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INVESTIGATION OF AIR FLOW IN A TWIN ROOFS OF RESIDENTIAL HOUSES

Деякі види плоских дахів з малою висотою вентильованого повітряного прошарку мають певні проблеми з тепловологісним режимом. Нижчі температури поверхні внутрішніх конструкцій у повітряному прошарку даху та надходження нагрітого і вологого повітря з внутрішнього середовища будинку у повітряний прошарок призводять до конденсації водяної пари на холодних внутрішніх поверхнях конструкцій дахів. Такий вид плоских дахів використовували в нашій країні в кінці XX століття. Конструкцію плоского даху розділено на дві частини, між якими знаходиться вентильований повітряний прошарок завтовшки 150 мм. Багатошарова конструкція над повітряним прошарком захищає будівлю від дощу і снігу, а багатошарова конструкція під повітряним прошарком захищає будівлю від теплових втрат. Багато проблем виникало при прокладанні вентиляційних каналів або каналізації через таку конструкцію даху. Центральна система труб для вентиляції квартир (кухня, туалет і ванна кімната) проходить через конструкцію даху, але повітропровід не пов'язаний безпосередньо з центральним вентилятором повітря на даху. Через конструкцію даху відбуваються витоки повітря. Такі місця є шляхом для природного руху теплого і вологого повітря з опалювального приміщення в повітряному проміжку даху. Мета статті полягає в тому, щоб отримати відомості про швидкість руху повітря, внутрішні температури поверхні в повітряному прошарку існуючого плоского даху та потенційних місць конденсації вологи за допомогою CFD-аналізу. В дослідженнях було використано CFD інструмент ANSYS CFX.

Ключові слова: плоский дах, CFD, конденсація вологи.

Some kinds of flat roofs with low height of ventilated air gap have certain problems with thermal and moisture regime. The lower surface temperatures of internal constructions in the air gap of roof and presence of hot and moist air in the air gap from indoor environment of building causes condensation of water vapour at the cold surfaces of roof internal constructions. This kind of flat roofs was used in our country at the end of the 20th century. The used construction of flat roof is split in two parts. Between them is ventilated air gap. The thickness of the air gap is 150 mm. Multilayer construction over the air gap protects the building against rain and snow. Multilayer construction under the air gap protects the building against the thermal losses. Many problems were at that time with the quality of work, with realization of roof penetrations by building equipments such as ventilation duct or canalization. The central ductwork for ventilation of flats (kitchen, toilet, and bathroom) enters to the roof chamber but the ductwork is not directly connected with the central roof air fan. In the roof construction are many leakages. These places represent the path of natural motion of warm and humid air from heated space into the air gap of roof. The aim of this article is to gain the view on the air velocity, internal surface temperatures in the air gap of existing flat roof and potential places of air condensation by using CFD analysis. We used commonly used CFD tool ANSYS CFX.

Key words: flat roof, CFD, air condensation.

Introduction. It is a fact that flat and low-slope roofs demand careful detailing and good workmanship. Flat roofs and low slope roofs also face potentially serious condensation problems that can in turn lead to costly rot or mold damage in buildings. The most common flat and low slope roof leaks occur at flashings and roof penetrations such as at plumbing vents, chimneys, and roof-mounted air conditioners or heat pumps. Roof flashing details that are not designed to absorb thermal or other building movement (thermal expansion of materials for a table of the coefficient of expansion of common building materials including brick, concrete, mortar, and stone) can lead to cracked broken metal flashings that leak badly into the building. While a well-installed flat or low slope roof can keep outside rain or snow-melt out of the building, water entering the roof cavity from inside the building in the form of water vapour can be more troublesome [4].

However even a compact-roof with good indoor vapour barrier design can suffer from under-roof moisture condensation, that is, condensation under the roof inside the occupied space, if the building interior moisture levels are excessive and proper ventilation or dehumidification are not provided. Condensation within a flat roof mainly occurs during cold weather when moisture vapour in the air which has been generated within the heated building rises from the room below into the cold roof void above the ceiling. When the temperature of the vapour falls to or below its dew point the water vapour condenses on cold surfaces [5].

The text above describes flat and low slop roofs without ventilated air gap. In our climatic conditions were designed the flat roofs with ventilated air gap. The construction of flat roof was split by the air gap in two parts. Multilayer construction over the air gap of the flat roof protects the building against rain, snow etc. Multilayer construction under the air gap of the flat roof protects the building (heated space) against the thermal losses. The vapour barrier is not used in this flat roof construction. In the external walls of roof construction were situated circular openings for inlet and outlet of air. The problem with flat roofs particularly with low height of air cavity is that there is no chimney effect. When the wind does not blow the air motion in the air gap is approximately zero.

Geometrical model and boundary conditions. The geometric model of flat roof was created in the first step. The next fig. 1 shows the view on the flat roof from the top. The highlighted part (dashed line) was used for the CFD analysis. The thickness of the air gap is 150 mm. The next table 1 contains all details about other boundary conditions.

Table 1

Boundary conditions

Diameter of air inlets/outlets (circular openings) in external walls	60 mm
Physical model	non-isothermal
Radiation model	surface to surface
Outside air temperature	-5.0 °C
Air velocity of wind	2.0 m/s
Outdoor relative air humidity	80 %
Turbulent model	k-epsilon
Air temperature of heated space (room)	22.0 °C
U-value (construction under air gap of roof)	0.52 W/(m^2.K)
U-value (construction over air gap of roof)	2.94 W/(m^2.K)
Dimensions of vertical ventilation shaft (duct)	200 x 200 mm
Air temperature in the vertical ventilation shaft (duct)	22.0 °
Air velocity in the vertical ventilation shaft (duct)	0.75 m/s
Indoor relative air humidity	40 %

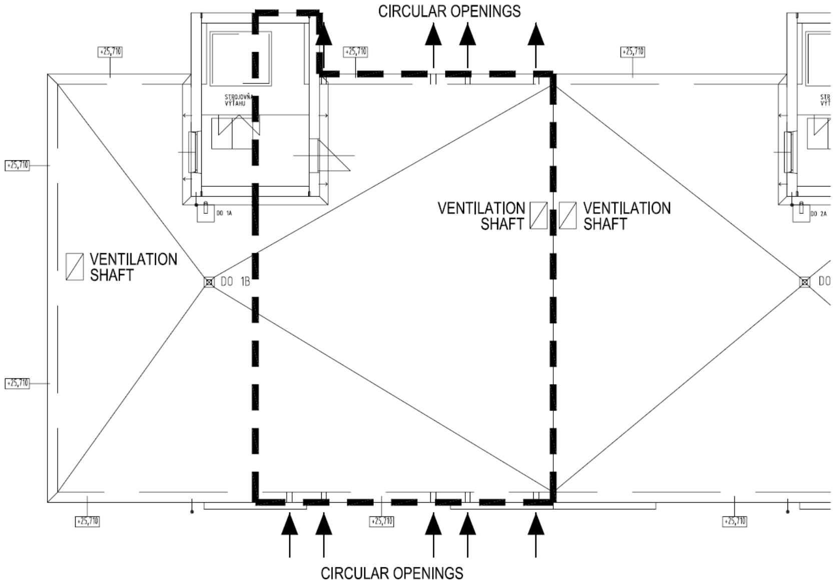

Fig. 1. The top view on the flat roof

The air temperature in the vertical shaft is from 22 °C to 25 °C, air velocity from 1.5 m/s to 2.5 m/s and the relative humidity from 40 % to 50 % [3]. The next figure 2 illustrates the detail of roof construction at the place of vertical shaft. The central vertical ductwork for ventilation of flats (kitchen, toilet, and bathroom) enters to the roof chamber but the ductwork is not directly connected with the central roof air fan. Its function was to pull the air from the roof chamber to the exterior. But the reality was another. The air fan did not work and the air from ductwork was accumulated in the chamber (overpressure). In the roof construction are many leakages because of the poor quality of works at that time. These places represent the path of natural motion of warm and humid air from heated space into the air gap of flat roof. Warm and moist air (air temperature $\theta a = 22$ °C, relative humidity $\varphi a = 40$ %) from heated space of building could get into the air gap of roof and could condense in these parts of the air gap with cold surfaces.

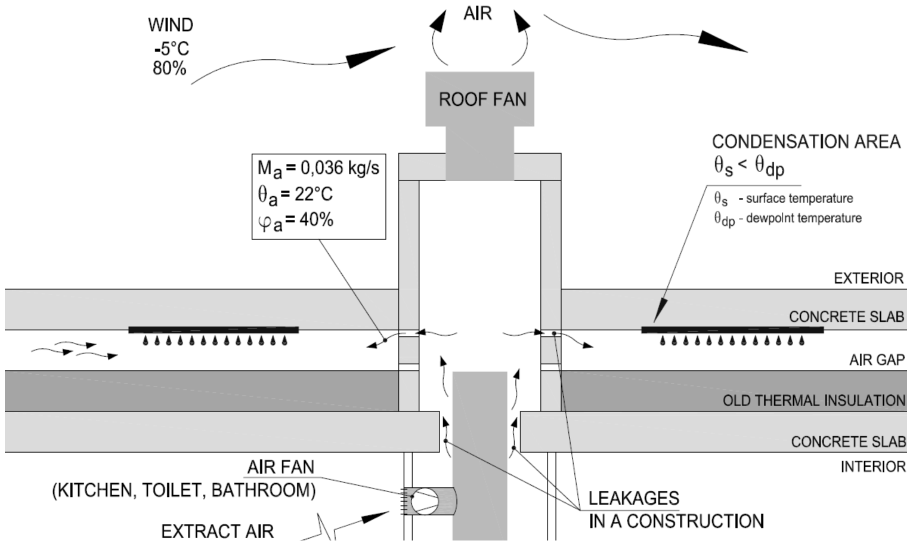

Fig. 2. Sketch of double skin roof with vertical shaft and leakages in roof construction

Analysis of results. The next fig. 3 shows air temperature in the air gap of the roof by the wind velocity at the value of 2.0 m/s and outdoor air temperature at the value of -5.0 °C. In the left top corner is the air temperature the highest because there is the outlet from the vertical shaft with the warm and moist air. The next fig. 4 shows motion of air from the vertical shaft into the air gap of flat roof. The warm and moist air blows directly out.

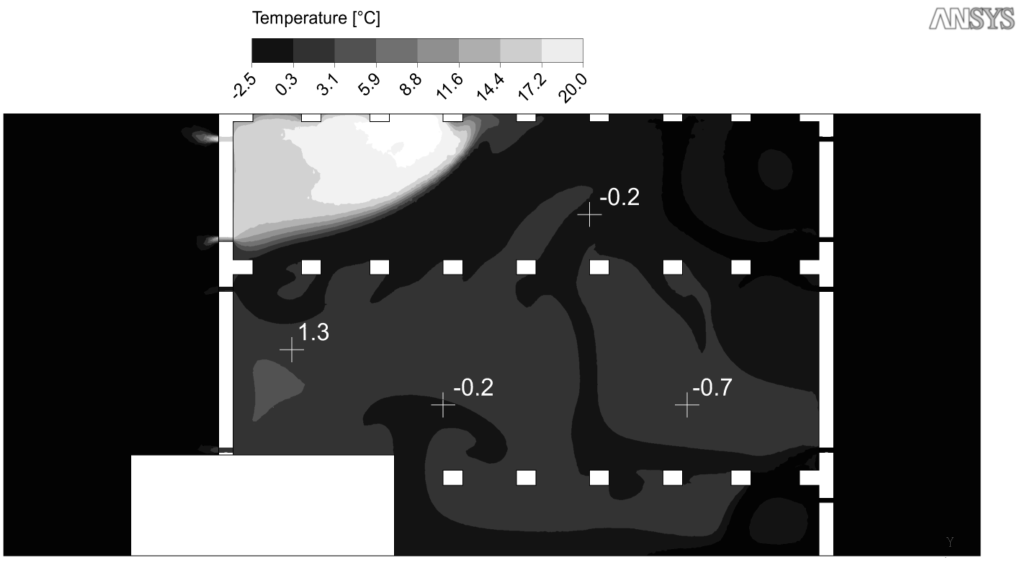

Fig. 3. Air temperature in the air gap

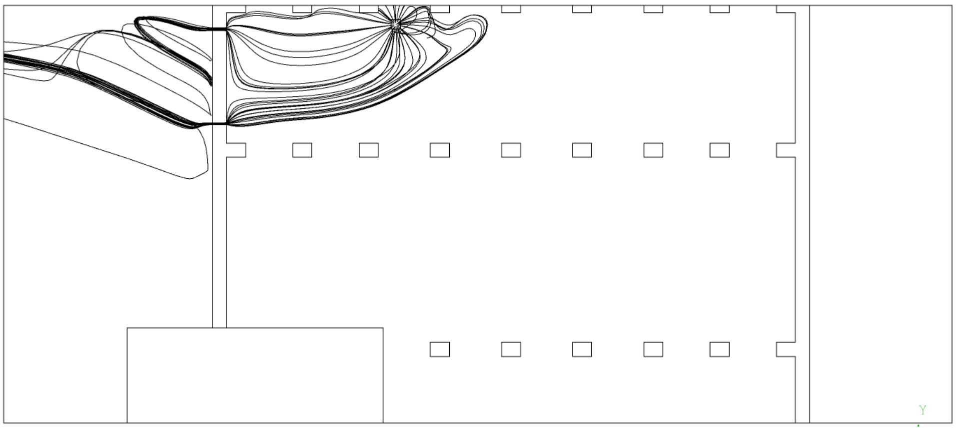

Fig. 4. Motion of air from the vertical shaft

In the most places the internal surface temperature of construction in the air gap is low according the fig. 5. In the left top corner the internal surface temperature of roof construction is the highest because there is the outlet from the vertical shaft with the warm and moist air.

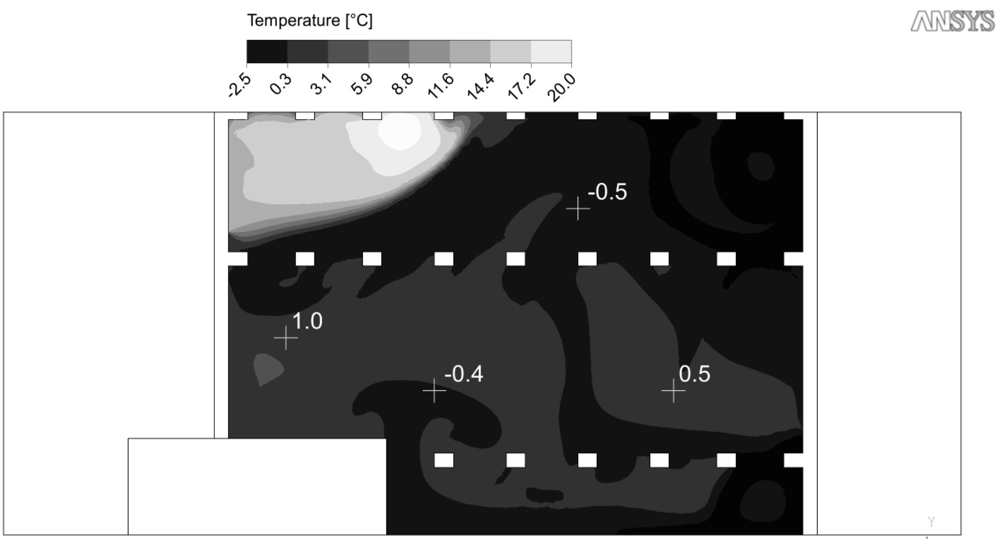

Fig. 5. Internal surface temperature of roof construction over the air gap

That was the situation when the wind blows. In the second step of the CFD analysis is simulated the situation when the wind does not blow. In the reality the wind does not blow constantly, the wind velocity is changing in time. The next figure 6 shows the air temperature in the air gap of the roof. The wind does not blow and the outdoor air temperature is the same at the value of -5.0 °C. The warm and moist air from the vertical shaft enters into the air gap and fills the space. The temperature in the air gap is changing. If we look at the previous situation the blowing wind causes the drop of the internal surface temperatures in the air gap (Figure 5). They are lower than the dew point for the warm and moist air entering into the air gap from the ventilation shaft when the wind does not blow (Figure 6). So the air condenses on the cold surfaces. The entering warm air gradually heats the internal roof construction what can we see in the next figure 8 (no wind). Look at the next figure 7 for better illustration of motion of air from the ventilation shaft in the air gap of flat roof.

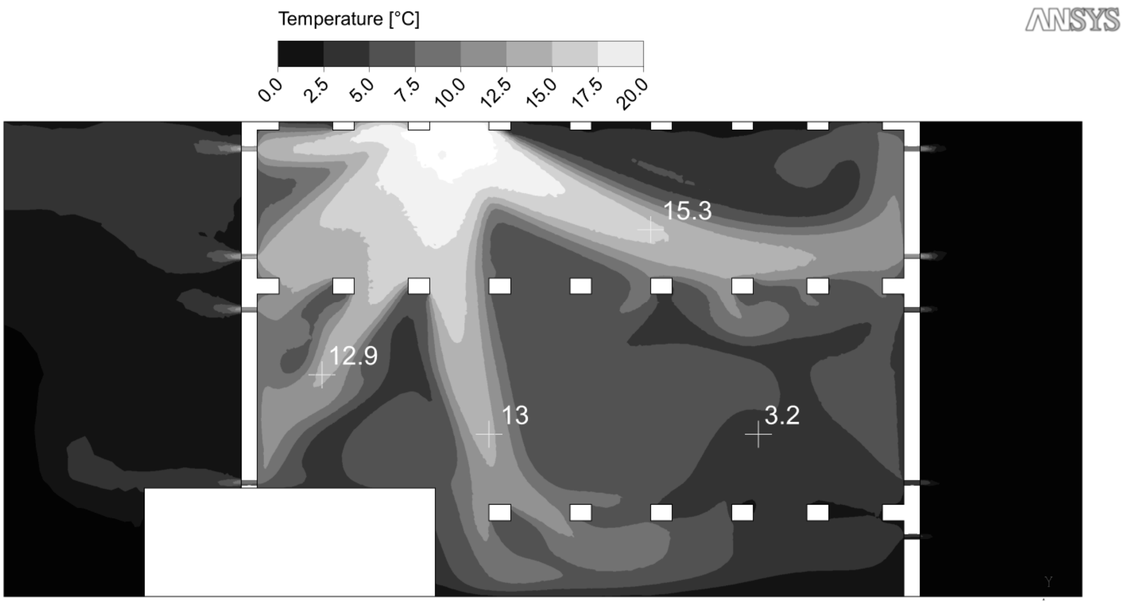

Fig. 6. Air temperature in the air gap –
the wind does not blow

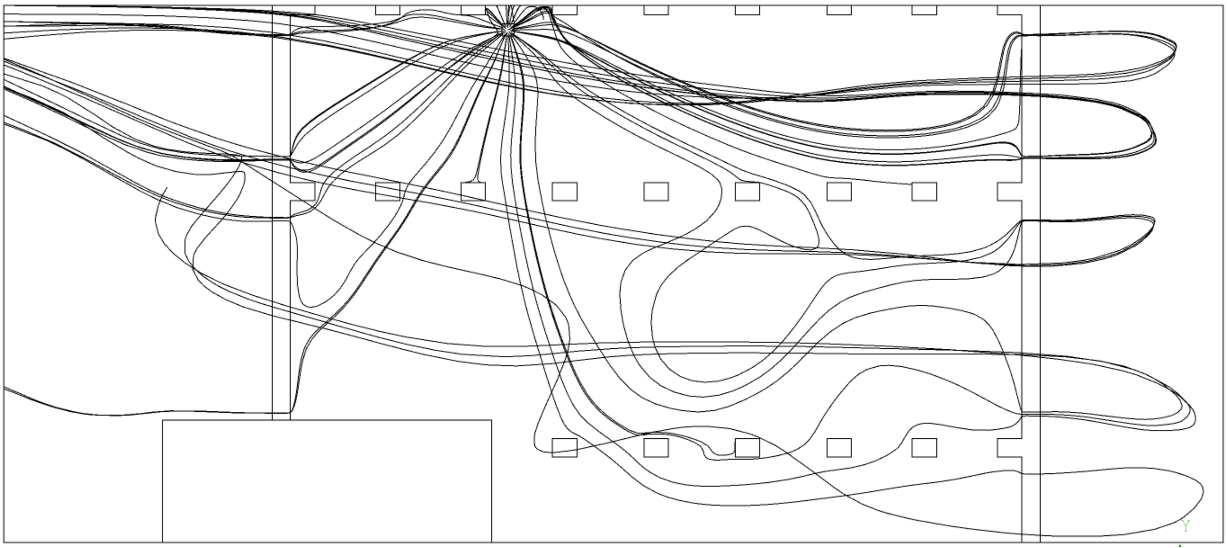

Fig. 7. Motion of air from the vertical shaft –
the wind does not blow

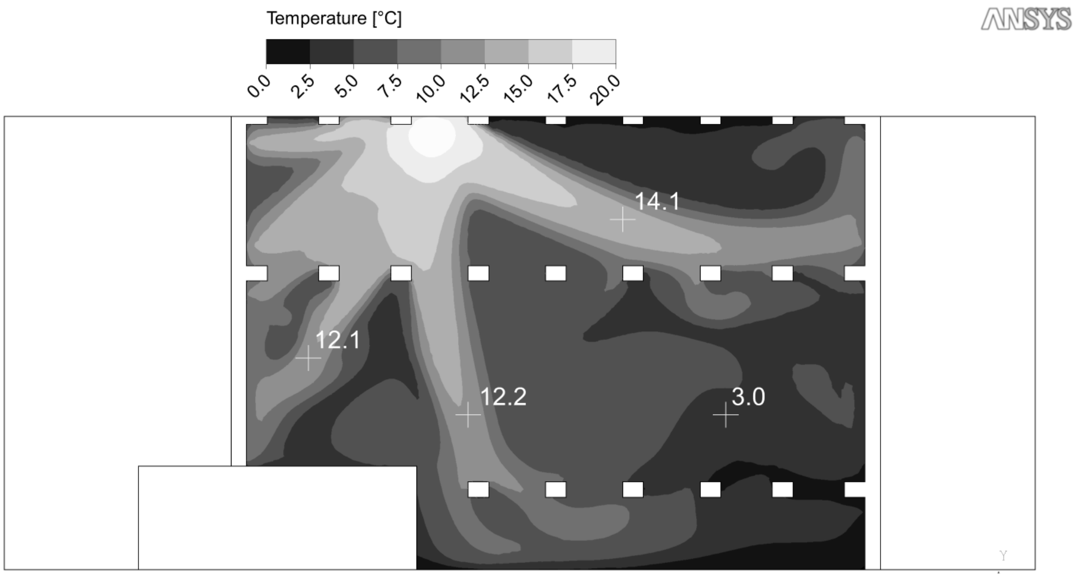

Fig. 8. Internal surface temperature of roof construction over the air gap – the wind does not blow

Conclusion. The results from this CFD simulation showed that the main problem of flat roof is at the place of vertical shaft where the ductwork is not directly connected with the air fan or wind turbine. If there is a dysfunctional air fan the warm air will accumulate in the space chamber. The warm and moist air enters into the air gap through the construction leakages where the air can condense. It is need to directly connect the ductwork to the air fan or wind turbine and close the construction leakages in the roof chamber.

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