Solving problem of airflow in the open air space in double pitched roofs of passive objects with concrete cover

J Plachy¹, J Šál¹

¹ Department of Civil Engineering, the Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 Czech Budweis, Czech Republic

E-mail: plachy@mail.vstecb.cz

Abstract. The paper deals with air flow in open air gap in pitched roofs with folded roofing. The sloping roof is thermally insulated to the passive standard. Double-skinned roofs work with the drainage of moisture from the air gap based on the difference in water vapor pressure that is generated by the warming of the air gap. Moisture removal is suppressed due to the large thickness of the thermal insulation. The paper compares experimentally measured values with values obtained by calculation using the appropriate computer software. For experimental verification of the air flow, a model of the roof cladding was constructed, on which air flow in the air gap was verified. There was no air flow on the roof model. In the theoretical calculation the flow occurred.

1. Introduction

Currently, the trend of building construction towards passive buildings is heading. The recommended heat transfer coefficient values for passive buildings are Upas, 20 = 0.15-0.1 W / (m².K). [1]. These buildings are covered with flat roofs with cladding or pitched roofs with folded roofing. This covering can be heavy (concrete, ceramics) or light (metal).

Roofs can be made as single-shell or double-shell. For double-skinned roofs, a ventilated air gap is designed between two roof claddings.

Double-skinned ventilated roof structures work on the principle of water vapor moisture removal depending on the air flow. The air flow is caused by the difference in the specific air masses in the gap due to the warming of the air from the interior, due to the radiation of the night sky, the influence of the outside air flow and the different amount of water vapor in the air. Previously, warming from the interior was critical. Warming is greatly reduced with increased thermal insulation thickness. In order to know how the roof works, it is necessary to answer the question of how the air flow in the ventilated roof structure occurs when the insulation thickness is higher.

According to our information nobody has dealt with this issue in detail yet and our article. [2]. This article deals with air gap flow in double-skin roofs with lightweight sheet metal roofing. This contribution follows the previous research. The standard ČSN 731901: 2011 [3] solves the problem of air flow in the air gap by the lack of air gap thickness without further explanation.
2. Material and methodology

The airflow verification methodology in the openair gap is based on two points. The theoretical verification will be done by calculation in the relevant software and experimental verification on the assembled roof section model.

2.1. Theoretical verification

For the calculation of the design of double-skinned roofs, the Czech Republic has traditionally used the methodology ČSN 73 0540-4. [1] The methodology of this standard does not allow for the spatial complexity of roofs, the influence of sunlight or the effect of radiation exchange with the sky.

The theoretical verification was carried out in the program MEZERA, which works according to the above standard and is accessible at VŠTE. The program has a Windows user interface. The program works on the principle of one-dimensional stationary conduction of heat and water vapor. More information about the program is available on the website of K-CAD. [4].

Program output:
- airflow velocity in the air gap
- air gap temperature
  all depending on:
  - thermal insulation thickness
  - air gap thickness
  - roof slope.

2.2. Experimental verification

In the VŠTE laboratories, a real roof cladding model was constructed to simulate boundary measurement conditions. The model size is 2 x 3 m. Shown in Figure 1. The model was installed indoors to eliminate the effect of wind. The model can be imagined as a sample roof section representing a field between 2 rafters with a variable slope of 0 ° to 35 °. The thermal insulation is placed above the rafters.

Figure 1. Roof model for experimental verification of air gap airflow. Source: own.

The roof structure consists of:
- concrete tile covering,
- battens 40x60 mm,
- contra battens 40x60 mm,
- air cavity (of adjustable height with levelling screws), thickness 40 - 150 mm,
- additional waterproofing layer (AWL) - breather underlay, three-layer high diffusion under-
  roof membrane (diffusion film and two layers of polypropylene film). Breather waterproof
  roofing underlay manufactured by thermally bonding outer spunbonded polypropylene layers
  and inner layer of microporous polypropylene film for pitched supported.
- thermal insulation of hard polyurethane foam boards, $\lambda_D = 0.021$ W / (mK), thickness =
  220mm
- vapor barrier, four-layer film (reinforcement grid and two layers of polyethylene laminate film
  and reflective aluminium foil). Vapor barrier manufactured as multilayer polyethylene sheet
  reinforced with tear-resistant mesh with heat reflective aluminized surface to be used against
  vapor and moisture penetration in pitched construction.
- rafters

The air gap in which the air temperature and the air flow rate were measured is made adjustable. Its
thickness can be adjusted from 60 to 140 mm with 4 adjustment screws. The model was clad to
achieve the necessary conditions for the roof. The cladding was made with an oriented strand board
(OSB) on which 180 mm thick expanded polystyrene (EPS) boards were attached. This cladding was
made from all four sides and covered from the top. The cladding was not made under the structure.
Indoor boundary conditions were provided by the heated laboratory interior. The exterior boundary
conditions were ensured by a closed stripped space in which cooling is located.

An aggregate and liquid vaporizer were used to cool the insulated space. In the model the
evaporator was placed above the roof covering so that it could be moved as required. The need to be
able to change the pitch of the roof meant the connections to the evaporator needed to be flexible.

The measurement will be continuously recorded using the Ahlborn ALMEMO 5690-2M universal
measuring center. Eight probes were used for the measurements. These probes were calibrated before
the experiment. Six probes measured only the temperature (probes 1, 2, 3, 5, 6 and 7) and the
remaining two probes measured the air flow velocity (probes 4 and 8). The probes were positioned in
the air gap (inlet, middle and outlet port) and in the cooled compartment (above the covering) and
inside (under the roof structure). The positions of the probes are shown in Figure 2.

Figure 2. Probe position for temperature and air velocity measurement. Source: [3].

**Probe description:**
Probe 1  ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
  Location: air gap, at the inlet port;
Probe 2  ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
  Location: inside the model in the same place as the evaporator (exterior) above the inlet port;
Probe 3  ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
  Location: air gap, in the middle of the length of the model;
Probe 4 ALMEMO FVAD 35 TH5, - air velocity m/s, pressure and temperature of the air (this sensor has a control function for the air temperature measured at probe 3) (accurate to 0.01 m/s)
Location: air gap, in the middle of the length of the model;
Probe 5 ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
Location: under the model, between the rafters (interior);
Probe 6 ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
Location: air gap, at the outlet port;
Probe 7 ALMEMO ZA 9020-FS Thermo E4, - temperature °C (accurate to 0.1°C)
Location: inside the model in the same place as the evaporator (exterior) above the outlet port;
Probe 8 ALMEMO FVAD 35 TH5, air velocity, air pressure and temperature (this sensor has a control function for the air temperature measured at probe 6) (accurate to 0.01 m/s)
Location: air gap, at the outlet port.

3. Results of tests

3.1. Theoretical verification.
The theoretical calculation is based on the above-mentioned publication [2]. The calculation has been extended by further gradients. Three slopes of 10, 22 and 30 ° were selected. The slopes were chosen with regard to the real application of the concrete covering. The thickness of the air gap of 100 mm was chosen with respect to ČSN 731901: 2011 [3].
Theoretical calculation in the MEZERA program was made for boundary conditions on the roof model:
Rafter length: 2415 mm, Inlet opening: 0.092 m², Outlet opening: 0.092 m², Hole rise: 0.42 m for 10° inclination, Hole rise: 0.90 m for 22 ° inclination, Hole rise: 1.21 m for inclination 30° \( \theta_e = -17°C \) (-50°C), rel. humidity 85% (95%), \( \theta_{ai} = + 21°C \), rel. humidity 50%, wind speed \( v = 0 \) m/s, Aerodynam. factors \( C_1 / C_2 = 0.6 / -0.3 \).
The results are shown in Table 1, 2.

3.2. Experimental measurements
Three measurements were taken for about 12 hours. Measurements were made for the air gaps of 100 mm and slopes of 10°, 22° and 30°. See results. Table 3,4. The table contains maximum temperatures.

Table 1. Air flow temperature in air gap depending on air gap length. Source: Own.

| Rafter length (m) | 0.00 | 0.51 | 1.02 | 1.53 | 2.04 | 2.55 |
|------------------|------|------|------|------|------|------|
| Air temperature (°C) for 10° inclination. | -17.00 | -16.86 | -16.76 | -16.68 | -16.62 | -16.57 |
| Air temperature (°C) for 22° inclination. | -17.00 | -16.90 | -16.81 | -16.74 | -16.69 | -16.64 |
| Air temperature (°C) for 30° inclination. | -17.00 | -16.91 | -16.83 | -16.77 | -16.72 | -16.67 |

Table 2. Airflow velocity (m / s) in the air gap depending on the air gap height and roof slope. Source: Own.

| Roof slope (°) | 10   | 22   | 30   |
|----------------|------|------|------|
| Air velocity (m / s) | 0.0804 | 0.1117 | 0.1282 |

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### Table 3. Air flow temperature in air gap depending on air gap length. Source: Own.

| Rafter length (m) | 0.00  | 1.27  | 2.55  |
|-------------------|-------|-------|-------|
| Air temperature (°C) for 10° inclination. | -17.00 | -15.90 | -13.60 |
| Air temperature (°C) for 22° inclination. | -17.50 | -15.70 | -15.00 |
| Air temperature (°C) for 30° inclination. | -17.30 | -16.40 | -14.50 |

### Table 4. Airflow velocity (m/s) in the air gap depending on the air gap height and roof slope. Source: Own.

| Roof slope (°) | 10  | 22  | 30  |
|----------------|-----|-----|-----|
| Air velocity (m/s). | 0.0 | 0.0 | 0.0 |

### 4. Discussions
The theoretical calculation showed air flow in the gap with selected heat transfer coefficient $U = 0.11 \text{ W}/(\text{m}^2\text{.K})$. The calculated speed was $0.0804-0.1282 \text{ m/s}$. Experimental airflow was not measured. There was no flow in the gap of the roof structure model, although different temperatures at the beginning and end of the gap were measured. The temperature gradient was from 2.5 to 3.4°C. Output temperatures must be re-verified. The device in the gap was able to measure the flow rate from 0.01 m/s). Heating the cavity from the interior was not sufficient to move the air based on the difference in specific air weights in the gap. The different result can be justified by the software used, which works with one-dimensional stationary heat conduction. This simplification is likely to be reflected in the result.

### 5. Conclusions
The experiment showed that if the roofs of passive houses are not exposed to the radiation of the night sky and the flow of outside air, there is no air movement in the gap.

If further research confirms that there is very low air flow in these structures, it will be necessary to consider this issue in more detail. Increased relative humidity in the ventilated roof gap leads to additional problems. These include the formation of condensate, the increased moisture content of wooden structures, thermal insulation and thus the life of these structures.

### References
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