Interior Temperature and Relative Humidity Distributions in Mixed-Humid and Cold Climates as Building Simulation Boundary Conditions

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ABSTRACT

Hygrothermal modeling is, in many countries, either required by code or has become an industry standard. Awareness of the required inputs has also been improved. Reasonable boundary conditions are necessary to obtain representative results for the hygrothermal simulation of building components. Furthermore, realistic assumptions for hygric and thermal loads for whole-building simulation are required to assess the practical building performance. This means that all boundary conditions need to be appropriately defined for each specific design application.

Standards that define internal boundary conditions for hygrothermal building component simulation are reviewed. These standards define deterministic input values. Realistic values for indoor temperature and relative humidity were obtained by measuring the conditions inside residential buildings in two different climate zones. For the assessment of the influence of the location within the building, in average five rooms per building were equipped with data loggers to continuously record the conditions.

These realistic conditions are analyzed. The density distributions of the measured values are used first to describe probabilistic input data for hygrothermal simulation and secondly to assess possible dependencies regarding the positioning in the building. It is shown that dividing the data into seasonal subgroups allows representation of the data per location as normal distributions. This is a first step in describing nondeterministic input values for hygrothermal simulation.

The found conditions are compared to the conditions assumed by using the standards. It is found that there are deviations between code-based internal boundary conditions and measured conditions. These differences may lead to wrong results in hygrothermal building component assessment and hygrothermal whole-building simulation.

INTRODUCTION

In recent years, hygrothermal simulation gained importance for a more holistic approach to building analysis. It is differentiated between building component simulation and whole-building simulation. The first assesses a building component, i.e., the composition of the material layers, with respect to keeping the components free of damage and exterior or interior biological growth. The component simulation, therefore, needs prescribed conditions for interior temperature and relative humidity (RH). Exterior conditions are usually measured weather data combined into a format readable by the software. The interior boundary conditions can be measured inner climate data. But in most cases these values are not available—especially in the case of new building or construction design. In these cases, different standards and codes can be used to define the inner climate conditions—usually depending on the exterior climate. These codes and standards are analyzed and explained. It will be shown, that they only provide deterministic inner climate conditions. In reality the inner temperature and RH depend on many different factors, such as user preferences or special events in the building. The result is a high variation of the conditions. A future point in hygrothermal component simulation should be to analyze the components with respect to the uncertainties in the internal boundary conditions.

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Hygrothermal whole-building simulation represents the interaction between a building and the space enclosed. The internal conditions in this case are a result of the energy and mass balances for the zones. This means that—in addition to building components—solar gain, natural and mechanical ventilation, HVAC systems, and internal loads are taken into account. Whereas the influence of building components, solar gains, and HVAC equipment can usually be calculated precisely, the influence of usage is subject to many different factors. No comprehensive usage and user behavior model is available.

In this paper, standards for the definition of interior climatic conditions for use with hygrothermal component simulation are assessed, and the values obtained by using these standards are compared to measurements of temperature and RH in residential buildings in two different climate zones. The comprehensive measurement data is assessed, and the distribution of thermal and hygric conditions in differently used rooms is analyzed in detail. This allows a closer look at possible dependencies, for example, the connection between moisture loads and usage of the room or a possible temperature layering/stack effect over the stories of a building.

The hygric conditions are often expressed as a result of the moisture balance technique. Rose and Francisco (2004) also used this technique for the assessment of measurements of 15 buildings during wintertime. They found that the moisture load tends to be higher in upper stories in multifamily buildings and argued that this is consistent with heating season stack effect. One suggestion is to further evaluate to what extent monthly differences can be explained by behavioral changes of the occupants.

A comparison of empirical indoor RH models with measured data can be found in Cornick and Kumaran (2008). The models tested are the European Indoor Class Model (DIN EN 2001) and the ASHRAE Standard 160-2009 (ASHRAE 2009) simple and intermediate models. The comparison is based on measurements of 25 houses with loggers on two different locations each. It is found that the European Indoor Class Model (EN performed well and that it can be used when data regarding moisture generation and/or air change rate is not available. The ASHRAE simple model exhibited large positive errors and does not trend well with the measured conditions. The design loads are overestimated.

Kalamees et al. (2006) measured indoor humidity load and moisture production inside 101 lightweight timber-frame detached houses. They found moisture loads of 4 g/m^3 during the cold period and 1.5 g/m^3 during the warm period. The moisture load during the cold period was significantly lower in rooms with balanced ventilation compared to rooms with natural ventilation and mechanical exhaust ventilation. The average moisture load was higher in bedrooms than in living rooms. This difference was small and not significant.

All approaches concentrate either on differences between rooms or the comparison with models. Probability density functions are derived only for a cold climate, where cooling and dehumidification are not found. This paper provides data for mixed-humid and cold climates and compares the measurement values with models.

METHODS

This paper presents measured interior climate conditions from two different climate zones in ten residential buildings each. The buildings were selected in a defined selection process to provide a broad basis for different building constructions, numbers of occupants, levels of airtightness, and so on. The measured interior climate conditions are compared to climate conditions produced with codes and standards that are recommended or required to be used for hygrothermal component simulation. The density distributions of the measured interior conditions are analyzed in an additional step. This can identify possible variations and allows determination of realistic fluctuations in loads and design conditions for hygrothermal whole-building simulation or stochastic input data for hygrothermal component simulation.

Building and Room Selection

Buildings in two different climate zones were selected for this study. Ten buildings in IECC Zone 4, Knoxville, and eleven buildings in IECC Zone 6, Madison. The homes are located within thirty miles of either the Oak Ridge National Laboratory (ORNL) for Knoxville or the USDA Forest Products laboratory (FPL) for Madison. As exterior climate data, the data from the Energy Plus homepage (EnergyPlus 2009) was used for the assessment of dependencies of interior from exterior climate conditions.

All homes chosen for this study are detached single-family dwellings that encompass a broad variety of types and allowed us to collect a wide variation of boundary conditions. Even though the actual number of buildings is low, the samples represent a broad cross section for all one-family houses in the respective area.

The airtightness of the buildings in Knoxville ranges for pressure difference of 50 Pa from 3.3 to 14.0 ach. In Madison, the range is from 0.9 to 12.2 ach. The median airtightness in Knoxville is 9.3 ach and in Madison 5.8 ach. A detailed analysis of the airtightness and dependencies of the airtightness on various factors can be found in Antretter et al. (2007).

Each building was instrumented with three to five HOBO loggers. The loggers were installed in the sleeping room, bathroom, living room, kitchen, and basement or crawlspace, where applicable. The type of room was documented in combination with the floor in which the room is located. This allowed us to gather differences in the spatial temperature distribution and moisture source loading.

The first set of homes was tested and instrumented in Knoxville around the end of September 2004. At the end of January 2005, the data loggers were collected from the homes, the data were downloaded, and the loggers were reinstalled in their original locations. All Madison location loggers were installed in February 2005 for the 11 homes. The data was also downloaded after half a year and the loggers reinstalled to gather a full year of data.

Equipment and Measurement Description

Two-channel loggers with internal temperature and RH sensors from the HOBO pro series were used for long-term interior monitoring. Installation height was sought to be approximately 1.5 m, with the exception of the crawlspace location. The loggers took a pair of readings for temp/RH every 15 minutes. They were installed somewhere in the middle of the room, at least 1 ft away from external walls. Prior to installation, each logger was calibrated at the ORNL Advanced Hygrothermal Laboratory. Three setpoint relative humidities (50%, 70%, and 90% RH) at one setpoint temperature (21°C) were used during the calibration. All loggers used were in the sensors' claimed accuracy range of 0.2°C and 2.5% RH.

Codes and Standards

Several standards are used to provide design conditions for hygrothermal component simulation. General information from these standards is included about the exterior conditions and about the usage of the room to compute temperature and RH as inner boundary condition.

The European standard DIN EN ISO 13788 (DIN EN 2001) is used to avoid critical surface humidities and condensation water in building components. It defines six humidity classes to compute the inner climate. These humidity classes depend on the usage of the room. They define fixed moisture loads for monthly mean exterior temperatures below 0°C, and decreasing ones from 0°C to 20°C monthly mean exterior temperatures. These values were deduced from buildings in Western Europe. For other climates, the use of measured values is permitted. The inner temperatures are not defined but should be assumed according to the planned use of the building. They should be defined nationally for every country using that standard.

DIN EN ISO 15026 (DIN EN 2007) is a standard targeting hygrothermal simulation and is used for the assessment of moisture transfer by numerical simulation. It defines interior temperature and RH conditions in absence of controlled, measured, or simulated values. It relates the daily mean temperature and RH indoors to the daily mean outdoor temperature. The inner temperature is fixed at 20°C in cases where the exterior daily mean temperature is below 10 °C. In the range of exterior temperatures between 10°C and 20 °C, the inner temperature is linearly interpolated between 20°C and 25°C. Above a daily mean exterior temperature of 20°C, the inner temperature is fixed at 25°C. For the RH in the room, two humidity classes for low and high occupancy are defined. Below 10°C daily mean exterior temperature, the RH in the room is constant at 30% (40% high occupancy), linearly interpolated between –10°C and 20 °C daily mean outdoor temperature up to 60% RH (70% RH high occupancy) and again constant at the latest value for daily mean exterior temperatures above 20°C.

ANSI/ASHRAE Standard 160-2009, Criteria for Moisture-Control Design Analysis in Buildings (ASHRAE 2009) defines criteria for design parameters. It relates the indoor temperature to the twenty-four-hour running average of the outdoor temperature. Below 18.3°C outdoor temperature, the indoor temperature is fixed to 21.1°C. It is free floating above 18.3°C exterior temperature, with an inner temperature 2.8°C higher than the twenty-four-hour running outdoor. In the case of heating and air-conditioning, the maximum inner temperature is fixed at 23.9°C in times the outdoor temperature is above 21.1 °C.

The indoor design humidity can be derived from three different methods, a simple and an intermediate method and a full parameter calculation. The simple method is the same as the method used in DIN EN 15026 and described above with high occupancy with varying RH between 40% and 70%. The intermediate method uses three different calculation methods, depending on the available HVAC. Without dehumidification or air conditioning, an indoor vapor pressure is calculated that takes into account the twenty-four-hour running outdoor vapor pressure, moisture generation in the building, and ventilation rate. In the case of running air conditioning, the indoor design humidity ratio is calculated by taking into account the 1% annual basis of the mean coincident design outdoor humidity ratio for cooling. If no humidity control setting is specified, it shall be 50%. With dehumidification but without air conditioning, either the humidity control setting or the value derived with the method without dehumidification shall be used, depending on which is lower.

Statistical Methods

The collected data are downloaded from the data loggers and output is produced as text files. The processing of the measurement data is performed with the GNU R software. As the maximum number of observations is limited by the internal storage of the data loggers, it is not possible to measure one continuous year, but two files per logger location have to be combined. The data loggers measure temperature and RH. For the assessment of the data, the resulting vapor pressures and absolute humidity are calculated using the Magnus formula according to Sonntag (1990).

Weather data is downloaded from EnergyPlus (2009). This data is combined together to get one continuous external weather data file. The calculation of exterior water vapor pressure and absolute humidity is performed similar to the calculation for the interior.

As the weather data is available only in one-hour time steps, the measured indoor data are rounded to one-hour values. Full hours are used as a basis, and all measured data with 30 minutes minus or plus this full hour are rounded to one hourly value. These hourly values are used for most of the assessments in this paper.

A full data set per logger location is produced by merging interior and exterior temperature, relative and absolute humidity, and the vapor pressure by the hourly date and time columns. Furthermore, the hourly moisture load as difference between the interior and the exterior absolute humidity is added to the full data set.

The external climatic conditions and measured internal conditions are shown as boxplots per month. A boxplot includes the median value of all observations (e.g., of all hourly temperature readings in one month). The box itself shows the 25th and the 75th percentile. This means that the box contains 50% of all measured values. The lines attached to the box show the smallest and the largest observation and possible outliers are identified with dots.

Density distribution plots are used to show the density distribution of measured values. This distribution describes the likelihood of a random variable occurring at a given point in the observation space, e.g., the probability with which one can expect a temperature of 22°C indoors in the winter in Madison.

By combining exterior climate data and measured interior climate data, an assessment of possible dependencies of the distribution of temperature and humidity in the buildings is possible.

Climatic Boundary Conditions

The external climate data is downloaded from the EnergyPlus real-time weather data database (2009). This data set is not complete, and the data has to be combined into one continuous file. Figure 1 shows monthly boxplots for temperatures in Madison and Knoxville for the whole period of internal climate measurement from September 2004 to June 2006. The number of hourly observations per month is given above the boxplots to show the data basis on which the boxes are built. Mean temperatures are 25.2°C in July and 2.9°C in December (Knoxville) and 23.0°C in July and –6.4°C in December (Madison). The absolute humidity outside varies from 18.6 g/m^3 in July and 4.0 g/m^3 in December (Knoxville) and from 13.9 g/m^3 in July and 2.6 g/m^2 in December (Madison).

RESULTS AND DISCUSSION

The found interior climate conditions vary from building to building within one climate location. The variations are caused by user behavior and needs. Moreover, it is of interest for hygrothermal assembly simulation if distribution of the indoor conditions depends on usage of the room, e.g., if it is a sleeping room or a kitchen. Also one would expect temperatures to rise with the level inside a building because of stack effect. The measured indoor climates are described and differences resulting from the location of the measurement equipment in the building, floor level, or usage of the room, respectively, are shown. Furthermore, the presentation of the data in terms of normal distributions is developed.

Derived Indoor Climate

The results of measurements of interior temperature and humidity load are presented in Figures 2 and 3. The graphs show boxplots of all monthly mean values in the living rooms

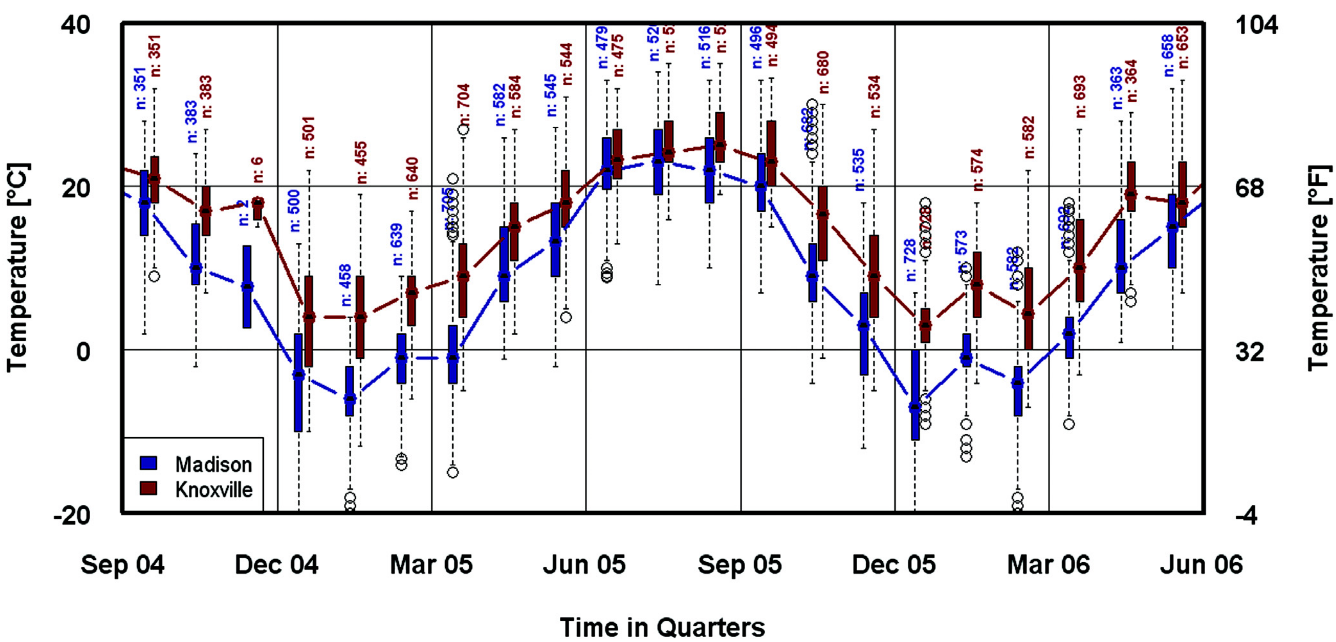

Figure 1 *Boxplots per month for external temperatures in Madison and Knoxville from September 2004 to June 2006.*

of all buildings. The median of all monthly mean values for Knoxville is in the range of 20.4°C in winter and 27.8°C in summer. In Madison, very low temperatures are found in the winter months. From December to April, 50% of all monthly mean temperatures in the living rooms are below 18.2°C.

The monthly mean temperatures in the living rooms vary less in Knoxville than in Madison. In Knoxville, an average monthly spread of around 2°C in the winter months and 2.5°C in the summer months is found for the 50% of all measurements around the median value. The spread in Madison is generally higher, but one cannot differentiate between winter and summer months.

The difference between absolute humidity inside and outside shows that in winter months a positive moisture load is found in all buildings in both climate locations; a negative moisture load in the summer months indicates that all living rooms are in some way dehumidified.

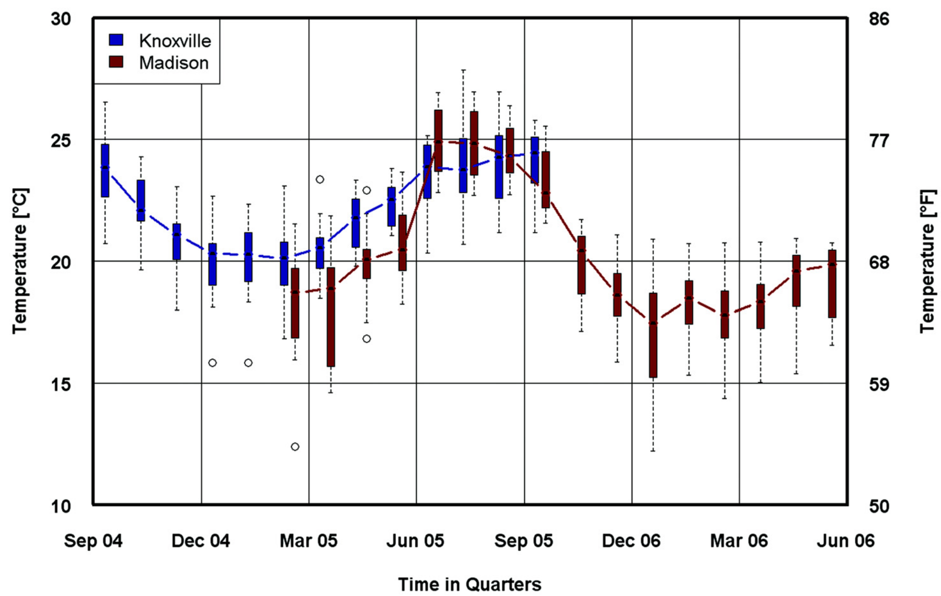

Figure 2 *Measured monthly mean temperatures in living rooms for Madison and Knoxville.*

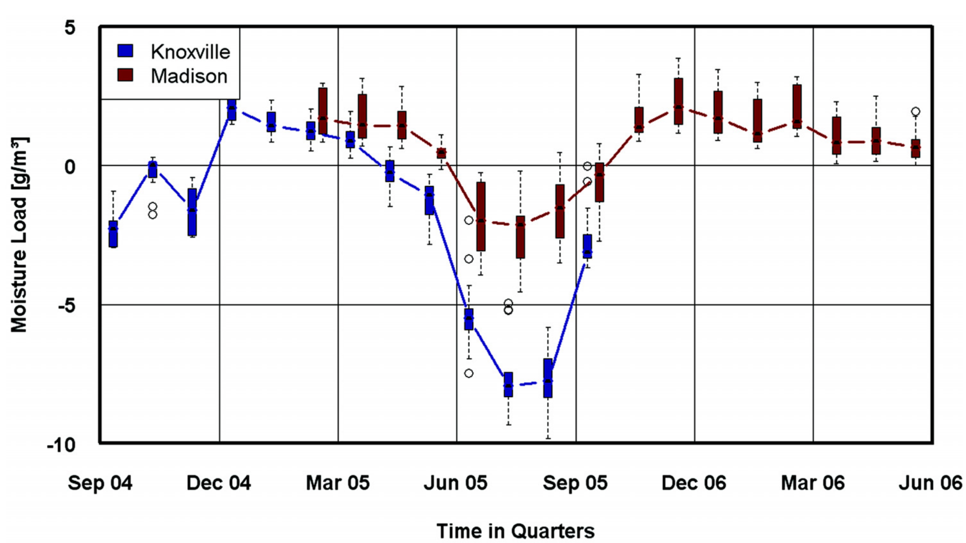

Figure 3 *Measured monthly mean moisture loads in living rooms for Madison and Knoxville.*

In Knoxville, indoor absolute humidity is 7.5 g/m^3 less than the exterior absolute humidity in more than 50% of all buildings. In Madison, 50% of all buildings are dehumidified to 2.0 g/m^3 less than exterior absolute humidity. Months with low exterior temperatures show moisture loads of not more than 2.5 g/m^3 in most of the buildings.

In Knoxville, the fluctuations of the monthly mean moisture load values for the living rooms of all measured buildings are higher in the warmer months than in the colder months. In Madison, it is the other way around. Especially in the winter months, in half of the buildings with lower moisture load, the moisture load varies little.

Seasonal Representation of the Measured Data

Figure 4 displays the density distributions for moisture load in the living rooms. The data basis is the hourly mean value. Distributions are plotted for every season, where winter is defined from December to February, spring from March to May, summer from June to August, and fall from September to November. Every thin dotted line represents the found distribution in one monitored living room. The thick full lines represent the average density distribution for Knoxville and for Madison. The thin full lines show the normal distribution for every location, which result from the mean and the standard deviation of the average of all locations. It is obvious that the assumption of a generalized normal distribution for moisture load in the buildings for a whole year does not correctly represent distribution of the data. The resulting distribution is multimodal. One first step to approach a normal distribution is to divide the data in seasons.

In Madison, a negative moisture load in the mean can be documented only in summer. The moisture loads in spring and

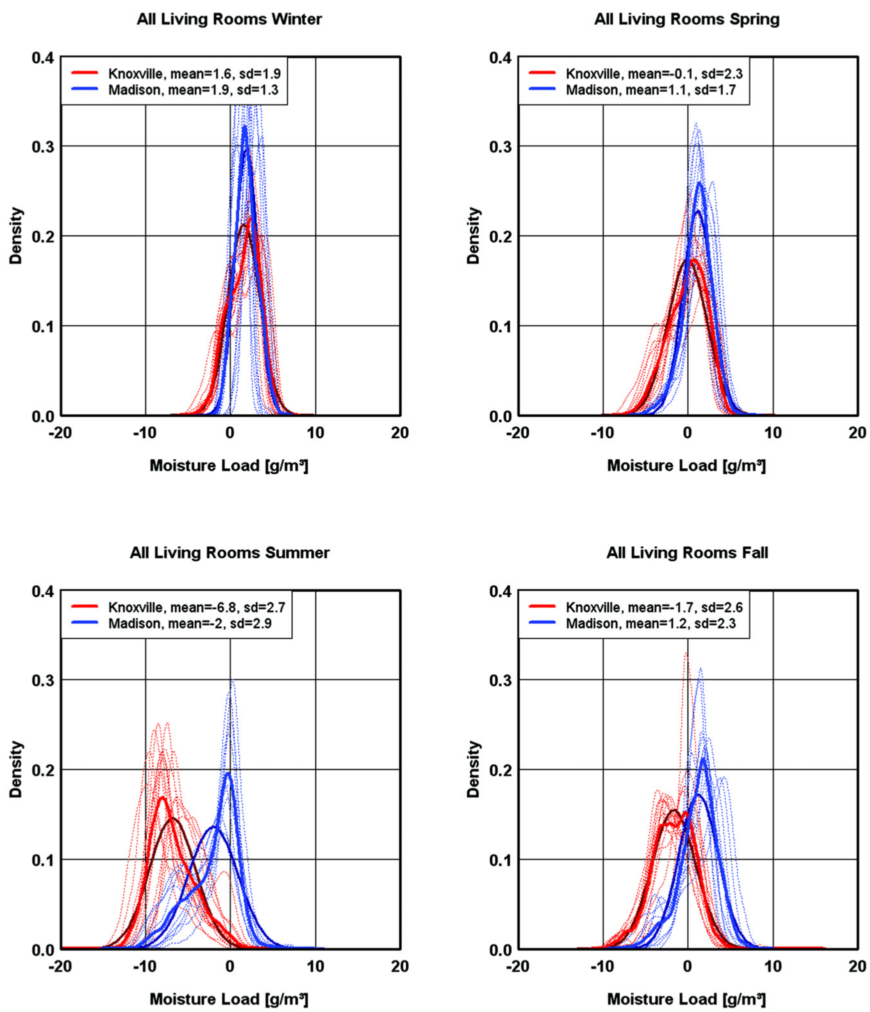

Figure 4 *Density distribution of all measured moisture loads in the living rooms divided into four seasons, with average distribution for all rooms per location and derived standard normal distribution.*

fall are almost identical, with a higher standard deviation in fall. The highest moisture load is found in winter, with a mean value of 1.9 g/m^3.

The standard deviation of the moisture load is smaller in winter than in summer. This is interesting, because one could expect moisture production cycles in winter to result in higher fluctuations and, thus, higher standard deviations. The opposite can be found; the summer graph in Figure 4 shows why. In Knoxville, 10 g/m^2 of negative moisture load seems to be the maximum for dehumidification and leads to a peak in the density distribution. However, during the investigated months, there are also periods with less demand for dehumidification and, therefore, lower negative moisture loads. This results in a positive skew of the summer distribution for Knoxville. In Madison, many of the living rooms have a peak moisture load around zero. A reason for this might be that homeowners open their windows when it is nice outside (not too hot, not too humid). Furthermore, only a few hours with high exterior absolute humidity and thus high dehumidification lead to the negatively skewed distribution in summer. The data cannot be represented very well with the generalized assumption of a normal distribution over all summer months. In the other cases, it seems reasonable to divide the data according to the seasons of the year and represent it with normal distributions.

Dependency of Indoor Climate Conditions on the Location within the Building

The normal distributions for different room types are shown in Figure 5. A slight difference in moisture load mean values is found between the rooms. As expected, a higher value can be observed in the bathrooms because of the higher loads in these rooms. In the winter, the mean distribution across all rooms can be represented as normal distribution for Knoxville as well as for Madison. In the summer months, the seasonal distribution for Knoxville skews right and the distribution for Madison skews left. This suggests that rooms in Knoxville are usually dehumidified, but after the dehumidification is turned off, the moisture load rises. In Madison, in all rooms, most of the time there is the same absolute humidity as outside, which suggests a high ventilation rate. Dehumidification in times of

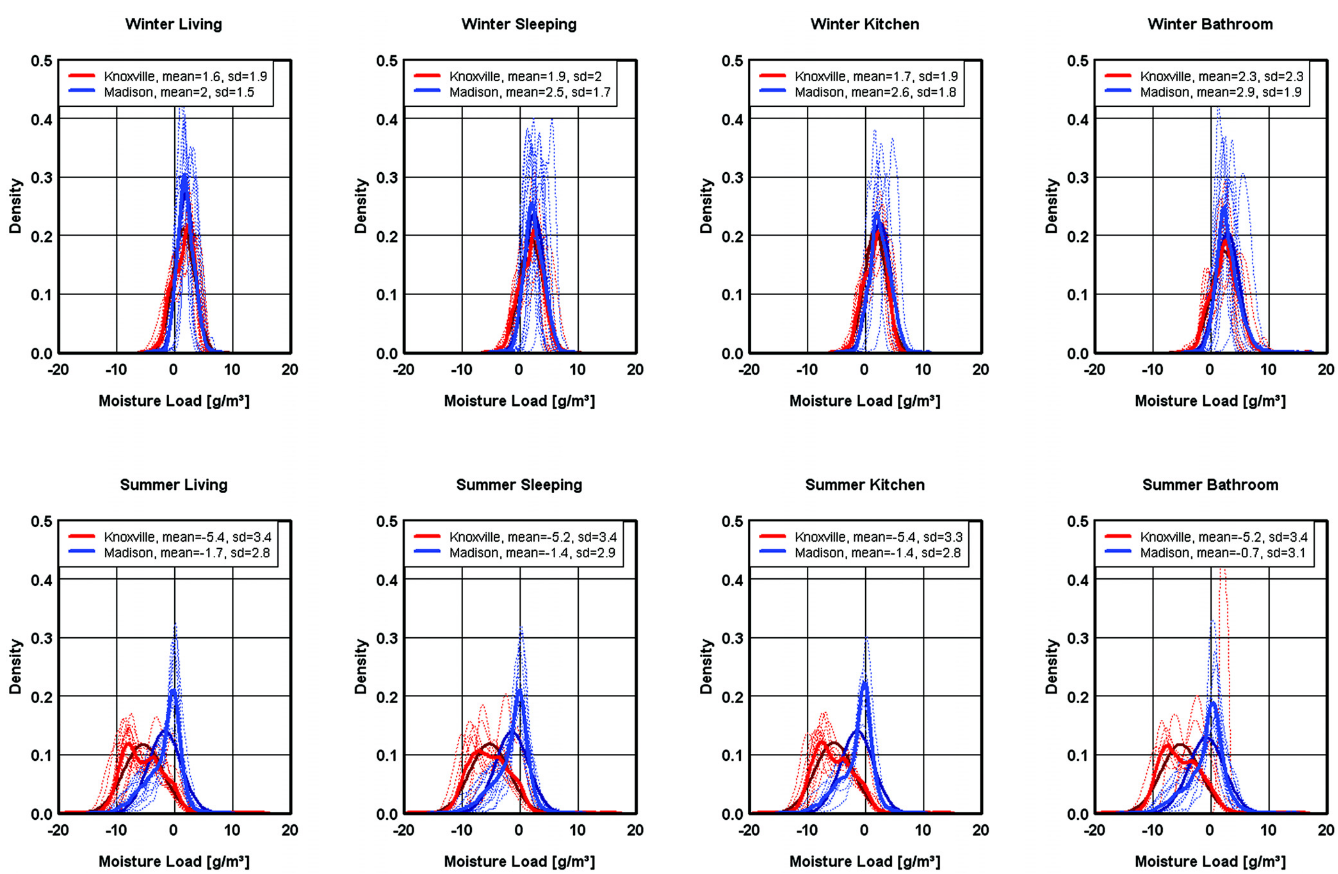

Figure 5 *Density distribution of all measured moisture loads in summer and winter months for living rooms, sleeping rooms, kitchens and bathrooms.*

very high exterior absolute humidities tends to result in negative mean values for the moisture load, and a left-skewed distribution.

A seasonal comparison of the moisture load distribution in all rooms for both locations is shown in Figure 6. The seasons for this plot are, as for Figure 7, defined from June to September for the summer distribution and November to February for the winter distribution.

In the summer months, almost no difference in moisture load distribution between the rooms is found for Knoxville. In winter in Knoxville, only the bathroom shows a higher standard deviation and a slightly higher mean moisture load. This can also be found in Madison, where the winter mean values vary around 0.9 g/m^3 between the rooms. In the summer in Madison, the mean value for the bathroom is higher than for all other rooms, which are dehumidified to a negative moisture load of 1.7 g/m^3. The tendency for skewed distributions in summer is again seen for both locations, which results in Madison, for example, in only a few positive moisture loads above 5 g/m^3 but some quite negative moisture loads, down to –10 g/m^3.

The temperature means and standard deviations for all rooms are shown in Table 1. In Knoxville, a higher temperature is found in the kitchens. In Madison, mean indoor temper-

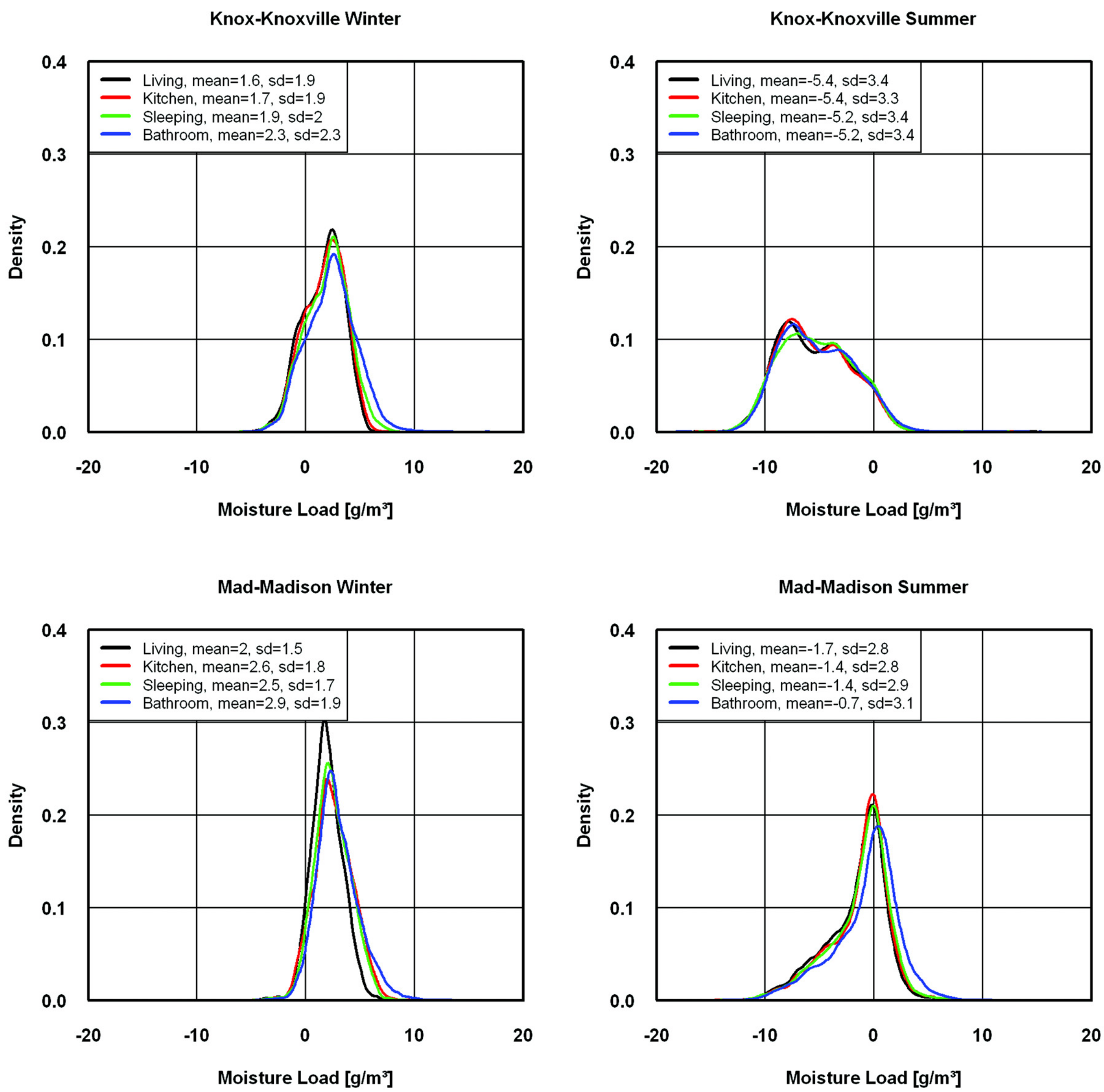

Figure 6 *Average density distribution of the measured moisture loads in summer and winter for Knoxville and Madison, depending on the type of room.*

ature over all winter months for Madison is within 18.1°C for the room with highest temperatures, the bathrooms, which is still low. On the other hand, the mean indoor temperatures in the summer months are higher in Madison than in Knoxville. The temperature differences between the rooms are small.

Figure 7 shows the temperature distributions, depending on the floor level at which the measurement equipment was installed. As expected, the mean basement values are lower in summer and in winter than the temperatures on ground and first-floor rooms. Except for the Madison locations in summer, the highest mean temperatures are found on the ground level of the buildings and not, as expected, on the first-floor levels. Standard deviations are higher in Madison than in Knoxville, which may result from higher natural ventilation in Madison and better HVAC-controlled indoor environments in Knoxville.

Table 2 shows the different moisture loads, depending on the level of the room in the building. The moisture loads are higher in the winter months on ground-floor levels. In the summer months, this floor level also shows the highest negative moisture loads in Knoxville. In Madison, the basement shows the highest negative moisture loads in summer. As explained above, the standard deviation is higher in the summer months than it is in the winter months. There is only a small difference in the standard deviations between the

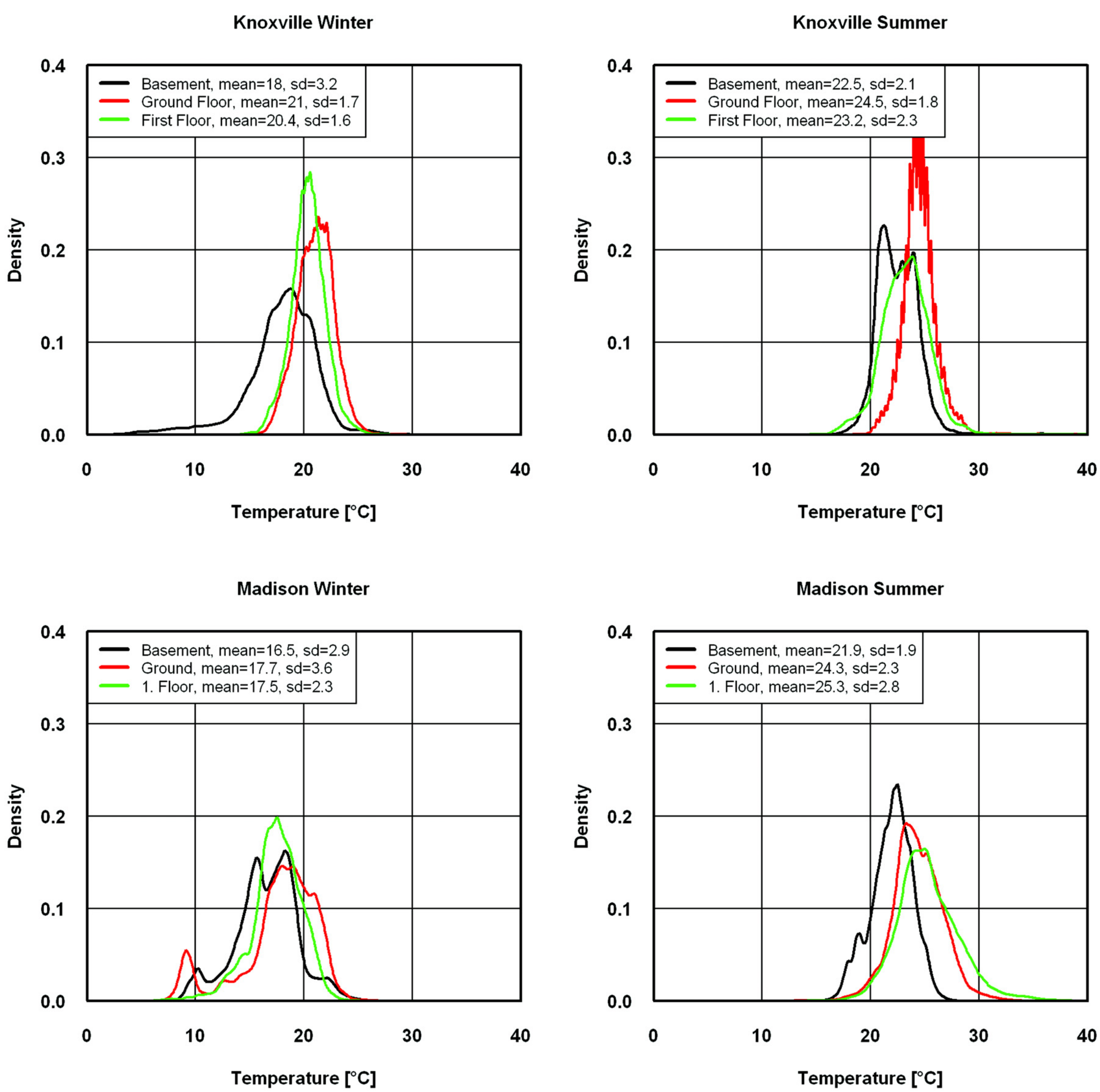

Figure 7 *Average density distribution of the measured inner temperatures in summer and winter for Knoxville and Madison depending on the floor level in the building.*

Table 1. Temperature Means and Standard Deviations in Rooms with Different Usage for Knoxville and Madison in Summer and Winter Months

Room	Knoxville		Madison	
	Winter Mean/SD, °C	Summer Mean/SD, °C	Winter Mean/SD, °C	Summer Mean/SD, °C
Living Room	20.2/2.0	23.8 / 2.1	17.7/3.0	24.4/2.5
Kitchen	21.3/1.8	24.8/1.8	17.5/3.5	24.9/2.4
Sleeping Room	20.7/1.5	23.5/2.4	17.1/3.0	24.7/2.7
Bathroom	20.3/1.7	23.5/1.5	18.1/2.8	24.5/2.5

Table 2. Moisture Load Means and Standard Deviations in Rooms with Different Levels in the Building for Knoxville and Madison in Summer and Winter Months

Room	Knoxville		Madison	
	Winter Mean/SD, g/m^3	Summer Mean/SD, g/m^3	Winter Mean/SD, g/m^3	Summer Mean/SD, g/m^3
Basement	1.8/2.0	–4.5/3.8	2.0/1.6	2.0/3.0
Ground Floor	1.9/2.1	–5.5/3.4	2.7/1.8	–1.4/3.0
First Floor	1.6/1.9	–4.9/3.1	2.1/1.6	–1.1/2.8

different floor levels. In general, the standard deviation is higher with higher positive or negative mean values. Furthermore, the standard deviation is higher in general in summer than in winter, due to part-time working cooling/dehumidification equipment.

Comparison with Standards

Temperatures defined in the standards, minimum 20°C (DIN EN 2007) or 21.1°C (ASHRAE 2009) and maximum 25°C (DIN EN 2007) or 23.9°C (ASHRAE 2009), only partially match the mean measured temperatures. Especially in Madison, the winter temperatures are much lower than as defined in the standards. The summer temperatures in most cases do not exceed the maximum threshold. These findings are important for whole-building simulation, as the user temperature preference plays an important role in the total energy use of the building.

DIN EN ISO 13788 (DIN EN 2001) accounts for different indoor temperatures by giving every country the responsibility to define appropriate temperatures. In Knoxville, the extremes of the monthly mean moisture loads are always below the humidity class 2 moisture loads in DIN EN ISO 13788. In Madison, humidity class 3 is not exceeded. On a daily or even hourly basis, the humidity classes are exceeded for a short time. With the density distributions above, the probability for the excess of a humidity class target value can be estimated.

The building component assessment is also influenced, especially if the interior RH is derived from the indoor vapor pressure or indoor absolute humidity, as in the intermediate method of ASHRAE Standard 160. An assessment with realistic interior temperatures would lead to a higher RH. On the other hand, the found indoor RHs shown in Table 3 are in the ranges of 30% to 60% RH for the mean values as suggested by DIN EN 15026. But some deviations from the mean value, especially in summer and fall, are above 70%, the maximum value assumed by the ASHRAE Standard 160 simple method.

Table 3 also shows that there is only a small difference in values between those found in bathrooms and those found in living rooms. This suggests that the simple approaches from standards to use a minimum and a maximum RH and use linear interpolation between those two values, depending on the exterior climate, are a simple first step to approximate the interior RH conditions. But this is only valid for the mean interior humidity run. Daily fluctuations by short-time humidity production are not taken into account. Very high humidities, which occur only for a short time during a day, may also influence the hygrothermal building component performance.

CONCLUSIONS

Temperature and moisture load—by which RH in a room is infered—found in the evaluated residential buildings vary in range. In addition to seasonal variations, a great variety of both is found in the monthly mean values of all buildings. The latter are a result of user preference, the building or room, and its use. The user sets the room temperature according to his needs, but these needs are not only influenced by thermal comfort requirements, they also depend on, for example, the energy costs or the building airtightness and, accordingly, the energy requirement. Moisture production in the room and the ventilation and infiltration rates are, in addition to mechanical installations for humidification and dehumidification, the main contributing factors to moisture load in the rooms. Moisture load in the rooms is positive in winter, i.e., a higher interior absolute humidity than outside, and thus dominated by the

Table 3. Relative Humidity Means and Standard Deviations in Rooms with Different Usage for Knoxville and Madison in Summer and Winter Months

Room	Knoxville		Madison	
	Living Mean/SD, %	Bath Mean/SD, %	Living Mean/SD, %	Bath Mean/SD, %
Winter	40.1/8.3	44.3/8.3	32.0/8.5	36.6/10.6
Spring	43.0/7.9	46.4/7.3	39.7/9.9	46.5/13.6
Summer	50.5/7.5	52.4/6.6	51.1/8.5	55.0/8.8
Fall	53.9/7.6	56.9/7.2	48.9/9.2	54.9/10.3

moisture production in the room. In summer months, both climate zones show negative moisture loads. This is a result of dehumidification, which was found in all locations in Knoxville and almost all in Madison. The spread of the monthly mean moisture load is not directly linked to the location and the time of year.

Statistical analysis and statistical data representation often depend on proper definition of the data distribution. A normal density distribution is preferred to provide mean values and standard distributions for stochastic input into hygrothermal component or whole-building simulation. The representation of the distribution of temperature and moisture load was not possible for a whole year in terms of a normal distribution. The data had to be divided into seasons. The results are close to normal distributions. Future models will investigate if a grouping of the data depending on external temperature or on external absolute humidity allows representation of the data in distributions even closer to normal.

Bathrooms are the only rooms showing a distinct difference in mean values for the moisture load. Looking at the location of the room within the buildings finds higher moisture loads on ground-floor level than in basement or first-floor level. Standard deviations are in general higher in summer than in winter. In winter, the exterior absolute humidity is constant, and the interior temperature is also kept at a constant level, which makes the moisture load fluctuate only because of indoor sources. In summer, the humidity in the rooms is allowed to rise to a certain setpoint until dehumidification (or cooling and with it dehumidification) takes place. So the higher fluctuations of the moisture load in summer can be explained by the use of air-conditioning systems.

The temperature layering in the buildings was not found as expected just by taking thermal layering into account. Temperature at the ground floor was in general higher and varied more than in basement or first-floor level. Ground-floor rooms are the rooms with highest occupancy rate. This results in higher indoor loads and in more diverse user requirements.

It can be concluded that a probabilistic model for boundary conditions for hygrothermal component or whole-building simulation is possible. This model needs to be based on a broad variety of data. Different usage types, such as for office or residential buildings, need to be investigated. On one hand, a data set for different exterior climate conditions combined with interior climate readings is necessary to check the ability of existing standards to predict the correct mean values. On the other hand, a deeper investigation of the dependencies of the standard deviations needs to take place.

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