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ANALYSIS OF WATER VAPOUR CONDENSATION IN GAP BETWEEN CASEMENT AND WINDOW FRAME OF WOODEN WINDOWS

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ABSTRACT

The paper deals with thermal-moisture performance of a wooden window in standard external and indoor climate conditions in a gap between casement and window frame. Condensation or ice coating in the gap is the main problem of wooden windows. Thus, destructive processes on the wood surface finish causing the moisture penetration into the wood occur. The surface condensation is sufficiently covered by the requirements in currently valid standards. The condensate generation in the gap is not described neither limited by the standards nor regulations. The frequent problem occurrence in practice is to be dealt with and solved. The experimental and computing investigation was carried out using four types of MIRADOR 682, 682T, 783, 923 euro-profiles. For computing investigation the ANSYS programme was applied.

KEYWORDS: Wooden window, water vapour, condensate, ice coating.

INTRODUCTION

The problem of moisture transmission in gaps (leakages) in building envelopes is not a newly discovered issue. The moisture penetration through leakages in building envelopes has been investigated mainly in relation to slab blocks development. The leakages due to imperfect structural design and materials applied in roof envelopes formed another area for investigation. In our country, Mrlík (1985), Palková et al. (2010) has dealt with research and moisture transmission in gaps of building envelopes Hauser and Kempkes (2005) dealt with the similar problem area: moisture transmission through gaps, mainly for wooden houses in Germany (Hauser and Kempkes 2005). While solving these problems the window structures were at a relatively low development level and had high leakage in terms of air infiltration and exfiltration. Due to these window characteristics as well as low requirements in energy efficiency field the relative humidity in buildings used to be approximately 30 % (Chmúrny 2003). By improving the thermal characteristics of building structures in relation to energy the relative air humidity has increased up to 50 %, which is also given in STN 73 0540 (2002). Taking into consideration the change of boundary conditions and characteristics of window structures the problem of water vapour condensation in functional gap between casement and window frame has occurred. Nowadays, Huber (2009) from IFT Rosenheim has been dealing with the problem. He analyzed the effect of the type of seal in the case of condensation in the functional joint (Huber 2009).

The condensate generation in functional gap (Fig. 1 and Fig. 2) is not described neither limited by the standards nor regulations. Seriousness of the problem varies depending on the material base. Considering the wooden window structures the degradation of surface finish occur and its thermal characteristics change.

Fig. 1: Demonstration of ice coating and condensation in gap between casement and window frame at exfiltration and 200 Pa pressure difference (lower part) (Palková 2011).

Fig. 2: Demonstration of condensation in gap between casement and window frame at exfiltration and 200 Pa pressure difference (upper part) (Palková 2011).

The moisture transport through gap between casement and window frame at condensation temperature is the main cause of condensation of water vapour. The transport causes (Fig. 3):

- Air pressure differences (taking water vapour) – infiltration a exfiltration,
- Diffusion of water vapour (different saturation of water vapour in exterior and indoor air).

Condensation of water vapour – phenomena for balancing water vapour partial pressure by interaction of molecules. The diffusing water vapours are moving from places having higher pressure to places with lower pressure. The indoor water vapour partial pressure (20°C and air humidity 50 %) is calculated by STN 73 0540-2 (Chmúrny 2003):

$$p_{di} = \frac{\varphi_e \, p_{sati}}{100} = 50.\frac{2337}{100} = 1168.5 \text{ Pa} \qquad (1)$$

where: p_{di} - indoor water vapour partial pressure in Pa,
φ_i - relative humidity of indoor air in %,
p_{sati}- saturated water vapour partial pressure of indoor air in Pa.

The outdoor water vapour partial pressure (-11°C and air humidity 83 %) is calculated as follows (Chmúrny 2003):

$$p_{de} = \frac{\varphi_e \, p_{sate}}{100} = 83.\frac{237}{100} = 196.7 \text{ Pa} \qquad (2)$$

where: p_{de}- outdoor water vapour partial pressure in Pa,
φ_e- relative humidity of outdoor air in %,
p_{sate}- saturated water vapour partial pressure of outdoor air in Pa.

It follows from the above given that the pressure difference between interior and exterior is 971.8 Pa.

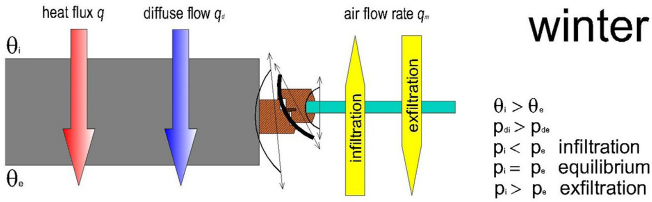

Fig. 3: Schematic representation of heat transmission, diffusion of water vapour and airflow through window structure (Palková and Palko 2010).

The warmer air can contain more water vapour as the cooler one, e.g. the air with 20 °C can contain up to 17.25 g.m^{-2} of vapour, but the air with -11°C can have only 1.96 g.m^{-2} of moisture. Interactive accumulation of infiltration or exfiltration and diffusion of water vapour leads to condensate or ice coating in winter period (Chmúrny 2003, Hens 2007, Bagoňa 2010).

MATERIAL AND METHODS

The experimental measurements were carried out in heat engineering laboratories at the Faculty of Civil Engineering. Measurement models represent real window structures. The big climatic chamber illustrated in Fig. 4 was used at measurements. The chamber A represents exterior climate (outdoor temperature - 11°C, pressure difference between exterior and interior from 0 to 2000 Pa, heat transfer coefficient 25 W.m^{-2} K, relative humidity 50 %). The chamber B represents balancing chamber for HOT-BOX and simulate the indoor climate (indoor temperature + 20°C, relative humidity 50 %). The HOT-BOX is used for measurement of heat transmission using measured element simulating the indoor conditions (indoor temperature + 20°C, relative humidity 50 %, heat transfer coefficient 7.7 W.m^{-2} K). Part D is a masking panel, in which the measured window structure is imbedded. In case of our measurement the HOT-BOX was not used as the conditions with infiltration or exfiltration were to be investigated.

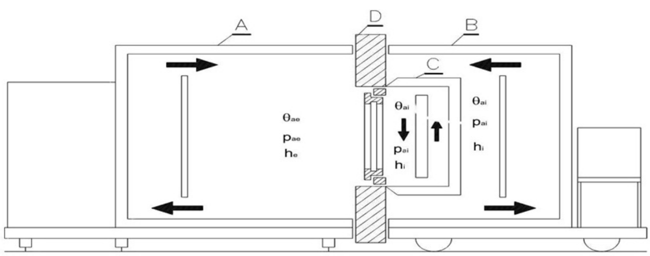

Fig. 4: Scheme of laboratory equipment of big climatic chamber (Palko et al. 2010).

Thermal and humidity parameters for ambient conditions are constant for all models. The indoor air temperature is 20°C and the relative air humidity is 50 %. The outdoor air temperature is -11°C and the relative air humidity is 83 %. The pressure differences are 200, 100, 75, 50, 25, 10, 5, and 0 Pa for infiltration and the similar pressure differences are also for exfiltration (Palko and Ďurinová 2007).

The measurements were performed on completed panel having real windows. Such panel having four windows with dimensions 540x695 mm, is illustrated in Fig. 5. The MIRADOR 682 with no external sealing is window No. 1, MIRADOR 682 with external sealing is window No. MIRADOR 783 is window No. 3 and MIRADOR 923 is window No. 4.

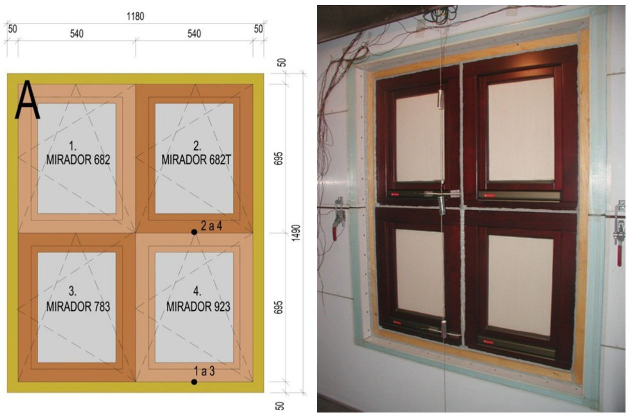

Fig. 5: Geometric parameters of window set ups in masking panel.

Measurement sensors are divided into two groups. The first group measures the surface temperatures (PT 100). The second one measures the temperatures and relative air humidity (SHT 75). The sensors distribution is presented in Fig. 6. For windows No. 1, 2, 3 the temperatures and relative air humidity are measured (SHT 75). For window No. 4 the surface temperatures (PT 100), temperatures and relative air humidity are measured (SHT 75). In Fig. 6 for MIRADOR 923 profile the placement of SHT 75 sensors on the left side and PT 100 on the right side are shown.

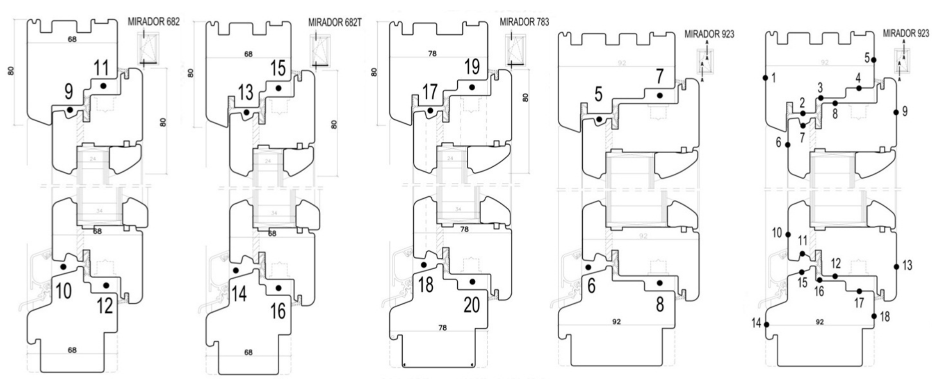

Fig. 6: Geometric parameters of window profiles and placement of measurement sensors.

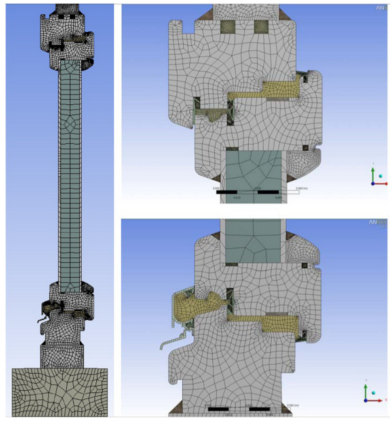

Fig. 7: Geometry and netting of MIRADOR 923 window computer model.

Computer simulation was carried out for MIRADOR 923 profile that is used mostly at low-energy and passive building construction. The geometry of computer model is identical with the measured window. Boundary conditions and material characteristics are also compatible with the experimental model in such a way that the comparison can be done. For the calculation the ANSYS programme was used. Geometry and netting of MIRADOR 923 window computer model is given in Fig. 7.

RESULTS AND DISCUSSION

The measurement and computer models results are classified into two groups. At experimental measurements in big climatic chamber the occurrence and amount of water vapour and ice coating condensate was found out after each completed measurement phase. Their occurrence is illustrated in Figs. 8, 9 and 10. The internal surface temperatures and air temperature including relative air humidity in gap measurement points (Fig. 6) belonged into the second valuation data group. The measured values are presented in Figs. 13 and 14.

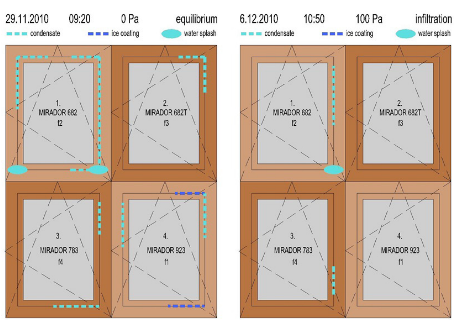

Fig. 8: Condensate and ice coating occurrence after equilibrium state (0 Pa) and infiltration (100 Pa) (Palková 2011, Palková and Palko 2009).

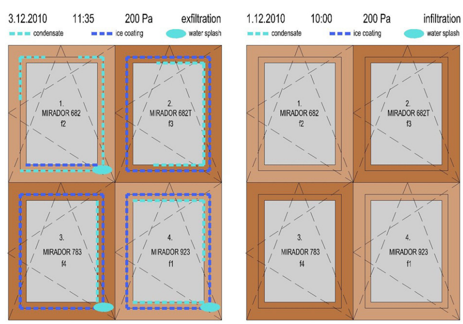

Fig. 9: Condensate and ice coating occurrence after exfiltration (200 Pa) and infiltration (200 Pa) (Palková 2011, Palková and Palko 2009).

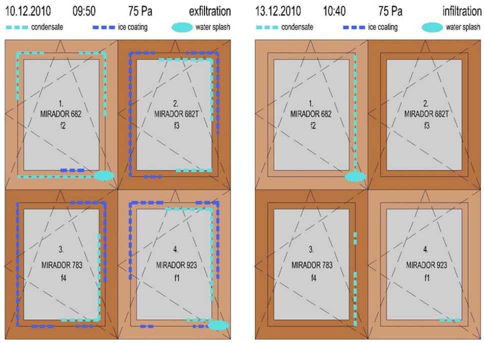

Fig. 10: Condensate and ice coating occurrence after exfiltration (75Pa) and infiltration (75Pa) (Palková 2011, Palková and Palko 2009).

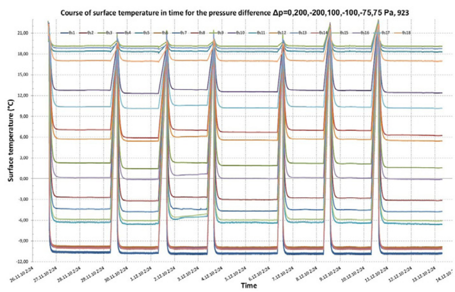

Fig. 11: Course of surface temperature in time for the pressure difference (MIRADOR 923).

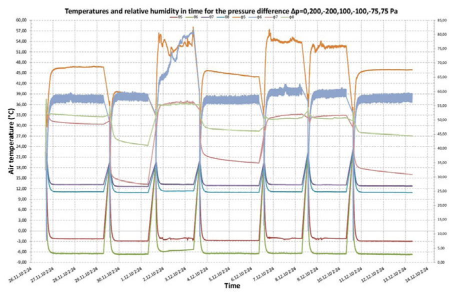

Fig. 12: Temperatures and relative humidity in time for the pressure difference (MIRADOR 923).

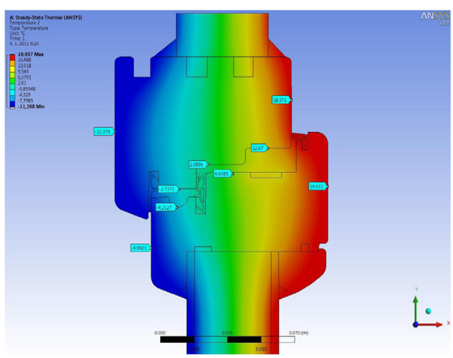

Fig. 13: Surface temperature fields and surface temperatures in investigated points (°C) of MIRADOR 923 window (upper part).

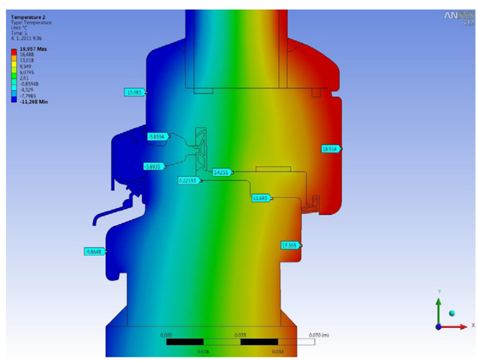

Fig. 14: Surface temperature fields and surface temperatures in investigated points (°C) of MIRADOR 923 window (lower part).

Considering the fact that it is not possible to distribute the sensors in ideal positions in gap the computer model was established. The computer simulation results show more detailed temperature distribution and enable more thorough investigation of condensation possibility in required positions. The simulation results are shown in Fig. 13 and Fig. 14.

Tab. 1: Comparison of measured and calculated surface temperature values for MIRADOR 923.

Identification	Measured values (°C)	Simulation values (°C)	Difference (K)
θs1	-10.67	-10.379	0.29
θs2	-2.69	-2.7371	0.05
θs3	2.27	2.0896	0.18
θs4	12.77	12.67	0.10
θs5	18.37	18.371	0.00
θs6	-9.92	-9.9901	0.07
θs7	-4.39	-4.2127	0.18
θs8	7.05	6.6085	0.44
θs9	19.16	19.011	0.15
θs10	-10.00	-10.083	0.08
θs11	- 6.29	-5.8594	0.43
θs12	5.69	5.4255	0.26
θs13	18.84	18.914	0.07
θs14	-10.06	-9.8648	0.20
θs15	-5.89	-5.8935	0.00
θs16	0.14	0.22193	0.08
θs17	10.36	11.695	1.34
θs18	17.03	17.305	0.28

Tab. 1 presents the comparison of the results gained from experimental measurement and computer simulation. The surface temperature results in investigated gap in identical points for simulation and experiment are evaluated. It can be seen from the numerical difference in the last column that the values for both methods are comparable.

Tab. 2 gives the evaluation of water vapour condensation risk in the gaps and the comparison with the real condition found out in the experimental measurement on MIRADOR 923 window profile. The first column presents the pressure difference between the interior and exterior with a note whether infiltration or exfiltration is considered. The second column gives the cavity identification according to Fig. 6 as well as the number of sensor measuring the temperature and relative air humidity in the gap between casement and window frame. The third column defines the relative humidity value for the particular cavity. For some points two different values are given: a maximum and a minimum value. In the forth column the cavity air temperature, at which the relative air humidity is measured, is given. The fifth column defines the dew point temperature for measured temperature and relative air humidity for the cavities. The sixth column presents the lowest surface temperature of wooden wing or frame reached in the cavity. Due to the fact that it was not possible to use PT100 sensor at the position with the lowest possible assumed temperature for measurement of surface temperature, the surface temperature was subtracted from the computer model. The seventh column gives a verbal evaluation whether assumption for water vapour condensation for given air temperature, relative air humidity and the lowest surface temperature in a cavity is or is not fulfilled. In the last column in Tab. 2 the information on the condensate formation in case of experimental measurement for the cavities is given. The evaluations in the last two columns are mostly compatible. The incompatible ones are marked in red. These cases can be explained by error of the measurement and the mathematic modelling. In these cases the dew point temperature values and the lowest surface temperatures are quantitatively very close to each other.

Tab. 2: Assessment of possible condensation in gap for MIRADOR 923 profile.

Pressure difference	Measurement point	Φ (%)	θ (°C)	θdp (°C)	θs,min,sim (°C)	Condensation risk	Condensation experiment
0 Pa without pressure difference	5	68.50 68.50	-2.28 -2.28	-6.72 -6.72	-7.95	yes	yes
	6	58.70 56.20	-6.50 -6.50	-12.52 13.00	-10.20	no	yes
	7	48.80 48.80	13.18 13.18	2.65 2.65	0.34	yes	yes
	8	51.50 51.50	11.09 11.09	1.48 1.48	-0.72	yes	yes
100 Pa infiltration	5	67.27 65.24	-2.76 -2,76	-7.39 -7.75	-7.95	yes	no
	6	58.13 55.40	-6.44 -6.44	-12.57 -13.10	-10.20	no	no
	7	36.90 34.92	12.95 12.95	-1.25 -1.91	0.34	no	no
	8	47.17 46.11	10.98 10.98	0.16 -0.13	-0.72	yes	no
100 Pa exfiltration	5	77.19 77.19	-2.23 -2.23	-5.29 -5.29	-7.95	yes	yes
	6	61.73 58,71	-6.30 -6,30	-11.77 -12,33	-10.20	yes	yes
	7	51,94 51,94	13,16 13,16	3.52 3.52	0,34	yes	yes
	8	50,58 50,58	11,15 11,15	1,29 1.29	-0,72	yes	yes
75 Pa infiltration	5	67,64 67.64	-2,92 -2.92	-7.49 -7.49	-7,95	yes	no
	6	59.13 56.38	-6.54 -6.54	-12.48 -13.00	-10.20	no	no
	7	32.94 30.92	12.86 12.86	-2.68 -3.43	0.34	no	yes
	8	50.00 50,00	10.96 10.96	0.95 0.95	-0.72	yes	yes
75 Pa exfiltration	5	75.80 75.80	-2.10 -2.10	-5.37 -5.37	-7.95	yes	yes
	6	60.67 58.05	-6.40 -6.40	-12.06 -12.55	-10.20	no	no
	7	51.51 51.51	13.14 13.14	3.38 3.38	0.34	yes	yes
	8	50.44 50.44	11.13 11.13	1.23 1.23	-0.72	yes	yes

In research works carried out by Mrlík (1985) and Hauser and Kempkes (2005) on building envelope gap and joint characteristics as well as research works on windows

Huber (2009) it has been proofed that water vapour transported through building envelope causes problems (Mrlík 1985, Hauser and Kempkes 2005, Huber 2009).

The results obtained in our research broaden and supplement the above given investigation works providing more comprehensive and more detailed knowledge of environmental physics bringing about water vapour condensation in functional gap between casement and window frame.

CONCLUSIONS

At an initial investigation stage it was known that condensation originated only in equilibrium state and at different pressure impact causing the exfiltration. However, it was found out during the measurements that the condensation also originates due to the infiltration. The condensation boundary for water vapour was being finding after the correct set up of circuit forging and, thus, also the sealing compression. After the measurements the value of differences of pressures between cool and warm chamber at which the condensate formation stops in the range 60 to 75 Pa.

The detailed computer simulation of the investigated problem is enormously demanding and the further investigation is needed. Although the mathematic algorithms for moisture transport are relatively well handled in ANSYS programme, it is not possible to continue in simulation without knowing the characteristics of used sealing materials. In order to succeed in this area it is inevitable to know the air permeability of sealing and window structure connection, diffusion constant of sealing and window frame connection. The air permeability has been already surveyed, but the diffusion constant of sealing for windows has not been investigated so far. The thermal model, which was compared with the experimental measurements in the previous chapter, has been authentically calibrated in the ANSYS programme. The total temperature distribution on the window frame was obtained by the simulation.

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