THE THERMAL INDOOR CLIMATE IN SIX LOW ENERGY HOUSES

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ABSTRACT

For funds granted by the Ministry of Commerce and the Danish building industry six one-family houses of 120 m^2 have been designed and constructed during 1978-79. The energy consumption for heating and hot water supply has been estimated not to exceed 5000 kWh/year per house.

To obtain the low energy consumption rather heavy demands for insulation, tightness etc. has been made. In order to investigate the influence of these demands on the thermal well-being of the inhabitants a parallel research programme has been undertaken supported by the Danish Government Fund for Scientific and Industrial Research. It concerns measurement of the thermal indoor parameters as well as of the expected degree of thermal comfort during both summer and winter conditions.

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INTRODUCTION

It has been claimed that the indoor climate in tight, highly insulated buildings is thermally more difficult adjustable to comfort conditions compared with the climate in traditional structures. Therefore it would be of interest to analyse the nature of the thermal indoor climate of the Thermal Insulation Laboratory's six low energy houses in Hjortekær, Denmark, built in 1978-79.

The houses were constructed to meet a demand of a maximal annual energy supply of 5000 kWh. The buildings are both as to architectural design and choice of building materials widely different. Thus another purpose of the investigations is to evaluate the importance of the design in relation to the indoor comfort level.

LOW ENERGY HOUSES

In 1978-79 six prototypes of low energy houses were built in Hjortekær, north of Copenhagen.

The size of each house is about 120 m^2 and it has been constructed to be run with an annual energy supply of 5000 kWh, covering spaceheating, ventilation and hot water supply for domestic purposes.

In order to obtain realistic figures for energy consumption, occupation of the houses has been simulated. All household appliances, including television, lighting, refrigerator etc., have been operated as if a family of two adults and two children lived in each house. The heat generated by four persons living a normal family life is supplied to the house by person simulators sited in all the habitable rooms. Hot water is run off in the kitchen and bathroom (altogether about 250 litres per 24 hours) at the normal times for washing, bathing etc. All the houses are provided with fresh-air ventilation systems with heat recovery. The heating systems are of different types, as shown in table I.

Table I.

House	Space Heating System
A	Electrical radiation foil in the ceiling
B	Radiators, electrical earth heat pump
C	Floor heating, heated by solar collectors or electricity
D	Warm air heating, heated by an oilburner
E	Warm air heating, heated by electricity or passive solar gain stored in a bed rock
F	Floor heating, heated by solar collectors or by a gas burner

A more detailed description of the houses is found in (1) and (2).

MEASUREMENTS

A large number of parameters are measured every ten minutes by a datalogging equipment placed in each house. A climate station built next to the houses is measuring all relevant outdoor climate parameters.

Investigating the indoor climate the Predicted Mean Value, PMV, (4) is of special interest. The measurement of this value is made by use of six separate measuring instruments, placed in the living room of the houses. The transducers of these instruments have been screened against direct solar radiation. The output of the instruments has been transmitted to a central datalogger, which is synchronized to the other datalogging system, and recorded for calculating the PMV value. Also an analog recording of the signal has been made by a multichannel recorder scanning the measuring instruments every twenty seconds.

CALCULATING THE PMV VALUE

A special instrument is used to measure the PMV value. This instrument is a modified version of the Thermal Comfort Meter (3) and (4) developed at the Thermal Insulation Laboratory. A very important part of this instrument is the tranducer which is able to measure continuously the combined influence of the air temperature, the air velocity and the mean radiant temperature on room occupants´ heat loss to the actual environments and thus on their thermal comfort. The output is the equivalent temperature, t_{eq}.

The PMV value is calculated in (5) from equation 1.1

$$PMV=A(t_{eqm} - t_{eqo}) + B(rhm - 50) \qquad \text{Eq.1.1}$$

where

- PMV is the Predicted Mean Value
- A and B are constants depending on the clo-value and metabolic rate
- t_{eqm} is the measured equivalent temperature
- t_{eqo} is the equivalent temperature at which the PMV=0 for a given clo-value and metabolic rate
- rhm is the measured relative humidity

The relative air humidity has very little influence on the PMV value at normal comfort conditions. Consequently the last term in equation 1.1 is negligible and equation 1.1 is reduced to

$$PMV = A(t_{eqm} - t_{eqo}) \qquad \text{Eq.1.2}$$

If measuring at a typical summer and winter period the task is to estimate a clo-value, I_{clo}, and a metabolic rate, MET, at both summer and winter conditions, which are characteristical for persons staying in a living room, ref. (4) and (5). Table II shows these estimates

Table II

	SUMMER	WINTER	A	t_{eqo}
I_{clo}	0.5	1.0	0.3075	24.6
MET	1.2	1.2	0.2250	21.4

MEASURING RESULTS

The equivalent temperature, t_{eqm}, is measured continuously from June 1979 to May 1980. Two specific periods are analysed in this paper, a summer period from August 16th to August 21th and a winter period from November 15th to November 20th 1979. The summer period consists of six warm days with sunshine most of the day and the winter period consists of six cloudy days with little sun and outdoor temperatures between 0 and 10 ^{o}C. The chosen test periods are representative for a warm Danish summer period and a normal Danish winter period. The measured and calculated PMV values are together with some climatic parameters shown in fig. 1 (summer) and 2 (winter).

Taking the summer period two characteristical facts are obvious. First the PMV values are high, for some houses far beyond the comfort limits. This is due to the heat accumulation taking place over a long period of time where only the fresh air venti-

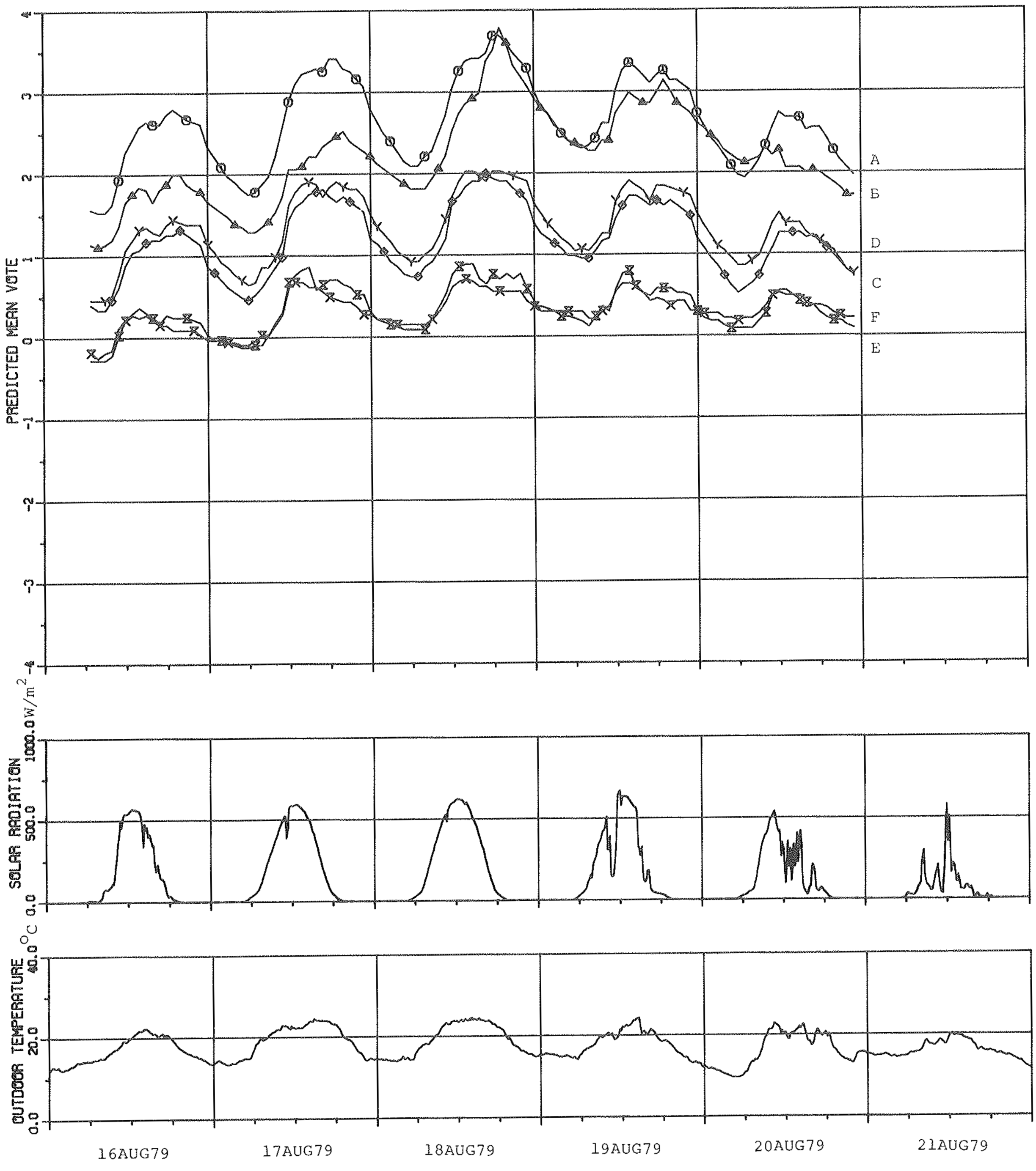


Fig. 1. PMV values for each house, outdoor temperature and solar radiation versus time at summer conditions.

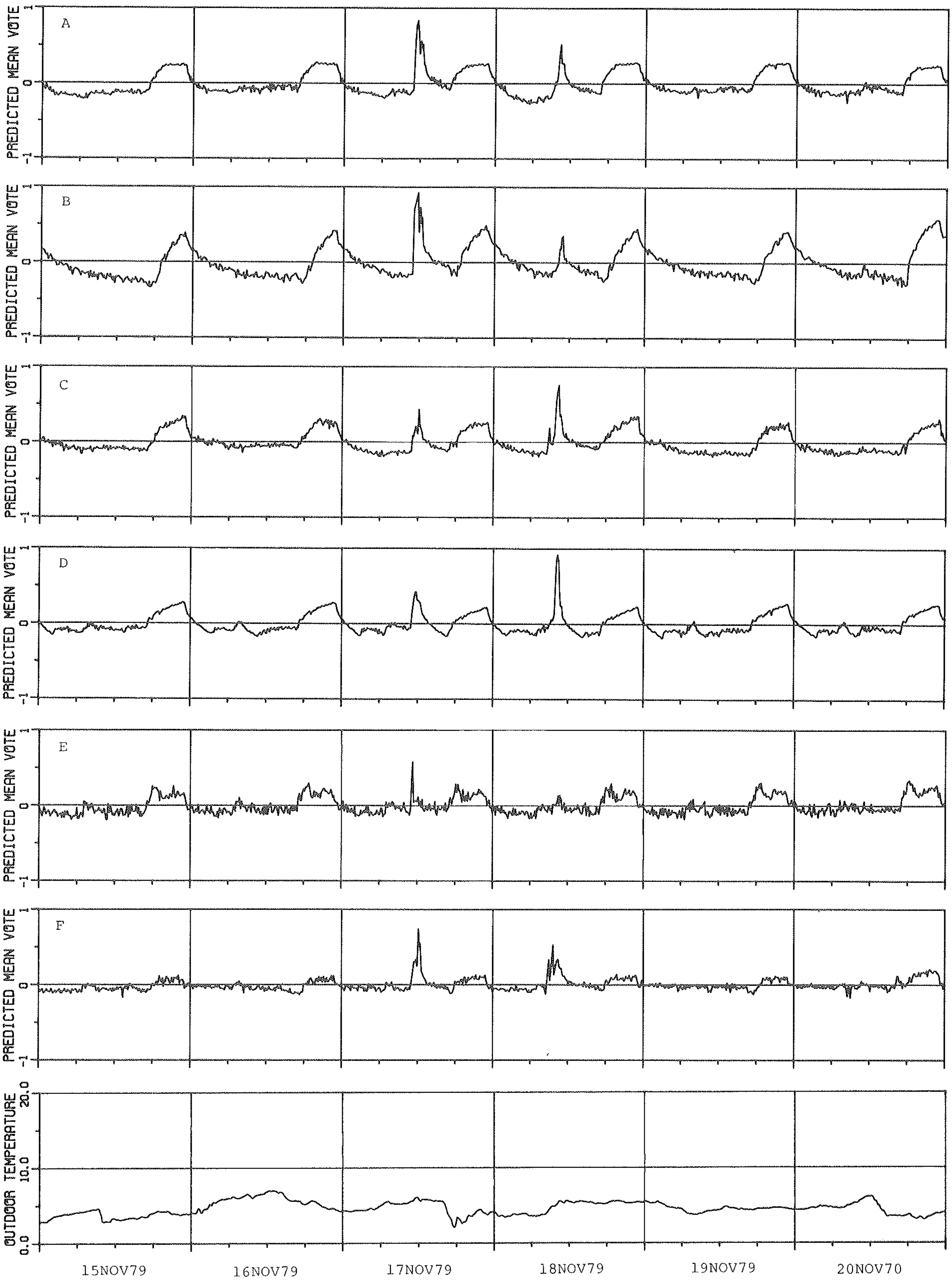


Fig. 2. PMV values for each house and outdoor temperature versus time at winter conditions.

lation (200 m^3/h) has been running, no doors and windows have been opened.

Secondly, three PMV levels are recognized each consisting of two houses. This grouping effect is mainly due to differences in the capacity of the heat accumulation, a problem which is more closely discussed in the next section.

As it can be seen on fig. 2 all heating systems are able to keep the PMV value within the limits of ±0.5 PMV during winter conditions. Only in the evenings when much free energy is produced or during periods with high solar radiation the PMV value is slightly above the 0.5 PMV limit.

On basis of these measurements it may be concluded that manual ventilation by opening doors or windows is necessary during summertime. If this is done the thermal indoor climate of the low energy houses is excellent compared with the thermal indoor climate of a traditional house. In wintertime it is seen that the houses thermally behave like traditional buildings equipped with well controlled heating systems.

SOLAR ENERGY TRANSMITTED

If solar energy of a certain amount is transmitted through the glazed areas of a house the indoor temperature increases, often causing a deterioration of the comfort level. It is therefore of interest to examine how the low energy houses will respond to the solar input.

As the summer 1979 has had few sunny days within the test period, and if it is remembered that the houses are of widely different constructions, the mechanism of heat accumulation will be very complex. It is therefore hardly possible to carry out a reliable quantitative analysis of the problem. So the investiga-

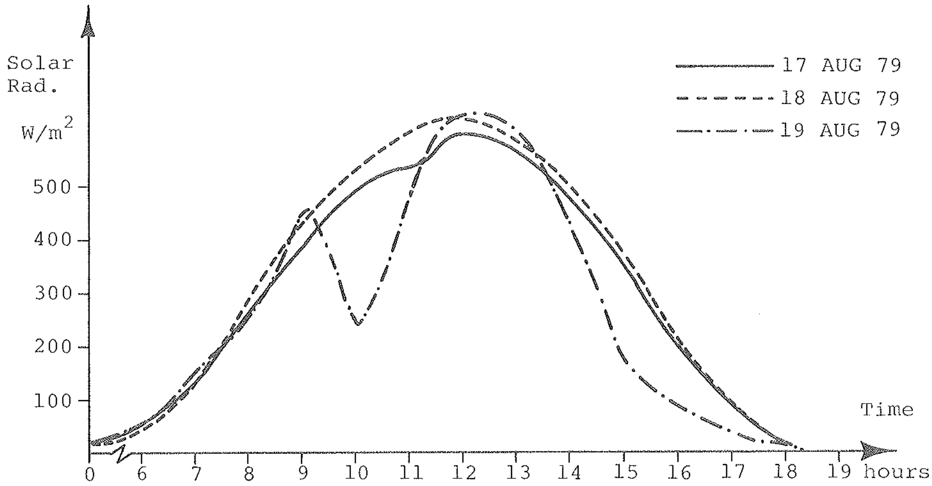


Fig. 3. Intensity on a vertical surface of 1 m^2 facing south.

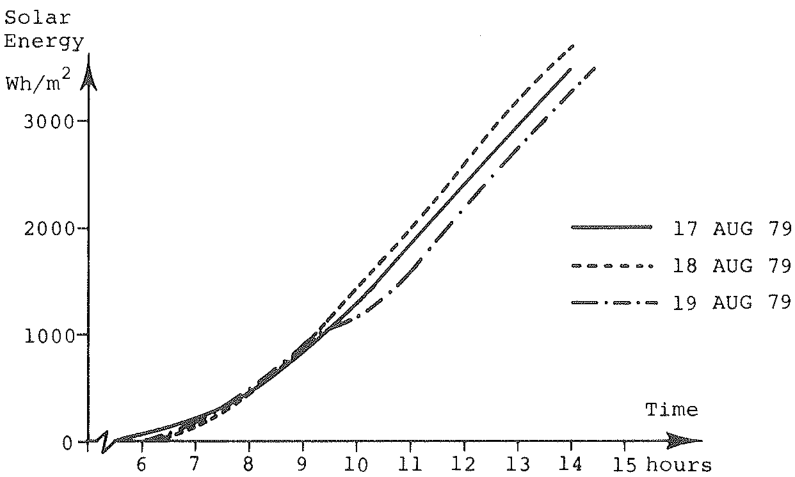
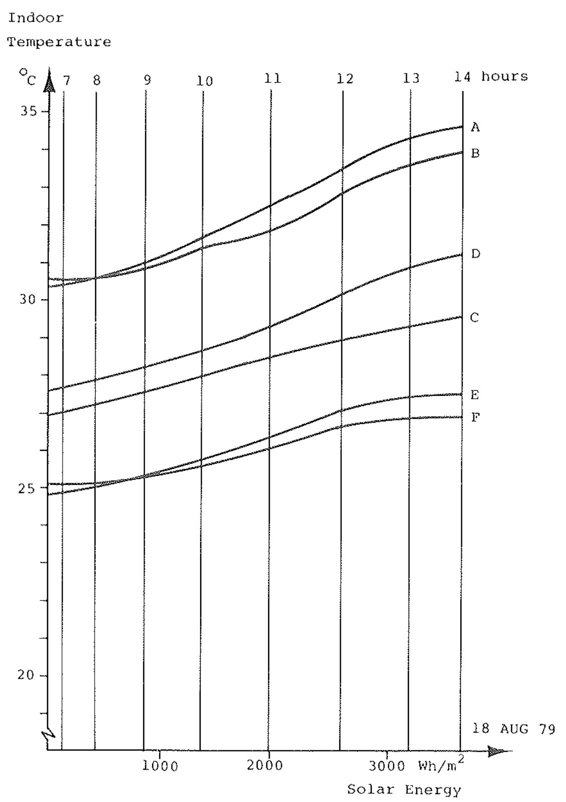
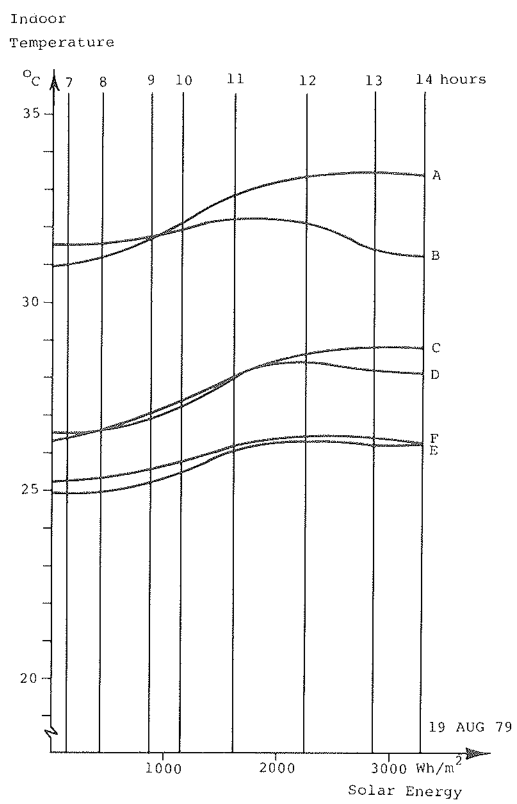


Fig. 4. Accumulated solar energy supplied to a vertical surface of 1 m^2, facing south.





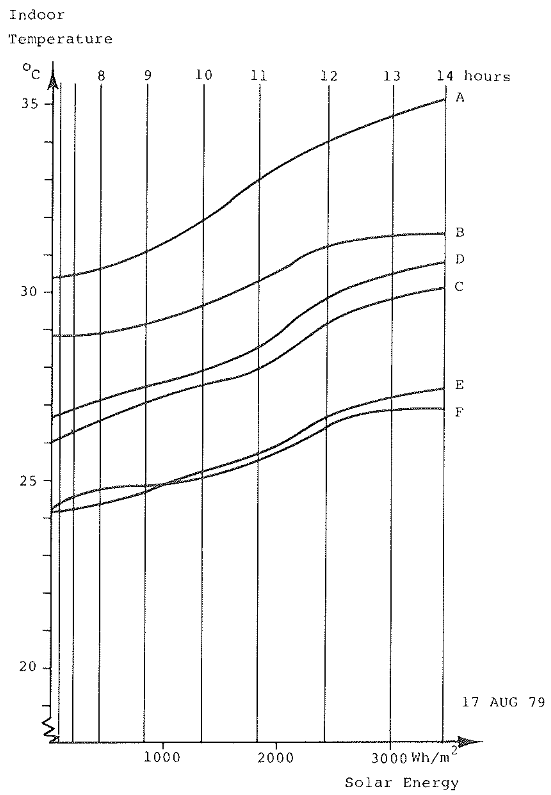


Fig. 5. The indoor temperature versus solar energy supplied to a vertical surface of 1 m^2, facing south.

tion made in this paper is only of qualitative nature, making an evaluation of the capability of heat accumulation of each house compared to the others in order to evaluate the results in respect to materials, architecture and capacity of maintaining the indoor comfort level.

Table III.

House	17AUG79			18AUG79			19AUG79		
	t_{eq}	CV	CV*	t_{eq}	CV	CV*	t_{eq}	CV	CV*
A	33.3	6.2	6.3	34.1	5.5	5.4	33.9	3.4	4.1
B	30.7	4.7	4.1	33.0	6.5	4.8	33.4	2.6	2.8
C	28.4	5.9	6.0	29.1	5.3	5.5	29.0	3.1	3.6
D	29.0	5.5	5.9	29.7	4.7	5.1	29.5	3.4	4.0
E	25.7	3.7	4.0	26.2	2.6	3.0	26.0	2.3	3.0
F	25.5	3.7	4.0	25.9	2.6	3.0	25.9	1.5	2.1
	deg.	-	-	deg.	-	-	deg.	-	-

CV = (standard deviation/mean value)100;
CV is the 24 hour value, CV* is a eight hour value, measured between 6.00 am to 2.00 pm.

Solar radiation has been measured for a three day period of August 1979 together with the indoor temperature. Fig. 3 shows the solar radiation intensity on a vertical area of one square meter facing south and fig. 4 shows the delivered energy (6.00 am to 2.00 pm) during each day of the trial period. The indoor temperatures plotted against the delivered solar energy are found in fig. 5. An organization of three groups is observed, AB, CD and EF. The differences in temperature level are mainly due to the ability of heat accumulation of the houses, having the heaviest structures (E and F) at the lowest temperature level and the light weight constructions (A and B) at the highest temperature level. The middle group is C and D, which also according to the weight of building materials are to be found between the two other groups.

Fig. 5 indicates that the smallest fluctuations of the indoor temperature are found for the heavy group and that the lightweight houses are showing much bigger fluctuations. The temperature level and CV values are shown in table III.

AIR VELOCITY

The air velocities at indoor conditions are mostly less than 0.15 m/s. In non-mechanically ventilated rooms of one family houses air velocities above this value occur only where openings to the open or bigger rooms are found or next to cold surfaces, i.e. windows etc. In mechanically ventilated rooms higher velocities may occur at places where fresh or warm air is injected.

Because air velocities that will exceed 0.15 m/s may locally be found in rooms with forced ventilation and because high velocities often lead to complaints about the indoor climate (6), a program of measuring air velocities in the low energy houses has been established.

The investigations have been limited to the living room. The measurements are carried out in the points of a 3 * 3 matrix. In each point the air velocity and air temperature are measured 0.1 m and 1.1 m above the floor. Two DISA ball anemometers, type 55R48, have been used for registrating the air velocity and the

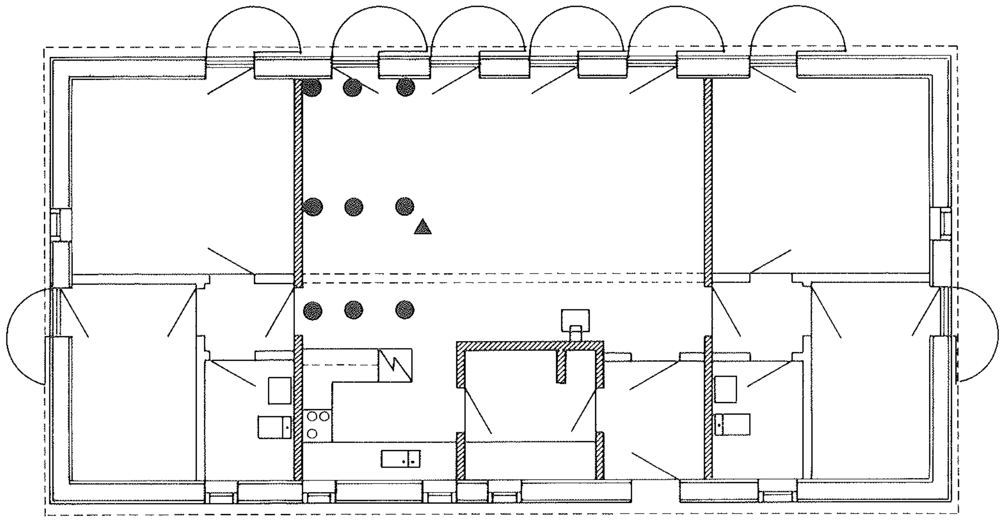


Fig. 6. Positions of measuring points (circular dots) of house E. The triangular dot is the position of the transducer of the Thermal Comfort Meter.

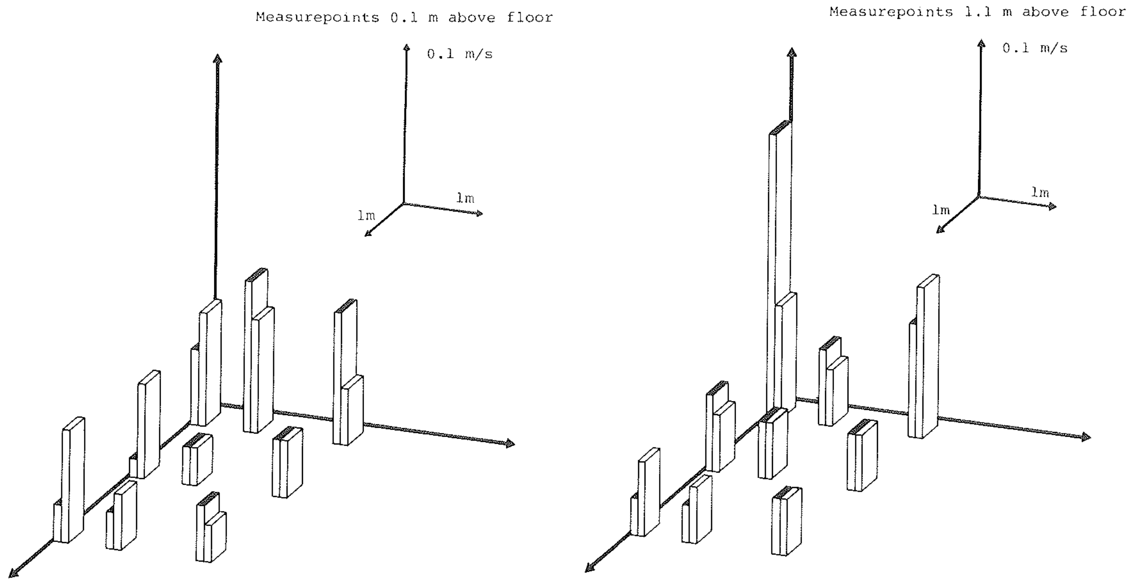


Fig. 7. Typical air velocity distribution (house E).
Left box (black top): Winter conditions.
Right box : Summer conditions.

air temperature. The velocities are recorded with a datalogger and punched on paper tape.

Fig. 6 shows the typical positions of the measuring points for the houses and fig. 7 shows the typical distributions of the air velocities at both summer and winter conditions. (The data shown are from the living room of house E, which has a high air change because of its warm air heating system.) The investigation shows that the mean air velocities do not generally exceed 0.10 m/s; only at very few points higher velocities are found. The temperature gradients between any point in the 3 * 3 * 2 matrix are overall less than 0.5 ^{o}C. Therefore it may be expected that none of the low energy houses will include draught problems and that changes in the outdoor climate conditions will have no important effect on the air velocity distribution in the rooms investigated. Futhermore it is found that the air velocity around the six PMV sensors does not exceed 0.10 m/s.

CONCLUSION

The investigations of the thermal indoor climate of six low energy houses during two test periods, a warm sunny summer period and a normal winter period lead to the following conclusions.

In all six low energy houses it is possible to maintain the comfort conditions, even if greater changes of the outdoor climate occur. This is mainly due to the effective insulation, the tightness and the well-controlled heating systems. The indoor climate of the houses with a heavy mass inside the insulation is seen to be quite steady. Especially, on warm sunny days it is observed that the heaviest structures, in spite of considerable glazed areas facing south, without any kind of extra ventilation are able to keep the indoor temperature on an acceptable level.

Though the buildings are equipped with ventilation systems yielding the necessary air change, the air velocities are so low that they give no rise to thermal discomfort or result in the occupant´s wish for a higher indoor temperature increasing the energy consumption. Only at few points air velocities exceed 0.1 m/s.

This investigation indicates that it is feasible to achieve very good and stable thermal indoor climate conditions in tight, highly insulated houses with a very low energy supply for space heating, ventilation and hot domestic water supply.

ACKNOWLEDGEMENTS.

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