EVALUATING THE THERMAL QUALITY OF A ROOM

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ABSTRACT
The ongoing development of international standards, which will probably introduce different quality classes of thermal comfort, will increase the need for on-site evaluation of thermal comfort. The question often raised will be “Do this room offer class A thermal comfort?” and the answer submitted must be based on a measurement of the actual environment if it is to have any credence.

The paper describes a measurement system to evaluate room thermal comfort, based on the ISO 7730 (Determination of the PMV and PPD indices) standard.

The measuring system executes one measurement and the data are subsequently used to evaluate system performance in three steps. The first step is calculating the average PMV level in the room and relating this to the outdoor environment; the next step is evaluating the thermal uniformity of the room; finally, the ability of the climate-control system to maintain a stable thermal climate is assessed.

INDEX TERMS
Thermal comfort, measurement, Calculation, PMV, Room evaluation.

INTRODUCTION
The quality of thermal comfort can be measured, but is there any reason for doing it? Why not just wait and see if anybody becomes dissatisfied and then act if there is a problem?

This is a common attitude that is very hard to kill and one that has been under pressure from scientists and other indoor climate debaters for a long time. New knowledge about the connection between productivity and the quality of the indoor climate indicates that it is an economic advantage to ensure a good thermal climate and this supports the request for evaluating the indoor climate. Future standards, which grade the indoor climate according to quality, increase the need for measurements. And, finally, new and efficient measuring equipment will ensure that performing indoor climate measurements is both faster and cheaper than previously. It is therefore to be expected that controlling or even certifying the quality of the thermal indoor climate will be more common.

How is the quality of the indoor climate in a room documented? The existing international standard for measuring thermal comfort, ISO 7730 (International Organisation for Standardisation, 1994), concerns one single workplace – not an entire room.

Here we will suggest a test method for evaluating the thermal comfort level in rooms. The method suggests evaluation in steps and is at present incomplete. The measurements, which are planned for spring 2002, will be used for improving and expanding the method.

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Only evaluation of general thermal comfort will be treated in this paper.

**DEMANDS**

The comfort demands are based on the measuring methods described in the standard ISO 7730 (International Organisation for Standardisation, 1994). Suggestions to classification in quality categories and matching acceptance levels are taken from Olesen (B.W. Olesen, 2000).

**Table 1.** Suggested categorisation of thermal indoor climate, taken from Olesen (B.W. Olesen, 2000). The demands must be met at each workplace.

<table>
<thead>
<tr>
<th>Category</th>
<th>General thermal comfort</th>
<th>Dissatisfied due to local thermal discomfort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PPD</td>
<td>PMV</td>
</tr>
<tr>
<td></td>
<td>DR</td>
<td>$\Delta t_a$</td>
</tr>
<tr>
<td></td>
<td>$t_{floor}$</td>
<td>$\Delta t_{plt}$</td>
</tr>
<tr>
<td>A</td>
<td>&lt;6&lt;0.2&lt;PMV&lt;+0.2</td>
<td>&lt;15%</td>
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<td>&lt;10%</td>
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<td></td>
<td>&lt;5%</td>
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<tr>
<td>B</td>
<td>&lt;10&lt;0.5&lt;PMV&lt;+0.5</td>
<td>&lt;20%</td>
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<tr>
<td>C</td>
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<td>&lt;25%</td>
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</tbody>
</table>

- **PPD** Predicted Percentage of Dissatisfied [%]
- **PMV** Predicted Mean Vote
- **DR** Draught Rating [%]
- **$\Delta t_a$** Vertical air temperature difference [°C]
- **$t_{floor}$** Floor temperature [°C]
- **$\Delta t_{plt}$** Radiant temperature asymmetry [°C]

When we evaluate thermal comfort in an entire room it is necessary to state at which stage in the building process it takes place. The acceptance level for a manufacturer who is testing a new product in a climate chamber should be narrower than that of a test of the same product in use. We use the following notation to distinguish between the different situations.

1. **As produced (AP):** A type test used by manufacturers to ensure the function of building components or design, or to ascertain that the control strategy works.
2. **As installed (AI):** A test that is used to evaluate whether the system is able to deliver the promised thermal quality in the actual building.
3. **As used (AU):** A test that discloses if the thermal indoor climate is destroyed by defects in components or altered heat load in the rooms.

**Figure 1:** The result of the evaluation method looks like this. It begins at the bottom with the interval that meets the comfort requirements and ends at the top with the interval for setting the thermostat. A disturbing element is dealt with at every step and the effect on the PMV is deducted from the available interval. The example builds on an AI category B requirement.
The evaluation method outlined in Figure 2 is the one we suggest for determining whether a room complies with the requirements in Table 1. The requirements in Table 1 are users’ requirements and must be regarded as “as used” requirements.

Start with relevant category PMV limit as stated in Table 1

Reduce limits to account for test condition.
E.g. AU test: no reduction in PMV limits, AI: reduce to 80%, AP: reduce to 64%.

Due to asymmetric conditions in room there will be different PMV values at different workplaces. Reduce acceptable room average PMV limits with the standard deviation of the PMV value (time averaged), measured at different workplaces.

If capacity of air conditioning system is not sufficient, the room may warm up during the day. Limit for the daily averaged PMV value should be reduced with 1/2 of the drift.

The control system for the air conditioning may introduce some slow oscillation in room PMV values. Reduce PMV interval with amplitude of the oscillation.

The control sensor is normally not positioned to measure the room average PMV value. The setting interval of sensor must be reduced with the uncertainty from positioning and possibly lack of PMV measuring capability.

Result: The interval for setting of control sensor

Figure 2: The evaluation method. Begin with the interval that meets the comfort requirements and end with the interval for setting the thermostat. A disturbing element is dealt with at every step and the effect on the PMV is calculated and deducted from the available interval.

If the calculated “Interval for setting of control sensor” is negative, the requested thermal comfort level cannot be obtained in the room.

WHAT MUST BE MEASURED
The following parameters must be determined as input to the evaluation system:

- Average PMV for the room for one working day.
- Deviation between average PMV for the room and local PMV values.
- Temperature slide for the room during the day.
- Stability of the temperature control system.
Three to five measuring stations that can determine the PMV for selected workplaces in the room are used to determine the input parameters. An example of a measuring station is shown in Figure 3 and an example of the positioning is shown in Figure 4.

**Figure 3:** The measuring station used for determining PMV. The station consists of three units that measure air velocity, operative temperature and humidity, as well as a battery. The measuring station measures at a height of about 60 cm when placed on a chair.

**Figure 4:** The positioning of three PMV measuring stations in a room. One station is placed in the middle of the room, one at what is presumed to be the coldest workplace and one at the presumed warmest workplace.

The measurements must be carried out during a period with high thermal load to provide the best result. The duration of the measurements must be at least one day. The outdoor climate is registered during the measurement and the size of the heat load compared to the heat load that the building is designed for is stated. The internal heat load is also registered.

Parallel to the measurements, the output from the thermostat in the climate-control system may be registered. This makes it possible to determine whether the climate-control system works reasonably and whether the thermostat for regulating the climate is reasonably positioned and designed.
DATA HANDLING
The calculation for providing thermal parameters for a room consists of the following steps:
1. Calculate the graph showing the average PMV value for the measuring points in the room as a function of time.
2. Calculate the mean PMV value for the working day average in both time and place.
3. Calculate the mean PMV value for each of the measuring points.
4. Convert the PMV value from step 2 to a difference in operative temperature. This value is the observed error setting of the thermostat.
5. Calculate the standard deviation from the PMV values calculated in step 3. This PMV value is the asymmetry in the room.
6. On the basis of the graph determined in step 1, the difference between the mean PMV value for the first working hour and the mean PMV for the last working hour is calculated. This value is the temperature slide in the room.
7. Draw a line that goes through the point calculated in step 2 and has an inclination as calculated in step 6. Subtract this line from the average PMV value graph calculated in step 1. Calculate the standard deviation on the curve and multiply the value by 2. This value is the overall uncertainty in the automatic climate-control system (control accuracy + thermostat error).

The quality of the thermal comfort in the room can now be calculated according to the model in Figure 2, beginning from the top with the relevant thermal comfort category and ending at the bottom with a positive or negative control sensor setting interval. A positive interval indicates that the room fulfills the selected comfort category and a negative one that it fails.

EXAMPLE
The practical course in the evaluation procedure is described in a simple hypothetical example. The room is an office with the following parameters and request:
- The activity level for the employee is estimated to be 1.2 met.
- The dress level that anybody can adjust to is estimated to 0.7 Clo.
- The humidity level of the room is around 50% RH.
- The air velocity is around 0.1 m/s.
- The test is carried out just after installation.
- The room is designed for category B thermal comfort.

The information about air velocity and humidity is only used to convert between PMV and operative temperature.

![Diagram](image-url)  

**Figure 5:** The “measurement result” used to estimate the comfort level in a hypothetical room. PMV curves from 3 workplaces are shown on the graph.
1. Requested comfort level is: Category B (AU) -0.5< PMV < 0.5.
   Corresponding temperature level: 21.5°C < \( t_o \) < 25.3°C.

   \( t_o = \text{Operative temperature} \quad [{^\circ}\text{C}] \)

2. Correction for test condition: Category B (AI): -0.4< PMV < 0.4.
   Corresponding temperature level: 21.9°C < \( t_o \) < 25.0°C.

3. Due to asymmetric heat load in the room, the operative temperature varies 0.22 PMV point (0.8°C) from the warmest to the coldest workplace. Correction for asymmetry: Category B (AI), Average -0.29 < PMV < 0.29.
   Corresponding temperature level: 22.3°C < \( t_o \) < 24.6°C.

4. During the day, the room is warmed up by 1°C. The acceptable day and room average temperature is now calculated:
   Category B (AI), Average, No drift: -0.17 < PMV < 0.17.
   Corresponding temperature level: 22.8°C < \( t_o \) < 24.1°C.

5. Controlling the temperature should allow the operative temperature in the room to be kept within ±0.4°C. The acceptable setting interval for the temperature-control system:
   Category B (AI), Average, No drift, Steady state: = -0.07 < PMV < 0.07.
   Corresponding temperature level: 23.2°C < \( t_o \) < 23.7°C.

6. The difference between what the thermostat measures and the operative average temperature is not measured separately. Like the control error, this error is not systematic and is therefore seen on the measurement as noise. The total error from control accuracy and thermostat positioning is calculated to be 0.05 PMV point. Correcting for this gives:
   The thermostat setting interval is: -0.02 < PMV < 0.02.
   Corresponding to 23.4°C < \( t_o \) < 23.5°C.

7. Requested comfort level can be obtained.

CONCLUSION
Although it seems that category B thermal comfort is not hard to obtain, this evaluation method shows that it is not so simple. The 3.8°C that the operative temperature is allowed to vary in a typical office environment can easily convert to a few tenths of a degree when the available interval is corrected by the temperature slide over the day and the asymmetric heat load in the room.

The measurement planned will show the utility of the method and will be used for improving the evaluation method. The aim is a calculation method that is unique and contains as few assessments as possible so that it can be built in as a calculation routine in the measuring equipment.

REFERENCES