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USING A THERMAL MANIKIN

Research on indoor thermal comfort

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There are reputed to be only ten examples of the thermal manikin (a computerized doll) in the world at present. Here, the author discusses their potential in microclimate research, and describes experiments with a thermal manikin at the Hungarian Institute for Building Science (ETI) to identify the quality of indoor comfort conditions. One study revealed that the correct heating system would yield better results than extra thermal insulation.

On ne compterait actuellement dans le monde que dix exemplaires de ce mannequin thermique (poupée informatisée). Ici, l'auteur expose les avantages qu'ils offrent pour la recherche sur les micro-climats et décrit les expériences réalisées avec ce type de mannequin à l'Institute for Building Science (ETI) de Hongrie pour cerner la qualité du confort intérieur. Une étude a montré qu'un système de chauffage correct donnerait de meilleurs résultats qu'une isolation thermique complémentaire.

The design of the indoor climate for thermal comfort is standardized and included in corresponding codes of practice in many countries (refs 1, 2). It has also become a routine task to check the design or prescribed parameters by measurements. There are, however, indoor spaces where the uneven or poor thermal insulation of the external walls causes thermal discomfort due to the asymmetric thermal radiation occurring. Intense local air movements and draughts can also result in adverse comfort conditions.

Measurement of these so-called local discomfort effects by traditional instrumentation is difficult, inaccurate and takes a long time, both in the laboratory and at the site. The recently-developed thermal manikins can be useful devices for such purposes and offer quick and accurate measurements. Though originally designed for modelling the heat transfer processes of the human body, thermal manikins may also successfully be used to qualify indoor thermal comfort itself.

LOCAL THERMAL DISCOMFORT

Local thermal discomfort occurs if the human body is placed in a thermally inhomogeneous environment and consequently the heat transfer from or to certain parts of the body increases above the value that would ensure the subjective thermal comfort sensation. Thus the thermal comfort of that particular part of the body is adverse. In indoor spaces of buildings there are two particular local discomfort effects that are necessary to consider when designing the indoor climate:

- effect of asymmetric thermal radiation
- draught effect.

Asymmetric radiation occurs when the radiant heat transfer from or to certain parts of the body increases due to adjacent cool or warm surfaces, and this exposure exceeds 0.5 h. One example is the desk close to the window in an office building. When designing the indoor climate more methods are used for quantifying this effect, ranging from simple calculations of the radiant heat transfer to Fanger's comfort equations and charts (ref. 3).

The latter is illustrated by figure 1. It is an assessment of the thermal environment in a lecture hall. A square grid is constructed covering the seating area (the occupied zone). Measurements are taken in the centre of each square and the corresponding *PMV* values (see below) are entered in the figure, *ISO–PMV* curves have been plotted in the occupied zone. The *PMV* is lowest near the window wall and the rear wall, which is also an outer one.

The adverse effect of draught on thermal comfort is well known; the convective heat transfer from the body increases. For quantifying this effect in design, different charts are used; one example is shown in figure 2, which presents the percentage dissatisfaction to be expected as a function of the air velocity, v, and the difference between the room temperature, t_a, and the temperature of the air flow, t_v, if the draught affects the neck.

THE THERMAL MANIKIN

The thermal manikin is a very complex measuring instrument, consisting of a thermal measuring body, two microprocessor-

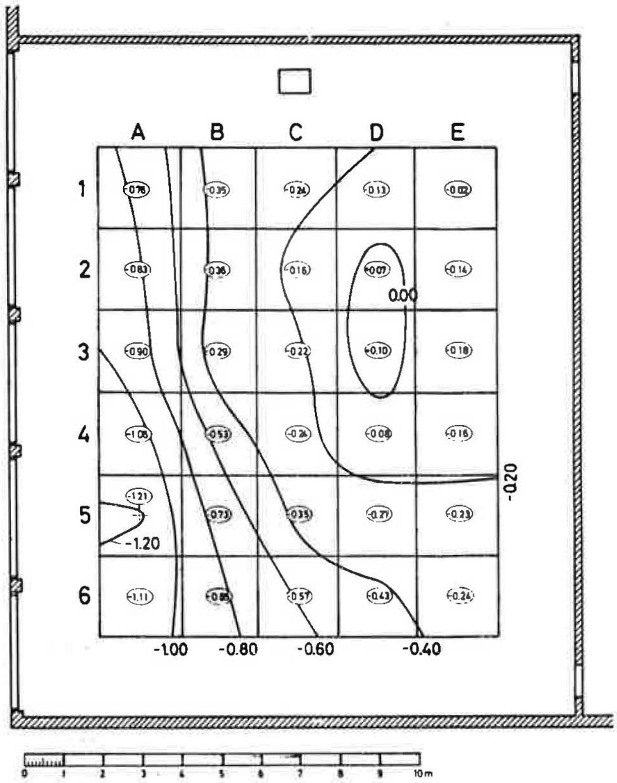

Fig. 1. Grid of thermal environment in a lecture hall using Fanger's equations

The thermal manikin in the ETI laboratory (fig. 3 in text)

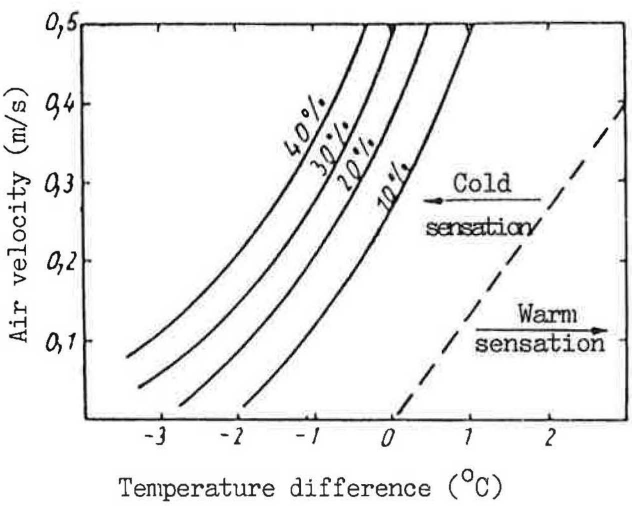

Fig. 2. Chart of draught effect on comfort (percentage of dissatisfaction)

Thermal manikin ambient temperature sensing*

Part	*DT*	*W/m*^{2}	*DW*	*Clo*	*EHT*
Face	−0.02	138.6	116	0.64	19.3
Chest	−0.01	48.3	−21	1.98	29.4
Back	0.00	67.3	−3	1.42	26.4
LUArm	0.01	52.3	−5	1.71	26.1
RUArm	−0.01	59.8	−13	1.49	26.7
LLArm	−0.01	53.4	−10	1.55	26.1
RLArm	0.01	71.9	15	1.15	24.8
LHand	0.00	96.0	102	0.80	20.2
RHand	−0.01	137.7	166	0.55	18.4
LFThigh	−0.01	77.3	5	1.15	24.9
RFThigh	−0.01	84.1	3	1.06	25.1
LLLeg	0.00	82.2	11	1.01	24.0
RLLeg	0.00	82.2	9	1.01	24.3
LFoot	−0.01	63.6	4	1.20	25.3
RFoot	−0.01	64.6	7	1.18	25.2
LBThigh	−0.01	54.4	−24	1.64	28.1
RBThigh	−0.01	41.0	−31	2.18	29.0
Scalp	0.00	72.8	−20	1.23	26.5
Tot	32.8	71.2		1.23	25.6
		File: 3 1/2 m: 3			
Time:	13:7	Sitting Room T: 19.2		19.2	

* See text for explanatory notes

based controllers and data acquisition units and a computer that processes and displays the data. The system is shown in figure 3.

The test body is made as a full-scale plastic doll of the dimensions of an average adult. Technical details can be found in other publications (refs 4, 5). The thermal manikin built in the Hungarian Institute for Building Science with the help of UNIDO is of so-called Swedish type, designed by Dr D.P. Wyon (ref. 6).

The principle of the thermal manikin can be summarized as follows. The body surface of the doll is subdivided into 16 or 18 parts, in standing or sitting positions respectively. Surface temperatures of those parts, or units, as shown in figure 4, are kept constant by special microprocessor-controlled electric heating. The principle of operation is the measurement of the electric power supply to the units that can maintain the required constant temperature.

Table 1 shows the results that can be obtained. Note that:

- The column 'Part' refers to names of the parts of the body of the manikin.
- Column *W/m*^{2}' shows specific heat transfers of the body parts.
- Column '*Clo*' shows the thermal resistance of the clothing that covers the body part (in *Clo* dimension generally used in qualification of clothing).

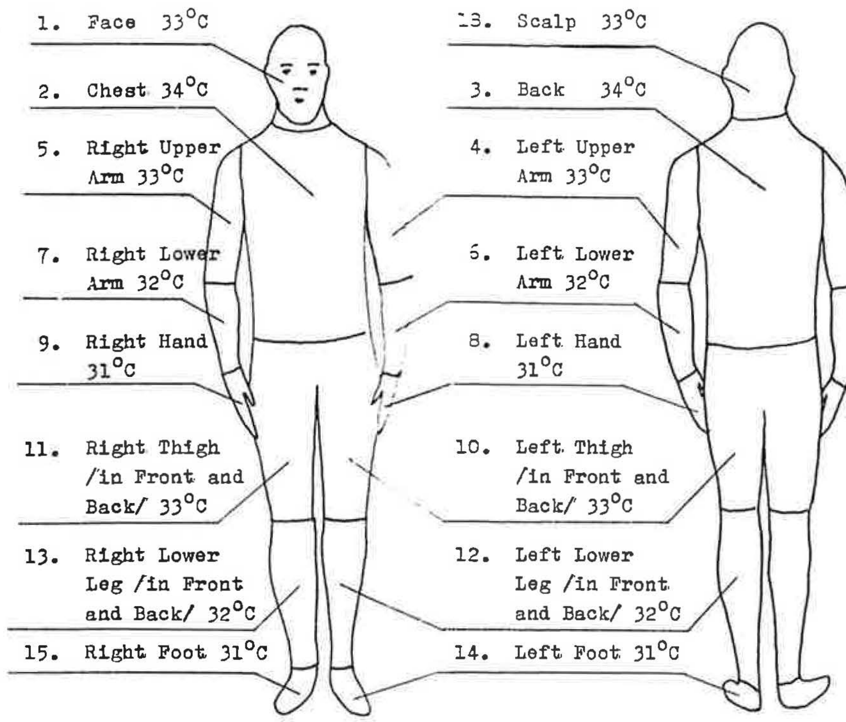

Fig. 4. The manikin body parts, codes and surface temperatures

- Column '*EHT*' shows the ambient temperatures as sensed by that body part.
- The line 'TOT' (total) gives averaged values of the columns above. Averaging is made by weighting with the surface areas of the body parts.
- 'Room T' is the room temperature.

USING THE MANIKIN

The validity of using the manikin to verify an indoor microclimate, which has been designed on a different basis, means the solution of a twofold task:

- checking the actual values of the design indoor climate parameters
- checking the human heat transfer conditions and the resulting subjective thermal comfort sensation.

The first task is now a simple routine measurement, and in most cases the design is verified by the measured values of the air temperature, bulb temperature and relative humidity.

As to the second task, various methods are used for the solution. For example:

(a) The simplest and least accurate design targets the room air temperature. A design value of 20°C measured 1.5 m above floor level has long been used in many countries as a condition of the optimal thermal comfort.

(b) The Fanger method; this can be considered as the most advanced (refs 1, 2). This takes into account the effect of the following parameters:

- air temperature,
- mean radiant temperature of the surrounding walls and structures,
- air velocity,
- relative humidity of the air,
- thermal resistance of the clothing,
- human metabolic rate as a function of the activity.

Predicted subjective thermal comfort for combinations of different values of these parameters has been determined by several thousand laboratory tests, and on the results the *PMV–PPD* theory was elaborated (ref. 7). The values of the Predicted Mean Vote (*PMV*) and the Predicted Percentage of Dissatisfaction (*PPD*) can be readily determined from the corresponding design chart.

Though the latter method can also be used for the determination of local discomfort values (see fig. 1), it is sufficient neither for accurate dimensioning nor for the elimination of local discomfort factors, for two reasons:

- only general discomfort can be determined, not local discomfort on parts of the body,
- actual heat transfer from parts of the body cannot be determined; thus accurate and simple local compensations must be found.

All the above considerations suggest the possibilities, scope and conditions for the use of the thermal manikin. Primarily it can be used where the indoor microclimate parameters are inhomogeneous. Such places are the vicinity of windows, poorly insulated external walls and ventilation inlets, etc. Its use is further justified by the speed and accuracy of a series of measurements by which the following data can be determined for an indoor space:

- best and worst locations from the human heat transfer aspect,
- actual values of heat transfer of body parts at these locations.

CONDITIONS OF USE

As regards the conditions of use, it has to be emphasized that the manikin technique cannot replace measurements with living subjects, though it largely accelerates, simplifies and completes them. The possibility of quick selection of best and worst locations significantly reduces the necessary number and time of measurements with human subjects.

Also, important data on heat transfer of the body parts can be obtained and used for the technical design. Such data cannot be obtained through living subjects. Of course, measurements with human beings will provide subjective thermal comfort sensations and reactions that the manikin cannot do.

By the spread of the manikin technique (only 10 are in use at present in the world) it can be expected that the joint application of the manikin and human subject-methods would result in the elaboration of data. This would provide the subjective human reactions – similarly to the Fanger data – for cases measured by the manikin technique alone.

EXAMPLE STUDIES

Two examples are presented here of the use of the ÉTI manikin for the qualification and design of indoor climate. In both cases energy-saving aspects played an important role. These examples were:

- A study of the effect of the reflection factor of the internal surface of external walls on the heat transfer from the occupants.
- A comparison of different heating methods from the aspect of human heat transfer.

Reflection factor studies

Theoretically it can be readily understood that the radiant heat transfer from the human body decreases if the thermal reflectivity of the internal surface of the cold external walls is increased. In this case the heat balance, and thus the subjective thermal comfort sensation, of the occupants can be acceptable at a lower temperature level. The question was the degree of temperature reduction that can be compensated this way.

The studies were carried out in the Microclimate Laboratory of ÉTI in a commission from the Österreichische Gesellschaft für Humanökologie. The method and the detailed results can be found in I. Müller's paper (ref. 8).

The findings of the manikin and subject tests proved that an increase of the reflectivity from 20 percent to 90 percent enables a 1.0–1.5°C reduction of the air temperature without affecting the subjective thermal comfort. Verification of this theoretical finding in practical conditions is under way.

Human heat transfer under different heating systems

Energy conservation research in Hungary brought up the idea of ensuring thermal comfort by using heating methods more favourable for human heat transfer instead of expensive and time consuming supplementary thermal insulation of the building envelope.

To study the problem, four different heating methods were compared in the Microclimate Laboratory (in rooms with one or two external walls) using the manikin technique:

- normal radiator heating,
- heating panels,
- heating panels integrated into the external wall,
- floor heating.

Tests were carried out for −2°C outdoor temperature, *U*-values of 0.6, 0.8, 1.0 and 1.2 W/m^2K, 20°C indoor air temperature and 0.8 *clo* (clothing).

The results gave the following order of magnitude for the effect of the factors tested on the heat loss of the body parts most exposed to local discomfort, based on the PMV and PPD for the whole body and the measured *EHT* values

- 1–7 percent for the thermal insulation of the walls.
- Much bigger, 6–26 percent for the heating methods.

This means in effect that the application of heating methods, such as low temperature large-area radiant heating which decreases the radiant heat transfer from the human body to the external walls, yields

- possible reduction of the required indoor air temperature by 1.5–3.0°C for rooms with one external wall,
- a reduction of 1.1–2.3°C in air temperature for rooms with two external walls.

Further details of the results can be found in references 9 and 10.

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