Indoor Climate Measurements in Buildings and Design Functions for Building Simulations

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Abstract. For the planning or energetic optimization of buildings, building physics simulation programs are indispensable tools. Even though relevant building physics standards and guidelines usually refer to stationary calculation methods to prove the serviceability of a building, these powerful planning tools usually also allow transient calculations in any time steps. However, the use of modern simulation programs leads to realistic evaluations only under the condition of valid, expected input variables. Well known are the building material parameters, as well as the site-related outdoor climate. For the indoor climate, such precise information does not exist yet. Nevertheless, the indoor climate is required as an essential input variable for many simulations and verifications in building physics. In this case, rough approximations are used in this case. Information in the literature on the development of the indoor climate is usually generally valid and does not differentiate between climate regions, occupancy profiles or room use. But especially for the increasingly powerful transient simulation programs, these data provide insufficient results. Indoor climate measurements are therefore carried out over a period of several years at various locations in Germany. Measurements are carried out in window-ventilated living spaces. This paper presents indoor climate measurements from this study over a measurement period of one year in twelve living rooms and nine associated bedrooms. From the measured values, the outdoor temperature and time-dependent compensation functions for indoor air temperature and dew point temperature are derived. During the measurement period, the living rooms were free of damage and showed different occupancy profiles. The comparison of both room types shows the great influence of room use on the indoor climate in residential buildings. This is especially true for the indoor air temperature. Model curves for the parameter of the indoor climate for both window-ventilated living rooms and bedrooms are derived from the measurement results. This information can be used as a basis for planning. Furthermore, it can also be used to check and evaluate simulation results with regard to the risk of condensation on the wall surface of the window-ventilated rooms.

1. Introduction
For the planning or energetic optimization of buildings, but also for structural damage analyses or the design of technical building equipment, building physics simulation programs are indispensable tools. Relevant building physics standards and guidelines usually require stationary calculation methods to
prove the serviceability of a building. However, the powerful planning tools also enable transient calculations at any time steps.

However, the use of modern simulation programs leads to considerably more detailed and realistic evaluations only under the condition of valid input variables. The building material parameters and the site-specific outdoor climate are sufficiently known. Such knowledge does not yet exist for the indoor climate.

Within the framework of a long-term study presented here [1], the indoor climate in various apartments has now been recorded and evaluated. In the presented results several different user groups are summarized. Of particular interest is the expected amount of humidity for minimum thermal insulation [2], for energy calculations of buildings [3] the preferred room air temperature and the ventilation behaviour of the user groups.

2. Implementation
In the rooms of various existing buildings, both the indoor air temperature and the relative humidity were measured. For the year 2012, measured values were recorded both in the living rooms and in selected bedrooms on interior walls, at head height without direct sunlight.

The massive existing buildings investigated are multi-family houses built up to 1970, and the buildings were renovated for energy efficiency between 1997 and 2005. As far as possible for reasons of monument protection, the facades were thermally insulated in addition to windows, heating and roof insulation. The buildings are located in Weimar, Germany.

Both couples and families with up to three children live in the apartments. The presence during the examination varies from senior citizens with high attendance to families with working parents and school-age children.

The data loggers recorded the climate data in minute intervals and stored the average value in 10-minute intervals. For the outdoor climate, the measured values from the DWD measuring station for the Weimar site were used.

3. Measurement results
Arithmetic hourly averages were calculated from the measured 10-minute values and plotted in the seasonal course in Figure 1. The temperature curves in the various apartments clearly show the individual usage habits of the different types of occupants. For example, senior citizens usually have higher temperatures throughout the day, working families with children usually have fluctuating indoor air temperatures throughout the day.

In the winter half-year (1st & 4th quarter) the indoor air temperatures range from 17-23°C. The average daily mean values across all apartments vary between 19.2 and 21°C indoor air temperature in the winter half-year. Overall, the average temperature during the winter months is 20.1°C.

For the apartments, recurring patterns can be seen for the room air temperature during typical periods of use. During periods of occupancy, the heating system ensures a room air temperature of more than 20 °C in the majority of the apartments. In absence, this is reduced by up to 5 K.

In the summer half-year (3rd & 4th quarter) the room air temperatures of the different apartments show a comparable pattern. From April onwards, the indoor air temperatures rise and the dependence of the indoor air temperature on the outdoor temperature is clearly visible since, with rising outdoor temperatures, the window opening times also increase (Figure 1). While in the winter half year, the curves of the different living rooms describe a wide range, these differences in the room air temperature
in the summer half year are much smaller. This is also an indication of the increasing window opening times and the equalisation of the room air temperatures independent of the user.

![Temperature and humidity graphs](image)

**Figure 1.** Hourly average values of the indoor climate in twelve living rooms for the year 2012 [4]; above: Temperature; below: relative humidity

4. Evaluation and discussions

In order to enable a better comparability of the measurement series, e.g. with regard to the different living situations or a better differentiation of user groups, compensation functions were calculated according to (1).

$$y = y_0 + Ae^{-\frac{(x-x_c)^2}{2w^2}}$$

(1)

For these compensation functions, in addition to the mean value $y_0$, the amplitude $A$ as well as the time of the maximum $x_c$ and the period duration $w$ were adjusted to the 10-minute measured values according to the least squares method. The results are plotted in Figure 2 (above) with the daily mean values of the room air temperature.
Figure 2. Daily mean values of the room air temperature with compensation functions for the living rooms individually (above) and in total as well as 95% forecast interval (below)

The compensation function shows clearly the different climatic preferences of the apartment users. This is especially true for the winter half-year, during which the average value for the individual apartments was calculated between 18 and 22.5 °C. In summer, the maximum values of the compensation functions increase up to 25 °C at the end of July.

If the measured values of the apartments are close to the associated compensation function in the winter half-year, a wider spread can be observed in the warmer months due to window ventilation and the high fluctuations in the outside air temperatures. The time of the maximum may be referred to as an indication of the influence of the regional outdoor climate.

For the compensation function of all apartments, shown in Figure 2 (below), the average temperature in the winter half-year was calculated at 20 °C and the summer maximum at the end of July at 23.7 °C. The additionally indicated 95% forecast interval at intervals of ±3 K describes the expected position of an additional observed value.

In nine of the twelve apartments studied, the indoor climate in the bedrooms was recorded in parallel with the living rooms. The determined compensation curve for the room air temperature of the bedrooms is plotted in Figure 3 together with the compensation curve of the living rooms. Comparing both curves, the different room use is clearly visible. Especially in the winter half year, the mean value is over 3.3 K lower. This is because in the vast majority of bedrooms heating is only rarely or not at all used. As a consequence of the increasing window ventilation in all apartments and rooms, the amplitudes in summer are equalized. Slight differences can be explained by the orientation of the windows. Living room windows, for example, are usually oriented to the south, bedrooms usually to the north. Accordingly, the living rooms have a higher solar energy input.
Both the water vapour saturation pressure and the partial water vapour pressure were determined from the measured values of temperature and humidity. The dew point temperature was then calculated according to DIN EN ISO 13788 [5].

The dew point temperature of room air describes the amount of water vapour contained in the air. Therefore, the dew point temperature can also be used to assess the risk of condensation on surfaces. Since condensation precipitates when the surface temperature falls below the dew point temperature.

The results for the calculation of the dew point are shown in Figure 4. It shows the daily mean values of the dew point temperature as well as the compensation functions calculated from the measured values according to (1) for the rooms investigated. Looking at the individual living rooms, the compensation functions show an average value of 7.8 to 12.5 °C in the winter half-year.

As a result of rising outside temperatures and the associated high relative humidities (see Figure 1), dew point temperatures rise in the summer months. The maximum values of the compensation functions are up to 15 °C. In addition, Figure 4 shows the mean compensation function for all measured dwellings. The average value for the winter half year is 9.5 °C, the summer maximum at the end of July is 13.5 °C. The 95 % forecast interval runs at a distance of 4.3 °C.

For a better classification of the measurement results, they are compared with an indoor climate model from DIN EN ISO 13788 [5]. These room-side conditions should be used as a simplified approach if no well-defined or measured data are available. The model describes the room air temperature and relative room air humidity as a function of the external daily mean temperatures. For the modelling of the relative room air humidity, the humidity content of the outside air is neglected, only the normal and high occupancy of the building is distinguished.
The comparison of the model with the daily mean values of the room air temperature (Figure 5 left) shows that the model assumption describes the mean value of the measurements quite well. However, it also shows a high dispersion of the measured values in a range of ±2.5 K around the model curve. The assumed plateau for high outdoor temperatures is not confirmed by the measurements.

When looking at the relative humidity in Figure 5 right, the measured values cannot be assigned to any model curve. Conclusions about plateau formation at high or low outside temperatures cannot be derived from the measured values. This may be due to the low number of measured values in the ranges. Overall, the measured values show a systematic deviation from the model curves for relative humidity.

![Figure 5](image_url)

**Figure 5.** Dependence of the daily mean values of the room air temperature (left) / relative room air humidity (right) on the outside temperature for 12 living rooms in 2012, cf. with DIN EN ISO 13788 [5]

Especially the cooler seasons are most critical for the formation of condensation and mould [4]. During this period of low outside temperatures, the measured indoor air temperatures exceed the model curve of the standard (Figure 5 left). At the same time, the relative humidity level in most of the window-ventilated rooms investigated is higher than assumed by the model (Figure 5 right). As a consequence, this means more absolute humidity in the room air, associated higher dew point temperatures and an increasing risk of condensation on room surfaces, often also on several days in a row.

5. **Conclusions**

Long-term measurements of the indoor climate in twelve living rooms and nine bedrooms were analysed for the period of one year. A first evaluation points out the range of different user groups. By means of compensation functions, these individual occurrences can be highlighted and enable their identification. In addition, the strong influence of room use could be determined by comparing the average room air temperature in the living rooms and bedrooms.

In comparison with the indoor climate model from DIN EN ISO 13788 [5], the measurement results yielded new findings, especially for the relative room air humidity. In most cases, the model of the standard assumes that the indoor climate is too dry, not least because of the neglect of the outside air humidity. This leads to unrealistic results, especially when it comes to clarifying damage events, e.g. due to condensation. The high scattering of the measured values around the model curve for the room air temperature should, therefore, be taken into account in order to perform simulations on the "safe
side". For example, lower room air temperatures could be used for energy calculations and higher room air temperatures could be used to avoid the formation of condensation.

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