Studies on internal surface heat transfer in the window area

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Abstract. In this paper reporting preliminary results from the ongoing research, heat transfer phenomena at window surfaces and adjacent areas of the building envelopes are studied. In the first step, in-situ observation of balcony door based on indirect estimation of temperature distribution close to window surface was carried out by means of infrared imaging (IR). In the second step, more advanced full-scale experiments were performed in a well-insulated laboratory testing room with floor heating, equipped with one window, under well controlled steady-state conditions. A combination of IR with particle imaging velocimetry (PIV) was used here with extra focus on situation close to the window frame at window sill. In such areas the reduced heat transfer by convection can be observed. As a consequence, the condensation risk free situation there seems not to be always guaranteed even by high performing building components despite the results of standard heat transfer calculations used in design practice.

1 Introduction

Low-energy and passive buildings are characterized by reduced heat losses and consequently changed energy distribution in rooms. Low-temperature heating bodies, floor heating systems, or warm-air heating, change the character of air movement in the area close to windows compared to typical situations in the past.

Occasionally, one can observe condensation of water vapor in specific areas of windows. Most sensitive are the lower parts above the sill or floor. Here, condensation may occur even at windows suitable for passive houses (thermal transmittance $U_w \approx 0.8 \text{ W}/(\text{m}^2\text{K})$), for which the heat transfer calculations in accordance with ISO standards don't show any risks.

Presence of condensate lowers the user comfort and may establish a milieu suitable for mold growth, especially at silicone based or similar sealing elements. Higher condensation rates can cause damage to moisture sensitive materials in vicinity of the condensation zone (paints, plasterboards, wooden elements etc.).

An exact *in-situ* analysis is in many cases difficult because of non-steady ambient conditions and missing precise information about quality of window components, but also about quality of installation. Moreover, local obstacles, like blinds, curtains, and drapes can significantly alter both convection and radiation heat exchange between the window and interior space.

2 Context

2.1 Presence of condensation

Due to positive development in recent years connected to low-energy building strategies, the temperatures at internal surfaces of building components, including

windows, are higher compared to the situation in the past. This is not only beneficial for occupants' thermal comfort, but it also largely prevents the surface condensation of water vapor.

If the condensation on windows still occurs, it can be due to the following reasons: i) the real quality of the entire window, or its individual parts, is lower than a declared value; ii) the window is not correctly installed or the surrounding opaque components are of poor quality; iii) the indoor environment does not meet the criteria specified by window manufacturer (exceeded humidity in most cases); iv) heat exchange between the window and surrounding internal environment is constrained, i.e. less intensive compared to design assumption (e.g. due to local obstacles, position of the window within the wall etc.); v) the heating system does not provide a uniform temperature distribution within the room.

A combination of these phenomena is often needed to cause condensation on quality windows. In that case, the problem occurs in their lower part at first, especially at the edge of glazing, at/or close to functional joint, and around the hinges.

This paper presents preliminary findings of the ongoing research project aimed at internal surface heat transfer in the window area with respect to geometric relations, heat distribution within the interior space, and presence of local obstacles.

2.2 Surface heat transfer

Surface heat transfer is described as a combination of convective and radiation phenomena influencing the surface of a building component [1]. In a standard engineering approach, both phenomena are aggregated into a single quantity, surface resistance in $\text{m}^2\text{K}/\text{W}$, which is given by:

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$$R_{si} = 1 / (h_c + h_r) \quad (1)$$

As the standards declare, the formula (1) should be understood as an approximate treatment of surface heat transfer. Precise calculations of heat flow can be based on the internal environmental temperatures in which the radiant and air temperatures are weighted taking into account the room geometry effects, air temperature gradients and forced convection. If the internal radiant and air temperatures are not markedly different, the operative temperature may be used [2].

Corresponding values of surface resistance are standardized [3,4] (see Table 1) for evaluating the water vapor condensation risks taking into account the orientation of the heat flow (horizontal, upwards, downwards), but typically as a fixed value for the whole evaluated component. In some cases, the local reduction, especially at edges, corners and other reduction for both, convection and radiation have to be considered [4] or it is recommended.

Table 1. Standard values of interior surface heat transfer resistance

Situation	Heat flow direction ¹	R_{si} [m ² K/W]	Source
Window/door frame, planar surface	Horizontally	0.13	[3]
Window/door frame, near to edges, corners	Horizontally	0.20	[3]
Opaque components	All ²	0.25	[4]
Window/door	Upwards	0.10	[4]
Window/door	Horizontally	0.13	[4]
Window/door	Downwards	0.17	[4]
Window/door, reduced convection and radiation	Horizontally	0.20, possibly higher than 0.25	Czech national remarks in CSN EN ISO 13788 [4]
Remarks: ¹ related to overall position of the component ² representing effects of edges, furniture, curtains or suspended ceilings			

Standard values of the surface resistance should be critically analyzed taking into account changed condition in surface temperatures due to higher thermal resistance of the building envelope and due to changed heat distribution in the rooms by modern, energy optimized buildings.

Another problem of the standard approach is clearly visible from the formula 2: It is based on the assumption that the interior can be represented by one single value of space temperature.

$$q = (\theta_{si} - \theta_i) / R_{si} \quad (2)$$

For practical reason the space air temperature distribution is neglected in engineering assessments.

The surface heat transfer seems to be so gentle phenomenon that the experimental investigation is

possible under very precise laboratory condition only. Nevertheless, preliminary in-situ observations can bring valuable illustrations of the studied phenomena.

3 Observation and measurements

3.1 Observation under real conditions

Observations concerning the surface temperature (Figure 1) and air temperature close to the surface of balcony door (dimension of 2.4 m × 0.8 m, with visible glazing dimensions of 2.15 m × 0.66 m, triple glazed) were performed in the living room [5] in passive house quality. There was no heating body near the balcony door.

Fig.1 Surface temperature at balcony door evaluated from IR picture: vertical profile from door head to floor. Exterior temperature -6.0 °C, interior temperature +20.5 °C.

Air temperatures near to the surface were measured indirectly using an IR camera: A paper sheet was placed perpendicular to glazing, in the lower and upper part of the balcony door (Figure 2), assuming the measured temperatures to be approximately equivalent to local air temperatures [6].

Alternatively, a special tape (width 25 mm, declared emissivity 0.95) was fixed on a fiber glass tape, normally used for plasterboards joints, which was placed vertically along the balcony door (Figure 3). Several infrared images were taken here (Figure 4 and 5 as examples) at winter conditions.

Using this technique an illustrative information about the real thickness of boundary layer was obtained (Figures 6, 7).

Fig.2 Set-up for illustrative observation at the top of balcony door – black paper sheet 210 x 420 mm and tape with reference emissivity placed on a soft tape with grid structure.

Fig.3 Set-up for illustrative observation at the bottom of the balcony door – tape 25 mm wide, with reference emissivity, perpendicular to the surface.

Fig.4 Infrared picture at the bottom of balcony door with black paper sheet (exterior temperature $-1.0\text{ }^{\circ}\text{C}$).

Fig.5 Infrared picture at the top of balcony door with the paper sheet (A) and tape (B) at exterior air temperature $-7.0\text{ }^{\circ}\text{C}$.

Fig.6 Temperature in the center of balcony door evaluated from IR picture. Glazing surface temperature $17.5\text{ }^{\circ}\text{C}$ measured by thermocouple, measured heat flux 15 W/m^2 , exterior temperature $-7.0\text{ }^{\circ}\text{C}$ and interior temperature $21.5\text{ }^{\circ}\text{C}$.

Fig.7 Horizontal temperature profile near to balcony door evaluated from IR picture (Fig. 4) – lower part at exterior air temperature $-1.0\text{ }^{\circ}\text{C}$ and interior temperature $21.5\text{ }^{\circ}\text{C}$ (a – 300 mm above the floor; b – in the center of the frame; c – 10 mm above the lower glazing edge).

3.3 Experiment in testing room

Advanced laboratory experiments under steady state conditions were performed in order to study these phenomena in detail. Particle Imaging Velocimetry (PIV) analyzing the velocity field near to glazing, frame, and window sill was combined with infrared imaging (IR) to capture the surface temperatures, and in an indirect way also the air temperatures near to surfaces.

3.3.1 Testing room

The experiment took place in a testing room with inner dimensions of 4.4 m $\times$ 3.1 m $\times$ 2.85 m (length $\times$ width $\times$ height) (Figure 8). The ceiling, floor, and two walls of the room were surrounded by controlled external environment. The remaining two walls were surrounded by controlled internal environment (adiabatic boundary). One external wall was equipped with a wooden window: size 1.5 m $\times$ 1.5 m, sill height 1.0 m, width of inner side lining 0.2 m, double glazed, declared thermal transmittance 1.2 W/(m²K). The room enables several heating options, floor heating was used in this study to minimize the vertical temperature stratification. The boundary conditions during the experiment were: internal air +21 °C, external air -12 °C.

Fig. 8 Testing room geometry (vertical section).

3.3.2 Experimental set-up

The window area was equipped with four narrow textile ribbons placed vertically in distances 6, 15, 28, and 215 mm from glazing (Fig. 9). The ribbons as well as surface of the window were photographed by a hi-res IR camera.

The velocity field in the bottom part of the window (near the sill) was captured using PIV [7,8]. The PIV method is based on an optical tracing of laser-illuminated seeding particles dispersed in the measured area. A camera placed perpendicular to the laser sheet records two images at a short time interval. In these images, the individual particles can be identified and their path and direction are determined. From the knowledge of the path, direction, and time interval, the system is able to create the resulting velocity vector field.

3.3.2 Results

Figures 10 and 11 show results of IR imaging for the whole window. Figures 12 and 13 show detailed results of IR imaging for its bottom part together with the velocity field near to window sill measured by PIV.

Fig. 9 Window equipped with narrow textile ribbons.

Fig. 10 Internal surface temperature of the window from IR measurement.

Fig. 11 Vertical temperature profiles along the window from IR measurement.

Fig. 12 Vertical temperature profiles along the window from IR measurement – detail at the window sill.

Fig. 13 Velocity field in a plane perpendicular to window from PIV – detail at the window sill.

4 Discussion

Observations and experiments carried out so far confirm that heat transfer phenomena at the interior surfaces are strongly influenced by local thermal resistances of building components, their geometry and type of heat distribution. The heat transfer value can differ significantly at non planar surfaces of the building envelope. Large differences in surface temperatures can be seen by functional joints and edges of glazing and close by. Very significant is the area of window sill, where a “pocket of stationary air” can be formed reducing convective heat transfer to minimum. Thus the dominant phenomenon here is radiative heat transfer among the nearby surfaces. The situation at the same location may vary depending on how the room is heated. Moreover, the air temperature and overall surface heat transfer in the window area can vary according to deepness and form of window linings, possibly also in connection with local obstacles such as curtains and blinds.

In general, the interior temperature which is used in the heat flow calculation is a subject of convention. Normally, it should represent the whole room. In specific cases local interior temperature can be applied instead, e.g. for studying of effects of very deep lining and/or curtains or other local obstacles. We have seen that the width of the boundary layer with the significant temperature change remains as expected within 15-25 mm from the surface. But the temperature at this distance from the surface is lower than the interior temperature, typically measured in the center of the room.

The only possibility how to study the problem more exactly and evaluate the eventually corrected surface heat transfer coefficients for specific cases is to perform a set of precise laboratory experiments under controlled boundary conditions, very likely in combination with advanced numerical modelling. It should be mentioned that we are facing the limits of measuring technique, e.g. the acceptable size and accuracy of heat flow sensors for studying the surfaces heat transfer at the frame profiles.

Our experimental program in laboratory continues with detailed studies on balcony door with the idea to compare different experimental set-ups (different frame geometry, several types of heat distribution in the room, presence of obstacles in front of the glazing).

Presented approach combining (PIV + IR) with direct measurements of local heat flows can contribute to better understanding of surface heat transfer phenomena in specific cases. Moreover, it can be used in the future in designing of new windows and their position in the building envelope, in parallel to CFD simulations. These methods can be understood as a supplement or validation tool for CFD simulations in specific rather complicated situation as well.

References

1. H. Hens. *Building Physics. Heat, Air and Moisture. Fundamentals and Engineering Methods with Examples and Exercises*; Wilhelm Ernst & Sohn: Berlin, Germany, 2012.
2. EN ISO 6946 *Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods*; CEN, Brussels.
3. EN ISO EN ISO 10077-2 *Thermal Performance of Windows, Doors and Shutters—Calculation of Thermal Transmittance—Part 2: Numerical Method for Frames*; CEN, Brussels.
4. EN ISO 13788 *Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods*. CEN, Brussels.
5. J. Tywoniak, V. Calta, K. Staněk, J. Novák and L. Maierová. The application of building physics in the design of roof windows. *Energies*. **12**(12) (2019)
6. M. Cehlin, B. Moshfegh and M. Sandberg, Visualization and measurement of air temperature using infrared thermography. *Proc. Conference Roomvent* Reading, UK, Vol.1 (2010)
7. G. Cao, M. Sivukari, J. Kurnitski and M. Ruponen. Particle Image Velocimetry (PIV) application in the measurement of indoor air distribution by an active chilled beam. *Building and Environment* 45, 1932–1940 (2010).
8. D. Adamovský and M. Kny. Influence of Airflow on Thermal Comfort in an Energy-Saving House. *Proc. Central Europe towards Sustainable Building 2019 (CESB19)*. Prague.

Nomenclature

R	surface heat resistance, $\text{m}^2\text{K/W}$
q	surface heat flow, W/m^2
h	surface heat transfer coefficient, $\text{W}/(\text{m}^2\text{K})$
θ	temperature, $^{\circ}\text{C}$

indices

c	convection
r	radiation
si	interior surface
i	interior