The influence of exterior walls on the level and stability of indoor humidity and temperature in detached houses

Minna Korpi, M.Sc.,
Department of Civil Engineering, Tampere University of Technology;
minna.korpi@tut.fi

Targo Kalamees, Ph.D.,
Laboratory of Heating, Ventilating and Air-Conditioning, Helsinki University of Technology;
targo.kalamees@ttu.ee

Juha Vinha, Dr.Tech.,
Department of Civil Engineering, Tampere University of Technology;
juha.vinha@tut.fi

Jarek Kurnitski, Dr.Tech.,
Laboratory of Heating, Ventilating and Air-Conditioning, Helsinki University of Technology;
jarek.kurnitski@tkk.fi

KEYWORDS: indoor climate, humidity, temperature, field study, moisture buffering.

SUMMARY:
This paper is based on field measurements conducted in 69 heavyweight detached houses. The temperature and relative humidity were continuously measured in bedrooms of each house at 1-h interval for a period of one year. In order to analyse the relative and absolute humidity in single-family houses, the houses were divided into different subgroups according to exterior wall: autoclaved aerated concrete (AAC), lightweight aggregate concrete, brick, shuttering concrete block, concrete element and, log. The results showed only minor difference in the level of relative humidity between the house groups. Some differences in the daily amplitude of humidity were shown in the comparison of different house groups. During the summer period, the group of log houses had the highest and the group of AAC houses the lowest daily amplitude of absolute humidity. In winter period houses with low ventilation rate (<0.25 l/h) had a significantly smaller amplitude of absolute humidity than houses with high ventilation rate (>0.5 l/h). The average of daily amplitude of temperature was significantly higher in log houses compared to some other house groups. Overall, the fluctuation of temperature (average values of different house groups 0.7…1.3 ºC) affects the relative humidity more than the type of exterior wall. The hygroscopic mass of furniture, textiles, etc. as well as real air change rates, including window airing are factors that probably play significant roles in indoor humidity.

1. Introduction
The influences of structures and materials on indoor air humidity and quality have been investigated in many studies (f.ex. Tsuchiya 1980, El Diasty et al.1992 and 1993, Cunningham 1994, Hagentoft 1996, Kurnitski et al. 2003 and 2006, Isetti et al. 1988, Padfield 1998, Simonson et al. 2002 and 2005). The matter has also been widely discussed in IEA Annex 41 project. In most of these studies, the heat and moisture balance of indoor air has been either mathematically modelled, or studied by laboratory experiments. The phenomenon has not been commonly studied by wide scale field measurements. However, it is important to study the influence of structures and materials in real conditions, because modelling and laboratory experiments include some indefinities that may not be present in real life. Such factors are real ventilation especially in summer when windows are often open, and the hygroscopic mass of furnishing or interior textiles etc. Most discussion in the literature has been focussed on the influence of interior surface on the indoor climate. In this paper, the possible effect of exterior walls on indoor climate is analysed.

This paper presents the indoor climate results from a large-scale field study conducted by the Department of Civil Engineering at Tampere University of Technology and HVAC-laboratory at Helsinki University of Technology in the years 2005-2007. In that study the indoor and outdoor climates, indoor moisture excess,
ventilation performance, energy consumption and airtightness in 20 log houses, in 50 other heavyweight houses and in 56 apartments in multi-storey houses were studied. In order to analyse the relative and absolute humidity in single-family houses, the houses were divided into different subgroups according to the exterior wall type. A brief comparison to the results of the previous study, in which 100 timber-framed houses were studied, is also made. The results of the timber-framed houses have been presented by Vinha et al. (2005) and Kalamees et al. (2006).

2. Measurements

2.1 The studied houses

The group of 69 heavyweight houses were measured at varying periods from summer 2005 to summer 2007. Temperature and relative humidity (RH) were measured in the main bedrooms in nearly all of the houses during winter period 2006-2007 and summer 2007. This group of houses consisted of 19 log houses, 10 houses built from blocks of autoclaved aerated concrete (AAC), 10 houses built from lightweight aggregate concrete (LWAC), 10 houses built from bricks (5 from calcium silicate brick, 5 from burnt clay (ceramic brick), 10 houses built from shuttering concrete blocks (CB) and 10 houses built from concrete sandwich element (CSE). The material named above describes the main exterior wall material used. Three log houses were built with inner additional insulation and one with exterior additional insulation. In all the rest of the log houses and AAC houses, the external wall was of a solid material. Rest of the houses had a thermal insulation layer between the inner load bearing and the outer cladding shell. In the houses made from LWAC and shuttering concrete blocks, the insulation layer was in the blocks themselves.

The mean age of the heavyweight houses was three years and the median two years. All of the houses had mechanical ventilation system; 93% of the houses had a mechanical supply and exhaust ventilation system with heat recovery. In most of the two-storey log houses upper storey was timber-framed. In addition, some of the two-storey houses had a first storey against ground and built from different material. The ceiling assembly in most of the cases was timber-framed. Most of the AAC houses (9 out of 10) had a ceiling assembly made of reinforced AAC. Three houses with shuttering concrete block walls and, two houses with concrete element exterior walls and one LWAC block house had a concrete hollow core slab as a ceiling structure.

The measured houses were randomly selected mainly from the databases of the manufactures of the houses. Some of the houses were found by delivering brochures to the dwellers of suitable looking houses. The houses were situated mainly in the Tampere and Helsinki region.

In the studied rooms the ceiling was usually either treated wooden boarding or plastered concrete/AAC slab or plastered/painted plasterboard. The intermediate walls were normally either block walls or timber-framed walls with plasterboard and they were normally treated with plaster or paint or covered with wall-paper. All the floors were covered with non-hygroscopic materials (mainly lacked wood or laminated parquet). The interior surface of the exterior log walls was normally treated with either lacquer, latex paint or some other kind of protective fluid. Only in two log houses the interior surface was untreated. The exterior walls of the other heavyweight houses were usually plastered and painted. In some of the houses also wall-paper was used as interior surface material. Studied bedrooms were normally furnished.

2.2 Measurements

Indoor temperature and relative humidity (RH) were measured with data loggers at 1-hour interval. The data logger’s temperature measurement range was from –20 to +60°C with an accuracy of ±0.5°C and the RH measurement range was from RH 0 to 97% with an accuracy of RH ±3%. Indoor loggers were located on the separating walls in every master bedroom. The representative outdoor data was received from the Finnish meteorological institute.

To study the fluctuation of RH and absolute humidity, the amplitudes of 24 h, i.e. the difference between daily maximum and minimum values, were calculated. An average value of these daily values over the summer/winter period is considered as a measure of the fluctuation of the parameter studied.

The average ventilation air change rate was 0.39 1/h. The ventilation rate was calculated based on measured return airflows in ventilation ducts at the normal operating level of the ventilation device. These values do not include window airing. The airtightness of the houses was measured with fan pressurisation method. The mean
air change rate at 50 Pa pressure difference of houses with AAC blocks was 1.5 l/h, LWAC blocks 3.2 l/h, bricks 2.8 l/h, shuttering concrete blocks 1.6 l/h and concrete elements 2.6 l/h. The mean n₅₀-value of log houses was 6.0 l/h. Pressure difference at the operating rate of ventilation was on average ~1.8 Pa. A questionnaire of the structures of the houses, type of HVAC system and its use, dwelling habits, occupants opinion on indoor air quality etc. was also conducted for each house.

3. Results

3.1 Outdoor climate

Outdoor temperature and relative humidity during the whole measurement period is shown in Figure 1 (left). Indoor relative and absolute humidity were analysed separately during the summer and winter seasons. Analysed periods were from the measurement year from fall 2006 to summer 2007. During this period, the measurements were done in all detached houses. The analysed summer season was 01.07…31.07.2007. The selection was made according to the outdoor climate; a period in which the mean outdoor temperature was mainly above 15ºC and the majority of the houses were still measured, was chosen. The analysed winter seasons lasted for three months, 01.12.2006…28.02.2007.

To give an overview of the indoor temperature conditions in studied houses, the dependence of the indoor temperature on the outdoor temperature was calculated, Figure 1 (right). Each line in Figure 1, right, represents the average value of the average daily indoor temperature at the corresponding average daily outdoor temperature. The value was calculated separately for each house group. No great differences in the indoor temperature were found between the house groups.

![Figure 1: The outdoor temperature and relative humidity during the measurement periods (left) and the dependence of indoor air temperature on the outdoor air temperature (right).](image)

3.2 Summer season

Figure 2 (left) shows the difference of the RH between the different house groups. Each column represents the average relative humidity of one studied house during the summer period 2007. Average indoor relative humidity of all houses during summer was 51%. To study the fluctuation of indoor RH and absolute humidity, the amplitudes of 24 h, i.e. the difference between the daily maximum and minimum values, were calculated. An average value of these daily values over the summer period is considered as a measure of the fluctuation of the parameter studied. Figure 2 (right) shows the difference between different house groups in the level of daily amplitude of indoor RH. There were no significant differences between the groups of houses in the values of relative humidities or their amplitudes.
As the stability of indoor RH is affected by the stability of temperature (includes influence of outdoor climate, internal heat gains, ventilation and thermal mass of the house) and absolute humidity (includes outdoor climate, moisture production, ventilation and moisture buffering of the house), these factors should be analysed separately.

Figure 3 (left) shows the average amplitudes of absolute humidity during summer period. Houses with AAC exterior walls had significantly (p<0.05) minor amplitude of absolute humidity than log, shuttering concrete block (CB) and concrete element (CE) houses. Also, the difference between log and cavity brick houses was significant. Figure 3 (right) shows the distribution of average daily amplitudes of temperature in the studied houses. The daily amplitude of temperature in log houses was significantly higher than in majority of the other house groups. Thermal mass of the exterior walls might have some influence on the results.

3.3 Winter season

Average indoor relative humidity during winter was 31%. The levels and daily amplitudes of relative humidities in different house groups during the winter period 2006...2007 are compared in Figure 4. Each column represents the average relative humidity/average daily amplitude during the studied winter period. Houses with concrete element exterior walls had significantly lower level of relative humidity compared to houses with autoclaved aerated concrete block, brick cavity and shuttering concrete block exterior walls. But as noticed in Figure 1 (right), the temperature in concrete element houses was also higher than in the rest of the house groups.
There were no significant differences in the average values of average daily amplitudes between different house groups.

![Graph showing relative humidity and amplitude of relative humidity](image)

**FIG. 4:** The level of relative humidity (left) and the amplitude of relative humidity (right) during the winter period 2006...2007 (1.12.2006...28.2.2007). Horizontal lines mark significant differences between the house groups. Average values of different house groups are presented.

The daily average amplitudes of absolute humidity show no significant difference between different house groups during winter (Figure 5, left). In Figure 5 (right) the average value of average daily amplitude of temperature in the studied houses is compared. The log houses had significantly higher daily amplitude of temperature compared to all the other house groups except the AAC and concrete element houses. The AAC houses had significantly higher daily amplitude of temperature than the shuttering concrete block houses.

![Graph showing daily amplitude of absolute humidity and temperature](image)

**FIG. 5:** The distribution of the average daily amplitudes of absolute humidity (left) and temperature (right) during the winter period 2006...2007 (1.12.2006...28.2.2007). Horizontal lines mark significant differences between the house groups. Average values of different house groups are presented.

Figure 6 shows a comparison of average daily amplitudes of absolute humidity in houses with low ventilation rate (<0.25 l/h) and high ventilation rate (>0.5 l/h). The amplitude was greater in houses with higher ventilation rate.
4. Discussion

In this paper, an overview on the level of relative humidity and daily amplitudes of relative and absolute humidity and temperature in real houses is made. For the indoor climate study, houses were divided into different house groups based on the main exterior wall type. Table 1 summarizes the results. The measured heavyweight houses did not have major differences in the level of relative humidity and the daily average amplitude of relative humidity. During the summer season the daily amplitude of absolute humidity in houses with AAC exterior walls was significantly minor than in log, shuttering concrete block and concrete element houses. Also, the log houses had significantly higher amplitude of absolute humidity than cavity brick houses. In winter period houses with low ventilation rate (<0.25 l/h) had significantly minor amplitude of absolute humidity than houses with high ventilation rate (>0.5 l/h). There were significant differences between the house groups in daily amplitude of temperature. Generally, log and AAC houses seemed to have higher amplitude of temperature than the rest of the house groups. The average values of average daily temperatures of the house groups varied from 0.7 to 1.3 °C. Overall, this kind of fluctuation of temperature has a more important effect on the relative humidity in the houses than the type of exterior wall.

<table>
<thead>
<tr>
<th></th>
<th>Number of houses</th>
<th>ΔT, [°C]</th>
<th>ΔRH, [%]</th>
<th>Δv, [g/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Log</td>
<td>19</td>
<td>1.2</td>
<td>1.3</td>
<td>7</td>
</tr>
<tr>
<td>Autoclaved aerated concrete (AAC)</td>
<td>10</td>
<td>1.0</td>
<td>1.1</td>
<td>5</td>
</tr>
<tr>
<td>Lightweight aggregate concrete (LWAC)</td>
<td>10</td>
<td>0.8</td>
<td>0.8</td>
<td>6</td>
</tr>
<tr>
<td>Brick</td>
<td>10</td>
<td>0.8</td>
<td>0.9</td>
<td>6</td>
</tr>
<tr>
<td>Shuttering concrete block (CB)</td>
<td>10</td>
<td>0.8</td>
<td>0.7</td>
<td>7</td>
</tr>
<tr>
<td>Concrete sandwich element (CSE)</td>
<td>10</td>
<td>0.7</td>
<td>1.1</td>
<td>7</td>
</tr>
</tbody>
</table>
Three years prior to the current study, a similar study in 100 timber-framed houses was made (Vinha et al. 2005, Kalamees et al. 2006). As both studies were conducted according to similar procedure, it is easy to compare the results. Envelopes of the timber-framed houses were divided into vapour tight envelope or vapour permeable envelope constructions. Vapour tight refers to an envelope where a plastic vapour barrier foil was used or polyurethane foam was used as thermal insulation. Permeable refers to a structure in which paper air barrier was used (permeability of the internal surface is not taken into account in this division). In addition, a more specific classification to hygroscopic and non-hygroscopic room envelopes was made: the rooms with the hygroscopic interior surface materials and the rooms with the fully non-hygroscopic interior surface materials. For example, the rooms where the walls were covered with the hygroscopic surface material and the ceiling was covered with the non-hygroscopic material were categorized as a hygroscopic subdivision. The main hygroscopic surface material of the walls was wallpaper made of paper on the wood chipboard or on the plasterboard and wooden boarding. The major non-hygroscopic surface materials were vinyl-wallpaper and paint. The paints most commonly used on the ceilings and usually on the walls were assumed to be non-hygroscopic.

Study showed significant differences of average daily amplitudes of humidity during summer. In timber-framed detached houses with hygroscopic indoor surfaces, the average daily amplitude of the humidity by volume and RH during the first measurement period was significantly lower than in rooms with non-hygroscopic indoor surfaces (8% vs. 9% and 1.9 g/m² vs. 2.1 g/m²). The ventilation, however, had a more significant role to the amplitude of daily relative and absolute humidity and temperature i.e. houses with balanced ventilation system had a lower amplitude than houses with mechanical exhaust ventilation (Vinha et al. 2005, Kalamees et al. 2006). The simulations by Kurnitski et al. (2006) showed that the permeable and hygroscopic structures improved the air quality considerably in the summer period. However, in practice the permeable and hygroscopic structures had only a minor effect on the indoor climate. This reduction was concluded to derive from window airing and furnishing that were not taken into account in simulations. The vapour tightness of the timber-framed building envelope did not show significant difference in average daily amplitudes of RH and absolute humidity.

The timber-framed houses had higher daily amplitudes of humidity and temperature than heavyweight houses. One must, although, notice that the measurement years were different.

There are many uncontrolled factors affecting the indoor climate in a field study. The orientation of the houses, architecture and surroundings were different in every case. Temperature sensors were located in the master bedroom and the orientation of this room plays an important role. As all the houses were different and situated in different areas, urban or natural surroundings, neighbouring houses or trees might directly influence the indoor conditions. Also in real houses the textiles, furniture or other furnishing may play a very important role in dampening the humidity fluctuation of indoor air. On the other hand, the influences of these factors decrease, when the number of houses is large, as in this study.

The classification of surface material properties in field test was found difficult to do (the correct paint type, the number of layers of paint and the moisture permeability of wallpapers) and for this reason only a rough classification based on exterior wall types was made and the internal surface of the envelopes was not considered. In the log houses, the interior surface of the external wall was usually treated with either lacquer, latex paint or some other kind of protective fluid. The exterior walls of the other heavyweight houses were usually plastered and painted.

5. Conclusions

The results of this study showed in general no major differences in the level of relative humidity between the measured house groups. However, the level of RH in concrete element houses during winter was significantly lower than in houses with autoclaved aerated concrete block, brick cavity and shuttering concrete block exterior wall, but the level of temperature in concrete element houses was also a bit higher. No significant differences in the daily average amplitude of relative humidity were found. During the summer season, the daily amplitude of absolute humidity in houses with AAC exterior walls was significantly lower than log, shuttering concrete block and concrete element houses. Also, the log houses had significantly higher amplitude than the cavity brick houses. In winter period houses with low ventilation rate (<0.25 l/h) had a significantly smaller amplitude of absolute humidity than houses with high ventilation rate (>0.5 l/h). There were some differences in the daily amplitude of temperature between the house groups. Generally, log and AAC houses seemed to have higher amplitude of temperature than the rest of the house groups, partly because smaller part of the walls participates
in temperature regulation. Overall, the fluctuation of temperature (average values of different house groups 0.7…1.3 ºC) affects relative humidity more than the type of exterior wall.

The timber-framed houses had higher daily amplitudes of humidity and temperature than the heavyweight houses although one must notice that the measurement years were different. The hygroscopic mass of furniture, textiles, etc. as well as real air change rates, including window airing are probably factors that play significant roles in indoor humidity.

6. Acknowledgements

This study is part of large field research project carried out by Department of Civil Engineering at Tampere University of Technology and HVAC Laboratory at Helsinki University of Technology. The project has been financed by TEKES (National Technology Agency of Finland) and Finnish companies and associations. We extend our thanks to all assisting people, residents of the houses studied, and financiers of the research for their co-operation during the study.

7. References


