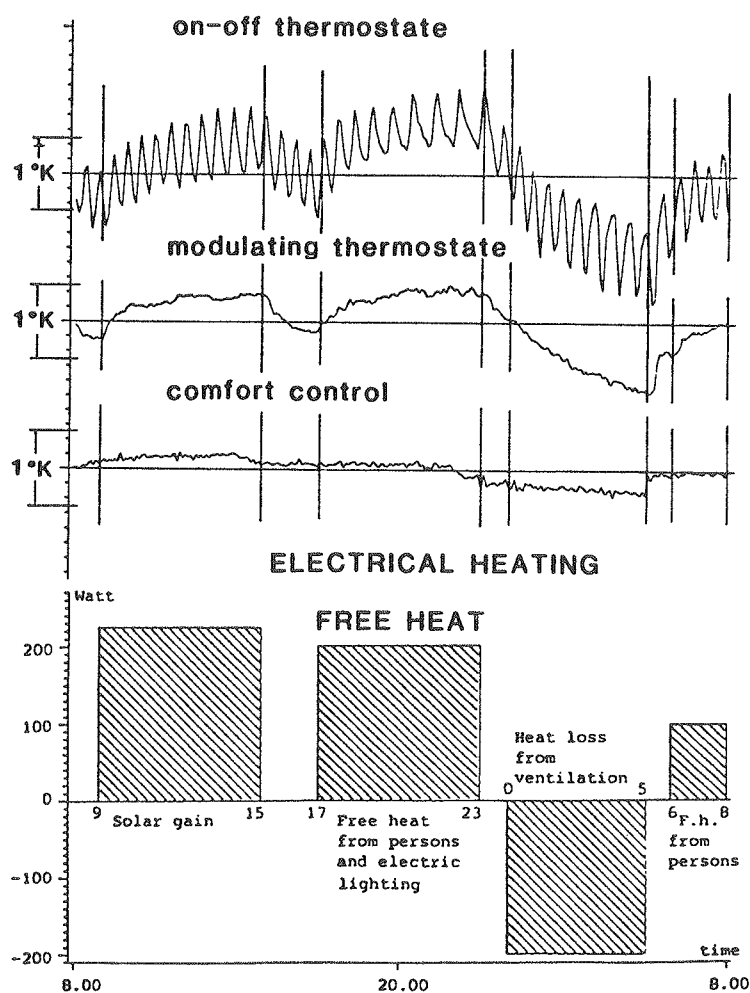# Measurement and Control of Thermal Comfort in Passive Solar Systems

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Measurement and Control of Thermal Comfort
in Passive Solar Systems

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## Introduction

   The efficiency of passive solar systems is strongly
dependant of to what degree the thermal climat parameters is
taken into account.  These parameters are in accordance with
ISO7730 (1).

      activity level and clothing
      air temperature and mean radiant temperature
      air velocity and air humidity

   As a rule the room temperature is, by experience,
expected to be around 22°C.  The temperature is given by a
thermometer placed on a wall.  The heat supply is controlled
by a thermostat of a type and in a position chosen from an
economic and mounting point of view more than out of regard
to the optimal function.

   Result: increased energy consumption and decreased degree
of thermal comfort. In this paper some ideas to improve the
thermal condition vill be given.

## Stipulation of Comfort Limits and Corresponding Temperature Intervals

   According to ISO7730 the PMV-value must be kept between
-0.5 and +0.5 which corresponds to less than 10% thermally
dissatisfied persons.  The small number of dissatisfied per-
sons is expected to adjust their clothing until they have
obtained thermal comfort.  Some typical examples of accepta-
ble temperature intervals are shown in fig. 1.  It can be
seen that 19 - 20°C is a commonly accepted lower limit as
long as the air velocity does not exceed 0.1 m/s.

   In order to accumulate as much solar heat as possible the
upper limit must be as high as possible.  26°C will be sui-
table if people will accept a clothing with a clo-value of
0.5 for the upper part of the range. If an increase of the
air velocity is accepted and possible the upper limit can be
increased about 1°C.

Fig. 1. Acceptable temperature range for maximum utiliza-
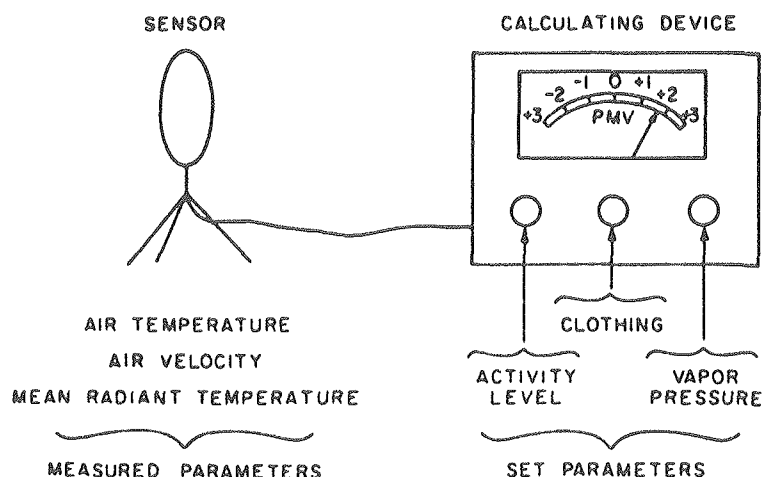tion of passive solar gain.
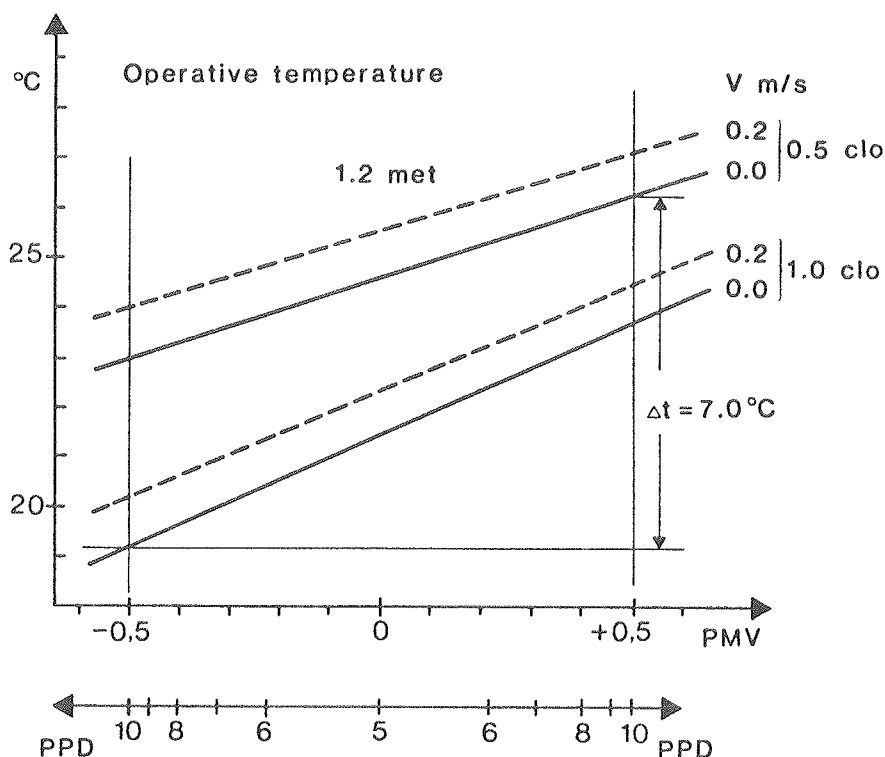


Measurement of Thermal Comfort

An intensive utilizasion of the passive solar gain
creates a considerable radiant heat exchange from solar gain
during the day, and in the evening from the solar heated
surfaces. It is, therefore, important that the mean radiant
temperature is included in the evaluation of thermal com-
fort. Another important parameter is the air velocity. An
increase from 0.1 to 0.2 m/s corresponds to an increase of
the operative temperature of about 1°C if the degree of
thermal comfort is to be unchanged. It is especially impor-
tant to know the air velocity at the lower end of the com-
fort range (PMV < 0). It is, on the other hand, possible to
increase the accumulation of heat if the air velocity is
increased at high temperatures (2).

As to the sensation of comfort it is finally important to
take both the activity level and the clothing into account.
All these parameters are automatically included if the in-
door environment is evaluated by means of a Thermal Comfort
Meter, fig. 2 (3). The transducer consists of a heated body
which integrates the influence of air temperature, mean
radiant temperature and air velocity on the human heat loss
and a measuring instrument on which the actual values of
activity, clothing and air humidity can be set. The degree

of thermal comfort, the PMV- and PPD-values, can then be read directly as well as the actual and optimal equivalent temperatures.

Fig. 2. Thermal Comfort Meter for evaluation of general thermal comfort



SENSOR      CALCULATING DEVICE

AIR TEMPERATURE
AIR VELOCITY
MEAN RADIANT TEMPERATURE

MEASURED PARAMETERS

CLOTHING
ACTIVITY LEVEL     VAPOR PRESSURE

SET PARAMETERS

## Control of Heating System

The ideal thermostat is able to maintain the PMV-value within the given limits when the activity and clothing are set on the controller.

    Example:  $-0.5 <$ PMV $< +0.5$
              activity 1.2 met
              clothing 0.8 clo
              comfort temperature range: 20.6 - 24.5°C.

As soon as the free heat is able to maintain an equivalent temperature of 20.6°C the thermostat must switch off the heat input, and when 24.5 is reached the thermostat must activate the solar shading or increase the air exchange.

The commonly used thermostat deviates from this ideal thermostat in a number of ways.

Thermostats usually have a time constant of 10 - 20 min., this fact causes some delay of the time at which the heat is switched off and on.

Most thermostats have a considerable hysteresis, and the heat source will, therefore, be connected at a lower temperature than the temperature at which it was disconnected. Previous investigations (4, 5) have shown that people will not set the thermostat in accordance with the mean temperature but in accordance with the minimum temperature. This

means that any hysteresis may narrow the acceptable temperature range and thereby the heat storage.

Traditional thermostats will sense a combination of operative temperature and the surface temperature of the wall on which it has been placed. If the wall in question has been heated by solar gain during the day the thermostat may sense a temperature higher than the equivalent temperature in the living area. This means that the room will become too cold before the heating system is activated. To avoid this situation the thermostat setting is increased. This may also narrow the temperature range and thereby the heat storage.

## Measurements

At the laboratory we have compared a couple of traditional thermostats to a new comfort control system based on the transducer from the Thermal Comfort Meter.

### Comparison of the Ability to Maintain a Constant Degree of Thermal Comfort of Various Different Thermostats

In a climat chamber with one wall facing a cold box three different thermostats have been tested in connection with different heating systems.

Free heat has been introduced in the test room, and this free heat varies during a period of 24 hours simulating a normal occupancy of the room. The heat loss from the test room is partly due to transmission through a window in the wall next to a room with a constant temperature of $-12^{\circ}C$ and partly to a ventilation heat loss to the same cold room.

The thermal condition in the test room is measured by three Thermal Comfort Meters with transducers positioned at 0.1 m, 0.6 m and 1.1 m above floor level. From these measurements the equivalent temperature in the living area can be calculated by the following equation:

$$EQC = 0.2 \cdot EQ_{0.1} + 0.7\ EQ_{0.6} + 0.1\ EQ_{1.1}\ {}^{\circ}C.$$

Fig. 3 shows the variation of EQC during 24 hours when an electric radiator is controlled by each of the three thermostats. At the bottom the variation of the free heat can be seen. The new thermostat creates a significantly more constant thermal comfort in the living area than the two traditional thermostats.

Fig. 3.  Variation of EOC (equivalent temperature in living
         area) caused by variation of the free heat when
         three different thermostats control an electrical
         radiator.
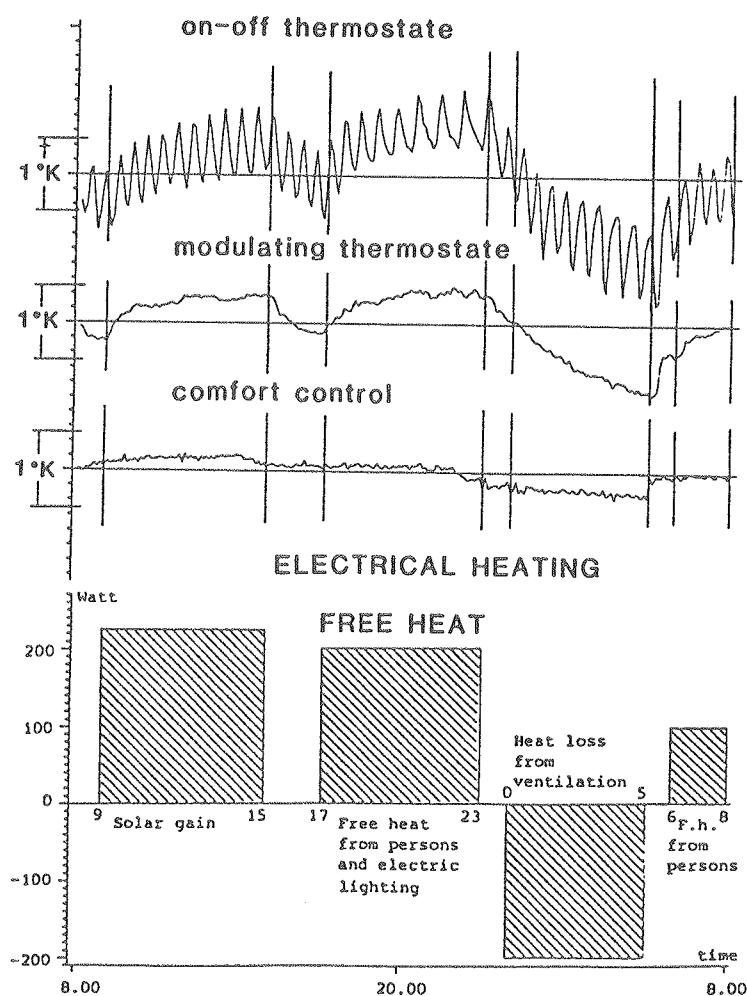


In table 1 a list of the differences between $EQC_{max}$ and
$EQC_{min}$ ($\Delta EQC$) during a period of 24 hours for 12 different
combinations of thermostats and heating systems is given.
$\Delta EQC$ is an expression that shows the ability of the control
system to maintain a constant room temperature. If a certain
minimum temperature may be maintained for comfort reasons,
then a bigger $\Delta EQC$ may cause a higher mean room temperature.
In modern well insulated buildings where the free heat is a
considrable part of the total heat loss, the energy consump-
tion may increase by 10 - 15% if the EQC is one degree
higher than necessary. This fact indicates the need for bet-
ter thermostats.  From table 1 it can be seen that the
influence on the EQC of the thermostat seems more important
than that of the heating system.

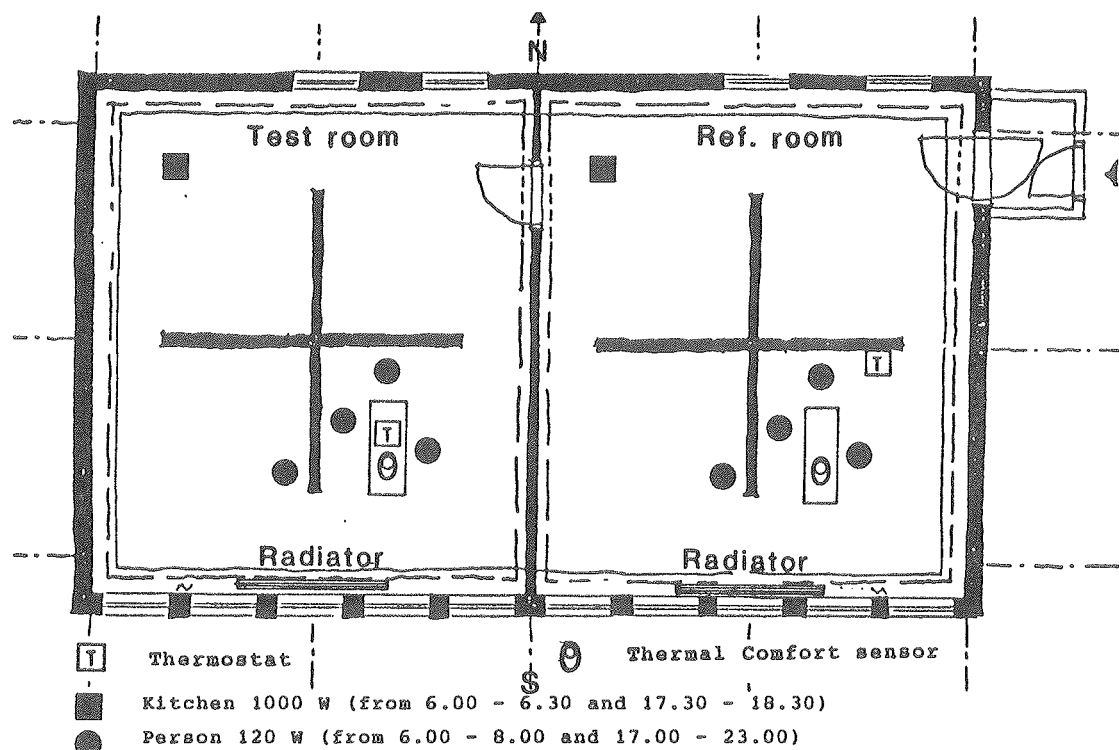| Control system / Heating System | Electrical radiator | Ceiling heating | Water heating | Air heating | Mean | Expected energy saving per cent |
|---|---|---|---|---|---|---|
| on-off thermostat | 3.6 | 2.4 | 3.9 | 2.9 | 3.2 | 0 |
| modulating thermostat | 1.4 | 1.7 | 1.6 | 1.6 | 1.6 | 8 |
| comfort control | 0.5 | 0.7 | 0.7 | 1.3 | 0.8 | 12 |
| mean | 1.8 | 1.6 | 2.1 | 1.9 | | |

Table 1. Temperature variation ($\Delta$EQC) in living area measured during 24 hours for different combinations of heating systems and control systems. In the right column the expected saving caused by a better thermostat is shown.

## The Importance of the Thermostat position

In an experimental house an investigation has been carried out in order to find the influence of the thermostat position on the temperature variation in the living area. In the house, fig. 4, there are two similar rooms with windows facing south and north. All walls, the ceiling and the roof is heavyly insulated (300 mm mineral wool), the rwo rooms are exposed to the same variation of the outdoor temperature and solar gain, and the free heat from persons, cooking and lightning is simulated by electrical heaters.

By an electrical as well as a water heating system, simultaneous measurements of the EQC have been performed in the two rooms. In one room (the reference room) the thermostat has remained in the same position on a wall, 1.7 m above floor level (see fig. 4) during all tests. In the other room (the test room) the thermostat has been placed in a corresponding position in the first part of each test (48 hours), in the second part of each test (48 hours) the thermostat was placed in the living area 1.2 m above floor level (see fig. 4). During each period of 48 hours the EQC was recorded on magnet tape in both room each 10 min. The standard deviation of the EQC in both rooms is calculated and the result is given in table 2.

Fig. 4. Positions of important heating, control and measuring elements in experiment house



| T | Thermostat |  | θ | Thermal Comfort sensor |

Kitchen 1000 W (from 6.00 - 6.30 and 17.30 - 18.30)

Person 120 W (from 6.00 - 8.00 and 17.00 - 23.00)

| Thermostat | Heating System | On wall 1.7 m above floor | In living area, 1.1 m above floor |
|---|---|---|---|
| On-off thermostat | electric heating | 1.67 | 1.30 |
| Modulating thermostat | | 1.61 | 1.46 |
| Comfort control | | 0.85 | 0.40 |
| Radiator thermostat with movable sensor | water heating | 1.61 | 0.96 |
| | mean | 1.43 | 1.03 |

Table 2. Standard deviation of the equivalent temperature in the living area (EOC) during 48 hours for different heating systems, thermostats and positions of the thermostats.

Because of the variation of the outdoor climat from one period to the other, it is impossible to give a quantitative evaluation of the improvement to be obtained when changing the position of the thermostat to the living area. But as can be seen from table 2 a remarkable reduction of the

standard deviation occurs for all the tested combinations when changing the traditional position of the thermostat on a wall to a free position in the living area. The average reduction has been 28%.

## Conclusion

The efficiency of passive solar heating systems can be improved if the following conditions are considered.

A. The minimum temperature is established in agreement with the expected activity level and the suggested clo-values.

B. The evaluation of the room temperature and its variations must take place regarding all relevant parameters.

C. The heat input must be switch off as soon as the necessary minimum temperature is reached. This calls for a better thermostat than those normally used.

D. A further improvement can be achieved if the position of the thermostat is changed to a central position in the living area.

## Acknowledgment

## Reference

(1) ISO7730. Moderate thermal environment. Determination of the PMV and PPD indices and specifications of the conditions for thermal comfort.

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(5) C.H. Spraque and P.E. McNall: The Effects of Fluctuating Temperature and Relative Humidity on the Thermal Sensation. ASHRAE Trans., 76 I, 1970