Thermal Comfort Investigation for Wall and Ceiling Heating

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1. Introduction

Low-temperature radiant heating systems have become increasingly important for heating private dwellings and public buildings over the last decade. Among these systems floor heating developed first, but tests conducted in several research institutes of the world have brought out the problems of this system. Floor heating has been shown to detrimentally affect the sense of comfort and health of human beings [1,2]. The most important problems are the slow heating-up attributable to the long response time, the greater chance of foot infections for the occupants [3], as well as the poor heat dissipation because of the low surface temperature.

Wall and ceiling heating systems have come about to eliminate these disadvantages. The side-walls and ceilings of the premises can be used for the incorporation of a heating surface, allowing the elimination of free standing radiators and permiting a better utilisation of the available floor space while granting greater freedom of interior design. Our tests were performed on a wall heating system which is a flexible plastic tube heating system built into the plaster. The heating element of the system is a 6 mm outer- and 4 mm inner-diameter heating tube of polyethylene which can be incorporated into the wall, ceiling and the floor alike. The thin heating tubes can be fastened onto the wall by means of rail pieces made of plastic and attached to each other. The characteristics of thermal comfort were measured at different points of the room. We prepared a computerised program by which the heat engineering and thermal comfort relations of the particular room were modelled. The results of the program were compared with the values measured. The purpose of the test was to develop a program by which inside a given room the thermal comfort of the heating system could be modelled. The model is also useful for simulating wall cooling in summer.

The European Draft Standard CEN / TC 156 / WG 6 [5] determines the PMV values necessary for complying with the categories related to the classification of the premises:

"A" $-0,2 < PMV < 0,2$
"B" $-0,5 < PMV < 0,5$
"C" $-0,7 < PMV < 0,7$

For the establishment of the categories we have to know the value of the PMV in any point of the room.

2. Heat Engineering and Thermal Comfort Measurements

2.1 Presentation of the Test Room and the Heating System

The demonstration room is located directly on the street front in Budapest. The NW wall of the room is an outer main wall, a door can be found on the SW wall - which opens to the staircase and links up the demonstration room with the other parts of the building. Behind the SE wall of the room a conference room was established which has a linkage with the demonstration room through two internal doors. The wall structure of the demonstration room consists of masonry blocks with double plastering, without supplementary heat insulation. The window and the glass door are double glazed, built into a wooden frame. The inner doors are compact wooden doors. The floor is covered with granite slabs, the inner wall surfaces are wall-papered and the ceiling is painted.

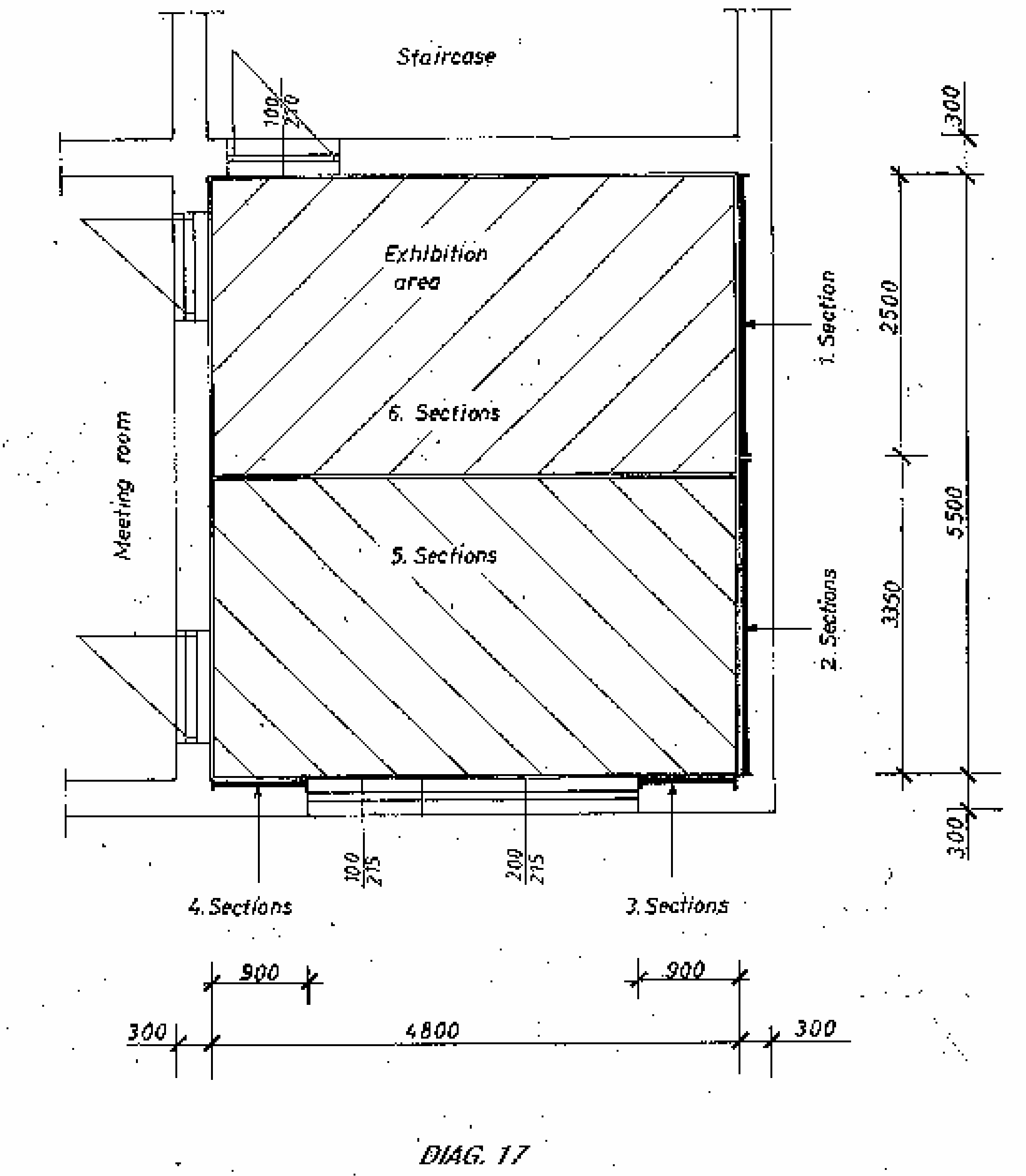

Figure 1

The heating and the summer cooling of the demonstration room is performed by wall heating/cooling plastic tubes built into the plaster layer. The design was prepared so that the heating surfaces of different spacing and layout could be tested in a common room. The room was provided with 6 independently controllable heating fields, 4 on the walls and 2 on the ceiling. Almost optimal air conditions and PMV values can be set up at each point of the demonstration room. The heating surfaces located on the walls were built only up to the height of the dwelling zone, approximately two metres from the floor level, thus - since the internal height is 2,8 m - there is an unheated band above the heated surface. The spacing of the fields from the staircase is perspectively illustrated by Figure 2. Each of the heating fields works as a coupled Tichelmann system, the spacing tube being located beneath the heating field in the wall structure, and mounted along the upper edge of the SE wall at the ceiling fields.

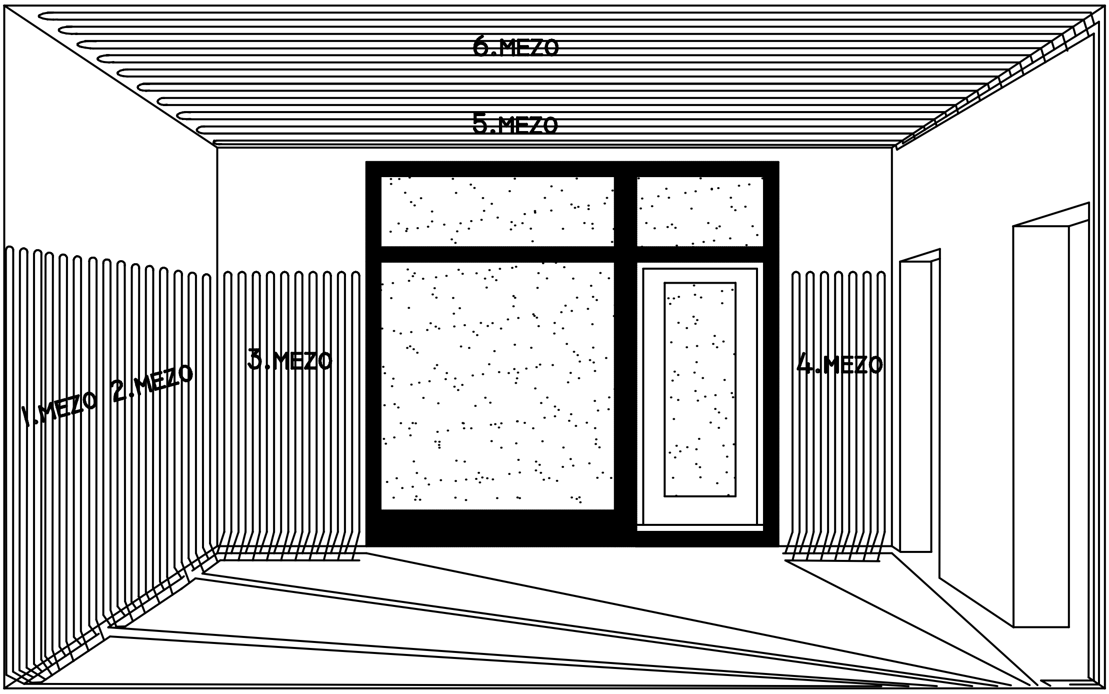

Figure 2
Perspective view of the demonstration room as seen from the staircase.

The data of the heating fields in the room is as follows:

Section number	Place	Area (m^2)	Pipe spacing (cm)	Number of registers
1	NW wall	5,04	6	7
2	NW wall	6,72	8	7
3	NE wall	1,6	8	5
4	NE wall	1,2	6	5
5	Ceiling (street part)	13	6	22
6	Ceiling (inner part)	13	6	22

Table 1

2.2. Comparison of Measurement and Calculation Results

We have examined the temperature fields developed in the room under the influence of the different heated surfaces, the surface temperatures of the heated and unheated building structures (outer and inner walls, ceiling, floor, windows), as well as the air condition in the surrounding premises and out of doors.

Using one of the heating fields with an 8 cm pipe spacing, we measured the distribution of the surface temperature of the wall using a heating water temperature of 55 °C. This was determined by analytic calculation, a numerical method, and empirically using an infra thermometer. The curve deriving from three different sources is represented in the following diagram.

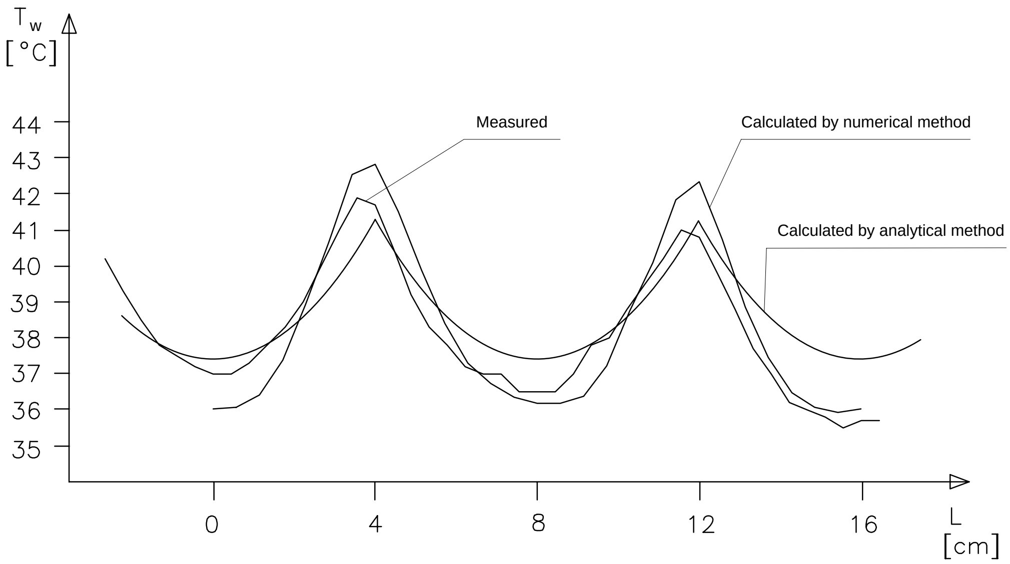

Figure 3
Temperature Distributions on the Surface of the Wall

It can be seen on Figure 3 that the curves determined with the various methods do not coincide entirely, there are even differences of 2 C degrees at places. This can be due to errors in setting up the individual computation models and/or to the variable nature of the wall surface selected for measurement. Accepting these errors, the extent of the difference of the curves from each other is not so high that the surface average temperature calculated by either of them could not be used as the surface temperature of the heated wall or practical purposes.

In the dwelling zone of the demonstration room the air temperature, as well as the PMV values have been measured at different heights above the floor level in points A, B, C,... H as shown on Figure 4. These heights were taken up to the following values on the basis of paragraph [4] of standard ASHRAE 55-1981:

- 0.6 m - waist height of a sitting man,
- 1.1 m - head height of a sitting man,
- 1.7 m - head height of a standing man.

The measurement were performed with a Brüel & Kjaer Thermal Comfort Meter type 1212.

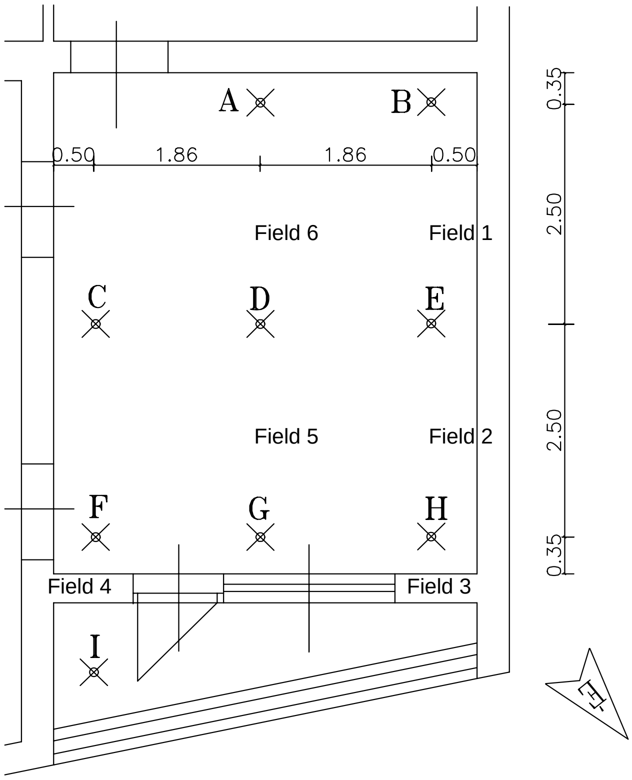

Figure 4
Location of the Measuring Points.

The PMV values measured were compared with the results of the computer simulation program outlined in paragraph 3. Table 2 shows the measured and calculated PMV values at a height of 1.1 m. The calculated values are somewhat more unfavourable than the measured values, thus satisfying us that we err on the side of safety when using the program.

	A	B	C	D	E	F	G	H
PMV (measured)	-0,73	-0,8	-0,7	-0,6	-0,68	0,23	-0,81	-0,26
PMV (calcul.)	-0,86	-0,89	-0,82	-0,7	-0,76	-0,32	-0,96	-0,29

Table 2

3. Calculation of the PMV Distribution in the Room

The calculation is based on the procedure recommended in the standard [5] CEN/TC156/WG6. This computerized procedure consists of two parts: the first one is an iteration cycle during which the surface temperature of the clothing can be determined from the data given by the user. The second one is an actual PMV value calculation relating to one point of the room which takes place by recording the thermal balance of the human body.
Input data:

Clo value of the clothing,
Metabolic heat development in met.,
External work performance in met.,
Air temperature in C degree,
Surface temperatures in C degree,
Relative air speed in m/s,
Partial water vapour pressure in Pa.

The result at the test point is the value of the PMV. The program performs the calculation in all the measuring points, then determines the PMV value by interpolation to every point of the room. The calculation procedure is followed by a graphic visualisation, where the heat sense characteristics can be seen under the influence of the input parameters. The figure illustrates the status near the measurement parameters.

4. Thermal Comfort Investigation of Wall and Ceiling Heating Systems

By switching on the different sections of the wall and ceiling heating system in the test room the same internal air temperature can be reached. The difference is in the thermal comfort characteristics. Further on, these effects will be examined. The following parameters are identical in every case for the sake of comparability:

- the metabolic heat development of the human body in case of office work = 1,2 met
- heat-insulating capability of the clothing in case of light winter clothing = 1,0 clo
- air temperature = 20 °C
- speed of air movement = 0,1 m/sec
- partial water vapour pressure with 40 % relative humidity = 850 Pa
- height of the tested points above the floor = 1,1 m
- heat transfer rate of the outer wall = 0,5 W / m2, K
- heat transfer rate of the window = 3,0 W /m2, K

To determine the heat demand in the case of -15 C degrees outside temperature we took into consideration the supply of the transmission and filtration heat loss while still ensuring a temperature of 20 °C in the room. Transmission heat loss was not taken into account for the surface of the heated fields on the outer walls.

Diagram number	Number of heated fields	Heated surface m^2	Heat demand W	Specific heat dissipation W / m^2	Surface temperature ^oC
1.	1.	5,04	1868	371	49
2.	2.	6,72	1833	273	42
3.	3.,4.	2,8	1915	684	70
4.	1.,2.	11,76	1728	147	33
5.	1.,3.,4.	7,84	1809	231	39
6.	1.,5.	18,04	1868	104	29,5
7.	1.,6.	18,04	1868	104	29,5
8.	3.,4.,5.	15,8	1915	121	31
9.	3.,4.,6.	15,8	1915	121	30,5
10.	5.,6.	26	1974	76	28
11.	Full floor	26	1974	76	27,5
12.	1.,2.,3.,4.,5.,6.	40,56	1672	41	24

The results of the modelling are represented on diagrams 1 - 12. The diagrams show the PMV distribution inside the room.

The modelling definitely proves the fact that by using heating fields of a large surface and low temperature we can achieve a much steadier heat sense distribution and by this a better sense of comfort for those staying in the room than by heating the same space with fields of a small surface and high temperature (see the results of diagrams 1,2 and 3 compared with the results of the other diagrams).

The heat sense also depends on the distance from the wall (diagrams 4 and 5). The heating of the outer walls provides a more favourable heat sense than that of the ceiling or the floor (diagrams 4 and 5 compared with diagrams 10 and 11). The heating of the ceiling is of lower value, but its uniform PMV distribution can be improved by increasing the surface temperature, with floor heating the cold effect of the window is felt in a larger area (diagram 11) than with wall or ceiling heating. The value of the PMV is considerably influenced by the humidity of the air, in addition to the activity and clothing of the occupants, so it is expedient to consider this in the course of designing the system.

5. Heat Sense Testing of the Wall and Ceiling Cooling Systems

The winter heating system can also be used as a summer cooling system. The wall system should have a surface temperature some 8-10 C degrees lower than the prerailing air temperature. This mode of cooling requires only water of approximately 16 °C has to be led into the pipe registers incorporated in the plaster. The cold water can come from a well bored into the ground or can be produced by a water chiller. Further on, we examine the PMV distribution in this cooling condition.

To test the summer heat sense the following parameters are kept identical:

- the metabolic heat development of the human body in case of office work = 1,2 met;
- heat-insulating capability of the clothing in case of light summer clothing = 0,5 clo;

- temperature of the air = 26 C degrees;
- speed of air movement = 0,15 m/s;
- height of the tested points above the floor = 1,1 m;
- partial water vapour pressure with 45 % relative humidity = 1550 Pa;
- (except for diagram 16, with 65 % relative humidity it is 2200 Pa).

Diagram number	Number of cooled field	Cooled surface m²	Cooling demand W	Spec. heat extraction W/m²	Surface temp. of the wall C degr.	Relative humidity %
13	5,6	26	1898	73	17,2	45
14	1,2,3,4,5	27,56	1823	66	18,4	45
15	1,2,3,4,5,6	40,56	1823	45	20,7	45
16	1,2,3,4,5,6	40,56	1823	45	20,7	65

To determine the cooling demand we considered window surfaces with a southward orientation, to have an external temperature of 32 °C and an internal temperature of 26 °C, with a fourfold air change due to frequently opening the door, as well as an occupancy by four persons. It can be seen well on diagrams 13 - 16 that with the internal air temperature of 26 °C a very good PMV value and distribution can be achieved using the cooling surfaces. Cooling with wall surfaces only should be avoided, since the surface temperature of approx. 11 °C necessary for achieving the required thermal effect is below the dew-point temperature and this would result in condensation. The effect of the changes in the relative humidity is illustrated by the comparison of diagrams 15 and 16. It is visible that the increase of 20 % leads to an increase of some +0,2 PMV.

6. Conclusion

When designing heating systems we must not be satisfied with ensuring we provide the heat necessary for maintaining the demanded air temperature, but we must allow for the required level of heat sense for the persons staying in the room. As a result of the researches conducted to this effect during the last decade such dimensioning procedures have been established, on the basis of which the expectable heat sense values (Predicted Mean Vote, PMV) can be determined with the knowledge of the parameters concerning the occupants and his/her clothing and the air in a given point of closed space. The knowledge of these helps us to design heating systems by which we can achieve not only an acceptable average temperature, but also a correct heat sense, contributing to the overall comfort of the occupants of the building.

In this paper we have examined the thermal comfort characteristics of a wall and ceiling heating and cooling system. We have found out that different heat sense characteristics come about as a result of the construction of the building. We are satisfied that we have developed a computerised model that predicts, within an acceptable level of accuracy, the thermal comfort characteristics of a wall and ceiling heating and cooling systems.

7. References

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