Increased Thermal Losses caused by Ventilation through Compact Pitched Roof Constructions – In Situ Measurements

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SUMMARY*:*
In the case of non ventilated compact roofs the wind tightness of the construction is usually warranted by a windproof underlay membrane and the flow resistance of the thermal insulation, as well as sealed eaves and ridge details. Because of the current construction practice of wind tight layers in Austria there are numerous small leakages in the eaves, the ridge and the underlay area. Because of this and the low density and length of the thermal insulation in common Austrian constructions the wind induced pressure differences between the eaves and loft area cause an air flow which cancels the thermal insulating effect of the rock wool partially or completely. During periods of high wind speed this leads however to uncomfortable low operative temperatures caused by an increased heat loss and lower surface temperatures. Different in-situ measurements (thermal performance and air propagation) of compact pitched roof constructions of single occupancy houses and apartment buildings in Austria were made. Validation results are presented as a comparison between measurements without wind and a dynamic simulation based on the measured in- and outdoor climate data. It was clearly shown by the measurements, that there is an air flow through the construction of the pitched roof area in such a way that the effect of the thermal insulation is lost. Especially the wind induced ventilation due to leaky eave or ridge details and unsealed underlay caused a tenfold increase of the heat flux nearby the eaves. The in-situ measurements show further a clear relation between rising wind speed, wind direction and the increasing heat flux as well as the decreasing inside surface temperatures.

1. Introduction

As already shown in Hens (1992) pitched light weight roofs with thermal insulation should be fully insulated air- and windtight sandwich constructions, where the diffusion resistance of the sub-roof can never be to small. Heat conduction seems to be just one of the factors causing heat transport, especially wind washing and wind and stack induced air flow through the building envelope insulated with mineral wool are important factors. Today the most common building practice for light weight pitched roof constructions in Austria is the described compact system with no intended air flow in or above the thermal insulation, as shown in figure 1. Janssens (1998) showed that appropriate air tightness is needed in order to guarantee a correct hygric and thermal performance of pitched roofs. The need of an AFVR and the requirements regarding to an airtight layer at the inner side of the construction are well defined in Austrian building standards and accepted in the building practice. However at present no one really cares about the wind tight layers of pitched roof constructions, especially in the area of connections and transitions. There is no regulation or Austrian standard which deals with wind tightness of the building envelope. The reason for the objective in-situ measurements were complaints from occupants of different single occupancy and apartment houses about the thermal comfort and performance of their houses. In fact there were inconvenient low surface and operative temperatures and uncommon high heat losses caused by wind induced airflow through the constructions.

The heat transport as a whole in a fiber glass thermal insulating material consisting of 95 % air is dependent to the heat conductivity of the fibers respectively air, to the heat radiation transport in the air, as well as to the convection caused by the air movements in or through the material (compare Økland (1998)). Rotational flows, flow through, local outdoor air flows around the roofing or other kinds of infiltration never appear separately. In fact it is a complex combination of all these flows. Hens (1992) showed a monotone increasing of thermal losses according to wind speed and temperature differences, the highest heat fluxes at the inner sheeting in the eaves area and that there is also a constrictive rotational flow in completely filled roofs caused by the high air permeability.

2. In Situ Measurements

The measurements were made in different single occupancy and apartment buildings each in the most wind sensitive rooms. The tested buildings are all located in a very wind exposed position in Austria and built like shown in figure 1.

The underlay foil with overlaps is not sealed and there is no wind tight connection with the seam sheeting and the seam gutter. The attic volume is vented and there is no airtight layer on the thermal insulation to provide wind washing and convection effects. In the eaves area the ingress of air into the thermal insulation takes place by numerous leakages. The air leaks through the ventilated attic. The present flow resistance of the thermal insulation is very low caused by the high air permeability of the mineral wool and the short distance (2,0m) between air inflow at the eaves and outflow in the attic.

The actual state without an adequate airtight AFVR and the improved state after tightening the AFVR as well as the impact of wind speed and direction on the heat fluxes were investigated:

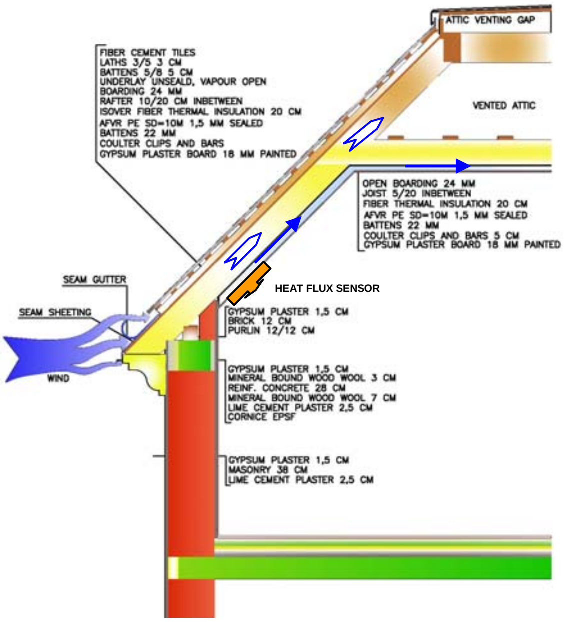


FIG. 1: System Cross Section of a tested one family house – top floor; points of wind infiltration

2.1 Thermal Performance

During the observation period outdoor air temperature, wind speed and wind direction were recorded with a Vaisala, QML 101 weather station. In the most wind sensitive room air temperature (PT 100, M-FK 222, Heraeus), relative humidity (humichip, Vaisala), surface temperature (PT100) at different points and heat flows (heat flux measuring film, RdF, typ 20457) at the interior surfaces were monitored. The dynamic heat loss coefficient was calculated according to formulae 1.

$$U^*(t) = \frac{\overline{q}(t)}{\overline{T}_i(t) - \overline{T}_e(t)} \qquad (1)$$

U^*	current heat loss coefficient in W/m²K (equals heat loss per m² according to a temperature difference of 1 K), hourly mean value
$\overline{q}$	Hourly mean value of the heat flux density at the interior surface in W/m²
$\overline{T}$	Hourly mean value of the interior- and outdoor air temperature in °C

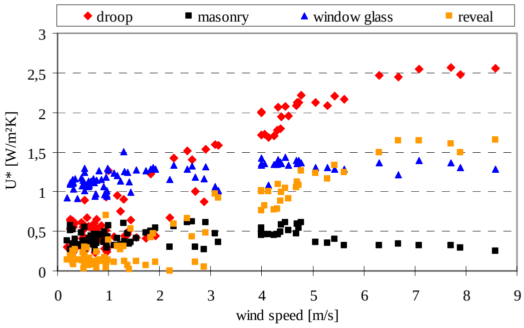


FIG. 2:correlation between wind speed and current heat loss coefficient - different building elements

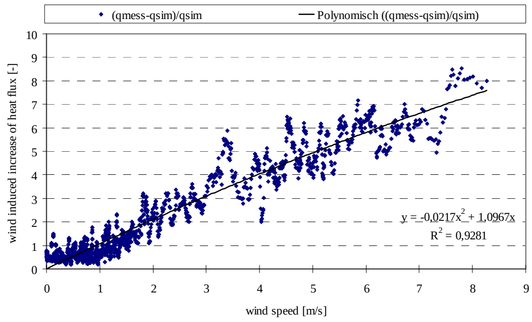
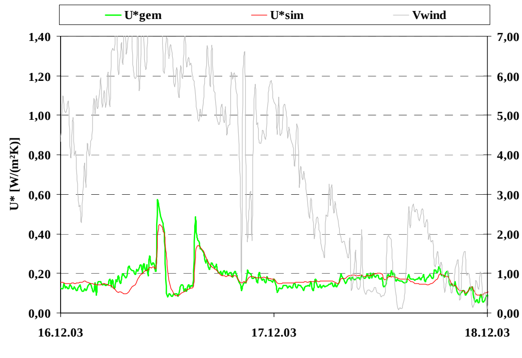


FIG. 3: correlation between wind speed and increase of heat flux in the droop area according to the simulation

Figure 2 shows the u-factor of the droop area between the rafters for a wind speed over 6 m/s, which tends towards 2.5 W/m²K (only the 50 mm air gap and 15 mm gypsum plaster board take thermal effect), and the u-factor of the reveal area, which tends to 1.6 W/m²K (5 cm timber and the 15 mm gypsum plaster board take thermal effect). In Houvenaghel et. al. (2004) is shown that in compact roofs especially internal air rotation causes a rising heat flux. Rotation lowers the apparent thermal resistance over a heating season by 9% from what is theoretically expected. In figure 3 a much more dominant effect according to the heat flux is shown caused by wind intrusion.

Because of the dynamic effects of the construction a simulation was necessary to get reference data. To compare the measurements the dynamic simulation model was created with MatLab – Simulink (compare Sasic Kalagasidis A. (2004)). Figure 3 shows the correlation between measured wind speed and the increase of heat flux at the eaves according to the simulation with Simulink based on the measured boundary conditions.

Figure 4 indicates the well fitting simulated and the measured dynamic U*-value at the leeward side of the building and the measured wind speed. Whereas Figure 5 shows the wind dependent measured dynamic heat loss coefficient compared with the simulated one.



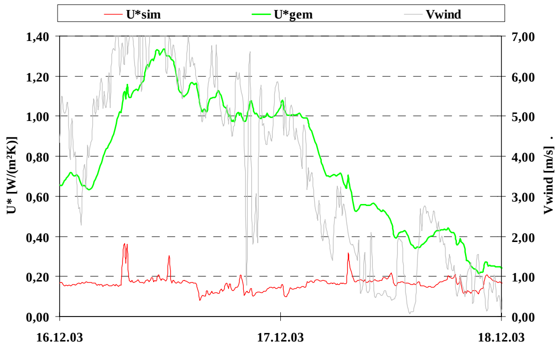


FIG. 4: Dynamic U-value leeward apart side *FIG. 5: Dynamic U-value windward side*

It was clearly shown by the measurements, that there is a wind induced rising of the heat losses especially in the eaves area.

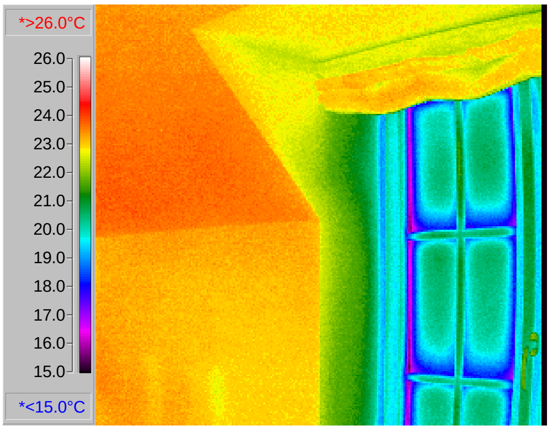


FIG. 6: Thermography at wind speed 0 m/s

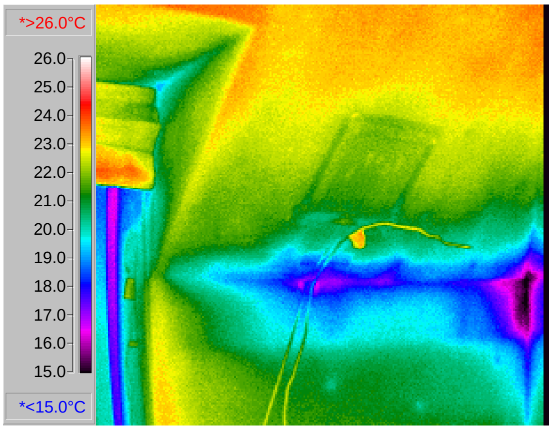


FIG. 7: Thermography at wind speed 7 m/s

Figure 7 shows the wind induced reduction of the interior surface temperatures (approx. 5 K) at the windward side of the building in the eaves area (jamb wall) compared to no wind effect at figure 6.

Based on the present temperature profiles of the indoor surfaces at wind speed of approx. 7 m/s and 0 m/s (figures 6 & 7) a thermal bridge calculating was created with Therm 5.2 (Lawrence Berkeley National Laboratory (LBNL), 1993). Figures 8 & 9 show the created thermal behaviour of the construction with and without wind influence. The increase of heat flux calculated with Therm and the difference of the measured heat flux according to the simulated one is approximately the same (661% - 660%).

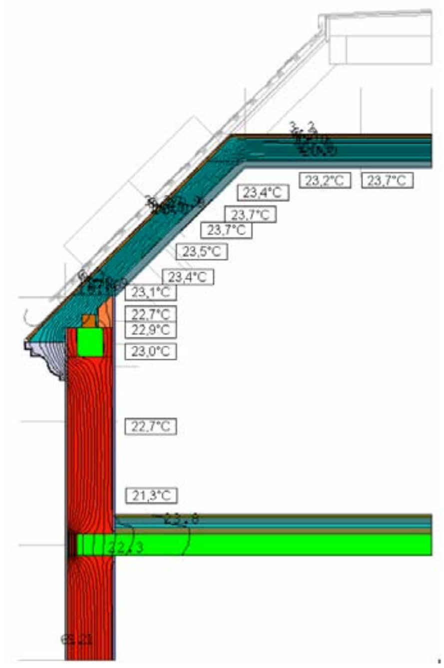


FIG. 8: Cross section at wind speed 0 m/s

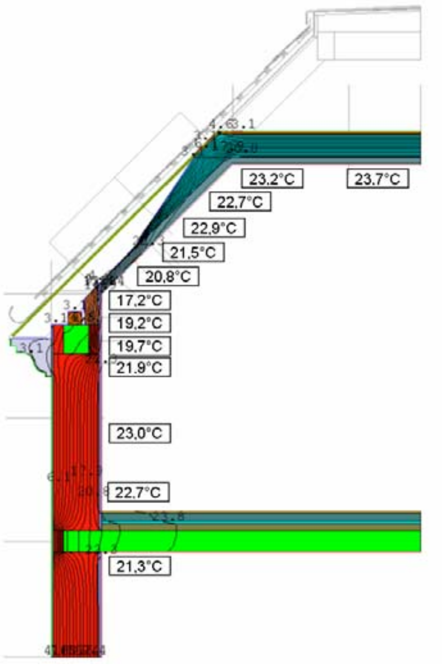


FIG. 9: Cross section at wind speed 7 m/s

2.2 Air Propagation

FIG. 10: a:General View Tested Eaves; b:Outside Horizontal Cross Section Eaves; c: Open Seam Sheeting

To qualify the air infiltration in the construction some air quality sensors (Figaro TGS 2600) were attached in the construction, the relative humidity (humichip, Vaisala), air temperature (PT100) and pressure difference (halstrup & walcher, Delta_p) were measured in the attic, the room and outdoors. Ethyl alcohol was dosed (atomized spray) to a certain point at the eaves (seam sheeting, gutter) at different wind conditions and the migration in the construction was measured. Figure 10a shows a general view on the tested eaves area, Figure 10b is a horizontal cross section through the roof construction in the eaves area and Figure 10c points at the cracks of the seam sheeting.

The curves shown in in Figure 11 are measured before the reconstruction had started and studies the air flow in the construction.

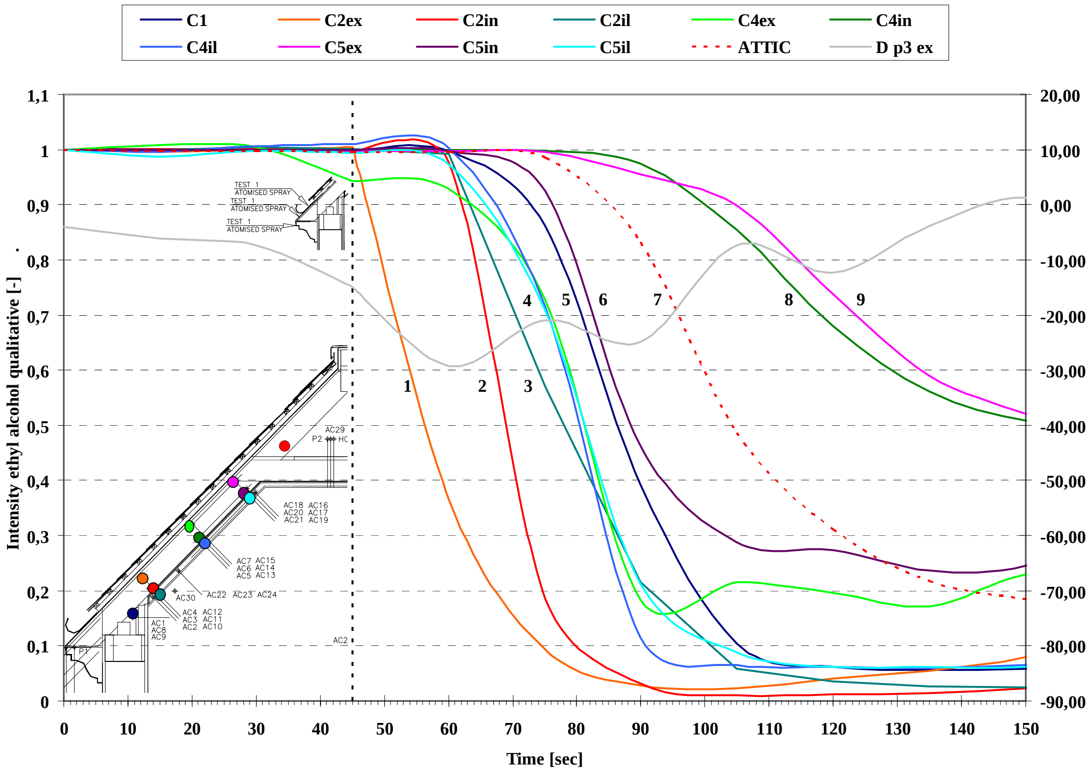


FIG. 11: Ethyl Alcohol Intensity qualitative - before reconstruction, $\Delta T < 5$ K, $v_{wind} > 7$ m/s

The measured pressure differences during the test period between the attic and the eaves are displayed as the grey curve and have a range of an average 10-20 Pa.

At high wind velocities the outside air charged with ethyl alcohol is entering the thermal insulation layer and in thence the attic very quickly (C2ex: 1s; C4ex: 24s; C5in: 29s; Attic: 38s). The air intrusion into the construction acts through cracks at the eaves and under the seam sheeting and through the ventilated attic.

Unlike figure 11 figure 12 shows the long time needed by the charged air to reach the thermal insulation layer (C2ex, C2in: 120s) without high wind velocities. In the rest of the construction there is only some kind of diffusion and air flow through very small leakages viewable.

Test 6 shows that if the ethyl alcohol is sprayed in the seam gutter the air is very quickly transported through the ventilation into the attic (attic: 1 s). The charged air infiltrates the thermal insulation (C4ex & C4in) and also the installation layer (C5) from the attic.

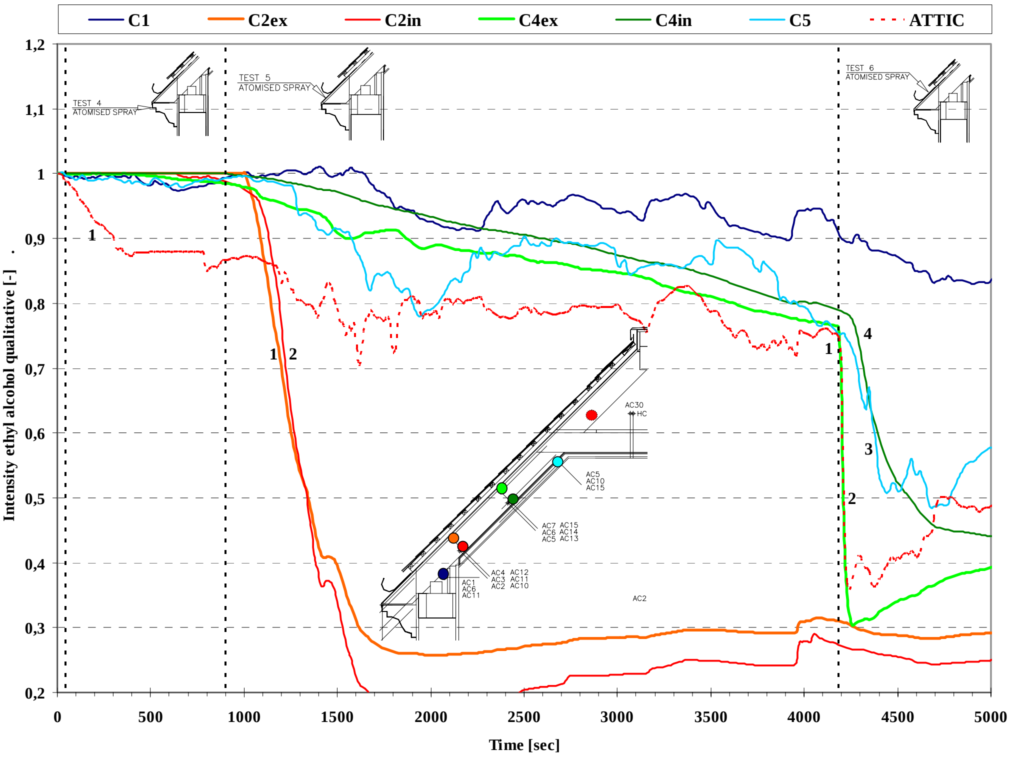


FIG. 12: Ethyl Alcohol Intensity qualitative-after tightening the AFVR, $\Delta T < 5$ K, $v_{wind} < 2$ m/s

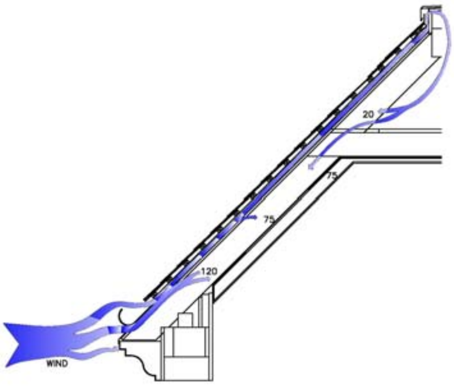


FIG. 13: air flow path through the construction $v_{wind} < 2$ m/s

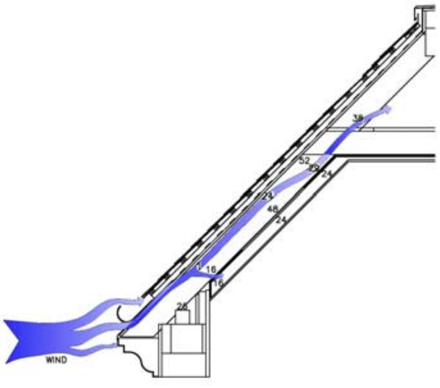


FIG. 14: air flow path through the construction $v_{wind} > 7$ m/s

Figures 13 & 14 show the air flow path through the thermal insulation with a wind speed lower than 2 m/s and higher than 7 m/s. The values in the figures describe the allocated time period, which is needed by the charged air to infiltrate the construction. Figure 13 is according to figure 11 and figure14 to figure 12.

3. Conclusions

This paper presented measured results of the wind dependent thermal performance of pitched roofs of single occupancy houses in Austria.

It was clearly shown by the measurements, that there is an air flow through the construction of the droop, in such a way that the effect of the thermal insulation is lost.

The magnitude of the wind effect depends on the orientation of the roof relative to the wind and of course on the quality of the workmanship and the construction detail of the eaves and the ridge.

The raise of thermal heat demand per anno caused by wind induced flow through the light weight construction based on Austrian wind statistics is not economically relevant.

Rising heat fluxes during periods of high wind speeds could only cause problems if there is a inertial heating system (e.g. floor heating systems) which cannot assure a comfortable operative temperature.

If a proper climate protection has to be achieved the building envelope as whole and especially the light weight pitched roof constructions have to be built wind- and airtight.

It is important to analyse all this kinds of air intrusion and probably air convection and their influence to the thermal heat demand and the durability of constructions and to define requirements for standards to make sure that the thermal performance and the durability of light weight building envelopes is ensured.

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