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Thermal comfort in office buildings: Two case studies commented

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ABSTRACT

Air conditioning in offices has become a current practice in North Western Europe. The main reasons for that are high internal loads, solar gains and increased comfort expectations. Hence, the move away from the naturally ventilated cellular office increased thermal comfort complaints.

The paper presents two cases. In both the results of a comfort enquiry are compared with measurements. The enquiries gave numbers of dissatisfied at a PMV zero that were much higher than the standard PMV/PPD curve does. Measurements instead showed that in one of the two offices only comfort complaints could be expected in summer. But even then, the enquired severity of complaints could not be related to the measured data.

Several hypotheses are forwarded to explain the results. Individuals interpret the −3 to +3 scale for thermal sensation differently, which has a direct impact on the number of dissatisfied. The standard curve further-on is a most significant mean of thousands of steady state comfort votes under well-controlled conditions while an on site enquiry involves much smaller numbers of people. These have a clear expectation: an improvement of comfort condition, thanks to the study. For that reason they may exaggerate their complaints when enquired. And finally, an alternative PMV versus PPD curve, published in literature, shows more people complaining at a given PMV than the standard curve forwards.

1. Introduction

For decades, office buildings in North Western Europe had no air conditioning. The reference typology was the cellular office with central heating, maximal usage of daylight, operable windows and low internal loads. From the 1960s onward, deep landscape offices with fully glazed facades and one employee per 10–15 m^2 floor surface gained popularity. That increased the need for artificial lighting, turning visual comfort into an important internal load. In the 1980s, personal computers replaced pen and typewriter, i.e. introduced an additional load, rated at one extra employee per employee. That doubled the heat they release. Even in mild climates, these extra loads could no longer be removed by ventilation only. The answer was full air conditioning. However, water-based systems also move large amounts of cooled air through these landscape offices, increasing the risk on overall thermal discomfort and draft complaints.

That situation surely was a driver behind the intense thermal comfort research deployed since the 1960s. Anyhow, prior to that, thermal comfort was already a subject of research in Europe and USA. In the late 1920s, ASHVE conducted a research project on equivalent environments, i.e. environments with different dry bulb and wet bulb temperatures and different air speed but identical comfort perception. These tests resulted in the definition of 'effective' temperature, i.e. the dry bulb temperature in an equivalent environment with relative humidity 100% and air speed zero (research referenced in Ref. [1]). In 1931, the ASHVE results were reinterpreted by the French HVAC-engineer Missenard [2], who stated that the tests overlooked an important environmental parameter: the radiant temperature. He therefore advanced a more general definition of 'effective' temperature that included the radiant temperature, which was assumed to be equally important as the dry bulb temperature, and called that generalised effective temperature the resulting temperature. His remarks drove ASHVE to redo the testing.

In Germany, comfort research was mainly conducted by physiologists, whose interest focussed on skin temperature and heat flux at the skin surface as indicators for the thermal comfort humans experience as exothermal and homoeothermic creatures under steady state and dynamic conditions [3,4]. Their studies underlined the importance of the heat flux at the skin surface. As that flux depends on the convective and radiant heat exchanges with the environment, the results confirmed the correctness of using resulting temperatures.

At the end of the 1960s Fanger [5] turned the physiological approach into an engineering tool by linking global satisfaction with the thermal environment to a steady state balance zero between the metabolic heat produced and the total heat a clothed human loses to the environment, using average skin temperature

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Fig. 1. Case 1: a view of the trading room.

and sweating as control quantities. The degree of discomfort, expressed in terms of a vote on a scale from −3 to +3 with 0 as neutral, −1 as somewhat too cold, −2 as too cold and −3 as much too cold, 1 as somewhat too warm, 2 as too warm and 3 as much too warm, was coupled to the imbalance between metabolic heat rate and heat rate exchanged. The diversity between humans got its expression in a PMV/PPD approach that linked a predicted percentage of dissatisfied (PPD) to a predicted mean vote (PMV). Dissatisfied with the given environmental conditions were those voting −2 or −3 and 2 or 3.

The PMV/PPD curve given in ISO standard 7730 [6] and ASHRAE standard 55-2004 [7] is based on numerous comfort evaluations under controlled steady state conditions using thousands of randomly chosen subjects. Everyone satisfied came out as being statistically impossible. Even at a predicted mean vote zero, still 5% of the tested individuals were dissatisfied. That changed the comfort approach into a discussion on acceptable percentages of dissatisfied. ASHRAE went for 80% acceptability while the EN-standards forward 90% acceptability as the objective.

From the 1980s on the PMV/PPD approach was questioned. One element of criticism was that it overlooked the adaptive principle. To some extent, the PMV/PPD approach takes it into account as diversity between humans is considered. However, based on the definition of comfort as a state of mind and using field results mainly collected in warm climates among people working in naturally ventilated office buildings, Humphreys, Nicol, de Dear, Brager, Baker and Standeven stated that comfort was much more adaptive [8–10]. Though the adaptive actions proposed vary from

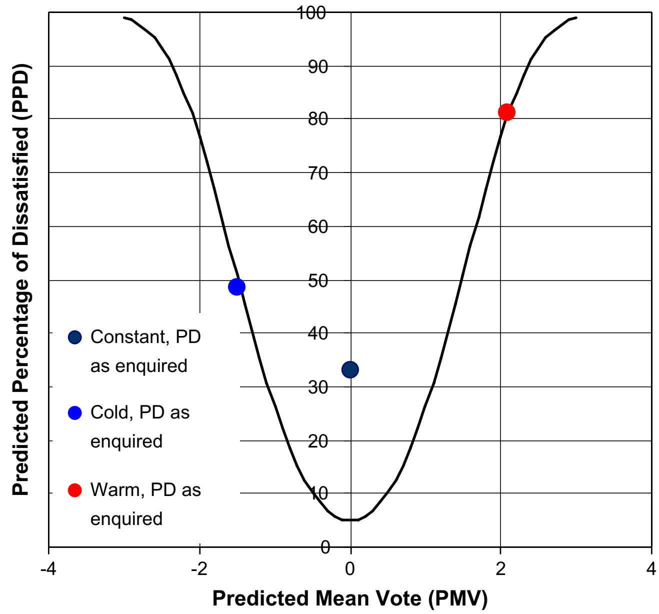

Fig. 3. Case 1: comparing the percentages of dissatisfied for the mean votes enquired with the standard PMV/PPD curve.

quite easy (turning up or down the thermostat, more or less activity, changing posture [11] and clothing, opening windows) to possible in theory but not doable in practice (building a new house or emigrating), the adaptive temperature model proposed gave better fits than Fanger's PMV/PPD model in naturally ventilated buildings. It, however, hardly differed from the PMV/PPD predictions in air conditioned environments.

Another element of discussion was the split Fanger introduced between global comfort and local discomfort by draft, air temperature gradient between head and feet, horizontal and vertical radiant imbalances and feet temperature. A too simple modelling of the human body as a heat exchanging homoeothermic system with constant core temperature and of the control system that varies the below-skin blood flow and sweat production depending on the heat or cold noted, figured as main reasons for that. Several authors proposed upgrades of the human model with the intention to come to one overall comfort picture [12–14].

Also transient environmental conditions returned as a subject of research. Measurements indicated that the mean skin temperature, the head core temperature and the rate of change of skin temperature are the governing factors in human thermal sensation in such a case [15]. Zhang et al., for example, developed an advanced

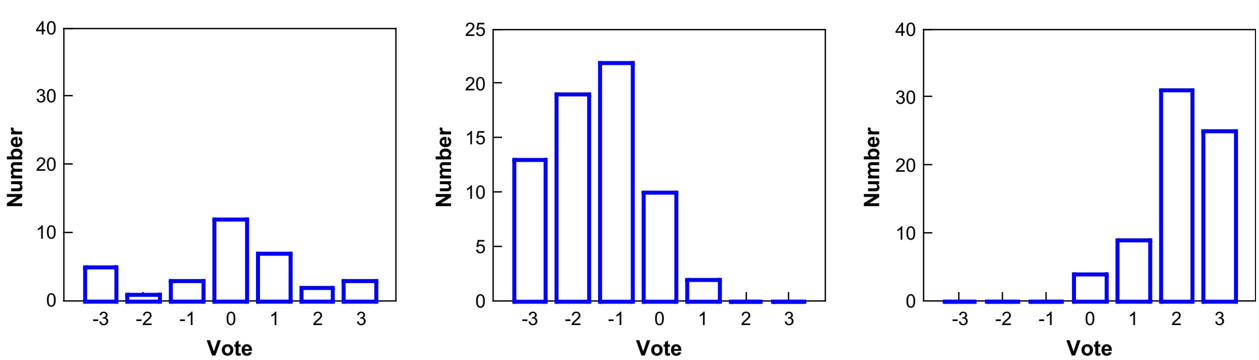

Fig. 2. Case 1: votes on the Fanger scale, left for those calling the thermal environment invariable, in the middle and right for those calling the thermal environment different from day to day. The vertical axis gives the number of votes and the horizontal axis the vote.