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three times higher than that prescribed by any existing ventilation standard."

Does Fanger now believe that the need for low air velocities will mean services engineers becoming more responsible for the types of materials put into buildings?

"I think," said Fanger after a long pause, "that the services engineer is the key person responsible for air quality. Any complaints will go back to the engineer, so he will be the key person, and will have to talk to the architect and screen whatever materials are used."

"I would hate to make carpets the scapegoat," said Fanger "but architects are not sensitive to this problem and may well want to use carpets that will raise the required ventilation rate by a given factor. Perhaps engineers should assume the responsibility for checking everything."

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Revisions to the CIBSE *Guide*

The environmental criteria for design section of the CIBSE *Guide* (Section A1) is currently being re-written. Although it is still under development, it is clear that the revision will incorporate an application table containing a recommended list of temperatures and humidities for a range of clothing levels.

This range will be based upon Professor Fanger's original comfort equation (as listed in *ISO 7730* 'Moderate Thermal Environments').

UK design rules OK?

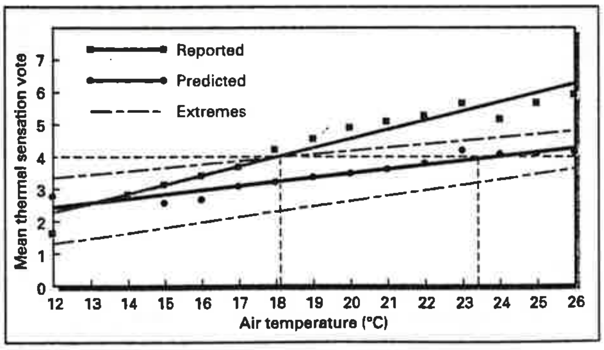
by Nigel Oseland

Recent research has thrown doubt on the validity of accepted thermal comfort equations. Should we be aiming for set-point temperatures, or simply providing better user control? Nigel Oseland sifts through the evidence.

Attaining the right internal temperature for occupants in buildings is fraught with problems. In the last 20 years, the efforts put into determining thermal comfort criteria have centred on finding an ideal temperature for a range of buildings and the zones within them; there has been much debate as to what those levels should be.

The international standard *ISO 7730*[1] is largely based on the work of the Danish professor Ole Fanger, who was the first to devise clothing and metabolic rate values (clo and met) derived from thermal exchange physics and climate chamber research[2]. The values contained in the CIBSE *Guide*[3], on the other hand, are reportedly based on "a consideration of the data, the circumstances under which they were obtained and of current practice in the UK", but appear to be mainly based on BRE field studies[4]. The result of all this is conflicting guidance.

ISO 7730 recommends that buildings are designed for an optimum room temperature of 22±2°C during the winter period and 24·5±1·5°C in summer. However, the CIBSE *Guide* suggests overall design temperatures of 19-20°C in winter and 20-22°C in summer.



Field trials have shown variations from Fanger's theories.

For the record the CIBSE *Guide* also distinguishes between design temperature for offices, ie 20°C, and that for homes, ie 21°C for living rooms and 18°C for bedrooms. The British Standards Institution[5] and the BSRIA[6] recommend similar design conditions to the CIBSE.

The Energy Efficiency Office suggests that people will be comfortable in their homes at 18-21°C[7]. Government legislation[8] prohibits the use of fuel to heat commercial premises above 19°C; there's no restriction on its use for cooling.

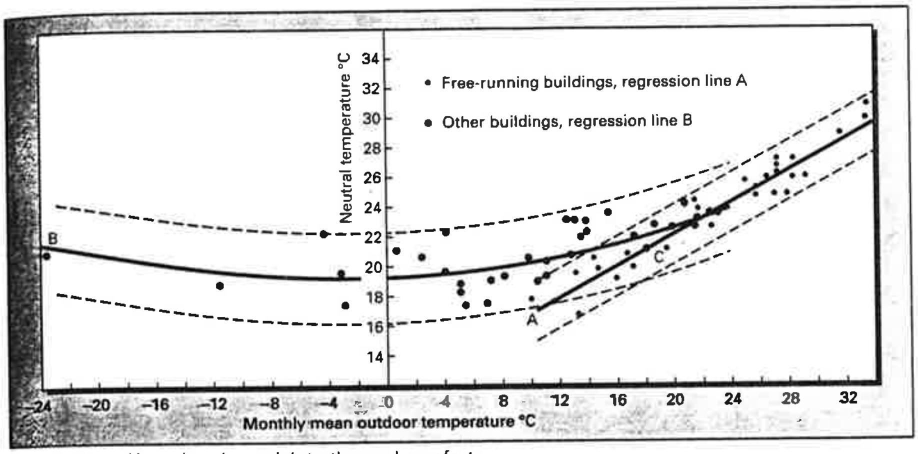
Although there is a 1-3°C discrepancy between the ISO and the CIBSE, both assume similar conditions, eg sedentary activity (1·2 met), light clothing (0·5 clo) in summer and heavier clothing (1·0 clo) in winter. ISO expresses the design criteria as operative temperature, and the CIBSE *Guide* as resultant temperature, but both are similar measures[9].

Points of divergence

The ISO/Fanger equation for determining neutral (optimum) temperatures was developed from the theory of thermal exchange physics combined with the results from climate chamber experiments in which students wearing standardised clothing (0·6 clo) sat for three hours.

The question is, how do these measurements compare with data derived from occupied buildings? Since Fanger first reported his research, numerous field studies have found significant differences in the thermal sensation reported by occupants and that predicted by the comfort equation. A recent study[10] found that the neutral temperature based on occupant response in offices was 2-4°C lower than that predicted by *ISO 7730*. Similarly, a recent BRE study found 5°C discrepancies for neutral temperatures in homes[11].

Climate chamber researchers attribute the above discrepancies in neutral temperatures to the inaccuracy of measurements in field studies. Initially the physical measurements were criticised, but modern data-logging equipment has alleviated this problem, so personal variables (ie clothing and activity) are now considered the main source of error.



Results from Humphrey's work into thermal comfort.

It is argued that many field studies ignore the clo value due to chair upholstery which could produce an extra 0·2-0·3 clo of insulation, half that of summer clothing[11]. Similarly, it has been claimed that in stressful work situations the metabolic rate will increase by up to 1·3 met, and in interview surveys possibly by as much as 1·5 met.

Nevertheless, adjusting field study data[10,11] on personal variables showed that, although the neutral temperatures could be forced to agree with predictions, the met and clo values required to do this were unrealistically high. The adjustment did not affect regression line gradient describing the relationship between temperature and reported thermal sensation.

Existing tables of clo values do not contain estimates for chair upholstery, and the standards do not sufficiently highlight the need to include upholstery insulation in the equation. There is insufficient data for determining metabolic activity, and existing methods of measurement are impractical in field studies.

Without sufficient guidance on the personal variables, the comfort equation cannot be used as a prediction tool: the *ad hoc* adjustment to clo and met values is not acceptable. It is not always possible for the designer to know in advance what furnishings will be fitted or what will be considered acceptable clothing. The activity may be more varied than expected, or in cooler situations an activity may be more vigorously performed than the same one in a warmer environment[12].

Fanger argues that ethnic differences and geographic location do not affect neutral temperatures[2]. But controlled climate chamber experiments conducted worldwide have reported neutral temperatures up to 3°C higher than in the original studies. One study[13] found that Malays resident in London had neutral temperatures 3°C lower than those in Malaysia. Such findings place doubt on the relevance of a universal thermal comfort equation.

The differences between reported and predicted neutral temperatures in field studies (2-5°C) questions the validity of using standards based on theory and climate chamber work. Despite appearing quite small, the differences in recommended design temperatures (eg 1-3°C for CIBSE and ISO) are significant in terms of energy conservation.

Reducing the thermostat temperature by 1°C can save 10% of the space heating bill[7], equivalent to a saving of 5% of the total fuel bill in homes and about 3% of fuel costs for most offices. Potential CO_2 emission savings are thus quite high.

An alternative approach

Humphreys[12] took a different approach to thermal comfort based on worldwide field study data. The reported neutral temperature was correlated with the recorded indoor temperature and also related to the mean outdoor temperature.

Humphreys argues that thermal comfort is best ensured by giving as much effective control to occupants as possible, rather than by fixing room temperature at some theoretically determined optimum.

Low control is associated with higher annoyance and stress, increased sick building syndrome symptoms and low productivity[14]. This may be because occupants are more tolerant of poor conditions if they feel they are in control, or because they can achieve an environment more suitable to their needs.

The latest SCANVAC thermal guidelines[15] recognise the importance of individual temperature control which is required to obtain the best building classification. However, individual control is not always possible particularly in open-plan offices, but there are now a range of systems available which offer microclimate control at each desk. Although there are potential problems with such systems (eg step changes in temperature when moving around the office), they offer the prospect of achieving greater comfort and productivity.

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BRE takes the initiative

Current guidelines for designing thermally comfortable buildings are largely based on experiments carried out 20 years ago. At an international conference entitled 'Thermal comfort: past present and future', to be held at the BRE headquarters in Garston on 9-10 June, 16 international experts will bring the thermal comfort debate up to date.

The conference will address the current issues and propose the way forward for future research and development. Presentations will include the following subjects: derivation of thermal comfort equations, applying the comfort equation and designing comfortable buildings, the adequacy of current guidelines and the link between heating and ventilation.

The fee for the conference, which includes accommodation, is £400 plus vat. Application forms are available from Patricia Rowley, conference and seminar manager, at: BRE, Garston, Watford (telephone: 0923 664488/664765). Further details can be obtained from Nigel Oseland at the BRE on 0923 664164.