Indoor Hygrothermal Loads in Estonian Dwellings

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ABSTRACT

This paper analyzes the indoor hygrothermal loads measured in 27 detached houses and in 13 apartments. A survey was conducted during the years 2003-2006 in Estonia. The temperature and relative humidity (*RH*) were continuously measured in bedrooms, living rooms, and outdoors at one–hour intervals. For the hygrothermal analysis, the determined design curve of the moisture excess for houses with low occupancy on the higher 10 % critical level was +4 g/m^3 during the cold period (T_{out} ≤ +5 °C) and +1.5 g/m^3 during the warm period (T_{out} ≥ +15 ºC). The determined moisture excess for apartments was +6 g/m^3 during the cold period. The daily average moisture production in studied detached houses during the winter season was 5.4 kg/day/house (1.6 kg/day/person) on the average.

KEYWORDS

Indoor climate, indoor hygrothermal load, moisture excess, moisture production.

INTRODUCTION

Hygrothermal analyses are attracting more attention in building design along with moisture damages being established as the main cause of building envelope deterioration. Simulation models are useful tools in assessing the hygrothermal performance of building envelope systems and in optimizing these for maximum hygrothermal performance and longer service life. The calculation and simulation results depend heavily on the input parameters including indoor climatic conditions.

To study the indoor hygrothermal loads in dwellings with low occupancy, measurements were carried out in 27 detached houses. To study the hygrothermal loads in dwellings with higher occupancy, measurements were carried out in 13 apartments. In total, 38 bedrooms and 17 living rooms were investigated.

METHODS

Measurements

Measurements of indoor climate in 27 detached houses lasted for two years, from April 2003 to July 2005. In both years, measurements covered about half of the houses. There was a one–month pause of measurements during summer 2004, when the data loggers were placed in new houses. Most of the houses were relatively new, built on average two-three years prior to the measurements. The houses were randomly selected from the databases of manufacturing and construction companies. The types of ventilation systems were the passive stack ventilation (13 %), the mechanical exhaust ventilation (50 %), and the mechanical supply and exhaust ventilation (37 %). The average floor area of the houses was 135 m^2; the average occupancy in studied houses was 46 m^2/pers. Measurements in 13 apartments lasted for four months, from December 2005 to April 2006. There was the natural ventilation (passive stack ventilation and window airing) in all apartments. The average floor area of the apartments was 55 m^2; the average occupancy in studied apartments was 17 m^2/pers.

In each house and apartment, temperature and *RH* were measured continuously with data loggers at one–hour intervals. The air change rates in detached houses were calculated on the basis of the measured exhaust airflows in the ventilation ducts at different speeds of the ventilation fan. Average actual ventilation air change rate in detached houses with mechanical ventilation system was 0.41 ach (13.3 l/(s·pers) and 0.28 l/(s·m^2)). The air tightness of each house and apartment was measured with the fan pressurization method. The mean air change rate at 50 Pa pressure difference of the studied houses was 4.9 1/h and of the apartments it was 6.7 1/h.

Assessment of Indoor Humidity Loads

The values of the internal moisture excess, $\Delta\nu$, [g/m^3], (the difference between indoor and outdoor air water vapour content, Eqn. 1) were calculated on the basis of the measured results of the indoor and outdoor temperatures and *RH*. The values of moisture excess were averaged for weekly average values.

$$\Delta\nu = \nu_i - \nu_e \tag{1}$$

where ν_i is indoor air water vapour content [g/m^3], and ν_e is outdoor air water vapour content [g/m^3].

To analyze the dependence of the moisture excess on the outdoor climate and to determine the values of the critical moisture excess, data from each room were sorted according to the outdoor air temperature, using a 1 ºC step of the outdoor temperature. From each room at each outdoor air temperature, the maximum values of the moisture excess from one-week periods were selected. From this data (each room represented by one weekly maximum moisture excess curve), the higher 10 % critical level (Sanders, 1996) was calculated. This level means that hygrothermal loads higher than determined critical value should not exceed 10% of the cases.

On the basis of the dependence of the indoor temperature and the moisture excess on the outdoor temperature, the critical moisture excess levels were provided for the warm period ($T_{out} \geq +15$ °C) and for the cold period ($T_{out} \leq +5$ °C).

Based on the ventilation air change rate, q_v [m^3/day], and the moisture excess, $\Delta\nu$ [kg/m^3], during winter months, the daily average moisture production, G [kg/day], was estimated in detached houses, Eqn. 2.

$$G = q_v \cdot \Delta\nu, \tag{2}$$

RESULTS

Dependence of the Indoor Temperature on the Outdoor Temperature

To give an overview of the indoor temperature conditions in studied dwellings, first the dependence of the indoor temperature on the outdoor temperature is calculated. Dependency between the indoor temperature and the outdoor temperature allowed for a conclusion that in detached houses a heating season would change to the warm season at +15 ºC of the daily average outdoor temperature, Figure 1.

Each line in Figure 1, left represents the average value of the average daily indoor temperature at the corresponding average daily outdoor temperature, while the dotted and rhomb line represent the average curves from all the rooms (in detached houses and in apartments correspondingly). The indoor temperature model (squared line) proposed in the following is based on the trend line of these curves. The average indoor temperature curve rises from +20 ºC (at T_{out} –25 ºC) to +22 ºC (at T_{out} +15 ºC) in the heating season and to +27 ºC (at T_{out} +25 ºC) during warm period. To calculate the critical levels of room temperature, from all the values of the daily average indoor temperature, the higher and the lower 10 % critical level were calculated Figure 1, right. Approximation curves of the lower and higher 10 % levels differ from the average ±2 ºC.

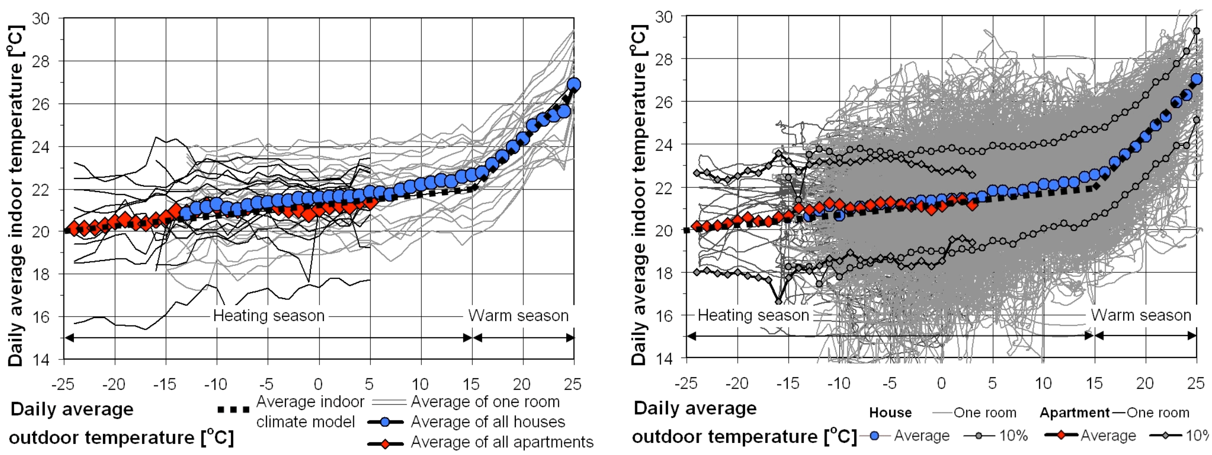

Figure 1: Dependence of the indoor temperature on the outdoor temperature (left). The higher and the lower 10 % level of the dependence of the indoor temperature on the outdoor temperature (right).

Moisture Excess and Moisture Production

The average value of the values of the weekly average moisture excess in detached houses over the cold period ($T_{out} \leq +5$ °C) was +1.5 g/m^3 and over the remaining time ($T_{out} > +5$ °C) +0.2 g/m^3. The higher 10 % critical level from the values of the weekly maximum moisture excess over the cold period was +3.8 g/m^3 and during the warm period ($T_{out} \geq +15$ °C) +1.2 g/m^3. In apartments during cold period the average value of the weekly average moisture excess was +3.2 g/m^3 and moisture excess on the higher 10 % critical level from the of the weekly maximum moisture excess was +6.4 g/m^3.

Figure 2, left show the curves of the maximum weekly average moisture excess in each room. Each line represents the maximum moisture excess in one of the measured rooms at the corresponding weekly average outdoor temperature. The value of the moisture excess is not of constant throughout a year, rather it is outdoor temperature dependent. During the warm period, the higher air change rate (probably more open windows and doors, possibly higher fan speed) and the smaller moisture production (probably less indoor living activities) lead to a reduction in the moisture excess. The dotted and rhombic lines in Figure 2, left represent the moisture excess in houses and in apartments on the higher 10 % critical levels that were calculated as described in the methods section. The design curves of the moisture excess are based on the trend line of these curves. In houses the design curve of the moisture excess on the higher 10 % critical level during the cold period is close to +4 g/m^3, during the warm period +1.5 g/m^3. In apartments the design curve of the moisture excess on the higher 10 % critical level during the cold period is close to +6 g/m^3.

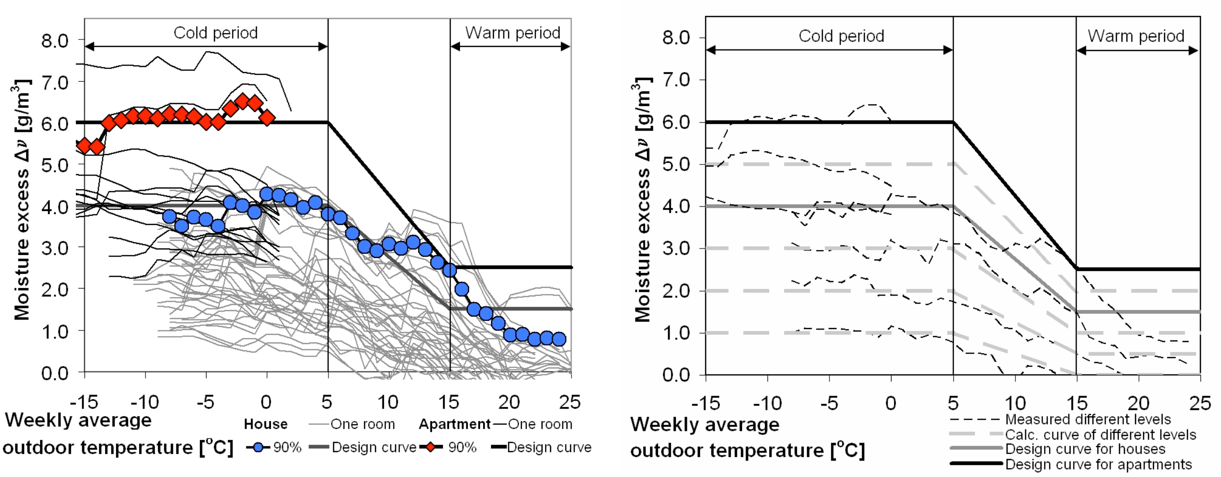

Figure 2: The maximum weekly average moisture excess as a function of weekly average outdoor temperature (left). Measured and simplified calculation curves of moisture excess at different humidity load levels (right).

To do hygrothermal calculations and sensitivity analysis under different hygrothermal loads, it is necessary to know the distribution of different moisture excess levels in the whole outdoor temperature range. To analyse the moisture excess performance of through the full range of moisture production, different curves were calculated from the maximum moisture excess curves of each room, sorting the curves such that during the cold period, the average values of moisture excess are as follows: +1 g/m^3, +2 g/m^3, +3 g/m^3, +4 g/m^3, +5 g/m^3, +6 g/m^3. On the basis of these curves, if the moisture excess changes 1 g/m^3 during the cold period, it changes about 0.5 g/m^3 during the warm period. It means that the in apartments with moisture excess during the cold period +6 g/m^3, the moisture excess design curve during warm period could be +2.5 g/m^3.

To analyze the influence of different moisture excess components on the indoor humidity load, the houses with the average moisture excess during the cold period ($T_{out} \le$ +5 °C) >+2 g/m^3 (8 houses) and <+1 g/m^3 (7 houses) were compared. Houses with higher average moisture excess (>2 g/m^3) were significantly (P<0.02) more airtight (3.1 1/h vs. 6.8 1/h). There was also higher occupancy (39 m^2/pers. vs.

52 m^2/pers.) and lower ventilation rate (8 l/(s·pers.) vs. 12 l/(s·pers.)) in the houses with higher moisture excess.

The daily average moisture production during the winter season in the detached houses was on average 5.4 kg/day/house (1.6 kg/day/person). An average value from the maximum moisture production values from each house during the winter season was 13.0 kg/day/house (4.1 kg/day/person).

Performance of the Indoor Humidity Load Model for Hygrothermal Calculations

In the following, it is tested how realistic indoor relative humidity conditions are achieved in detached houses by using the design curve of the moisture excess all the year round. As the moisture excess approach is a robust simplified method, it should be checked that not too low neither too high *RH* values are calculated by the model.

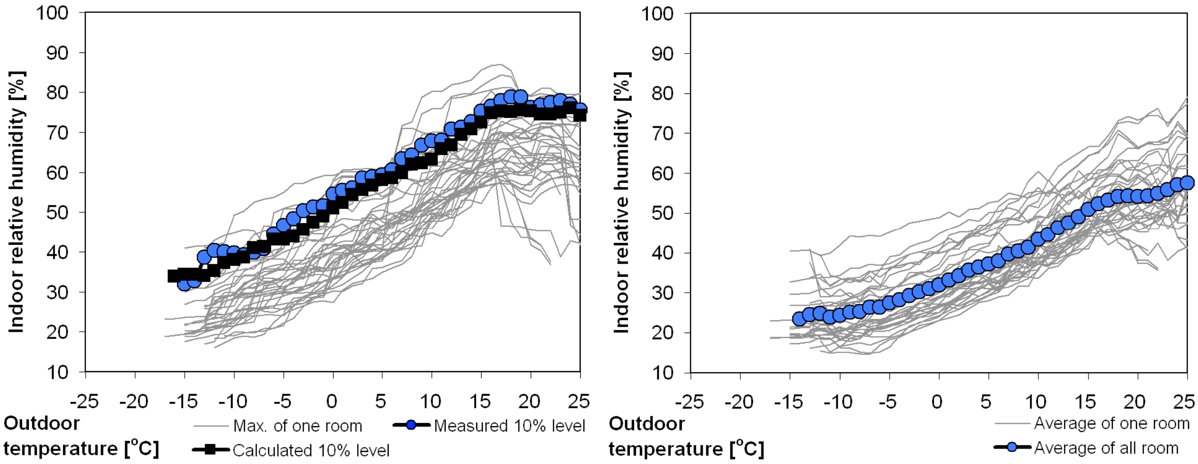

Figure 3: The maximum (left) and average (right) daily average indoor *RH* dependence on the daily average outdoor temperature

Figure 3, left shows the measured daily average indoor *RH*. Each curve represents the measurement result of the maximum daily average *RH* at the corresponding outdoor temperature in one room. In the dotted curve, the higher 10% critical level is selected from these curves. The corresponding calculated values are shown by the squared curve. This is calculated with the use of the design curve of the moisture excess (moisture excess on the higher 10 % critical level, Figure 2, left), the average temperature curve (Figure 1, left), and the daily average outdoor climate during the two measurement years. The calculated *RH* values were sorted according to the outdoor air temperature from where the 10 % critical level was calculated (squared curve). The measured and the calculated indoor *RH* show a good agreement. Figure 3, right shows the measured average values of the daily average indoor *RH* from each room at the corresponding daily average outdoor temperature. From all the data concerning the rooms, an average level was determined (dotted curve).

DISCUSSION

According to statistics (Statistics Estonia 2005), the average living area per occupant of the overall Estonian housing stock is 28 m^2/pers. An overall living density of all detached houses is 31 m^2/pers and in houses built after 1996 it is 45 m^2/pers. An overall living density of all apartment buildings is 21 m^2/pers and in houses built after 1996 it is 27 m^2/pers. In this study, the average living density in detached houses was about 46 m^2/pers. and in apartments 17 m^2/pers. It means that the studied detached houses correspond to houses with low occupancy and studied apartments correspond to slightly higher occupancy than the average.

According to the dependence of the indoor temperature on the outdoor temperature shown in Figure 1, the deflection point to the warm period was selected to be +15 ºC. According only to the moisture excess curve in Figure 2, the choice could be +20 ºC, where the moisture excess curve on the higher 10 % level was stabilized. Still, the final selection was +15 ºC, as the indoor *RH* dependence on the outdoor temperature in Figure 3 showed the same deflection point as the temperatures. Using the deflection point of +20 ºC, a slightly lower moisture excess is obtained during the warm period and a slightly higher moisture excess between +5 ºC…+17 ºC.

CONCLUSION

For the hygrothermal calculations of the building envelope, on the higher 10 % critical level is +4 g/m^3 during the cold period (T_{out} ≤ +5 °C) and +1.5 g/m^3 during the warm period (T_{out} ≥ +15 ºC). Between these cold and warm period levels, the moisture excess decreases linearly. The critical level of the moisture excess for apartments is +6 g/m^3 during the cold period. The average indoor temperature rises from +20 ºC (at T_{out} –25 ºC) to +22 ºC (at T_{out} +15 ºC) in the heating season and to +27 ºC (at T_{out} +25 ºC) during summer.

The design curve of moisture excess was validated and is suitable for all types of hygrothermal analyses of the building envelopes, e.g. for steady state calculations and detailed dynamic simulations. These nominal values of the moisture excess are to be used in dwellings with no humidification. For sensitivity analysis and hygrothermal calculations, different levels of the moisture excess values change 1 g/m^3 during the cold period and 0.5 g/m^3 during the warm period. The air change rate and the living density were significant factors influencing the moisture excess.

The daily average moisture production during the winter season in the studied detached houses was on average 5.4 kg/day/house (1.6 kg/day/person). An average value from the maximum moisture production values in detached houses during the winter season was 13.0 kg/day/house (4.1 kg/day/person).

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REFERENCES

Sanders, C. (1996). International Energy Agency, Annex 24 Heat, Air and Moisture Transfer in Insulated Envelope Parts (HAMTIE), *Final Report: Environmental conditions*, 2: 2: Laboratorium Bouwfysica, K.U.–Leuven, Belgium.

Statistics Estonia (2005). *Statistical database.* Statistical office of Estonia.