Thermal performance of roofs suitable for developing countries in tropical climate

P Čanda and P Kopecký

Czech Technical University in Prague, Faculty of Civil Engineering, Department of Building Structures K124, Thákurova 7, 166 29 Prague 6, Czech Republic

*Corresponding email: petr.canda@fsv.cvut.cz

Abstract. Roof structures have been traditionally built from reed or straw in tropical climate locations. Now, traditional materials are often replaced by pure metal sheets. The roof construction is improved in terms of durability and cost effectiveness, but the roof built from pure metal sheets can cause excessive overheating of interior spaces. The aim of this paper is to compare dynamic thermal performance of different roof assemblies under real boundary conditions. For this purpose, a thermally insulated test box was built on the roof of the university. Six roof samples (0.9 m × 1.1 m) can be mounted on the roof. The roof covering made of pure steel sheet with Zn coating was the reference case. This assembly was then modified step-by-step either by change of colour, or by additional material layers of reed and earth boards, or by 2cm thick ventilated air cavity on the rear side of the sheet. In total, 18 different roof assemblies were tested in three consecutive test runs (approximately three-week periods between 07 – 09-2020). Ventilated air gap and white paint are the best adjustments to reduce heat flux. Dark colours of the metal sheet have the opposite effect. Influence of reed and earth boards was in many cases similar. One roof assembly was selected for use in real project.

1. Introduction

Roof assemblies for buildings located in developing countries have changed in the last decades. Straw and reed as roof covering are often replaced by factory made materials such as metal sheets. Therefore, roof constructions are more durable, faster to build and more labour effective. But they have different thermal and moisture characteristics from traditional roof materials. Metal roofs can cause overheating and thermal discomfort in buildings located in tropical climate [1]. This paper deals with a short-term experiment with the thermal performance of roof assemblies that all have a metal sheet as roof covering. Various construction alternatives with locally available building materials in Zambia were compared.

2. Experimental setup

An experimental test box was built on the roof (unshaded horizon) of the CTU in Prague. The box has a built-up area of 6.2 m × 0.8 m with a south-west oriented shed roof by a slope of 15 °. The walls and floors are made from timber frames, insulated with 60 mm of mineral wool, closed by an OSB board from the inside. Spruce planks are attached on the external side. The roof construction is composed of wooden fibre boards with a thickness of 15 mm. The boards serve as a supporting layer for all roof assemblies. The roof area is split into six 0.9 m × 1.1 m roof samples. Three test runs were performed, i.e. 18 roof assemblies were examined in total. The test run comprised approximately three weeks.
All tests were performed in the time period from June to November of 2020. Thermocouples were placed on the interfaces between individual layers of each roof assembly. Heat flux plates were stuck to the supporting wooden fibre board from the interior in all cases. In addition, global solar irradiance on the surface parallel to the roof and internal and external air temperature were measured. The data was recorded in 5-minute time steps.

| Table 1 Roof assemblies used in individual test runs (m.s. stands for metal sheet). |
|-----------------------------------------------------------|
| First test run                                           | S1 | S2 | S3 | S4 | S5 | S6 |
| unpainted m.s. (ref. case)                               |    |    |    | m.s. reed insulation board (20 mm) | m.s. unburn earth board (22 mm) | m.s. vent. air cavity (20 mm) |
| S7                                                        |    |    |    | S10 | S11 | S12 |
| unpainted m.s. (ref. case)                               |    |    |    | m.s. double reed insulation board (2x 20 mm) | m.s. double earth board (2x 22 mm) | m.s. vent. air cavity (40 mm) |
| Second test run                                          | S13 | S14 | S15 | S16 | S17 | S18 |
| unpainted m.s. (reference case)                          |    |    | m.s. painted white with vent. air cavity (20 mm), reed insulation board and unburn earth board | m.s. vent. air cavity (20 mm), reed insulation board | m.s. vent. air cavity (20 mm) and unburn earth board | m.s. reed insulation board and unburn earth board |

3. Results

A clear-sky day was looked up in each test run (see Fig. 2). The measured data in these selected days is presented in Fig. 1. The third test run was affected by lower values of global solar irradiance. Therefore, differences between individual assemblies are not so noticeable. The data from the last roof assembly (S18) was not included.

Figure 1. Measured data – heat flux through internal surface (on the left) and surface temperature measured on the bottom side of the metal sheet (on the right) of the individual roof assemblies (S1-S17) measured in selected days in three test runs.
4. Discussion

Black paint (S2) caused the highest value of heat flux and temperature of the metal sheet. On the other hand, the temperature of the white-painted metal sheet was the lowest in the first test run. The reed insulation board (S4) and unburned earth board (S5) had a similar influence on the thermal performance of the roof assembly. Air cavity (S6) also significantly decreased the interior heat flux.

The heat flux of the assembly with metal sheet and aluminium foil without any air cavity (S8) is almost identical to the reference case (S7). On the contrary, if aluminium foil was positioned in the unventilated air cavity, the heat flux and surface temperature of this assembly (S9) notably decreased. By doubling the thickness of materials used in the first test run the accumulation layer of unburn earth boards is working better than the insulation from the reed boards. A doubled air cavity (S12) led to the best results in thermal performance of assemblies incorporated in the second test run.

The third test run was based on a combination of previously measured assemblies. Reed boards (S16) and earth boards (S17) used as a layer under the air cavity did not show a significant difference to the reference case (S13). Placing both layers on each other and adding a ventilated air cavity (S15) slightly lowered interior heat flux and the surface temperature of metal sheets. White-painted metal sheet in combination with reed and earth boards (S14) led to a notable decrease of both monitored quantities.

The ventilated air cavity and white paint are simple provisions that were most beneficial for a reduction of the interior heat flux when compared to the reference assembly with a single metal sheet. Aluminium foil can be used only in combination with an air cavity, otherwise it had no noteworthy effect. Painting of the metal sheet should avoid dark colours.

5. Conclusion

The experiment demonstrated that the thermal performance of a low-slope roof composed of pure metal sheets can be considerably improved by utilizing low-cost natural building materials such as straw and reed and light-coloured external paint. The roof assembly with a reed insulation board and unburn earth board, a ventilated air cavity and white paint was selected for use in the real project of school building in Kashitu, Zambia.

Acknowledgments

This work has been supported by SGS Student Grant Competition, under supervision of department of Architectural Engineering in the faculty of Civil engineering CTU in Prague.

References

[1] Krüger, Eduardo & Djamila, Harimi & Harimi, M. & Kurian, V.J.. (2005). Assessment of Thermal Performance of Roof System with Galvanized Steel in East Malaysia.