occupant is in direct sunlight, he will either move or close the drapes.

3. MONITORING OF THERMAL COMFORT

3.1 The Building

A major portion of this study into thermal comfort focused on monitoring of a passive solar home. The monitored data was collected to gain a better understanding of thermal comfort, and to allow a limited validation of the computer model.

The monitored house is located approximately 20 kilometres north of Oakville, Ontario. The large bungalow is well-insulated (to values typical of R2000 homes) and features large south-facing Heat Mirror 88 windows (see Figure 3.1). The main passive solar area of the building is the living room (see Figure 3.2 for layout). This room has a floor area of 48.3 square metres and a high, sloped ceiling. The 14 square metres of Heat Mirror windows gives the room a 23% glass-to-floor area ratio. Marble panelling covers most of the interior east wall and the remainder of the interior surfaces are 16mm gypsum wall board.

The living room has entrances to the kitchen, dining room and hall and is also connected to an indoor swimming pool (the connecting doors are always kept closed). There is a full basement below the living room.

Air is continuously exhausted from the room through a high wall return duct. Outdoor air, brought in via a heat recovery ventilator, is supplied at floor level at the back of the room. Space heating is accomplished by a forced air heating system. The circulation fan operates only when heat is supplied.

The monitoring objectives were to collect data to evaluate the Fanger comfort equation, to assess temperature stratification, and to provide weather data for input into the ENERPASS computer program.

The data gathering activity utilized two systems detailed in Table 3.1; a Bruel and Kjaer indoor climate analyzer (ICA) Model 1213, and a Hewlett-Packard 3421 data acquisition system (DAS) controlled by a PC-compatible computer. The ICA measured indoor air temperature, relative humidity, mean radiant temperature, and air velocity. The DAS system measured outdoor air temperature, south-facing solar radiation, and eight indoor air temperatures at heights of 10, 80, 150, 220, 290, 360, 430, and 500 cm above the floor. Outdoor relative humidity, wind speed, and off-south solar radiation were not measured, because it was assumed that these parameters had only a second-order effect in the calculation of thermal comfort. Additional instruments included a Hewlett-Packard X-Y plotter and a Nicolet storage oscilloscope that were used to record data stored by the ICA in chart form and on floppy diskette.

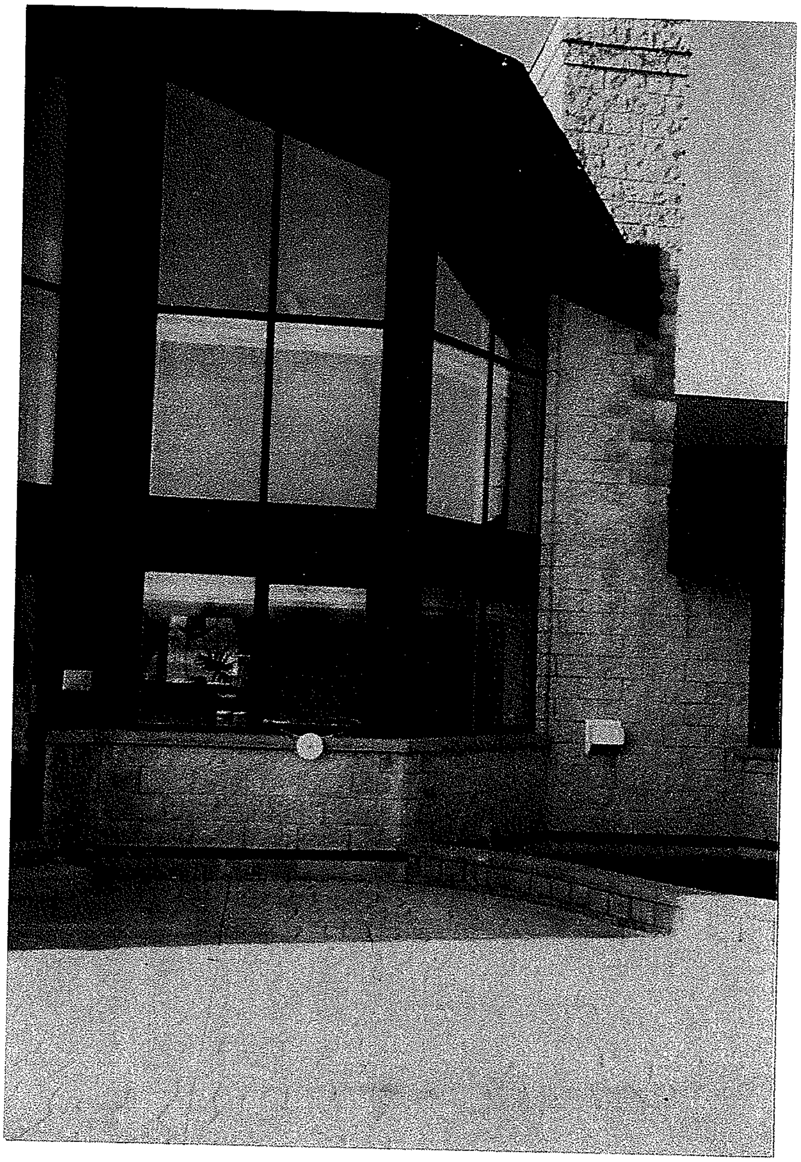


Figure 3.1 Large South-Facing Heat Mirror 88 windows

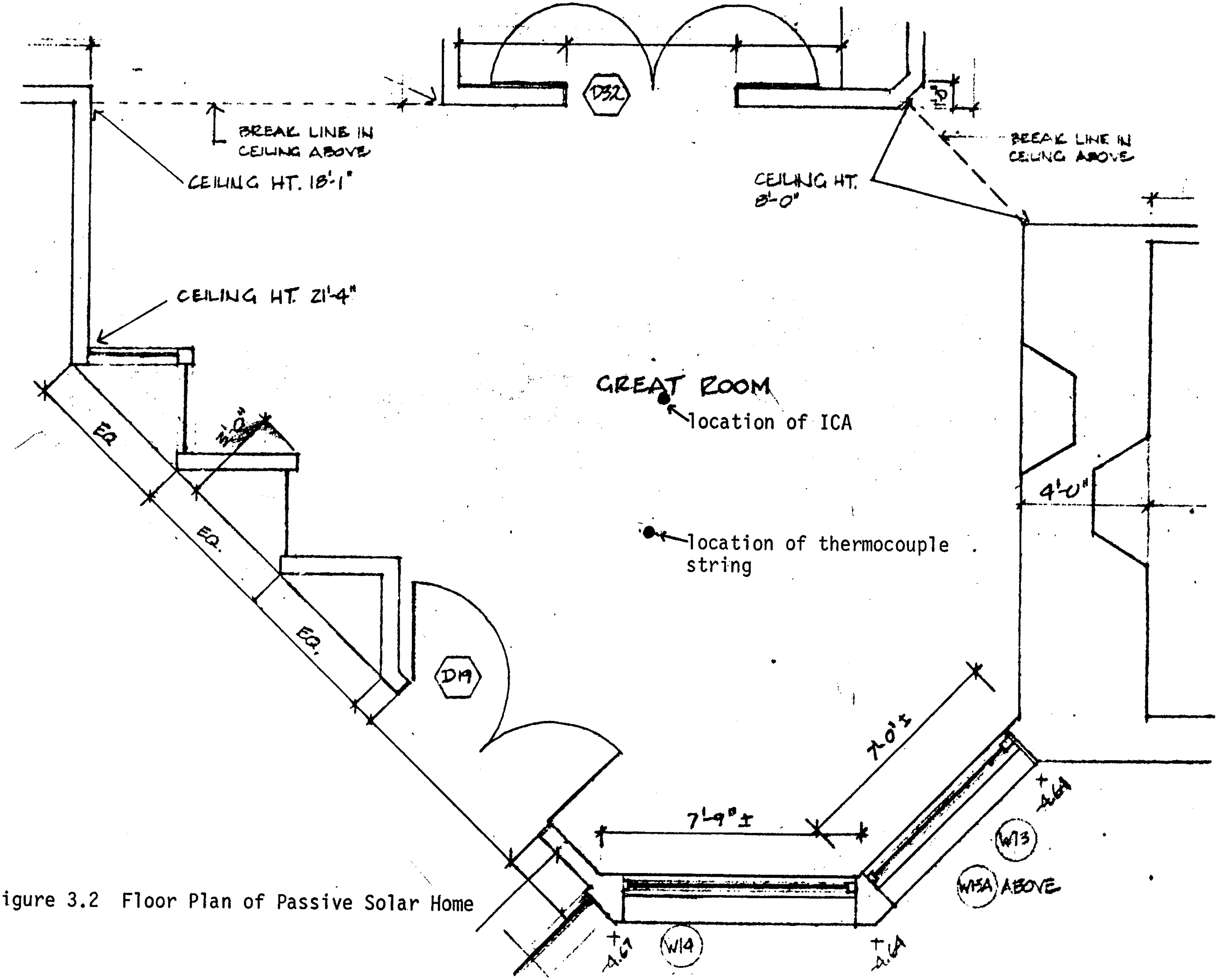


Figure 3.2 Floor Plan of Passive Solar Home

Table 3.1

Measuring Instrumentation

B & K Indoor Climate Analyzer Type 1213 with:

TRANSDUCER	PRECISION
Air Temperature Transducer (MM0034)	± 0.2 C
Surface Temperature Transducer (MM0035)	± 0.5 C
Radiant Temperature Asymmetry Transducer (MM0036)	± 0.5K
Humidity Transducer (MM0037)	Dew point ± 0.~~[illegible]~~5K
Air Velocity Transducer (MM0038)	±5% ± 0.05 m/s

Hewlett-Packard 3421 Data Acquisition System:

Eppley Precision Spectral Pyranometer (South Vertical Incident Solar Radiation)	± 5%
Shaded Thermocouple (Outdoor Air Temperature)	±1.0 C
Thermocouple Stratification String (Indoor Air Temperature Stratification***)	±1.0 C

*** With measuring junctions at 10, 80, 150, 220, 290, 360, 430 and 500 cm above the floor (interchangeable within 0.3 C).

The ICA system and the indoor air temperature stratification probe were installed in the living room of the subject house (see Figure 3.3). The pyranometer and outdoor air temperature sensor were installed on the outside of the south wall of the same room. The ICA measured and stored the data required to calculate an occupant's comfort level at one position in the room, which was chosen as representative of a typical occupant location. The computer-based DAS added to this information the vertical air temperature stratification within the room and the outdoor parameters (air temperature and incident solar radiation) which should be expected to influence indoor comfort.

The DAS was operated continuously for the six-day monitoring period from March 21 to March 27, 1989. Sensors were scanned every thirty seconds, and this data was averaged over 5 minutes and recorded on floppy diskette. The ICA was generally operated in its 24-hour test duration mode, so that it measured and stored data from each connected sensor every 24 minutes. At the end of each 24-hour period the memory-stored data was recorded on chart and diskette before the next 24-hour test was begun.

Two significant monitoring-related events took place during the monitoring period . When it was discovered that direct solar radiation was striking part of the stratification probe, tubular radiation shields were installed on each junction. At approximately the same time, in the evening of March 23, 1989, one of the probe temperatures became inoperative due to an open-circuit. The remainder of the monitoring system operated reliably for the monitoring period.

3.2 The Results

The weather data for the five complete days of monitoring are shown in Figures 3.4 and 3.5. The first two days were sunny, the next two were cloudy, and the final day cleared at noon. The days became progressively warmer over the monitoring period, with a low of -11C on day 1 and a high of 17C on day 5.

This measured weather data was used to produce an ENERPASS weather data file. Construction drawings and site measurements were used to produce an ENERPASS building data file. The ENERPASS program was run for eight days (three days for the building to reach equilibrium and the five days of monitoring).

Figures 3.6 and 3.7 show the indoor air temperature as measured by the ICA and the thermocouple string, respectively, and as predicted by the computer program. In a large room with high ceilings and large solar gains, there can be significant temperature variations. Because the thermocouple string is located closer to the front of the room and measures over the full room height, it gives consistently higher readings than

Figure 3.3 Indoor Temperature Sensors

Figure 3.4

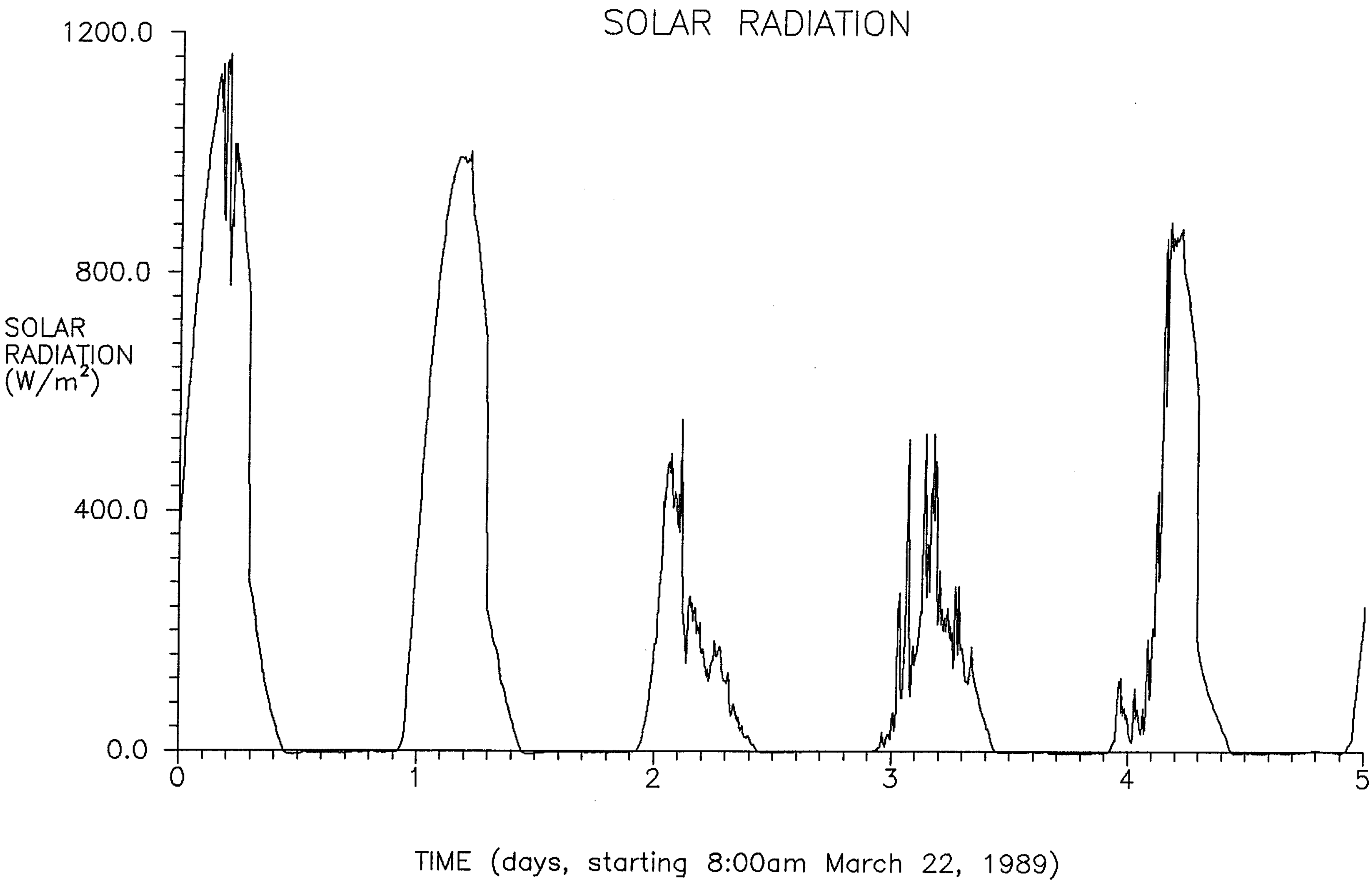

SOLAR RADIATION
1200.0
800.0
400.0
0.0
SOLAR RADIATION (W/m^2)
0
1
2
3
4
5
TIME (days, starting 8:00am March 22, 1989)

Figure 3.5

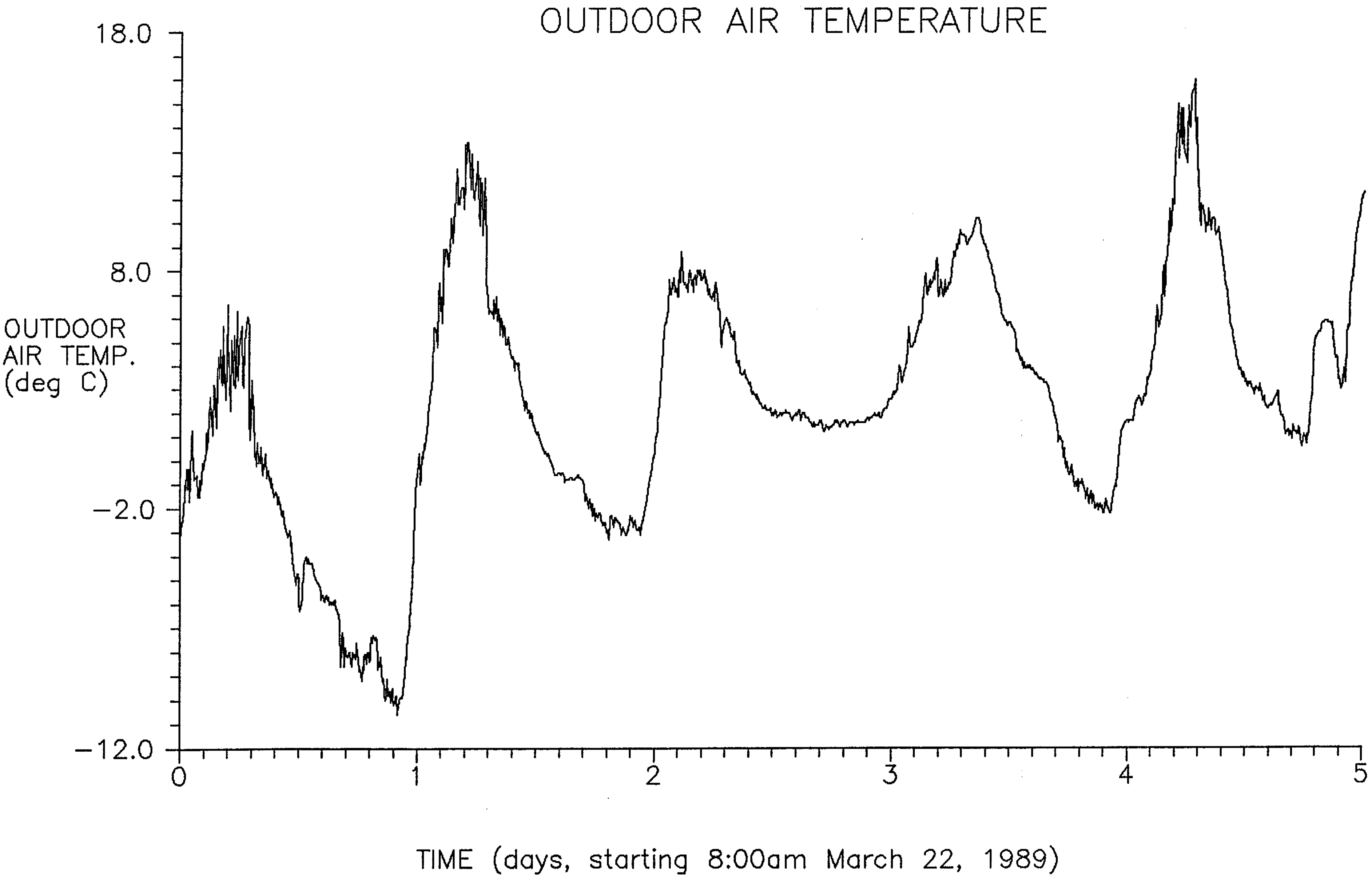

OUTDOOR AIR TEMPERATURE
18.0
8.0
OUTDOOR
AIR TEMP.
(deg C)
−2.0
−12.0
0
1
2
3
4
5
TIME (days, starting 8:00am March 22, 1989)

Figure 3.6

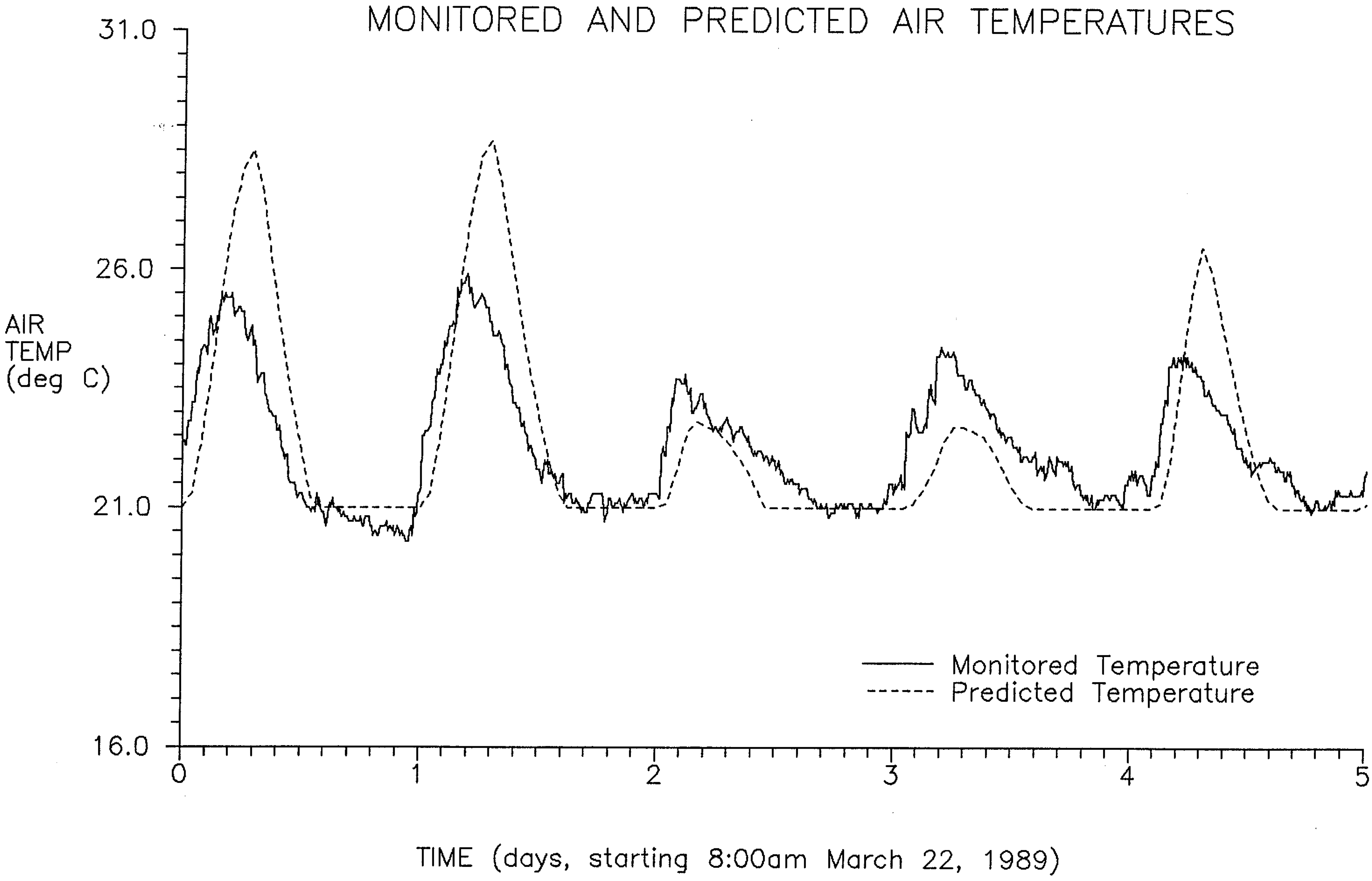
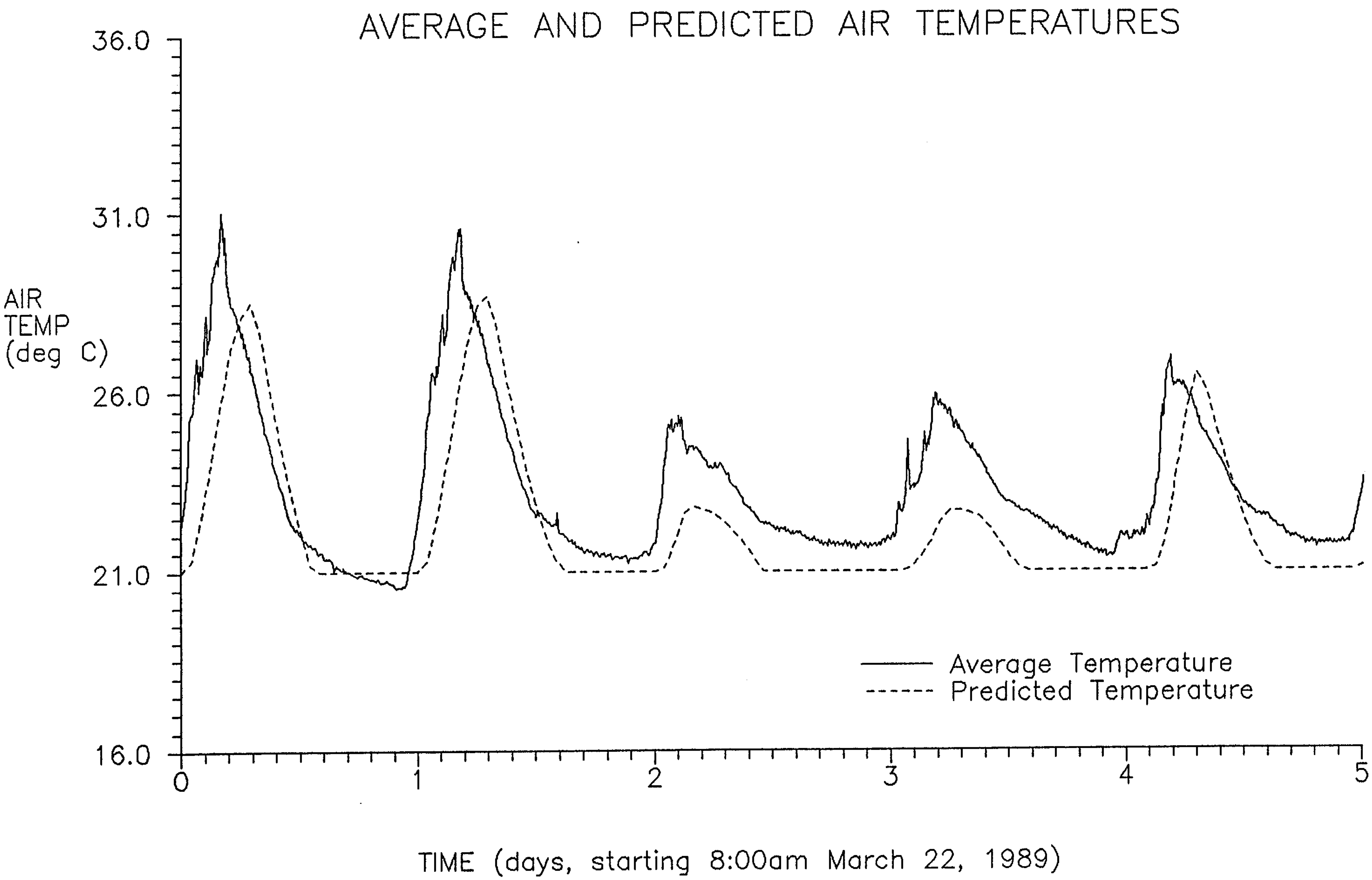

MONITORED AND PREDICTED AIR TEMPERATURES
AIR TEMP (deg C)
31.0
26.0
21.0
16.0
0
1
2
3
4
5
Monitored Temperature
Predicted Temperature
TIME (days, starting 8:00am March 22, 1989)

Figure 3.7


AVERAGE AND PREDICTED AIR TEMPERATURES
AIR TEMP (deg C)
36.0
31.0
26.0
21.0
16.0
0
1
2
3
4
5
Average Temperature
Predicted Temperature
TIME (days, starting 8:00am March 22, 1989)

the ICA sensor. The basic algorithm in the ENERPASS program assumes that a building zone is uniform in temperature and, as such, only one predicted line is shown. The predicted value generally falls between the two monitored values on sunny days. On the two cloudy days, even though the monitored temperature values are consistently higher than the predicted value, the day/night temperature swings are reasonably close. Thus, the ENERPASS prediction, as bracketed by the two monitored results, is probably a reasonable estimate of the average air temperature. Nevertheless, the air temperature measured by the ICA is what will be experienced by a seated person at that location.

There is also a phase shift of up to two hours in the temperature distribution. There are two factors causing the phase shift. First, some of the windows face slightly east of south, whereas the program assumed all windows faced south. The south-east facing windows receive more sun in the morning and less in the afternoon than do south-facing windows. Second, the program stores solar radiation as a series of constant hourly values. The program uses this solar radiation to update the temperature of the thermal mass every half hour. This algorithm tends to delay solar effects by up to one hour.

Figure 3.8 shows the monitored and predicted values of relative humidity. Prediction of relative humidity is complicated in the house because of the indoor pool. Although the doors to the pool are normally closed, moisture will enter the living room around the door seals--and, of course, when the doors are opened. The large jump in relative humidity at noon on the fourth day is probably due to this latter effect. Nevertheless, the computer predictions are as good as can be expected, given the uncertainties in the amount of moisture generation.

The monitored and predicted mean radiant temperatures are shown in Figure 3.9. Unlike the temperature sensors, the radiant temperature sensors are not shielded from solar radiation. The effect of direct solar radiation on the mean radiant temperature can be seen in Figure 3.9 on days one, two, and four, and to a lesser extent on day three. At approximately noon, sunlight incident on the sensor is blocked by the wall framing separating the south-east and south windows. There is a corresponding drop of about 1.5C degrees in mean radiant temperature on these days. This is the maximum expected effect for this house.

There is fairly good agreement between monitored and predicted radiant temperatures. The monitored radiant temperature is slightly above the predicted value, although most of this difference is due to solar radiation on the sensor (not included in the program prediction). As with the air temperature, the program under-predicts radiant temperature on the cloudy days. On the first night of monitoring, the mean radiant temperature dropped to 19C, 2 Celsius degrees below the thermostat setting. Part of this drop is caused by cold outdoor temperatures.

Figure 3.8

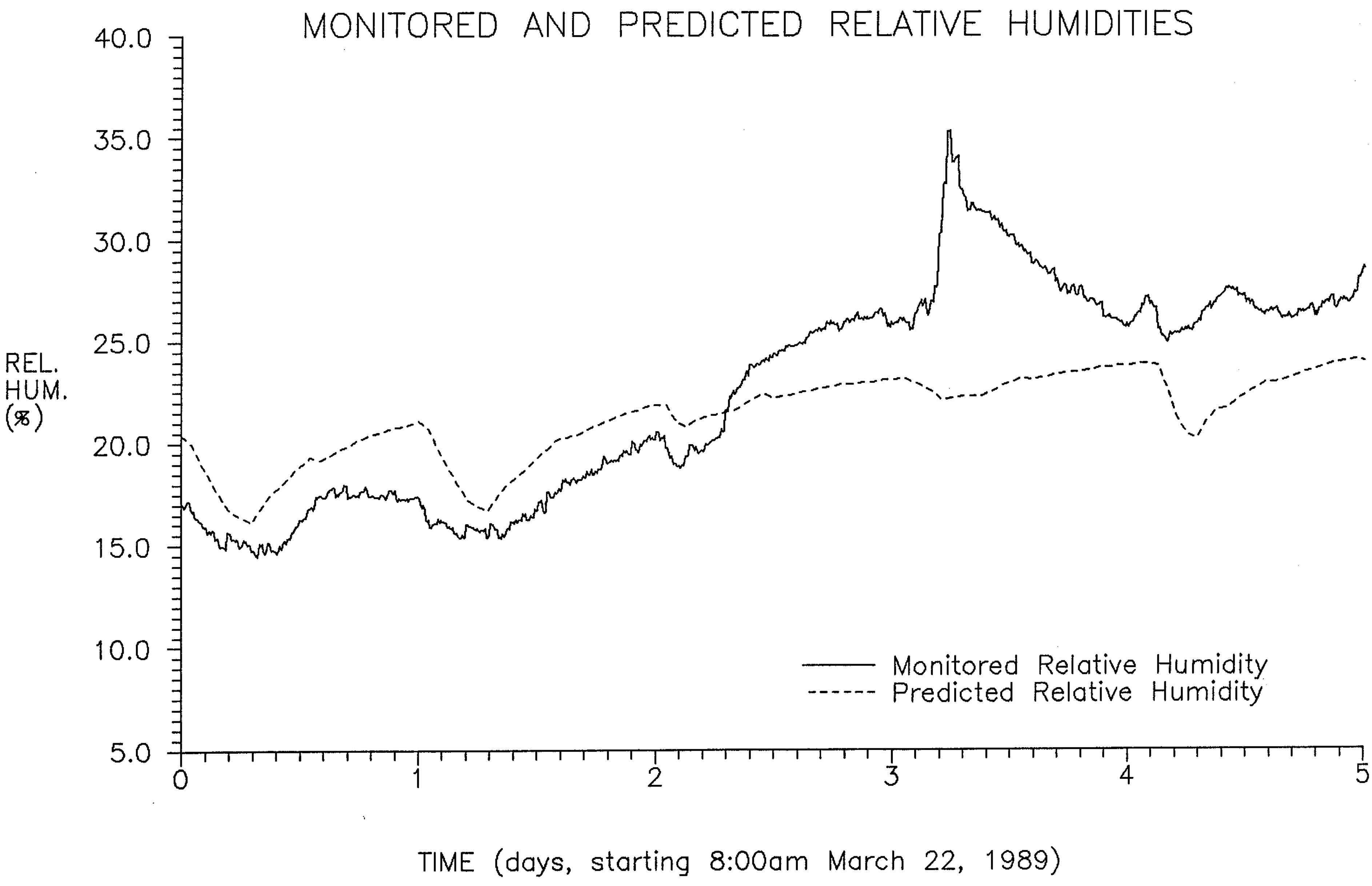
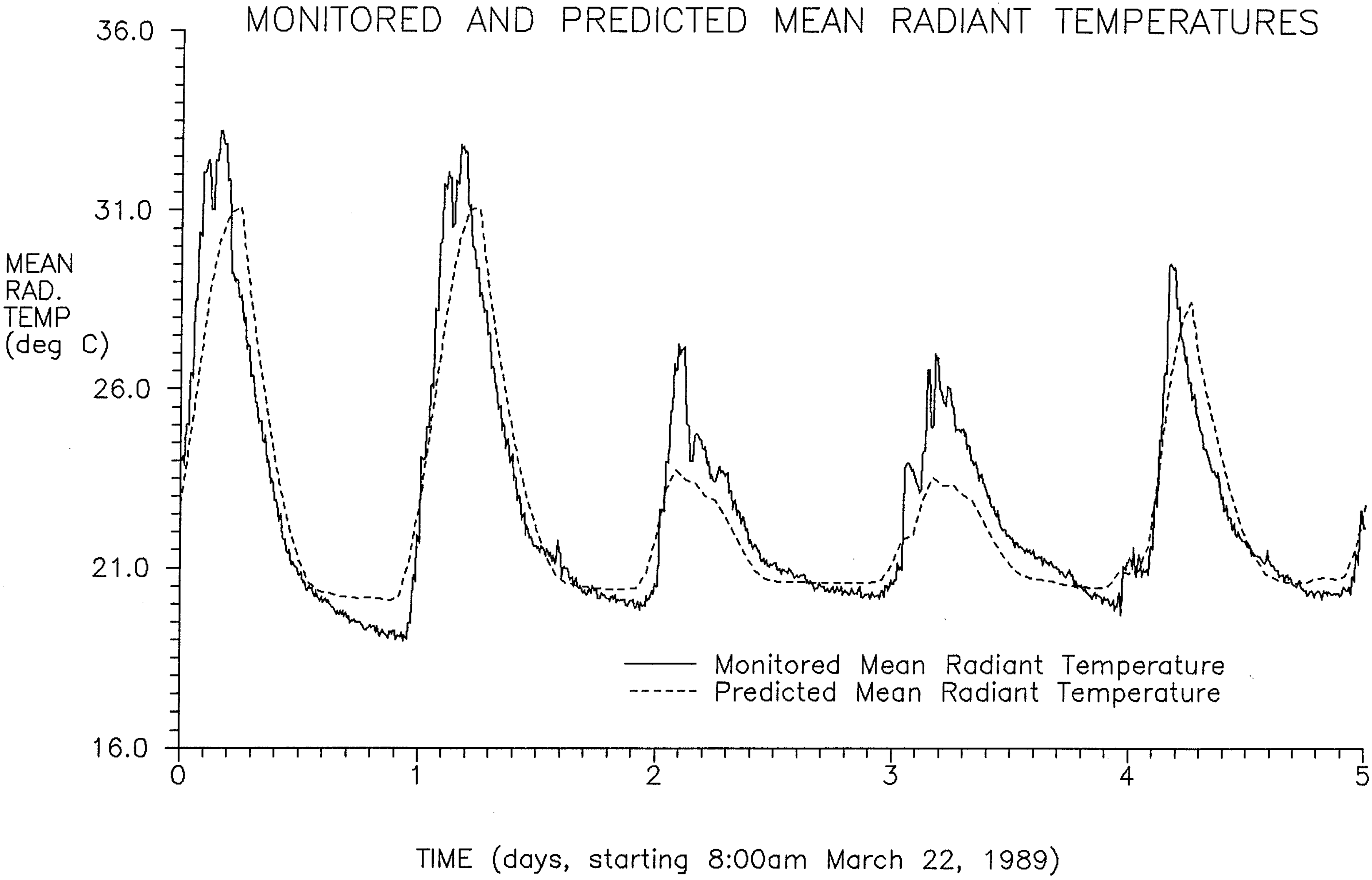

MONITORED AND PREDICTED RELATIVE HUMIDITIES
REL. HUM. (%)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0
1
2
3
4
5
Monitored Relative Humidity
Predicted Relative Humidity
TIME (days, starting 8:00am March 22, 1989)

Figure 3.9


MONITORED AND PREDICTED MEAN RADIANT TEMPERATURES
MEAN RAD. TEMP (deg C)
36.0
31.0
26.0
21.0
16.0
0
1
2
3
4
5
TIME (days, starting 8:00am March 22, 1989)
Monitored Mean Radiant Temperature
Predicted Mean Radiant Temperature

The ability of the program to predict comfort as measured by Fanger's Predicted Mean Vote (PMV) is of primary importance. The PMV's, as calculated from monitored data and from program simulation, are shown in Figure 3.10. The slight dip around noon on the first and second days in monitored PMV is due to shading of the ICA sensor by the window mullion (see Figure 3.1). In general there is very good agreement, although the tendency of the program to over-predict temperatures on sunny days and under-predict on cloudy days is also evident in the PMV. Indoor air velocity was always less than 0.1 m/s, and thus had no effect on thermal comfort. Because the value of thermal comfort is of most interest on sunny days, it is concluded that the computer predictions of thermal comfort are sufficiently accurate for this study.

There was a 2.0 day/night swing in PMV in the monitored house, far outside the 1.0 range (-0.5 to 0.5) acceptable range. The 23% glazing-to-floor ratio is too large for the house to maintain thermal comfort.

As discussed in Section 1.2, thermal discomfort could arise if there is significant temperature stratification. Figures 3.11 and 3.12 show the measured ceiling and floor temperatures over the monitoring period. During the night, the floor-to-ceiling temperature stratification was less than one Celsius degree. In the afternoon of the sunny days, the temperature stratification rose to seven Celsius degrees. The temperature stratification would have been even higher had it not been for the high wall air exhaust. It is interesting to note that the floor temperature reached a maximum temperature almost as great as the ceiling temperature. The main difference between the two temperatures was that the floor cooled off more quickly in the afternoon.

Although the maximum floor-to-ceiling temperature difference was seven Celsius degrees, the temperature difference over a height difference of 1.1 to 1.7 metres is of more interest in assessing thermal comfort. Figure 3.13 shows the temperature difference between the 150cm and the 10cm heights. On the sunny days, the temperature stratification was as high as seven Celsius degrees, although its duration was relatively short (approximately one hour). This degree of stratification exceeds the four-degree maximum recommended in Section 1.2 (as discussed previously, the large window area caused air temperatures in excess of comfortable levels). It is likely that, if the window area were reduced to achieve acceptable air temperatures, the temperature stratification would also be acceptable.

Figure 3.10

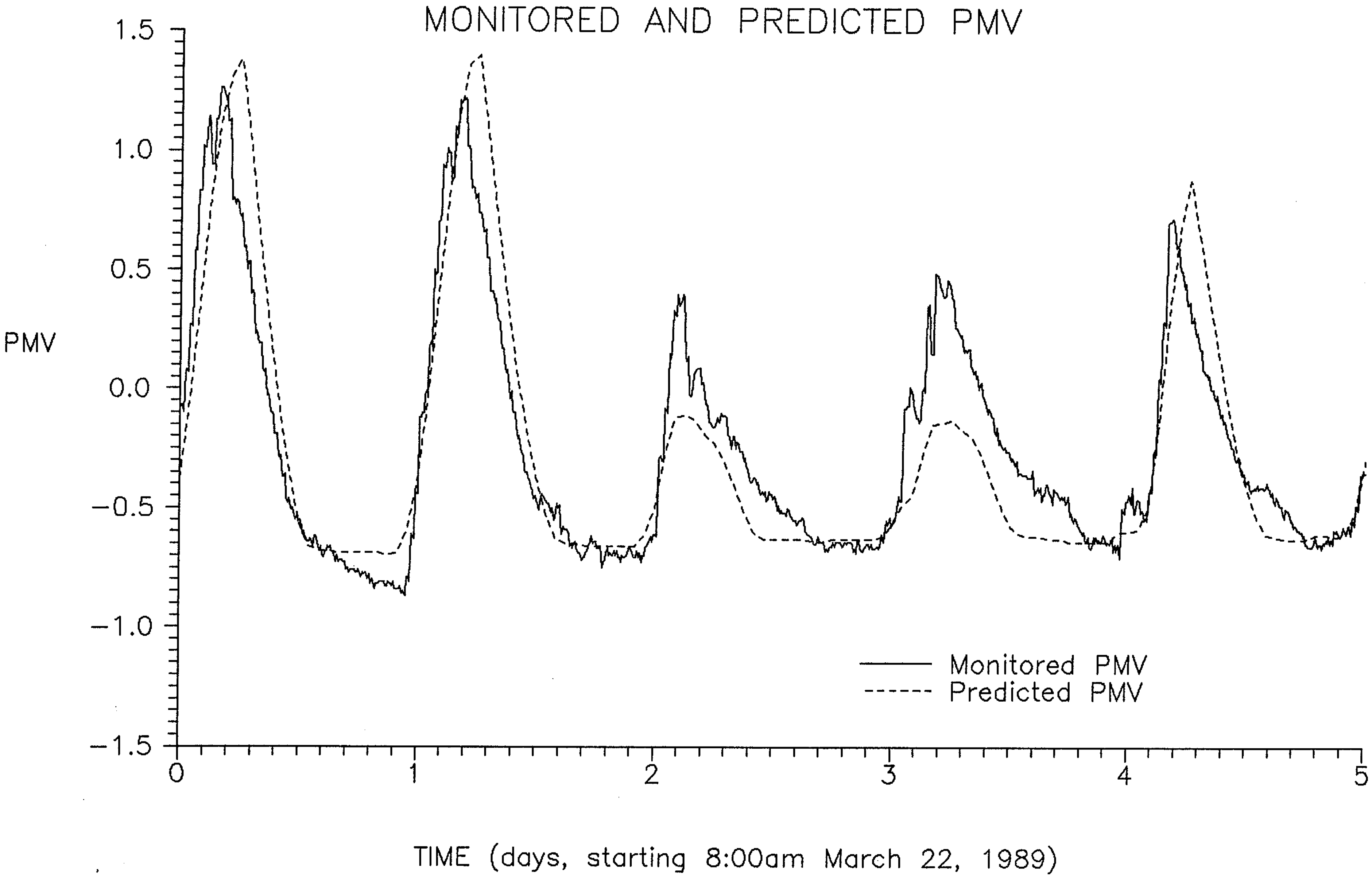

MONITORED AND PREDICTED PMV
PMV
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
1
2
3
4
5
Monitored PMV
Predicted PMV
TIME (days, starting 8:00am March 22, 1989)

Figure 3.11

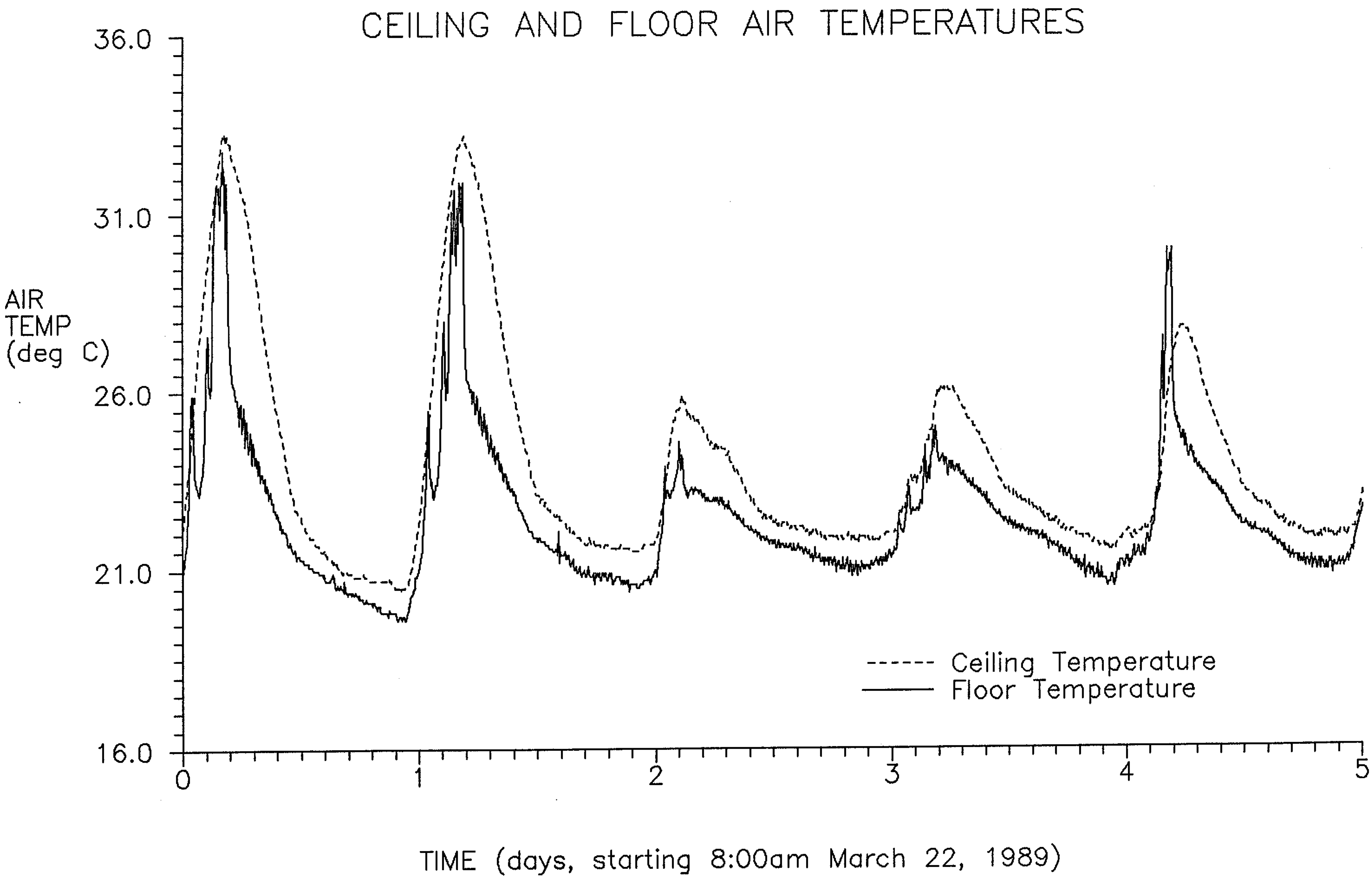

CEILING AND FLOOR AIR TEMPERATURES
AIR TEMP (deg C)
36.0
31.0
26.0
21.0
16.0
0
1
2
3
4
5
TIME (days, starting 8:00am March 22, 1989)
Ceiling Temperature
Floor Temperature

Figure 3.12

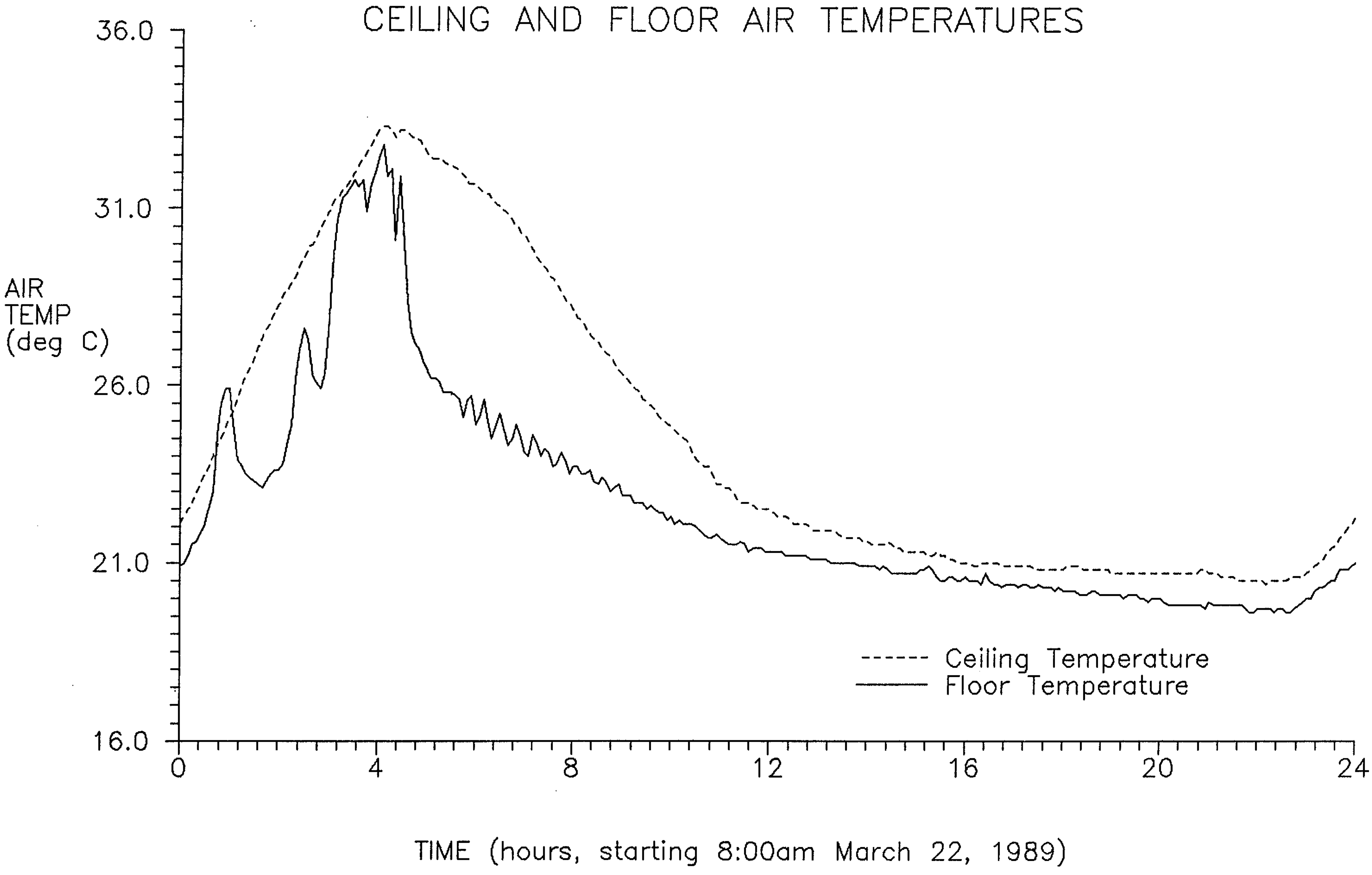
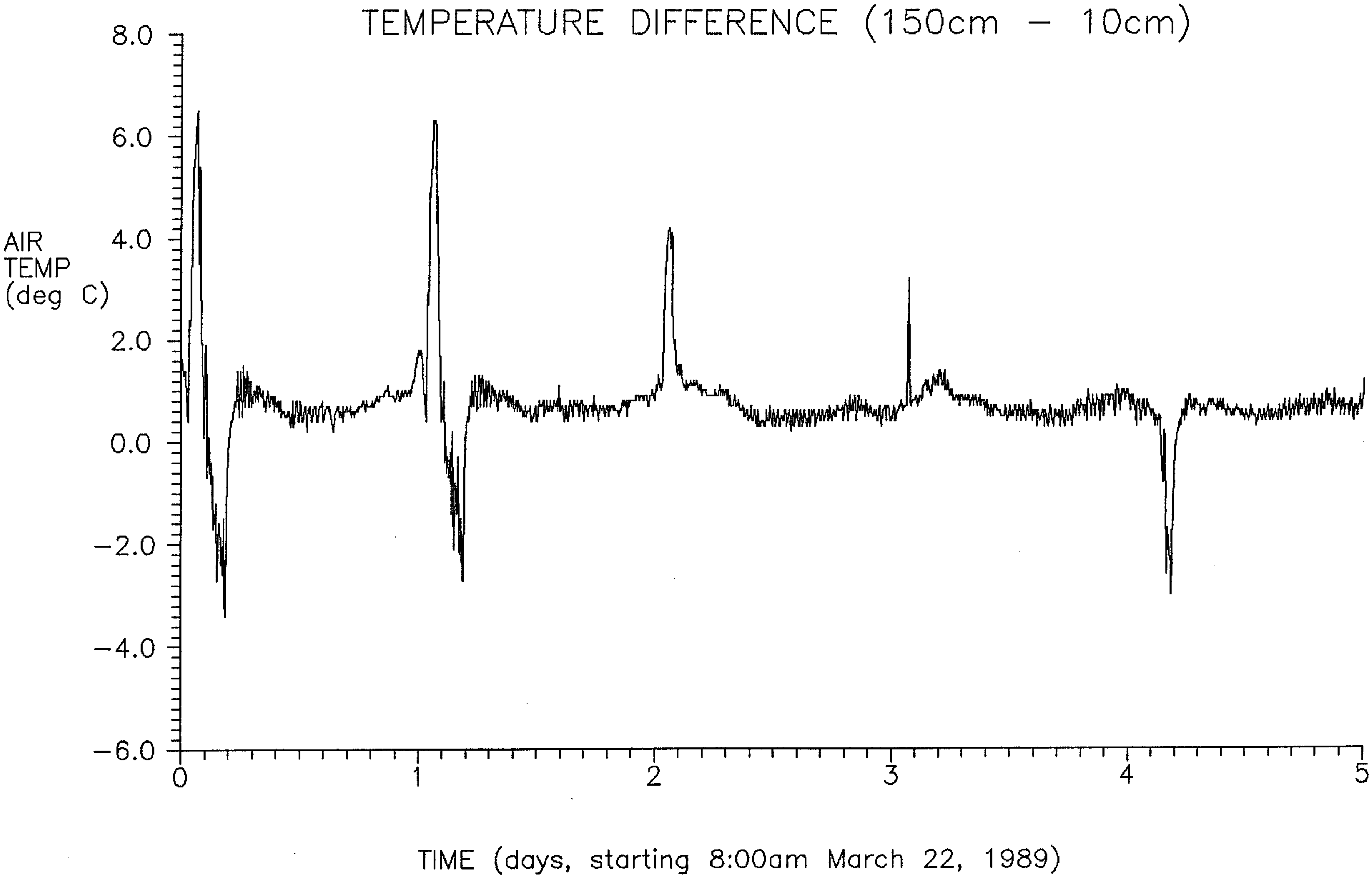

CEILING AND FLOOR AIR TEMPERATURES
AIR TEMP (deg C)
36.0
31.0
26.0
21.0
16.0
0
4
8
12
16
20
24
TIME (hours, starting 8:00am March 22, 1989)
Ceiling Temperature
Floor Temperature

Figure 3.13


TEMPERATURE DIFFERENCE (150cm − 10cm)
AIR TEMP (deg C)
8.0
6.0
4.0
2.0
0.0
−2.0
−4.0
−6.0
0
1
2
3
4
5
TIME (days, starting 8:00am March 22, 1989)

An interesting phenomenon, reverse stratification, occurs each afternoon on sunny days: the air at chest level is two to three degrees cooler than at the ankles. It is not clear why this is happening. Although the radiation shields were not in place for the first two days, they were for the fifth day. It is possible that the shading effect seen in the radiant temperature graphs could be causing the reverse stratification (i.e., the floor gets cold when it is shaded).

4. APPLICATION OF THE THERMAL COMFORT MODEL

The ultimate use of the thermal comfort model described in Section 2, and evaluated in Section 3, is to assist in the design of thermally comfortable buildings. This section demonstrates the use of the model.

4.1 Effect of Window Thermal Resistance

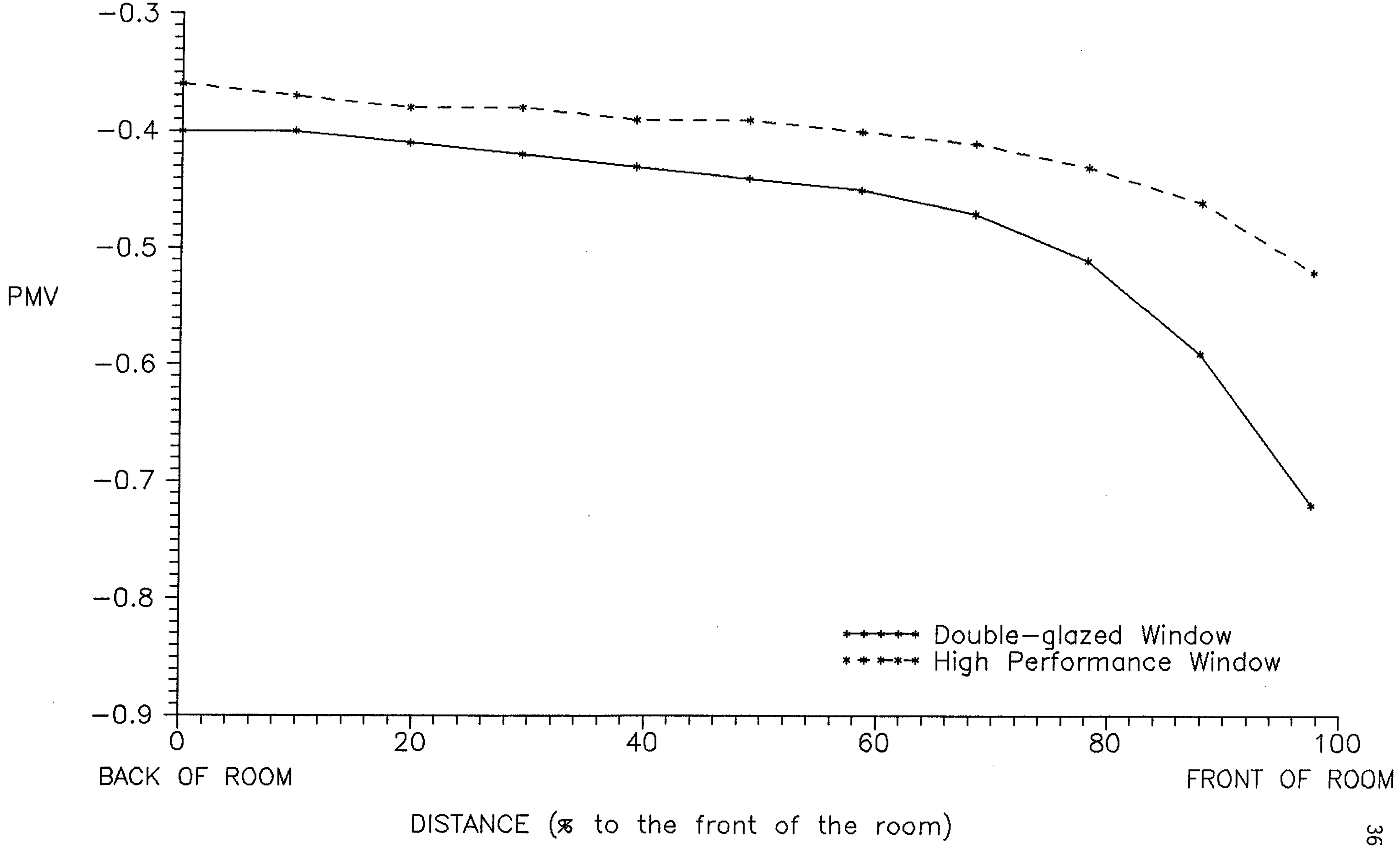
It is claimed that a major benefit of high-performance or high-R-value windows is improved thermal comfort. To assess this claim, the thermal comfort of a house with standard (RSI 0.35) and high-performance (RSI 0.9) windows was investigated.

The room floor plan is shown in Figure 2.2. The south and west walls are exterior walls and the north and east walls are interior walls. The room has three square metres of south-facing windows (10% glass-to-floor ratio). The PMV for a person wearing medium-weight clothing (clo=1.0) seated in the room on a cold winter night (-24 C outdoor temperature) is shown in Figure 4.1. The two windows were assumed to have the same shading coefficient to eliminate any possible solar effects. The PMV at the back of the room is 0.04 higher with the high-performance window than with the standard window. At a distance of 20 centimetres from the front windows, the house with the high-performance windows has a PMV 0.20 higher than the standard house.

Another way of analyzing the thermal comfort of the two windows is to examine the difference in indoor air temperature and energy consumption for the same PMV. The house performance was simulated for the month of January in Ottawa. The person was assumed to be 0.6 metres from the window. At a thermostat setpoint of 21C, the heating energy consumption of the house with standard windows was 34.9 kWhr per square metre of window higher than the high performance window house for the month of January. The thermostat setting in the house with standard windows had to be raised 0.8 Celsius degrees to have the same monthly average PMV as the house with high performance windows. (Note: because the houses were identical other than the R-value of thw window, the hourly values of PMV were also very close when the thermostsat setting was raised by 0.8 C.) The raised thermostat setting increased heating energy consumption by a further 8.4 kWhr/m^2 of window (a 24% increase). This analysis was repeated for other winter months and approximately the same percentage increase was found.

Figure 4.1

PMVS FOR HIGH PERFORMANCE AND DOUBLE-GLAZED WINDOWS



4.2 Effect of WIndow Size

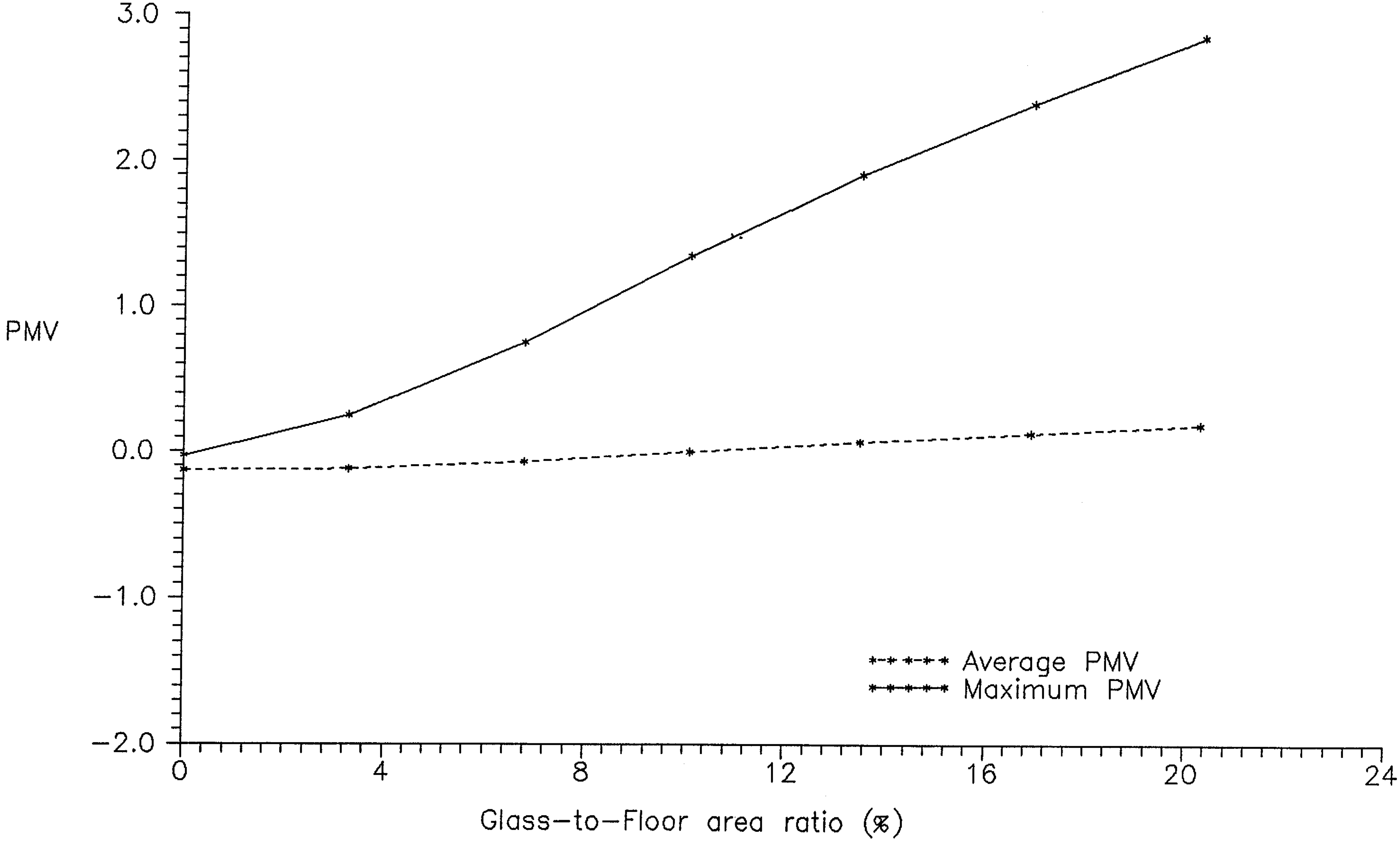
Design rules-of-thumb for proper sizing of windows in passive solar homes suggest a figure of 6 to 8% glass-to-floor-area ratio for light-weight structures. This figure is based more on minimizing energy consumption than on thermal comfort. To check the suitability of this rule-of-thumb, ENERPASS thermal comfort simulations were performed for the room shown in Figure 2.2. The simulations were carried out using Ottawa January weather data.

Figure 4.2 shows the average and maximum PMV as a function of glass-to-floor area. The occupant was assumed to be seated in the middle of the room wearing medium-weight clothing (clo=1.0). The windows were double-glazed with a shading coefficient of 0.8. The maximum PMV rises rapidly as window size is increased. The maximum allowable PMV is probably 1.0, corresponding to feeling "slightly warm" for those few hours of peak solar gains. From Figure 4.3, it is seen that the glass area should be kept below 8% of the floor area to ensure thermal comfort. Therefore, the rule-of-thumb appears reasonable. The average PMV rises only slightly as window size is increased. The higher air temperatures during the day are partially offset by lower mean radiant temperatures, especially at night.

Because most high performance windows have a reduced shading coefficient, the window sizing guideline would be better stated that the window shading coefficient multiplied by the percentage glass-to-floor area should be under 6.4. Thus, larger window areas can be used with lower shading-coefficient windows. From a passive solar energy perspective, however, low-shading-coefficient windows are undesirable because the larger window area loses more heat and costs more than an equivalent area of wall.

Figure 4.2

PMV VERSUS GLASS-TO-FLOOR AREA RATIO



5. CONCLUSIONS

In summary, excessive temperatures, large temperature swings and direct solar radiation incident on the occupants have the greatest potential for causing thermal discomfort in passive solar homes. Heavy-mass floors can cause discomfort if the occupants do not wear shoes.

The ENERPASS computer program predictions of thermal comfort (PMV) agreed reasonably well with the monitored data for a passive solar home. There was some discrepancy between monitored and predicted air temperatures on sunny days: this was attributed to the monitoring equipment being located close to the floor and, as such, measuring temperatures not representative of the "average" room temperature.

The passive solar home, with a 23% glass-to-floor area ratio, had air temperatures as high as 28C at 600mm above the floor. The day/night swing in the PMV of 2.0 (from slightly cool to slightly warm) is twice the recommended range. The head-to-floor temperature stratification was as high as seven Celsius degrees--greater than the recommended four-degree maximum.

Application of the ENERPASS Thermal Comfort Model developed as part of this study confirmed the 6 to 8% glass-to-floor area ratio design guideline for thermal comfort. For a person located near a window, the air temperature must be 0.8 Celsius degrees warmer if double-glazed instead of high-performance windows are used. The energy benefit of high-performance windows is 24% higher than would be calculated by a straight comparison of R-values, because of the need for a higher thermostat setting when double-glazed windows are used.

6. RECOMMENDATIONS

It is recommended that the thermal comfort model developed as a part of this study be used to perform a more complete analysis of the thermal comfort benefits of high-performance windows and other passive solar technologies such as phase-change drywall. The results of this analysis could be used to develop thermal comfort guidelines for passive solar homes. The guidelines could be published as a short technical note suitable for architects, builders and homeowners.

7. REFERENCES

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APPENDIX A: ANGLE FACTOR CALCULATION PROGRAM

```
rem * * * ANGLE FACTOR CALCULATING PROGRAM * * *
defint i
dim mx(100), my(100), lx(100), ly(100), lbl$(100), ul$(100), ulc$(100)
dim wall$(100), glaze$(100), element$(100), ar(10), br(10), shape(100)
dim gshape(100), wndoarea(100),wagf(100), gagf(100), cagf(100), fagf(100)
dim ceilarea(100),flarea(100), skyarea(100), sagf(100), bfagf(100)
dim wndowdth(100)

main:
 open "control" for input as #4 len=128
 input#4,a$
 while not eof(4)
ctmain:
  lgth = 0
  wdth = 0
  ach = 0
  if lgth = 0 then
   for i = 1 to 100
    wagf(i) = 0
    gagf(i) = 0
    cagf(i) = 0
    fagf(i) = 0
    sagf(i) = 0
   next i
   bwagf = 0
   bfagf = 0
  end if
  c = 0
  d = 0
  k = 4
  n = 0
  if fflag = 0 then
   input#4,cfile$
  end if
  compfile$ =  left$(cfile$,8) + " AGF"
  filename$ =  left$(cfile$,8) + ".AGF"
  filesource$ = left$(cfile$,12)
prestart:
  shell "dir > dirfile"
  open "dirfile" for input as #1
  answer$ = "n"
  while not eof(1)
   line input#1,tmp$
   if answer$ <> "y" then
    if compfile$ = left$(tmp$,12) then
      answer$ = "y"
     end if
   end if
  wend
  close#1
  kill "dirfile"
  if answer$ = "y" then
   open filename$ for input as #2 len=128
   open "temp.agf" for output as #3 len=128
   while a$ <> "***"
    input#2,a$
    print#3,a$
   wend
   a$ = ""
   input#2,lgth
```

```
   input#2,wdth
   input#2,ach
   input#2,lg
   input#2,wd
   input#2,k
   input#2,l
   input#2,n
   input#2,nwall
   input#2,nceiling
   input#2,nfloor
   for i = 1 to k
    input#2,my(i)
    input#2,mx(i)
   next i
   for i = 1 to n
    input#2,ly(i)
    input#2,lx(i)
    input#2,lbl$(i)
    input#2,wndoarea(i)
   next i
   for i = 1 to nceiling
    input#2,ceilarea(i)
   next i
   for i = 1 to nfloor
    input#2,flarea(i)
   next i
   input#2,bsmtwal
   input#2,ibsmtflr
   input#2,ubsmtflr
   for i = 1 to l
    input#2, ulc$(i)
   next i
   input#2,x
   input#2,y
   input#2,ox
   input#2,oy
   input#2,g$
   for i = 1 to nwall
    input#2,wagf(i)
    input#2,gagf(i)
   next i
   for i = 1 to nceiling
    input#2,cagf(i)
    input#2,sagf(i)
   next i
   for i = 1 to nfloor
    input#2,fagf(i)
   next i
   input#2,bwagf
   input#2,bfagf
   input#2,av
   input#2,clo
   close#2
   flag = 1
  else
   flag = 0
  end if
  fflag = 0
  gosub start
 wend
```

```
 close#4
end
rem****************************************************************************
start:
 if answer$ <> "y" then
  if lgth = 0 then
   open filename$ for output as #3 len=128
  else
   close#3
   kill filename$
   open filename$ for output as #3 len=128
  end if
  open filesource$ for input as #1 len=128
  for i = 1 to 5
   line input#1,a$
  next i
   nzone = val(a$)
  for i = 1 to 67
    line input#1,a$
  next i
 else
  open filename$ for input as #1 len=128
 end if
 cls
 input#1,nwall
 if answer$ <> "y" then
  for i = 1 to nzone-1
   input#1,g
  next i
 end if
 input#1,nceiling
 if answer$ <> "y" then
  for i = 1 to nzone-1
   input#1,g
  next i
 end if
 input#1,nfloor
 if answer$ <> "y" then
  for i = 1 to nzone-1
   input#1,g
  next i
  write#3,nwall
  write#3,nceiling
  write#3,nfloor
 end if
 nwall = nwall + 1
 nceiling = nceiling + 1
 nfloor = nfloor + 1
 if answer$ <> "y" then
  line input#1,a$
 end if
 color 15,0:print "ENERPASS 3.0: Editor"
 color 0,15:locate 1,55:print "CURRENT FILE:";:color 7,0:print " ";filename$
 for i = 1 to 80
  locate 2,i:print chr$(205);
 next i
 print "WALL   AREA  DIR    WALL       WINDOW  AREA  WINDOW       CEILING    ARE
AGF"
 print "       (m^2)        AGF                (m^2)  AGF                    (m^
 print "------------------------       --------------------      --------------
```

```
---"
 for i = 1 to nwall
  if answer$ <> "y" then
   input#1,g
  end if
  input#1,wallarea
  if answer$ <> "y" then
   input#1,g
   direction$ = input$(1,#1)
  else
   input#1,direction$
  end if
  input#1,wndoarea
  if answer$ <> "y" then
   input#1,g
   input#1,g
   input#1,g
   print#3,wallarea
   print#3,direction$
   print#3,wndoarea
  end if
  pwall$ = " W" + right$(str$(i),len(str$(i))-1)
  wall$ = "W" + right$(str$(i),len(str$(i))-1)
  glaze$ = "G" + right$(str$(i),len(str$(i))-1)
  if answer$ <> "y" then
   exist = 0
   for j = 1 to c
    if wall$ = element$(j) then
     wagf(i) = shape(j)
    end if
    if glaze$ = element$(j) then
     gagf(i) = shape(j)
     exist = 1
    end if
    if exist = 0 then
     gagf(i) = 0
    end if
   next j
   for j = 1 to c
    if left$(element$(j),1) = "C" then
     cagf = shape(j)
    elseif left$(element$(j),1) = "F" then
     fagf = shape(j)
    end if
   next j
  end if
  print pwall$;"   ";wallarea
  locate i+5,15 : print direction$
  locate i+5,34 : print glaze$
  locate i+5,40 : print wndoarea
  locate i+5,20 : print int(wagf(i)*1000)/1000
  locate i+5,46 : print int(gagf(i)*1000)/1000
  if lgth = 0 then
   d = d + 1
   ul$(d) = "W" + right$(str$(i),len(str$(i))-1)
   ulc$(d) = ul$(d)
   if wndoarea <> 0 then
    d = d + 1
    ul$(d) = "G" + right$(str$(i),len(str$(i))-1)
    ulc$(d) = ul$(d)
```

```
    wndoarea(i) = wndoarea
   end if
  end if
 next i
 row = 6
 for i = nwall + 1 to nwall + nceiling
  input#1,ceilarea
  ceilarea(i-nwall) = ceilarea
  if answer$ <> "y" then
   input#1,g
  end if
  input#1,skyarea
  skyarea(i-nwall) = skyarea
  if answer$ <> "y" then
   print#3,ceilarea
   print#3,skyarea
  end if
  locate row,60 : print " C";right$(str$(i),len(str$(i))-1);"      ";ceilarea(i-
)
  locate row,76 : print str$(int(cagf(i-nwall)*1000)/1000)
  row = row + 1
  if answer$ <> "y" then
   for j = 1 to 2
    input#1,g
   next j
  end if
 next i
 locate row + 2,59 : print "FLOOR"
 locate row + 3,59 : print "-----"
 for i = nwall + nceiling + 1 to nwall + nceiling + nfloor
  if answer$ <> "y" then
   input#1,g
  end if
   input#1,flarea(i-nwall-nceiling)
  if answer$ <> "y" then
   print#3,flarea(i-nwall-nceiling)
   input#1,g
   input#1,g
  end if
  locate row + 4,60 : print " F";right$(str$(i),len(str$(i))-1);"      ";flarea(
ll-nceiling)
  locate row + 4,76 : print str$(int(fagf(i-nwall-nceiling)*1000)/1000)
  row = row  + 1
 next i
 input#1,bsmtwal
 if answer$ <> "y" then
  print#3,bsmtwal
  input#1,g
  input#1,g
  input#1,g
 end if
  input#1,ibsmtflr
  input#1,ubsmtflr
 if answer$ <> "y" then
  print#3,ibsmtflr
  print#3,ubsmtflr
 end if
 if answer$ <> "y" then
  write#3,"***"
 end if
```

```
 bsmtfl = ibsmtflr + ubsmtflr
 locate row + 6,59 : print "BSMT WAL"
 locate row + 7,59 : print "--------"
 locate row + 8,59 : print "  BW";right$(str$(i),len(str$(i))-1)
 locate row + 8,69 : print bsmtwal
 locate row + 8,76 : print str$(int(bwagf*1000)/1000)
 if lgth = 0 then
  if bsmtwal > 0 then
   d = d + 1
   ul$(d) = "BW" + right$(str$(i),len(str$(i))-1)
   ulc$(d) = ul$(d)
  end if
  l = d
  ul$(d+1) = "    "
 end if
 i = i + 1
 locate row + 11,59 : print "BSMT FLR"
 locate row + 12,59 : print "--------"
 locate row + 13,59 : print "  BF";right$(str$(i),len(str$(i))-1)
 locate row + 13,69 : print bsmtflr
 locate row + 13,76 : print str$(int(bfagf*1000)/1000)
 close#1
 locate 11,2 : print "PLEASE ENTER THE DIMENSIONS OF THE ROOM:"
 if flag <> 1 then
1:locate 12,2 : input "LENGTH (m):";lg
  if lg <= 0 then goto 1
2:locate 13,2 : input "WIDTH (m):";wd
  if wd <= 0 then goto 2
3:locate 14,2 : input "HEIGHT (m):";ach
  if ach <= 0 then goto 3
4:locate 16,2 : input "AIR VELOCITY (m/s):";av
  if av < 0 then goto 4
5:locate 17,2 : input "CLOTHING (clo):";clo
  if clo < 0 then goto 5
  flag = 1
  if lg > wd then
   lgth = lg
   wdth = wd
  else
   lgth = wd
   wdth = lg
  end if
 else
  locate 12,2 : print "LENGTH (m):";lg
  locate 13,2 : print "WIDTH (m):";wd
  locate 14,2 : print "HEIGHT (m):";ach
  locate 16,2 : print "AIR VELOCITY (m/s):";av
  locate 17,2 : print "CLOTHING (clo):";clo
 end if
 for i = 1 to c
  element$(i) = ""
  shape(i) = 0
  gshape(i) = 0
 next i
 c = 0
 for i = 1 to nwall
  wndowdth(i) = 0
 next i
 if acflag = 1 then
  avcloflag = 1
```

```
 end if
 locate 19,2 : color 15,0 : print "F1:
 locate 19,6 : color 7,0 : print "Edit floor plan"
 locate 20,2 : color 15,0 : print "F2:"
 locate 20,6 : color 7,0 : print "Change air velocity and/or clothing"
 if answer$ = "y" then
  locate 21,2 : color 15,0 : print "F3:
  locate 21,6 : color 7,0 : print "Restart"
  locate 22,2 : color 15,0 : print "F10:"
  locate 22,7 : color 7,0 : print "Exit"
 end if
 key(1) on
 key(2) on
 key(3) on
 key(10) on
 on key(1) gosub floorplan
 on key(2) gosub changeavclo
 on key(3) gosub restart
 on key(10) gosub xit
 idle:goto idle
return
rem*******************************************************************************
flpl:
 if avcloflag = 0 then
  cls
 end if
 a = 70
 b = int(a/2.5*wdth/lgth)
 while b > 20
  a = a - 1
  b = int(a/2.5*wdth/lgth)
 wend
 if a/2 <> int(a/2) then
  a = 2*int(a/2)
 end if
 if b/2 <> int(b/2) then
  b = 2*int(b/2)
 end if
 if b < 2 then
  b = 2
  a = 2*(int(b*2.5*lgth/wdth)/2)
  if a > 70 then
   a = 70
  end if
 end if
 ulx = (80-a)/2
 uly = (24-b)/2
 if avcloflag = 0 then
  locate uly,ulx : print chr$(206) : my(1) = uly : mx(1) = ulx
  locate uly,ulx+a : print chr$(206) : my(2) = uly : mx(2) = ulx+a
  locate uly+b,ulx+a : print chr$(206) : my(3) = uly+b : mx(3) = ulx+a
  locate uly+b,ulx : print chr$(206) : my(4) = uly+b: mx(4) = ulx
  for i = ulx+1 to ulx+a-1
   locate uly,i : print chr$(205)
   locate uly+b,i : print chr$(205)
  next i
  for i = uly+1 to uly+b-1
   locate i,ulx : print chr$(186)
   locate i,ulx+a : print chr$(186)
  next i
```

```
  end if
  if x = 0 and y = 0 then
   x = ulx+a/2
   y = uly+b/2
  end if
  if avcloflag = 0 then
   color 0,15:locate 1,14:print "CURRENT FILE:";:color 7,0:print " ";filename$
   locate 1,1 : print "VALID"
   locate 2,1 : print "LABELS"
   locate 1,75 : print "UNUSED"
   locate 2,75 : print "LABELS"
   for i = 1 to d
    locate i+3,77 : print ul$(i)
   next i
   for  i = 1 to l
    locate i+3,2 : print ulc$(i)
   next i
   color 15,0: locate 23,5 : print "F1:"; : color 7,0 : print "Data Scrn"
   color 15,0: locate 23,22 : print "F2:"; : color 7,0 : print "Add Mark"
   color 15,0: locate 23,38 : print "F3:"; : color 7,0 : print "Add Label"
   color 15,0: locate 23,55 : print "F4:"; : color 7,0 : print "Clear     "
   color 15,0: locate 23,68 : print "F10:"; : color 7,0 : print "Exit"
   locate 1,48 : print "X:          Y:"
 end if
 ox = x:oy = y
move:
  xpos = int((x-ulx)/a*lgth*10)/10
  ypos = int((y-uly)/b*wdth*10)/10
  if avcloflag = 0 then
   locate 1,46 : print "                              "
   locate 1,48 : print "X:          Y:"
   locate 1,50 : print xpos;"m"
   locate 1,61 : print ypos;"m"
   if skip <> 1 then
    locate oy,ox
    if oy = uly and ox = ulx then
     print chr$(206)
    elseif oy = uly and ox = ulx+a then
     print chr$(206)
    elseif oy = uly+b and ox = ulx+a then
     print chr$(206)
    elseif oy = uly+b and ox = ulx then
     print chr$(206)
    elseif oy = uly or oy = uly+b then
     print chr$(205)
    elseif ox = ulx or ox = ulx+a then
     print chr$(186)
    else
     print " "
    end if
    for i = 1 to k
     locate my(i),mx(i) : print chr$(206)
    next i
    if n > 0 then
     for i = 1 to n
      locate ly(i),lx(i) : print lbl$(i)
     next i
    end if
   end if
   skip = 0
```

```
   locate y,x : print chr$(206)
  end if
  if avcloflag = 1 then
   gosub quit
  end if
  key(1) on
  key(2) on
  key(3) on
  key(4) on
  key(5) on
  key(10) on
  key(11) on
  key(12) on
  key(13) on
  key(14) on
  key(15) on
  on key(1) gosub start
  on key(2) gosub mark
  on key(3) gosub label
  on key(4) gosub clr
  on key(10) gosub quit
  on key(11) gosub up
  on key(12) gosub left
  on key(13) gosub right
  on key(14) gosub down
  wt: goto wt
 return
return
rem***************************************************************************
up:
 if y-1<uly then y = y + 1 :
  oy = y : ox = x : y = y - 1
return move
rem***************************************************************************
left:
 if x-1<ulx then x = x + 1 :
  oy = y : ox = x : x = x - 1
return move
rem***************************************************************************
right:
 if x+1>ulx+a then x = x - 1 :
 oy = y : ox = x : x = x + 1
return move
rem***************************************************************************
down:
 if y+1>uly+b then y = y - 1 :
  oy = y : ox = x : y = y + 1
return move
rem***************************************************************************
mark:
 if x=ulx or x=ulx+a or y=uly or y=uly+b then
  skip = 1
  cmark = 0
  for i = 1 to k
   if mx(k) = x and my(k) = y then
    cmark = 1
   end if
  next i
  if cmark = 0 then
   k = k + 1
```

```
   mx(k) = x
   my(k) = y
  end if
 end if
return
rem*****************************************************************************
label:
 if x=ulx or x=ulx+a or y=uly or y=uly+b then
  def seg = 0
  poke 1050, peek(1052)
  locate 23,55 : print "                          "
  locate 23,55 : input " LABEL";label$
  color 15,0: locate 23,55 : print "F4:"; : color 7,0 : print "Clear     "
  color 15,0: locate 23,68 : print "F10:"; : color 7,0 : print "Exit"
  if left$(label$,1) = "w" then
   label$ = "W" + right$(label$,len(label$)-1)
  end if
  if left$(label$,1) = "g" then
   label$ = "G" + right$(label$,len(label$)-1)
  end if
  if left$(label$,2) = "bw" then
   label$ = "BW" + right$(label$,len(label$)-2)
  end if
  h = 0
  for i = 1 to 1
   if label$ = ulc$(i) then
    h = 1
   end if
  next i
  if h <> 1 then
   locate 23,55 : print "                          "
td:locate 23,55 : print "*INVALID LABEL*"
   b$ = inkey$
   if b$ = "" then goto td
   gosub label
  else
   clabel = 0
   for i = 1 to n
    if lx(i) = x and ly(i) = y then
     clabel = 1
    end if
   next i
   if clabel = 0 then
    locate y,x : print label$
    n = n + 1
    lx(n) = x
    ly(n) = y
    lbl$(n) = label$
    for i = 1 to d
     if ul$(i) = label$ then
      for j = i to d
       ul$(j) = ul$(j+1)
      next j
      d = d - 1
     end if
    next i
    for i = 1 to d+1
     locate i+3,77 : print ul$(i)
    next i
   end if
```

```
  end if
 end if
return
rem***************************************************************************
clr:
 for i = 5 to k
  my(i) = 0
  mx(i) = 0
 next i
 for i = 1 to n
  ly(i) = 0
  lx(i) = 0
  lbl$(i) = ""
 next i
 for i = 1 to l
  ul$(i) = ulc$(i)
 next i
 ul$(l+1) = "    "
 k = 4
 n = 0
 d = 1
 gosub flpl
return
rem***************************************************************************
quit:
 if avcloflag = 0 then
  cls
 end if
 if x=ulx or x=ulx+a or y=uly or y=uly+b then
  print "*CURSOR MUST BE OUTSIDE THE BOUNDARY OF THE WALLS*"
  print "    *IN ORDER TO CALCULATE THE ANGLE FACTORS*"
  goto ct
 elseif k <> n then
  print "*INCORRECT NUMBER OF MARKERS OR LABELS*"
 goto ct
 elseif d > 0 then
  print "*NOT ALL LABELS WERE USED*"
ct:locate 23,2: print "F5:Continue"
  key(5) on
  on key(5) gosub flpl
ht:goto ht
 end if
 if avcloflag = 0 then
  locate 17,2 : color 15,0 : print "One moment please ....":color 7,0
 end if
rem # # # SIDE 1 # # #
 check = 1
 st = ulx
 for i = ulx+1 to ulx+a
  for j = 1 to k
   if mx(j) = i then
    if my(j) = uly then
     if check = 1  then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed
```

```
    for v = 1 to n
     if u = lx(v) and uly = ly(v) then
      if left$(lbl$(v),1) = "G" then
       cst = (st - ulx)/a*lgth
       ced = (ed - ulx)/a*lgth
       r = val(right$(lbl$(v),len(lbl$(v))-1))
       wndowdth(r) = wndowdth(r) + abs(ced - cst)
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem # # # SIDE 2 # # #
 st = uly
 for i = uly+1 to uly+b
  for j = 1 to k
   if my(j) = i then
    if mx(j) = ulx+a then
     if check = 1  then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed
    for v = 1 to n
     if u = ly(v) and ulx+a = lx(v) then
      if left$(lbl$(v),1) = "G" then
       cst = (st - uly)/b*wdth
       ced = (ed - uly)/b*wdth
       r = val(right$(lbl$(v),len(lbl$(v))-1))
       wndowdth(r) = wndowdth(r) + abs(ced - cst)
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem # # # SIDE 3 # # #
 st = ulx+a
 for i = ulx+a-1 to ulx  step -1
  for j = 1 to k
   if mx(j) = i then
    if my(j) = uly+b then
     if check = 1 then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed step -1
    for v = 1 to n
     if u = lx(v) and uly+b = ly(v) then
```

```
      if left$(lbl$(v),1) = "G" then
       cst = (st - ulx)/a*lgth
       ced = (ed - ulx)/a*lgth
       r = val(right$(lbl$(v),len(lbl$(v))-1))
       wndowdth(r) = wndowdth(r) + abs(ced - cst)
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem # # # SIDE 4 # # #
 st = uly+b
 for i = uly+b-1 to uly step -1
  for j = 1 to k
   if my(j) = i then
    if mx(j) = ulx then
     if check = 1  then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed step -1
    for v = 1 to n
     if u = ly(v) and ulx = lx(v) then
      if left$(lbl$(v),1) = "G" then
       cst = (st - uly)/b*wdth
       ced = (ed - uly)/b*wdth
       r = val(right$(lbl$(v),len(lbl$(v))-1))
       wndowdth(r) = wndowdth(r) + abs(ced - cst)
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem * * * SIDE 1 * * *
 check = 1
 st = ulx
 for i = ulx+1 to ulx+a
  for j = 1 to k
   if mx(j) = i then
    if my(j) = uly then
     if check = 1  then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed
    for v = 1 to n
     if u = lx(v) and uly = ly(v) then
      c = c + 1
```

```
      element$(c) = lbl$(v)
      cst = (st - ulx)/a*lgth
      ced = (ed - ulx)/a*lgth
      cc = ypos
      if xpos > cst and xpos < ced then
       aa = xpos - cst
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
       aa = ced - xpos
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
      else
       if xpos <= cst then
        aa = ced - xpos
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = cst - xpos
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       elseif xpos => ced then
        aa = xpos - cst
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = xpos - ced
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       end if
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem * * * SIDE 2 * * *
 st = uly
 for i = uly+1 to uly+b
  for j = 1 to k
   if my(j) = i then
    if mx(j) = ulx+a then
     if check = 1  then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed
    for v = 1 to n
     if u = ly(v) and ulx+a = lx(v) then
      c = c + 1
      element$(c) = lbl$(v)
      cst = (st - uly)/b*wdth
```

```
      ced = (ed - uly)/b*wdth
      cc = lgth - xpos
      if ypos > cst and ypos < ced then
       aa = ypos - cst
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
       aa = ced - ypos
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
      else
       if ypos <= cst then
        aa = ced - ypos
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = cst - ypos
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       elseif ypos => ced then
        aa = ypos - cst
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = ypos - ced
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       end if
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
rem * * * SIDE 3 * * *
 st = ulx+a
 for i = ulx+a-1 to ulx  step -1
  for j = 1 to k
   if mx(j) = i then
    if my(j) = uly+b then
     if check = 1 then
      ed = i : check = 2
     end if
    end if
   end if
  next j
  if check = 2 then
   for u = st to ed step -1
    for v = 1 to n
     if u = lx(v) and uly+b = ly(v) then
      c = c + 1
      element$(c) = lbl$(v)
      cst = (st - ulx)/a*lgth
      ced = (ed - ulx)/a*lgth
      cc = wdth - ypos
```

```
        if xpos < cst and xpos > ced then
         aa = cst - xpos
         gosub shape
         shape(c) = shape(c) + shape
         gshape(c) = gshape(c) + gshape
         aa = xpos - ced
         gosub shape
         shape(c) = shape(c) + shape
         gshape(c) = gshape(c) + gshape
        else
         if xpos => cst then
          aa = xpos - ced
          gosub shape
          shape(c) = shape(c) + shape
          gshape(c) = gshape(c) + gshape
          aa = xpos - cst
          gosub shape
          shape(c) = shape(c) - shape
          gshape(c) = gshape(c) - gshape
         elseif xpos <= ced then
          aa = cst - xpos
          gosub shape
          shape(c) = shape(c) + shape
          gshape(c) = gshape(c) + gshape
          aa = ced - xpos
          gosub shape
          shape(c) = shape(c) - shape
          gshape(c) = gshape(c) - gshape
         end if
        end if
        st = ed
        check = 1
       end if
      next v
     next u
    end if
   next i
  rem * * * SIDE 4 * * *
   st = uly+b
   for i = uly+b-1 to uly step -1
    for j = 1 to k
     if my(j) = i then
      if mx(j) = ulx then
       if check = 1  then
        ed = i : check = 2
       end if
      end if
     end if
    next j
    if check = 2 then
     for u = st to ed step -1
      for v = 1 to n
       if u = ly(v) and ulx = lx(v) then
        c = c + 1
        element$(c) = lbl$(v)
        cst = (st - uly)/b*wdth
        ced = (ed - uly)/b*wdth
        cc = xpos
        if ypos < cst and ypos > ced then
         aa = cst - ypos
```

```
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
       aa = ypos - ced
       gosub shape
       shape(c) = shape(c) + shape
       gshape(c) = gshape(c) + gshape
      else
       if ypos => cst then
        aa = ypos - ced
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = ypos - cst
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       elseif ypos <= ced then
        aa = cst - ypos
        gosub shape
        shape(c) = shape(c) + shape
        gshape(c) = gshape(c) + gshape
        aa = ced - ypos
        gosub shape
        shape(c) = shape(c) - shape
        gshape(c) = gshape(c) - gshape
       end if
      end if
      st = ed
      check = 1
     end if
    next v
   next u
  end if
 next i
 ar(1) = xpos
 br(1) = ypos
 ar(2) = lgth - xpos
 br(2) = ypos
 ar(3) = xpos
 br(3) = wdth - ypos
 ar(4) = lgth - xpos
 br(4) = wdth - ypos
rem * * * CEILING * * *
 cr = ach - 0.6
 for i = 1 to 4
  shape = 0.047*atn(1.161*ar(i)/cr)*atn(1.253*br(i)/cr)
  tcshape = tcshape + shape
 next i
 for i = 1 to nceiling
  tceilinga = tceilinga + ceilarea(i)
 next i
 for i = 1 to nceiling
  cagf(i) = tcshape*ceilarea(i)/tceilinga
  sagf(i) = skyarea(i)/ceilarea(i)*cagf(i)
  cagf(i) = cagf(i) - sagf(i)
 next i
 c = c + 1
 element$(c) = "TC" : shape(c) = tcshape
rem * * * FLOOR * * *
```

```
cr = 0.6
for i = 1 to 4
 shape = 0.047*atn(1.161*ar(i)/cr)*atn(1.253*br(i)/cr)
 tfshape = tfshape + shape
next i
for i = 1 to nfloor
 tfloora = tfloora + flarea(i)
next i
tfloora = tfloora + bsmtflr
for i = 1 to nfloor
 fagf(i) = tfshape*flarea(i)/tfloora
next i
bfagf = tfshape*bsmtflr/tfloora
c = c + 1
element$(c) = "TF" : shape(c) = tfshape
for repeat = 1 to 2
 for i = 1 to c
   for j = i+1 to c
    if element$(i) = element$(j) then
     shape(i) = shape(i) + shape(j)
     for m = j to c
      element$(m) = element$(m+1)
      shape(m) = shape(m+1)
      gshape(m) = gshape(m+1)
     next m
     c = c - 1
    end if
   next j
 next i
next repeat
for i = 1 to c
if left$(element$(i),1) = "G" then
  shapeadd = shape(i) - gshape(i)
  for j = 1 to c
   if "W" + right$(element$(i),len(element$(i))-1) = element$(j) then
    shape(j) = shape(j) + shapeadd
   end if
  next j
  shape(i) = gshape(i)
 end if
next i
write#3,lgth
write#3,wdth
write#3,ach
write#3,lg
write#3,wd
write#3,k
write#3,l
write#3,n
write#3,nwall
write#3,nceiling
write#3,nfloor
for i = 1 to k
 write#3,my(i)
 write#3,mx(i)
next i
for i = 1 to n
 write#3,ly(i)
 write#3,lx(i)
 write#3,lbl$(i)
```

```
 write#3,wndoarea(i)
next i
for i = 1 to nceiling
 write#3,ceilarea(i)
next i
for i = 1 to nfloor
 write#3,flarea(i)
next i
write#3,bsmtwal
write#3,ibsmtflr
write#3,ubsmtflr
for i = 1 to 1
 write#3, ulc$(i)
next i
write#3,x
write#3,y
write#3,ox
write#3,oy
write#3,"###"
for i = 1 to c
tshape = tshape + shape(i)
next i
for i = 1 to nwall
 wall$ = "W" + right$(str$(i),len(str$(i))-1)
 glaze$ = "G" + right$(str$(i),len(str$(i))-1)
 exist = 0
 for j = 1 to c
  if wall$ = element$(j) then
   wagf(i) = shape(j)
  end if
  if glaze$ = element$(j) then
   gagf(i) = shape(j)
   exist = 1
  end if
  if exist = 0 then
   gagf(i) = 0
  end if
  if left$(element$(j),2) = "BW" then
   bwagf = shape(j)
  end if
 next j
next i
for i = 1 to nwall
 wagf(i) = wagf(i)/tshape
 gagf(i) = gagf(i)/tshape
 write#3,wagf(i)
 write#3,gagf(i)
next i
for i = 1 to nceiling
 cagf(i) = cagf(i)/tshape
 sagf(i) = sagf(i)/tshape
 write#3,cagf(i)
 write#3,sagf(i)
next i
for i = 1 to nfloor
 fagf(i) = fagf(i)/tshape
 write#3,fagf(i)
next i
write#3,bwagf
bfagf(i) = bfagf(i)/tshape
```

```
 write#3,bfagf
 write#3,av
 write#3,clo
 close#3
 if answer$ = "y" then
  gosub constructname
  shell "erase " + name$
  shell "rename temp.agf " + name$
 end if
 tshape = 0 : tfshape = 0: tcshape = 0 : tceilinga = 0 : tfloora = 0
 if avcloflag = 0 then
  gosub prestart
 else
  avcloflag = 0
  end
 end if
return
rem*****************************************************************************
shape:
 if cc < 0.00001 then
  cc = 0.00001
 end if
 if left$(element$(c),1) = "G" then
  e = val(right$(element$(c),len(element$(c))-1))
  bb = wndoarea(e)/wndowdth(e)
  gshape = 0.05*atn(1.206*aa/cc)*atn(1.32*bb/cc)
 else
  gshape = 0
 end if
 bb1 = 0.6
 bb2 = ach - 0.6
 wallsf1 = 0.05*atn(1.206*aa/cc)*atn(1.32*bb1/cc)
 wallsf2 = 0.05*atn(1.206*aa/cc)*atn(1.32*bb2/cc)
 shape = wallsf1 + wallsf2
return
rem*****************************************************************************
constructname:
 ccount = 0
 for i = 1 to 8
  if mid$(filename$,i,1) <> " " then
   ccount = ccount + 1
  end if
 next i
 name$ = left$(filename$,ccount) + ".AGF"
return
rem*****************************************************************************
changeavclo:
 avcloflag = 1
 acflag = 1
 gosub 4
return
rem*****************************************************************************
floorplan:
 avcloflag = 0
 gosub flpl
return
rem*****************************************************************************
restart:
 close#3
 gosub constructname
```

```
 shell "erase " + name$
 fflag = 1
 gosub ctmain
return
rem****************************************************************************
xit:
 if avcloflag = 1 then
  gosub flpl
 end if
 end
return
```