The distribution of the air leakage places and thermal bridges of different types of detached houses and apartment buildings

Targo Kalamees\textsuperscript{1}, Jarek Kurnitski\textsuperscript{1}, Minna korpi\textsuperscript{2}, Juha Vinha\textsuperscript{2}
\textsuperscript{1} HVAC-Laboratory, Helsinki University of Technology  
P.O. Box 4100 FIN-02015 TKK FINLAND
\textsuperscript{2} Institute of Structural Engineering, Tampere University of Technology  
P.O. Box 600 FIN-33101 Tampere FINLAND

Abstract
Air leakage path affect infiltration and air pressure conditions in building. The main objectives of this study were to analyse the distribution of the air leakage places and thermal bridges in detached houses and apartment buildings. Field measurements of the airtightness and thermography measurements have been carried out in 8 detached houses and 9 apartments during the years 2005-2006 in Finland.  
Using the standardized BlowerDoor pressurization technique, the air leakage rate of each house and apartment was determined during summer season. To determine typical air leakages and thermal bridges and their distribution, an infrared image camera and a smoke detector were used during cold period. Temperature factor was used to determine and to classify thermal bridges. Relative decrease of the surface temperature was used to determine and to classify air leakage places.  
Typical thermal bridges in the studied detached houses were around the doors and windows. Low temperatures were determined also in the junction of the base floor with the external wall. Typical air leakages were in the junction of roof with the external wall, penetrations through the air barrier systems, and around and through windows and doors.  
Typical thermal bridges in the studied apartments were around the doors and windows. Typical air leakages were around and through windows and doors, in the junction of ceiling/floor with the external wall, penetrations through the air barrier systems, and walls and floors between apartments.

Keywords: air leakage places and thermal bridges
Introduction

The uncontrolled air movement through a building envelope leads to problems related to the hygrothermal performance, health, energy consumption, performance of the ventilation systems, thermal comfort, noise, and fire resistance. Air leakage through a building envelope depends on the result of air-pressure differences across the envelope, distribution of the air leakage places and airtightness of the building envelope. Air and moisture convection through the building envelope may cause severe moisture loads imposed on the structure. Indoor air exfiltration in cold climates may cause moisture accumulation or condensation [1, 2], leading to the microbial growth on materials, change of the properties of the material or even to structural deterioration. Air leakage through a building envelope could introduce outdoor or crawl space airborne pollutants [3, 4] as well radon gas into the indoor air [5, 6, 7]. Uncontrolled air leakage results in an increased air change rate and energy use [8,9].

Almost all building envelopes have thermal bridges - locations where the thermal resistance of the assembly is locally lower. Thermal bridges are caused mainly by geometrical or structural reasons. In cold climates, the assessment of thermal bridges is important for many reasons. Thermal bridges may lead to surface condensation, mould growth, and staining of surfaces. Due to lower temperatures on the thermal bridge, higher RH occurs. While surface condensation starts at the RH 100%, the limit value for RH in respect of mould growth is above RH 75% to 90% depending on the material [10]. Thermal bridges lead to an increase of heat losses. An increase in the thermal insulation level will increase the relative significance of the thermal bridges in the energy consumption of buildings. If there exist large poorly insulated or uninsulated areas of the envelopes, the surfaces will be cold in the winter and may cause thermal comfort problems due to cold draughts or radiation (in particular, asymmetric radiation).

The distribution of the air leakage places affects infiltration and air pressure conditions in building. The main objectives of this study were to analyse the distribution of the air leakage places and thermal bridges in detached houses and apartment buildings. Field measurements of the airtightness and thermography measurements have been carried out in 8 detached houses and 9 apartments in Finland.
Methods

Studied dwellings

Analysis of the distribution of the air leakage places and thermal bridges were carried out in eight detached house and in nine apartments in different buildings. Studied dwellings were selected from the databases of an ongoing research project: “Airtightness, indoor climate and energy efficiency of residential buildings” and a concluded research study: “Moisture-proof healthy detached house”. Dwellings in research project have different structures: 170 detached houses with timber-frame, log, lightweight concrete, autoclaved aerated concrete, brick, concrete sandwich element, and shuttering concrete block external walls and 60 apartments in buildings with concrete and timber-frame structures. Dwellings are randomly selected from the databases of the companies manufacturing and building houses. During winter 2005-2006 measurements were carried out in part of the houses and there are plans to carry out measurements also in winter 2006-2007, allowing the analysis in all representative types of houses in Finland.

Main data of the studied dwellings are shown in Table 1. In the case of timber-frame envelope, the vapour barrier that controlled water vapour diffusion through the envelope was designed to function also as an air barrier. Brick and block walls were plastered from inside or from both sides.

Table 1. The main characteristics of the studied detached houses (DH) and apartments (A)

<table>
<thead>
<tr>
<th>Code</th>
<th>External wall</th>
<th>Base floor</th>
<th>Roof</th>
<th>Air leakage n50, ach</th>
<th>Ventilation air change rate, ach</th>
<th>Number of floors</th>
<th>Construction year</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH 3602</td>
<td>Concrete sandwich element</td>
<td>Concrete slab on ground</td>
<td>Timber-frame</td>
<td>4.1</td>
<td>0.24</td>
<td>1</td>
<td>2004</td>
</tr>
<tr>
<td>DH 3603</td>
<td>Concrete sandwich element</td>
<td>Concrete floor with crawlspace</td>
<td>Timber-frame</td>
<td>2.5</td>
<td>0.73</td>
<td>1</td>
<td>2003</td>
</tr>
<tr>
<td>DH 3405</td>
<td>Silicate brick-block</td>
<td>Concrete slab on ground</td>
<td>Timber-frame</td>
<td>2.4</td>
<td>0.19</td>
<td>1</td>
<td>1997</td>
</tr>
<tr>
<td>DH 1042</td>
<td>Timber-frame</td>
<td>Timber-frame floor with crawlspace</td>
<td>Timber-frame</td>
<td>3.4</td>
<td>0.32</td>
<td>1.5</td>
<td>1994</td>
</tr>
<tr>
<td>DH 3302</td>
<td>Light expanded clay aggregate block</td>
<td>Concrete slab on ground</td>
<td>Timber-frame</td>
<td>3.0</td>
<td>0.35</td>
<td>2</td>
<td>2004</td>
</tr>
<tr>
<td>DH 3204</td>
<td>Autoclaved aerated concrete (AAC) block</td>
<td>AAC floor with crawlspace</td>
<td>AAC panel</td>
<td>1.5</td>
<td>0.47</td>
<td>1</td>
<td>2000</td>
</tr>
<tr>
<td>DH 3503</td>
<td>Shuttering concrete block</td>
<td>Concrete slab on ground</td>
<td>Timber-frame</td>
<td>1.9</td>
<td>0.5</td>
<td>1.5</td>
<td>2005</td>
</tr>
</tbody>
</table>
Measurement methods

The air tightness of each house and apartment was measured with the standardized fan pressurization method, using “Minneapolis Blower Door Model 4” equipment with an automated performance testing system (flow range at 50 Pa 25–7.800m³/h). To determine typical thermal bridge and air leakage places and their distribution, an infrared image camera FLIR ThermaCam P65 (thermal sensitivity of 0.08 °C, measurement range -40 °C to +500 °C) and a smoke detector were used. The difference between the indoor and the outdoor air temperature was at least 20 °C. Thermography investigations were done twice. First, to determine the thermal bridges the surface temperature measurements were performed without any additional pressure difference. Next, to determine the air leakage places, the 50 Pa negative pressure under the envelope was set with fan pressurization equipment. After (~30…45 min) the infiltration airflow had cooled the inner surface of the envelope, the surface temperatures were measured with the infrared image camera from the inside of the building.

Assessment of thermal bridges and air leakages

Temperature factor was used to assess and to classify thermal bridges. The temperature factor at the internal surface ($T_{r,si}$) shows the relation of the total thermal resistance of the building envelope ($R_T$, (m²·K)/W) to the thermal resistance of the building envelope without the internal surface resistance ($R_{si}$, (m²·K)/W) and it depends on the indoor ($T_i$, °C) and the outdoor ($T_e$, °C) air temperature and on the temperature on the internal surface of the building envelope ($T_{si}$, °C), see Eq. 1.
Temperature factor values were classified in five groups: $f_{Rsi} < 0.6$, $0.61 \ldots 0.65$, $0.65 \ldots 0.69$, $0.70 \ldots 0.74$, and $0.75 \ldots 0.80$. According to Finnish instructions regarding housing health (Asumisterveysohje 2003) temperature factor for floors $f_{Rsi} \geq 0.97$ and for walls $f_{Rsi} \geq 0.87$ reflect good level and temperature factor for floors $f_{Rsi} \geq 0.87$ and for walls $f_{Rsi} \geq 0.81$ reflect tolerable level. Temperature factor values for the thermal bridge are $f_{Rsi} \geq 0.65$ on good level and $f_{Rsi} \geq 0.61$ on tolerable level. According to mould growth criterion in cold climate the temperature factor on the thermal bridge should be $f_{Rsi} \geq 0.80$ in dwellings with high occupancy and/or low ventilation and $f_{Rsi} \geq 0.65$ in dwellings with low occupancy and normal ventilation [12]. Finnish guide of thermography investigations of building [13] classifies temperature factors: $f_{Rsi} 0.70 \ldots 0.74$ fulfils of the requirements of the good level, $f_{Rsi} 0.65 \ldots 0.79$ includes obvious hygrothermal defects or faults but fulfils of the requirements of the housing health, $f_{Rsi} 0.61 \ldots 0.64$ possibility for healthy hazards or structure risks, the details/structure must be checked and repairing necessity should be clarify, $f_{Rsi}<0.61$ includes healthy risks or hazards and should be repaired immediately.

Relative decrease of the surface temperature was used to determine and to classify air leakage places. Relative decrease of the surface temperature shows the relation of the difference between indoor ($T_i, ^\circ C$) and the outdoor ($T_e, ^\circ C$) air temperature to the temperature difference between internal surface of the building envelope measured before ($T_{si1}, ^\circ C$) and after ($T_{si2}, ^\circ C$) the depressurization, see Eq. 2.

$$\Delta T_s = \frac{T_{si1} - T_{si2}}{T_i - T_o} \times 100\%$$

The values of the relative decrease of the surface temperature were classified into five groups: 5-9%, 10-14%, 20-24% 25-30%, and >30%.

Air leakages and thermal bridges were classified as linear or spot and typical or occasional.
Results

To determine typical air leakage and thermal bridge places and their distribution the infrared image camera was used. Figure 1 shows the example of a thermal bridge around the roof window.

![Thermal bridges around the roof window](image1)

<table>
<thead>
<tr>
<th></th>
<th>Sp1</th>
<th>Sp2</th>
<th>Sp3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor temp.</td>
<td>+21.5 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor temp.</td>
<td>-4.0 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air pressure diff.</td>
<td>0 Pa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp. Sp1</td>
<td>+19.5 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp. Sp2</td>
<td>+9.9 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp. Sp3</td>
<td>+9.3 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_{Rsi} Sp1</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_{Rsi} Sp2</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_{Rsi} Sp3</td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Thermal bridges around the roof window

Figure 2 shows the example of an air leakage place on the junction of the ceiling and external wall.
Figure 2. Thermal bridges (upper) and air leakages (middle) on the junction of the roof and external wall.

Typical thermal bridges in the studied dwellings were around the doors and windows, Figure 3 left. Low surface temperatures under normal conditions were determined also in the junction of the external wall with the floor and walls. In detached houses
37 % and in apartments 25 % from determined thermal bridges include hygrothermal risks or need to be repaired.

Figure 3  Location (left) of the thermal bridges \( f_{Rsi} < 0.8 \) and severity of the thermal bridges (right)

Typical air leakages were around and through windows and doors, in the junction of ceiling/floor with the external wall, penetrations through the air barrier systems, and walls and floors between apartments, Figure 4 and 5.

Figure 4  Location (left) and severity (right) of the air leakage places
Discussion

In this study the distributions of the air leakage places and thermal bridges were analysed in detached houses and apartment buildings. Field measurements of the airtightness and thermography measurements have been carried out in 8 detached houses with different structures and in 9 apartments in timber-frame buildings during the years 2005-2006 in Finland.

In the current study one of the main typical air leakage place in detached houses was in the roof with the external wall. Other studies [14] have shown that one of the main critical junctions is also the junction between intermediate floor and external wall. In the current study there were only few two-storey detached houses, Table 1. Therefore the criticality of the junction between intermediate floor and external wall did not come into view so strongly in the current study. In winter 2006-2007 more two storey detached houses will be measured.

Relative decrease of the surface temperature was used to determine and to classify air leakage places. If the junction has also a thermal bridge, this factor shows lower criticality than a junction without thermal bridge. The air distribution of the air leakage place. Different air leakage paths affect the temperature profile and two air leakages with the same airflow may show different surface temperature. Therefore the relative decrease of the surface temperature is not direct and absolute characteristic of air leakage.
Conclusions

Typical thermal bridges in the studied dwellings were around the doors and windows. Typical air leakages were around and through windows and doors, in the junction of ceiling/floor with the external wall, penetrations through the air barrier systems, and walls and floors between apartments.

To get a whole overview of the distribution of air leakages, measurements also in winter 2006-2007 will be carried out. This allows a closer analysis in all representative types of houses in Finland to be done.

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References


