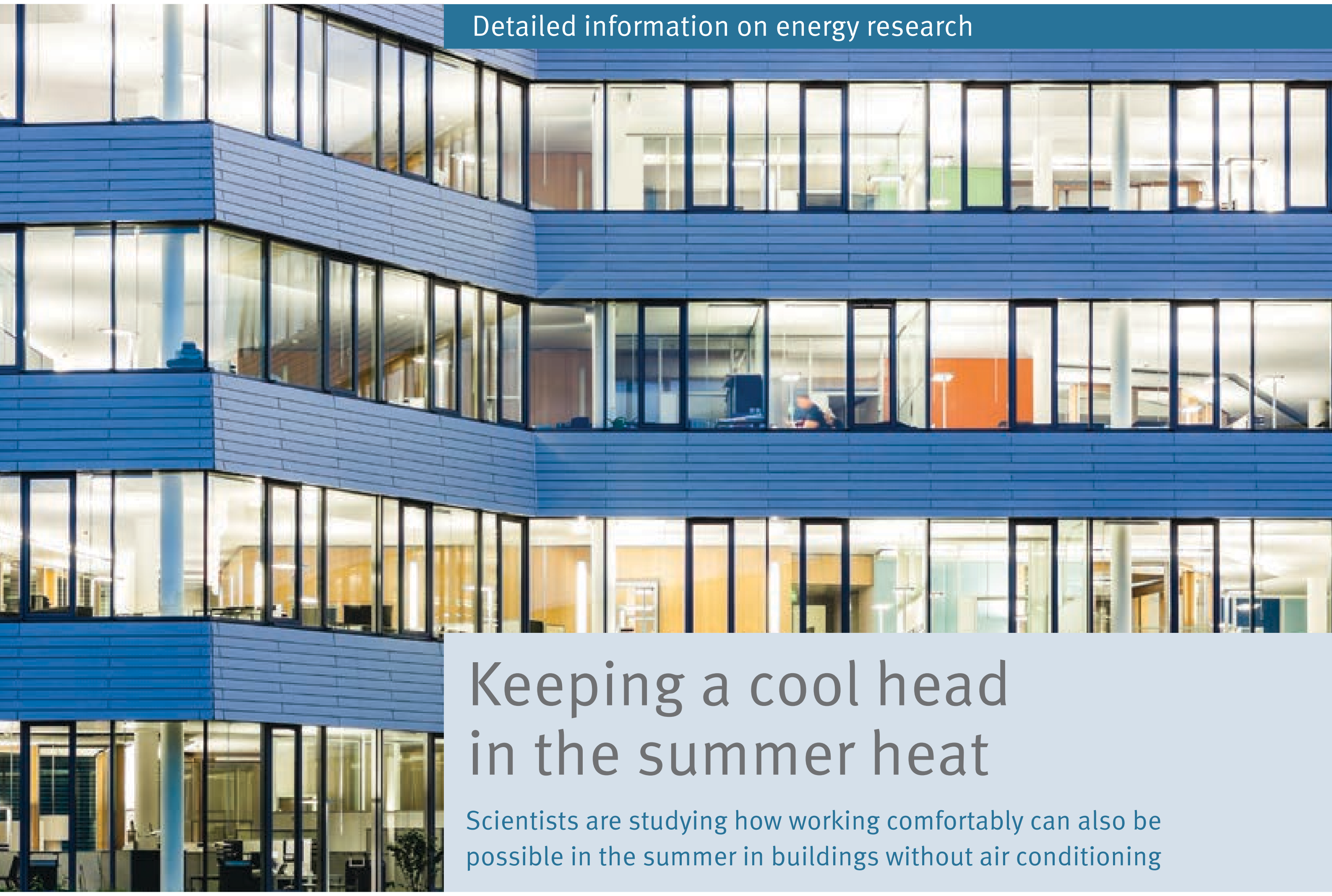
Projektinfo 04/2016
Detailed information on energy research



Keeping a cool head in the summer heat

Scientists are studying how working comfortably can also be possible in the summer in buildings without air conditioning

BINE Information Service

Many present-day office and administrative buildings are not air conditioned. When the temperatures rise during the summer, this can have a negative effect on the thermal comfort of the users. Scientists analysed what effect improved protection against the sun and the use of ceiling fans can have on user behaviour and satisfaction. So-called comfort models are also important influencing factors.

Comfort models serve to objectively evaluate and model the degree of thermal comfort in buildings. They are, among other things, an element of the standards which determine the indoor environment for designing and evaluating the energy efficiency of buildings. Standard models used are the PMV (Predictive Mean Vote) model and the adaptive model. With the latter, it is assumed that the person adapts to the changing environmental conditions physiologically, psychologically and through their behaviour. Researchers at the Karlsruhe Institute of Technology (KIT) studied the scale of influence of these factors as part of the „Passive cooling" project.

In order to obtain the required data, the researchers conducted field studies in six office buildings in Karlsruhe and Stuttgart. Additionally, various series of tests were conducted in an experimental facility (btga box) on the campus of the University of Wuppertal and in the LOBSTER (Laboratory for Occupant Behaviour, Satisfaction, Thermal Comfort and Environmental Research) facility on the campus of the Karlsruhe Institute of Technology. In the LOBSTER, the test persons and investigators could manually and automatically influence the indoor environment. Climate chamber studies at the Technical University of Denmark in Lyngby, Denmark, supplemented the tests.

This research project is funded by the

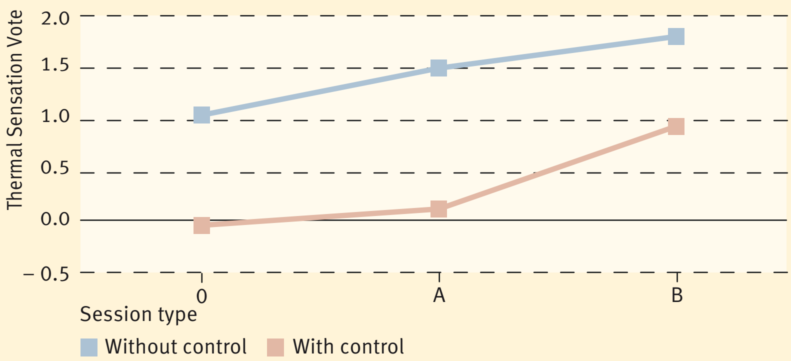
Federal Ministry for Economic Affairs and Energy (BMWi)

One influencing factor on thermal comfort are the expectations of the users. Regardless of the type of climate control, users of new or modernised buildings have higher expectations with respect to thermal comfort. This makes it harder to achieve a high proportion of people being satisfied with the indoor environment: with actively cooled buildings, the users expect cooler temperatures in the summer than in passively cooled buildings, for example, and are dissatisfied more quickly when it becomes warm.

The tests in the btga box showed that users are more satisfied with warm indoor temperatures when they can influence the indoor thermal environment themselves, i.e. they have a high level of subjective control (Fig. 1). This includes control options such as opening the window or using an individually controllable solar shading device. If these measures to increase comfort are effective, this has a positive effect on satisfaction levels.

The tests in Lyngby were designed to demonstrate seasonal differences in the physiological reactions and their effects on the assessment of thermal conditions. The study showed that the acceptance of increased temperatures is higher in the summer than in winter. While there are no significant differences in thermal perception between the seasons, there are differences in levels of acceptance. During the summer, users tolerate high indoor temperatures of between 27 °C and 29 °C more than they do in winter. Even higher temperatures are regarded as being unacceptable, regardless of the time of year (Fig. 2).

In the LOBSTER test stand, the scientists examined e.g. how the number of people working in the office influences the perceived level of comfort. The participants were able to adjust the indoor environment by means of opening the window, using solar shading devices, and ceiling fans. It emerged that the perceived room temperature increased with the number of people in the office. The more people there were in the room, the poorer the levels of perceived thermal comfort. To compensate for this, the temperatures possibly need to decrease in the summer in line with the number of people in the office. However, this would result in increased energy requirements for cooling. Further studies must be conducted in order to transfer these insights to a generally valid basis. A further result was that there were more discussions between the participants regarding the usage and speed of the ceiling fan compared to the decision on window opening.



Session type 0: *Reference condition with moderate indoor temperature and with outdoor temperatures between approx. 10 and 20°C*
Session type A: *Technically increased indoor environment temperature through cooling ceiling, outdoor temperature: approx. 10-20°C, thus lower physiological and psychological adaptation (conditions appear unnaturally warm)*
Session type B: *Naturally increased indoor environment temperature after longer warm outdoor period (outdoor temperature daily average: › 20°C, thus higher physiological and psychological adaptation (conditions appear naturally warm)*

Fig. 1 *The comfort assessment is more positive when there are control options available. Values between - 1 and + 1 are regarded as being a comfortable assessment. The tests were conducted with 17 test persons over 109 sessions.*

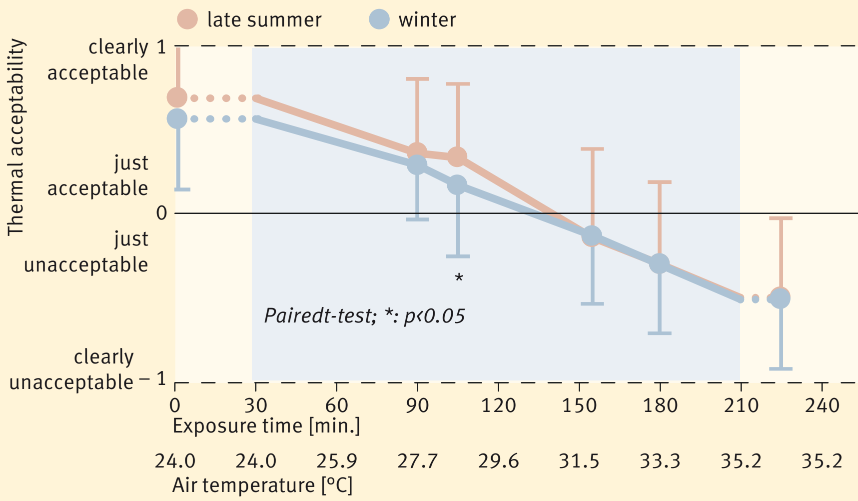


Fig. 2 *During the summer, the acceptance of users of increased temperatures (27 ° to 29 °C) is higher than during the winter. The average assessments of the 48 test persons can be seen who took part in both seasons.*

Standard comfort models linked together

Based on the data of above described experimental studies, the KIT researchers combined the PMV model and the adaptive model (infobox). For the new adaptive thermal heat balance model (ATHB), coefficients were defined for behavioural, physiological and psychological adaptive processes. The factors known to have an effect on thermal sensation such as air temperature, air humidity, radiation temperature, air speed, amount of clothing, and degree of activity are retained from the PMV model, as is the weighted running mean outdoor temperature from the adaptive model. Furthermore, the model offers the possibility to include new factors. Examples of these are psychological factors such as the „perceived level of control“, as well as building-relating factors such as the type of climate control, or number of people in the room. When these and other coefficients are integrated into the extended model, the perceived level of comfort among the users can already be better predicted during the planning phase of a building for different climate control variants. It is advantageous that the factors from both comfort models can now be calculated with one single model. However, the scientists have not yet been able to validate the results with a large random sample. This means that the values for the coefficients to date are still only temporary. A broader data basis is needed to ensure that the approach can be regarded as generally valid.

In the long term, the KIT researchers are planning to adapt the extended comfort model, which has been developed to date, to individuals. They are also planning to validate the new knowledge gained to date with a larger data basis. A further development of the adaptive comfort model is being made within the scope of Annex 69 of the International Energy Agency. Here, the scientists from the KIT are also involved.

Fig. 3 *Static solar protection on the mathematics building in the south campus of the Karlsruhe Institute of Technology*

Fig. 4 *Grid ceiling with integrated, workplace-specific fan: As well as the fan, two LED lights are installed. Extended metal mesh panels are installed in the edge area of the ceiling.*

Optimising static solar protection

As part of the „Passive cooling“ project, scientists at the University of Wuppertal have developed a software tool with which the dimensioning of a static solar protection facility (Fig. 3) can be optimised. Here, the creation of the geometric form is automated through a simulation method which takes into account both the material properties and the energy and comfort aspects.

Static solar protection reduces heat loads during the summer. Movable glare protection which can be operated individually by the user (e.g. blinds or screens) still remains necessary, however.

Static solar protection does nevertheless change the frequency with which the movable system is used. It is needed less often. This increases the amount of time during which it is possible to enjoy an undisturbed view out of the window. These changes can be examined using the simulation method.

Perception of comfort in the model

The **PMV (Predictive Mean Vote)** model is based on climate chamber studies by the Danish professor Ole Fanger. The model is designed to predict the mean vote of a group of persons with regard to thermal comfort under certain conditions. The factors influencing this vote are air temperature, air humidity, radiation temperature, air speed, amount of clothing worn and degree of activity. The model is based on the energy balance in the human body: people feel comfortable when the energy emitted is the same as the level of energy in the body, which is generated by metabolic processes and activity.

The adaptive model is based on field studies. It is assumed that a person can adapt to changing environmental conditions. This adaptation is made through behaviour (e.g. opening the window), physiologically (e.g. reduced level of sweating for a longer period of time under warm conditions in the summer) and psychologically (e.g. changed expectations).

The standard (DIN EN 15251) prescribes that the **adaptive model** should be used in buildings in which the users have the opportunity to adapt. If this is not the case, the PMV model must be used. This model is also used when the outdoor temperatures fall within the area of application of the adaptive model, i.e. below 10 degrees. In the adaptive model, the only variable is currently the weighted running mean outdoor temperature.

The **adaptive thermal heat balance model (ATHB)** links the approach of the adaptive comfort model with existing thermal balance models such as the PMV model.

Greater comfort and user satisfaction with ceiling fans

Increased air movement is advantageous for thermal comfort at high temperatures. A number of different studies have already been conducted in this area. According to DIN EN ISO 7730, a rise in air speed on the body by 0.5 m/s correlates with an upward expansion of the comfort zone of around 1.7 Kelvin. Against this background, the use of ceiling fans in office spaces is an interesting idea. At the University of Wuppertal, experiments have been conducted on classic ceiling fans with regard to energy efficiency, effectiveness and user acceptance. New concepts were also developed. The perceived air speed was felt by most of the test persons to be pleasant. The users were particularly positively influenced by the fact that the effect of the ceiling fans could be felt without a time delay, and its method of functioning is visible and easy to comprehend. On this basis, a concept was developed especially for suspended acoustic ceilings such as those frequently to be found in existing buildings (Fig. 4). Here, an energy-efficient small-scale fan (6 W) was integrated directly above the work place in a grid field and individually triggered by a computer applet. In this way, individual preferences can also be taken into account.

In further studies at the University of Wuppertal, the integration of ceiling fans into an adapted night ventilation concept will be studied.

Survey highlights need for optimisation

Users are often dissatisfied with the perceived thermal comfort during summer, both in air-conditioned and passively cooled buildings. Users had rated – on average – almost all of the nine queried comfort criteria positive in a previous study carried out by KIT. These factors include, for example, the user-friendliness of the building, the acoustic properties, and sun and glare protection. One exception was the evaluation of the thermal comfort in summer: temperature and air quality in summer were rated negative on average. This shows that things could be improved here. The Building Science Group (fbta) at KIT evaluated 4,336 questionnaires on 45 buildings. More detailed results are available for selected buildings. Site inspections and measurements provide supplemental information that is included in the analyses, and that complement the results of the user surveys.

Throughout all four seasons, the scientists carried out partial surveys of comfort conditions in 15 selected rooms in a building with office and laboratory space (13,150 m^2 of heated net floor area). The building has passive cooling with night ventilation as well as a daylight-optimised façade design. They found that 62 % of the respondents in summer were dissatisfied with the temperatures at their workplaces. A value of 7 % is to be expected according to DIN EN 15251. The high level of dissatisfaction could be related to the fact that almost all of the surveyed users work both in uncooled offices as well as in air-conditioned laboratories. This change may affect the assessment of temperature.

In addition, the outside temperature was very high during the measurement period and the survey. Further studies were carried out in an administrative building (22,610 m^2 of heated net floor area) with regenerative passive cooling via a geothermal heat exchanger and natural night ventilation. A number of measures should be able to increase user satisfaction in this case. For example, the employees took part in a detailed tutorial on using the exterior blinds. This improved the indoor environment continuously. In addition, the operating state of the ventilation system was visualised on the office doors. The ventilation system is turned on when the temperature is high in summer and low outside in winter. At medium ambient temperatures, the employees ventilate the rooms via the office windows.

Project participants

- **Comfort model research:** Karlsruhe Institute of Technology (KIT), Prof. Andreas Wagner; Dr Marcel Schweiker, marcel.schweiker@kit.edu; Dipl.-Psych. Maren Hawighorst
- **Research into fans, static solar protection:** University of Wuppertal, Prof. Dr.-Ing. Karsten Voss, kvoss@uni-wuppertal.de

Links and literature

- www.enob.info/en
- Wagner, A.; Höfker, G.; Lützkendorf, T.; Moosmann, C.; Schakib-Ekbatan, K.; Schweiker, M.: Nutzerzufriedenheit in Bürogebäuden. FIZ Karlsruhe. BINE Informationsdienst, Bonn (ed.). Stuttgart: Fraunhofer IRB Verlag, 2015. 224 pages, 59,00 euros, ISBN 978-3-8167-9305-2 (print), ISBN 978-3-8167-9306-9 (e-book)
- Schweiker, M. & Wagner, A. A framework for an adaptive thermal heat balance model (ATHB) Building and Environment , 2015, 94, 252 - 262
- Voss, K.; Voß, T.: Integrated design approach for improving personal summer thermal comfort in existing office buildings with suspended ceilings, in: "Proceedings of Clima 2016", Aalborg, Denmark

More from BINE Information Service

- Taking user behaviour into account with refurbishments. BINE-Projektinfo brochure 2/2015
- This Projektinfo brochure is available as an online document at www.bine.info under Publications/Projektinfos.

BINE Information Service reports on energy research projects in its brochure series and newsletter. You can subscribe to these free of charge at www.bine.info/abo

Imprint

Project organisation
Federal Ministry for Economic Affairs and Energy (BMWi)
11019 Berlin
Germany

Project Management Jülich
Forschungszentrum Jülich GmbH
Matthias Hensel
52425 Jülich
Germany

Project number
0327241D

ISSN
0937-8367

Publisher
FIZ Karlsruhe · Leibniz Institute for Information Infrastructure GmbH
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Author
Birgit Schneider

Contact · Info

Questions regarding this Projektinfo brochure? We will be pleased to help you:

+49 228 92379-44

kontakt@bine.info

BINE Information Service
Energy research for application
A service from FIZ Karlsruhe

Kaiserstraße 185-197
53113 Bonn, Germany
www.bine.info

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Concept and design: iserundschmidt GmbH, Bonn – Berlin, Germany · Layout: KERSTIN CONRADI · Mediengestaltung, Berlin, Germany