INDOOR COMFORT

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GENERAL RELEVANCE

Maintaining indoor comfort that meets the occupant's expectations is one of the major efforts in building design, construction and operation. The reason is, that in most locations in the world, the typical outdoor conditions are more or less far from thermal comfort as defined in typical comfort standards such as ISO EN DIN 7730 (air conditioned buildings, [1]) or EN DIN 15251/ASHRAE 55 (adaptive thermal comfort, non air-conditioned buildings [2], [3]). On the other hand, expectations of peoples are changing. Example are the rising need for cooling due to increased income in the fast economic growing countries of the world and the introduction of air conditioning as standard in private cars. It is a current major task to reduce energy use in buildings while at the same time providing comfortable indoor environments for the occupants (EBC Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings).

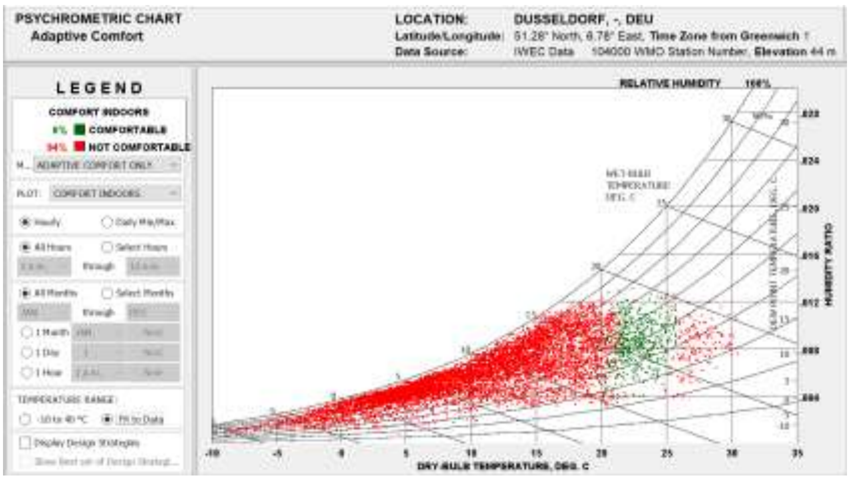

Figure 1: Example of a climate analysis with respect to thermal comfort. For this example (Duesseldorf, Germany) only 6% of the annual hours provide comfort conditions according to the adaptive thermal comfort approach. Source: Climate Consult tool

In most climates, the (operative) temperature is in the focus of thermal comfort. The relative humidity gains importance in connection with high temperatures (e.g. Singapore) as the evaporative cooling of the human body becomes more and more limited (>60%). In heating conditions, unfavorable low humidity (<30%) may occur due to the drying of ambient air by the temperature increase.

Air quality is typically addressed with CO_2-concentration analysis. The topic has a major relevance in the discussion on low energy buildings due to increased air tightness of building envelopes and the performance of fan assisted ventilation systems. CO_2-concentrations are also effected by the occupation density of buildings. Volatile Organic Compounds (VOC) are another issue of indoor air quality but mainly a topic for new constructions and new materials or paints used for internal cladding or furniture in building renovation. Concentrations are usually far from critical and decreasing fast.

Focusing on visual comfort in residential buildings (no constant computer work place conditions) the main issue is the visual contact from interior to exterior, especially in summer conditions with shading systems active. Keeping the indoor temperature within the comfort limits should be possible without blocked view. Today's national and international standards don't cover this issue. Minimum illuminance levels are an issue for non-residential buildings only.

RELEVANCE IN BUILDING COMPETITIONS & LIVING LABS

Typically, teams in building energy competitions address thermal comfort in the planning by dynamic simulation tools with a wide range of complexity and accuracy. No standard tool was provided in the SD up to now, but standardized simulation input reports have to be delivered. Output reports have not been standardized up to now. In the 2014 SDE the organizers simulate all buildings with an identical tool additionally [4].

Comfort is always addressed in an own discipline within the SD. It was mostly associated with a maximum of 100 points (of 1,000) and always fully based on monitoring data. Comfort monitoring was performed in SDE2010 and 2012 with tripod mounted sensors, 1.5 m above the floor with a resolution of 1 minute and 15 minutes averaging before storing the data [5]. Air temperature sensors were shielded and actively ventilated by a micro fan to avoid radiation influence. Typically two sections or rooms were observed per house (bedroom, living room). Starting in 2014 comfort in SDE is evaluated according to the adaptive thermal comfort model.

In SDME2018 operative temperatures were measured at two locations with globe thermometers and data with 1 min resolution were provided [5]. Fixed limits for temperatures have to be kept (22-25°C) as buildings have been fully air-conditioned (no adaptive thermal comfort approach).

In SDE 2010/12 air quality was measured in the form of continuous CO_2 monitoring in combination with one of the tripods for thermal comfort evaluation. VOC measurements were performed separately on one competition day. A light sensor was placed on the work space desk in each house to detect the illuminance level continuously. Visual contact was not part of the investigation up to now.

In none of the competitions user satisfaction was evaluated. Only monitored comfort was addressed. Living labs in general allow to address this issue as buildings are occupied and questionnaires can be applied for user centered research.

PARAMETERS

There are a big number of parameters influencing indoor comfort. Beside the ambient climate, the building design and its construction quality the user behavior are in the center of interest. Increasing ambient temperatures due to the predicted climate change are to be considered for new designs as well for the retrofit of buildings.

PERFORMANCE INDICATORS

Indoor comfort is mostly qualified on the level of performance classes. Performance classes are defined by the relevant standards such as ISO EN DIN 7730 or EN DIN 15251/ASHRAE 55. Simulated or measured data can be analyzed against performance class boundaries and times of consistency with classes can be cumulated. The analysis centers on the times of occupation, as indoor comfort is not a relevant topic in unoccupied situation (e.g. nights or weekends in office buildings).

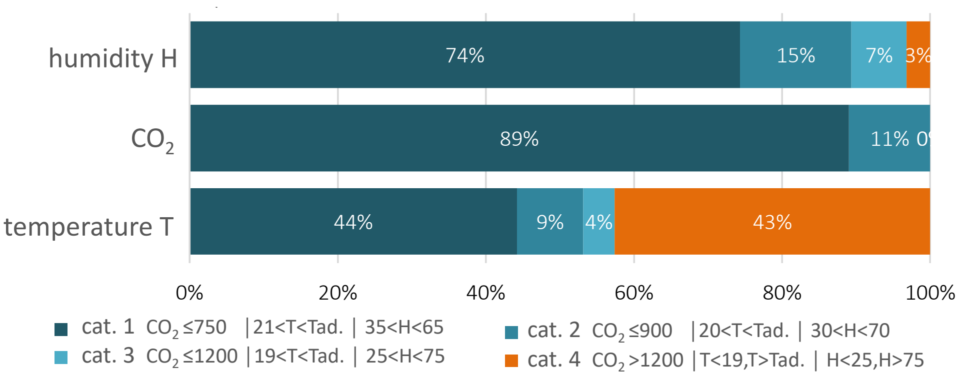

Figure 2: Example of a performance class analysis by simulations for temperature, humidity and air quality according to EN DIN 15251. Data address a full year, but occupation times only. Source: SimRoom

SIMULATION

Simulation of indoor comfort needs fully dynamic building simulation programs with minimum hourly time resolution (Wufi, TRNSYS, IDA ICA, ….). Information on phenomena such as the temperature stratification in a room is provided by CFD calculations (Fluent,…) but typically not dynamically calculated for a full year analysis.

Most building simulation tools provide information on air temperatures and operative temperatures as well but mostly as values per zone (fully mixed air). The calculation of the operative temperature as a function of the place in a room needs a geometrical model to investigate view factors for all surfaces, relative to the point of interest. In the case of humidity- and CO_2-concentration, the models need extended algorithms and input data for time dependent humidity and CO_2-sources (people, plants, showers…) in the rooms or zones. Internal heat gains and user behavior with respect to occupancy, window ventilation and blind control are important factors to describe the thermal phenomena. Practically all these information's are not easy to receive for occupied buildings and tackle the field of information privacy. A further issue in many cases is the unknown infiltration rate of a building in real operation.

The use of monitored weather data of the same time resolution is essential when simulation results are to be compared to measurements. Critical aspects are the influence of external shading and the algorithms for the solar radiation calculation on the various building surfaces based on global radiation measurements only. Better results are achieved with irradiation data separated in the direct and diffuse component.

MONITORING

Typically monitoring is performed with sensors for temperature and humidity combined and sometimes added by an air quality sensor (indoor climate station). Beside sensors for the scientific market more and more equipment on the consumer level shows up with suitable quality (Netatmo, IC meter,…). Adding air quality sensing mostly creates the need for active power supply and wiring to an AC plug due to increased power consumption.

Temperature

Typical sensors are resistance thermometers (PT100, PT1000,…) or thermocouples (NiCrNi,…) hardwired to a data logger or central data acquisition system or wireless connected to a cloud service. The advantage of thermocouples are the smaller construction with less surface to absorb solar radiation and less thermal mass. Typical installations for the air temperature shield the sensor from direct radiation and/or actively ventilate the sensor surrounding, whereas the operative temperature is measured by globe thermometers in the form of a black sphere of about 15 cm diameter, non-vented. Compromises e.g. for the purpose of building automation apply wall mounted sensors build into small plastic boxes (installation boxes) with openings for passive ventilation. These sensors measure a mixture of air and operative temperature due to the effect of the thermal mass of the wall. Whereas simulation programs (except CFD tools) deliver a single temperature per room (refer above) the reality shows more or less differences with respect to room height (stratification) or room depth (distance from façade). These differences have to be carefully considered when comparing simulation and monitoring results.

Humidity

Many aspects are equal to those mentioned for the temperature measurement. The air temperate surrounding the humidity sensor influences the relative humidity reading as due to the changing carrying capacity with temperature. Typical sensors use the change of the electric capacity and provide an electric signal in the form of 4-20 mA or 0-10 VDV for 0 to 100% relative humidity. Generally, the accuracy is not as high as a temperature measurement and more sensitive to sensor costs. A resolution lower than 5 minutes doesn´t make sense for most sensor types due to their reaction time.

Air Quality

Sensing the CO_2-concentration is currently shifting from the scientific to the consumer market. Most sensors apply the IR-Absorption method to detect concentrations in the range from 200 to 5,000 ppm. Typically, sensors automatically recalibrate themselves based on the knowledge that outdoor concentrations are about 400 ppm and more or less constant.

Visual Contact

Monitoring of blind positions is a very complex task as more than the status “closed” and “opened” is relevant for most moveable shading devices. This creates the need for position sensing and in cases of venetian blinds the sensing of the slat angles. In general, this is possible in the case of “smart controls” with additional logging of the signal. Another approach is based on watching a façade with a camera (indoor or outdoor mounted) and apply automated image post processing. In the case of camera systems, especially when indoor mounted) occupant’s privacy is heavily affected.

Post Processing of Results from Simulation & Monitoring

Simulation and monitoring deliver a large number of data, especially when long time series are stored in high resolution. High resolution is a critical factor to capture user behavior (window opening …) and indoor comfort peaks. High quality visual post processing of data allows quick general performance view. The examples below describe typical outputs here as graphical outputs of the simulation tool “SimRoom”. A performance view in the form of a compact calcification graph is already presented with figure 2.

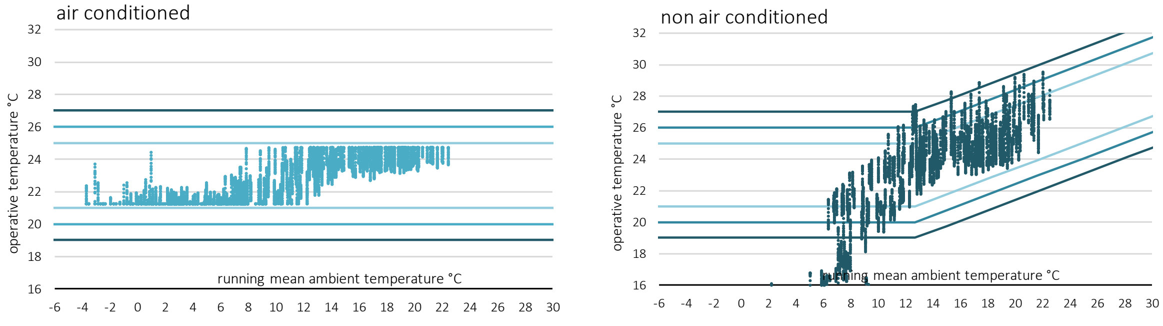

Figure 3: Analysis of the operative temperature during occupation of a room during a full year. SimRoom results. The right diagram shows the non-conditioned situation, in the left diagram heating and cooling was active during simulation (21°C, 25°C).

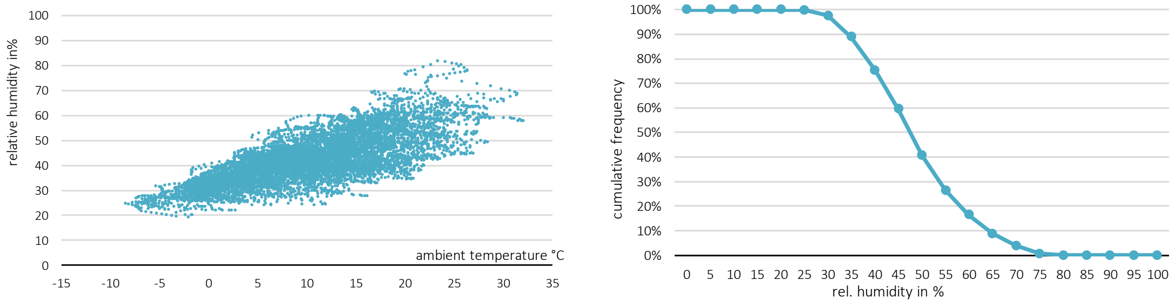

Figure 4: Analysis of the relative humidity during occupation of a conditioned (heating & cooling) room during a full year. SimRoom results. The left diagram illustrates the relative humidity as a function of ambient temperature, the right diagram the correlated frequency distribution.

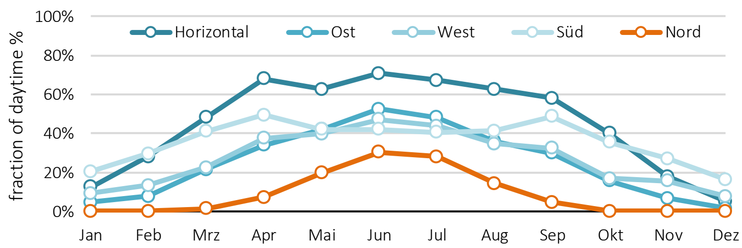

Figure 5: Analysis of the monthly activation time of moveable sun-shading devices based on indoor and outdoor climate as well the radiation and temperature based control algorithm. SimRoom results.

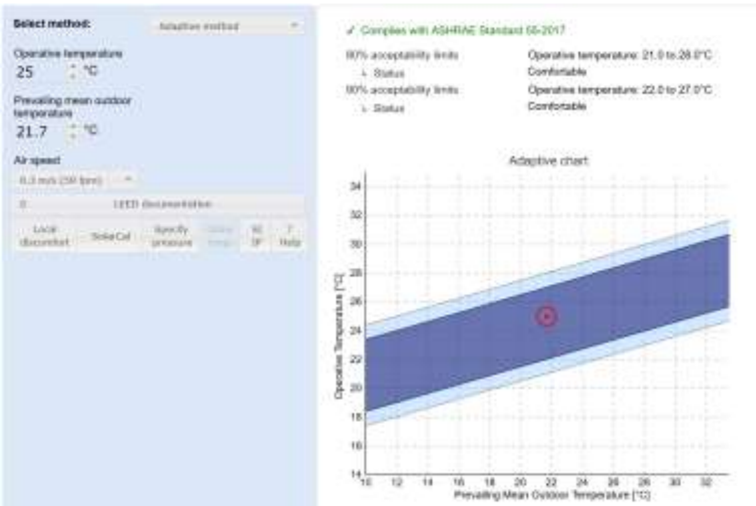

Figure 6: Analysis of the thermal comfort based on measurement or simulation data uploaded in a web based tool. http://comfort.cbe.berkeley.edu/

Further Reading

[1] ISO EN DIN 7730: Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, 2006-05

[2] EN DIN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, 2012-12

[3] Ashrae 55: Thermal environmental conditions for human occupancy, 2017

[4] Competition Rules & Building Code SDE 2014, version 5, page 40.

[5] Vega, Sergio: Monitoring Processes of the Spanish Competitions Solar decathlon Europe 2010-12, UPM, internal report of IEA EBC Annex 74, May 2018

[6] Competition Rules & Building Code SDME 2018, version 2.0

[7] SDME Monitoring Panel – Sensors and Meters configuration, TUEV Rheinland, 2018-07