European Project ThermCo

Thermal Comfort in Buildings with Low-Energy Cooling

Supported by

Intelligent Energy Europe

Contract No. EIE/07/026/SI2.466692

ThermCo

low-energy cooling and thermal comfort

Thermal Comfort and Productivity

Submitted by Technical University of Denmark

May 2009

Project Partners:

Fraunhofer Institut Solare Energiesysteme

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Summary

An unpleasant sensation of being too hot or too cold (thermal discomfort) can distract people from their work and disturb their well being. This may lead to reduced concentration and decreased motivation to work. The consequence of such a state is usually reduced productivity. An extensive literature review of the effects of room temperatures on office work was given by Wyon (1993) and further complemented and updated by Clements-Croome (2006).

The effect of room temperature

In the field study conducted in a call centre by Tham et al. (2003), the effect of air temperature and the effect of the outdoor air supply rate were both investigated. The duration of incoming calls was used as a metric of operator performance. The results showed that lowering the temperature 2 K from 24.5ºC resulted in an increase in operator performance of approximately 5% even though subjects were more thermally comfortable at the higher temperature. Another, much smaller and less well controlled study in call centers conducted by Niemalä et al. (2002) concluded that higher temperatures in an office environment decrease performance. A temperature intervention study carried out in an office building found a significant negative effect of raising the room temperature set-point by 4ºK (from 20-22ºC to 24-26ºC) on the performance of an addition task (Toftum et al. 2005). When a calculator was used to perform the task, no effect of temperature was found, i.e. raised temperature affected only the cognitive task of performing mental arithmetic, not the relatively trivial task of entering numbers on keyboards. The hypothesis that thermal conditions that provide thermal comfort do not necessarily lead to optimum work performance is supported by the results of several studies. Besides Tham et al. (2003 op. cit.), an earlier study by Pepler and Warner (1968) showed that subjects performed best at a temperature of 20ºC despite the fact that they felt uncomfortably cold at this temperature. The dose-response relationship between thermal sensation and relative office work performance introduced by Jensen et al. (2008), based on a statistical analysis of the data from laboratory and field measurements, also supports this hypothesis (Figure 1).

According to Wyon (1993), it seems to be the thermal state of the body, however achieved, that determines arousal and thus also performance. This interpretation is supported by Wyon's study of the mental performance of 36 subjects who were clothed for comfort at two different air temperature levels (Wyon et al. 1975). The clothing insulation levels were 0.6 clo and 1.5 clo, and each exposure lasted 2.5 hours. Whenever the subjects felt it necessary, the temperature was adjusted, so that they remained in comfort. The study showed that the performance of widely different kinds of mental work (addition test, word memory test, cue-utilization test) was reliably the same (the differences were less than 10%) under the two test conditions of thermal comfort. When subjects wore light clothing their average comfort temperature was 23.2ºC, while with heavy clothing their average comfort temperature was 18.7ºC. The difference in the mean preferred air temperature between the conditions was approximately 4.5 K. With thermal conditions below neutrality, Wyon (1993) found them unlikely to have any direct negative effect on performance; in the study of Langkilde et al. (1973) no such a negative effect was found for temperatures 4 K below neutrality. However, attention should be paid to the distracting and de-motivating effect of cold discomfort.

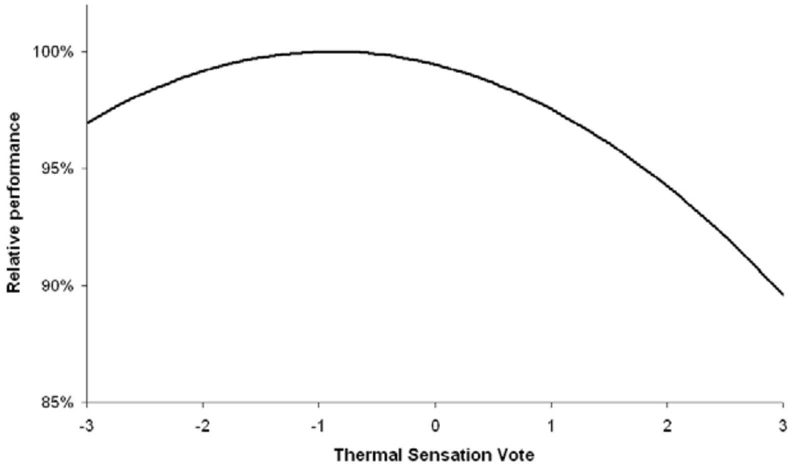

Figure 1: Relationship between subjective thermal sensation vote and relative performance (addition task) obtained using data from laboratory and field experiments; reproduced from Jensen et al. (2008)

In order to establish quantitative relations between indoor environmental quality and work performance, Seppänen and Fisk (2005) reanalyzed data including 150 assessments of performance from 26 studies (Figure 2). The data were obtained in office environments, factories, field laboratories and school classrooms. A meta-analysis was used to derive a model that integrates the economic outcomes of improved health and performance into building cost-benefit calculations, together with initial, energy and maintenance costs. The model considers the effect of ventilation rate, perceived air quality, indoor temperature and both the intensity and prevalence of SBS symptoms on performance. Considering the effect of temperature, the percentage change in performance per degree increase in temperature was calculated. Because the analyzed studies varied greatly in sample size and outcome the data were weighted by both sample size and relevance of the outcome (i.e. objectively reported work performance was assigned a higher weighting than simple visual tasks). The analysis showed that performance increased with temperature up to 20-23ºC and decreased with temperature above 23-24ºC. Maximum performance was predicted to occur at a temperature of 21.6ºC. Figure 2 shows the predicted relationship between relative performance and temperature that was derived using the results of this analysis.

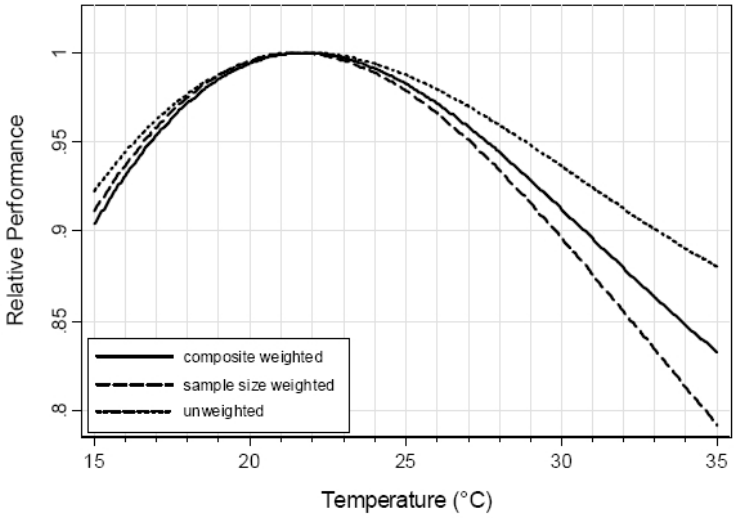

Figure 2: Normalized performance as a function of temperature (for example at the temperature 30ºC performance is predicted to be 90% of the maximum performance at 21.6ºC – the reduction in performance is 10%); reproduced from Seppänen and Fisk (2005)

Temperature and school performance
In a recent series of field experiments by Wargocki & Wyon (2006, 2007a, b) the performance of schoolwork by 10-12 years old children was measured during week-long experimental periods of improved classroom air quality (by increasing outdoor air supply rates from 3 to 9.5 L/s per person (6.4 to 20.1 cfm/person)) and during weeks in which moderately elevated classroom temperatures were avoided (by cooling from about 24-25 to 20^{o}C (75-77 to 68^{o}F). The results show (Figure 3) that doubling the ventilation rate would improve school performance by 8-14% while reducing the temperature by 1^{o}C (1.8^{o}F) would improve it by 2-4%, depending on the nature of the task. Improving classroom conditions should thus be an urgent educational priority.

The effect of thermal transients

Cyclical temperature swings were studied in climate chambers to determine the influence on human performance of the temperature transients caused by HVAC control systems. Wyon et al. (1971) investigated the factors affecting subjective tolerance of temperature swings. Subjects were exposed to continuously changing temperature and were able to reverse the direction of the temperature change by pressing a button, so the amplitude of the swings was under the subjects' control. The researchers concluded that subjects tolerated greater amplitudes when performing mental work than when resting.

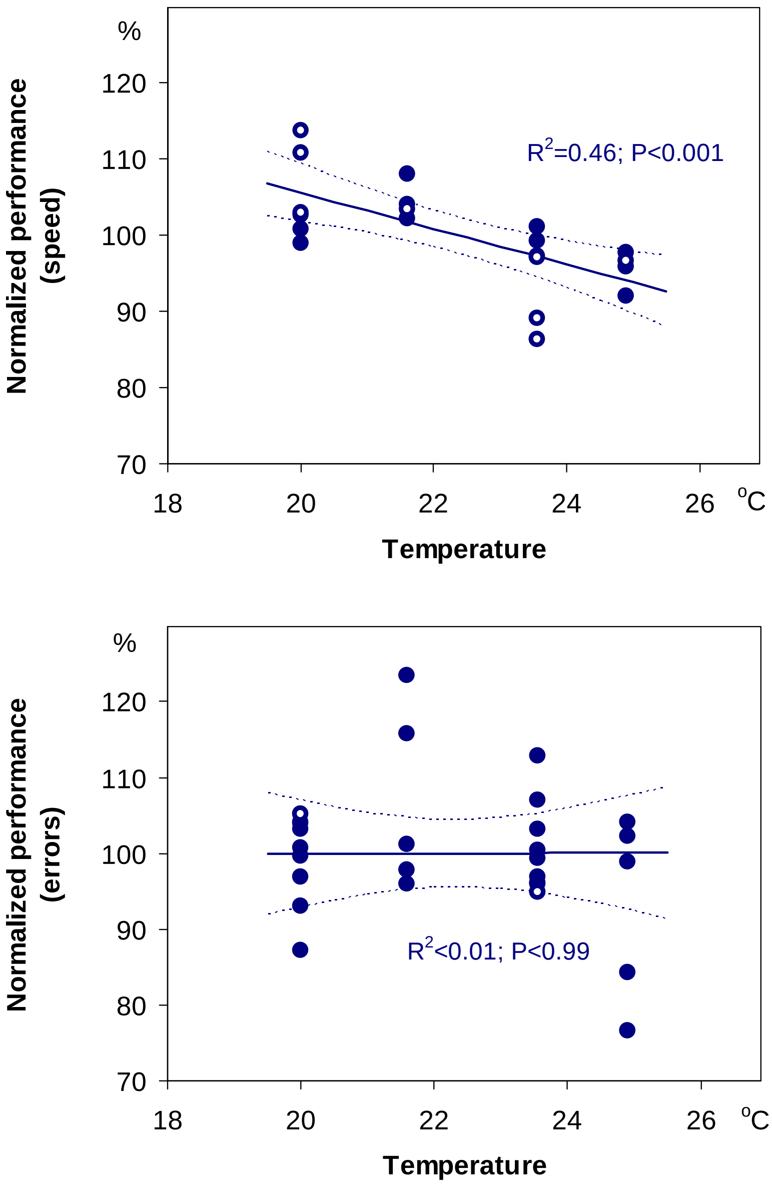

Figure 3: Performance of schoolwork as a function of classroom temperature; performance is expressed in terms of the speed at which tasks were performed (top) and the percentage of errors committed (bottom); dots show the performance of individual tasks (open dots indicate those tasks in which performance differed significantly between conditions) while lines show the regression (solid line) with 95% confidence bands (dashed line)

In another study (Wyon et al. 1973), subjects dressed in standard uniforms providing a clothing insulation of 0.6 clo were exposed to 8 different temperature swings, which occurred around the average preferred ambient temperature. The following combinations of peak-to-peak amplitude and period were investigated: constant temperature, 2 and 4ºK/8 min; 2, 6 and 8 ºK/16 min; 4 and 8 ºK/32 min. Each condition was maintained for three consecutive periods. Subjects were asked to evaluate their thermal discomfort. Their performance of an addition test was also measured. After experiencing three complete periods, subjects were asked to assess their level of arousal, degree of fatigue and the freshness of the air. The skin temperatures of several body parts were also measured on one subject. The researchers identified two types of effect of temperature swings on working subjects. Small, rapid swings around the preferred temperature resulted in a decreased work rate and decreased accuracy. Larger, slower temperature swings were associated with faster rates of working and the accuracy seemed to tend towards that achieved at a constant temperature. It was concluded that large temperature swings may have a positive effect on performance, but they increase discomfort and should thus be self-imposed, while small rapid temperature swings were equivalent to a small increase in temperature.

Laboratory exposures of human subjects to **temperature ramps** have not found any systematic significant effect of such ramps on objectively measured performance (Kolarik et. al. 2007, 2008). Nevertheless, analysis of each simulated performance task separately indicated that, in individual cases, performance metrics changed significantly during the exposure. With constant clothing experiments, increasing temperatures, especially at temperature levels above 24ºC, seemed to negatively influence the speed of repetitive tasks that required mental effort. No significant effect on complex tasks that require concentration, vigilance and logical thinking was observed. The data from the addition tasks examined in these experiments were used by Jensen et al. (2008) to determine dose-response relationship between thermal sensation and mental performance. The model was used to determine the average yearly performance decrement caused by the thermal conditions in a building with TABS (Thermo-Active–Building-System, with pipes integrated in the building structure fro heating and cooling, Kolarik-2008). The observed average yearly performance decrement was not higher than 1%. This result indicates that temperature drifts, with the rates of change and within the starting and ending temperatures used in the current study, may be used as a practical means of reducing energy use in buildings. In practice, indoor temperature drifts are usually a consequence of the climate conditioning system used. The simulations conducted as a part of the present study demonstrated that such systems can save a significant proportion of the primary energy. The simulations also showed that both energy savings and a comfortable indoor climate can be achieved by an appropriate building and system design that takes account of the relevant building characteristics like window size, wall and window U-values, building mass, ventilation rate and climatic conditions.

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