Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 132 (2017) 333–338

Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Thermal insulation performance of reflective foils in floor cavities - Hot box measurements and calculations

Sivert Uvsløkk[a], Christian Schlemminger[a], Silje Asphaug[a]*
[a]SINTEF Building and Infrastructure, 7465 Trondheim, Norway

Abstract

In the present study both experimental measurements and calculation models have been used to investigate the practical performance of reflective foils in air filled floor cavities. The laboratory measurements were performed in a pivotal guarded hot-box. Both heat flow down through the floor area and the temperature distribution in the cavities were measured. The number of reflective foils and the amount of edge insulation at the edge beams has been varied as well as the environmental temperature conditions. Measured and calculated results show good agreement for most of the tested timber floor variants.

Keywords: Heat transfer; Themperature distribution; Floor cavities; Reflective foils

1. Introduction

Reflective foils may be applied, on certain conditions, as a supplement or a substitute to traditional thermal insulation in cavities in building envelope parts [1]. In roofs and walls in cold climate, the practical application is limited to thin cavities, giving R-values equivalent to a few cm of mineral wool. In thicker cavities in walls and roofs, natural convection will develop and dominate the heat transfer [1,2,3,4]. The thermal resistance will remain relatively constant when the air layer thickness exceeds 2 and 3 cm in roofs and walls respectively. In floors however, the thermal insulation potential of reflective foils is high [1,4,5]. In air-filled floor cavities and crawl spaces, where the heat flow direction is downwards, the air can be relatively stable and the heat transfer by convection limited even in thick air layers. The heat transfer by conduction in the stagnant air will also be small, because the thickness of the cavity is high and the thermal conductivity of air is low, about 0.025 W/(mK). In cavities with ordinary surfaces with high emissivity,

* Corresponding author. Tel.: +47-915-20-838; fax: +47-73-59-33-50.
E-mail address: sivert.uvslokk@sintef.no

1876-6102
10.1016/j.egypro.2017.09.742

the heat transfer is dominated by net thermal radiation from the hot, uppermost surface down to the colder surface of the floor cavity or to the ground. The radiation heat transfer can be limited by use of one or several reflective foils mounted horizontally in the cavity, parallel to the floor area, and on all bounding surfaces.

Low temperatures at the cold edges of the floor structure can cause considerable convection in the peripheral areas and hence a higher heat loss through the floor structure. The risk of convection in the cavities can be reduced by use of edge insulation, for instance of mineral wool, at the peripheral edges of the floor structure. Edge insulation reduces the temperature difference between the cold edge of the cavities and the air temperature in the cavities and thereby reduces the driving force for natural convection. Most serious studies of reflective foils used in building elements apply to roofs and walls, while there are relatively few studies of full scale floors, [2,3].The main objective of the present study [6] was to investigate the performance of reflective foils as thermal insulation of cavities in floors in general and in timber frame cavities in particular.

2. Methods

The study comprises full-scale measurements on a timber frame floor section in a pivotal guarded hot box as well as heat flow calculations for the same element. For building elements where the heat flux is unevenly distributed over the surface, such as timber frame structures and structures with air cavities and possible convection, it is important to make full-scale measurements to obtain representative results. Measurements by use of heat flow meters will not give reliable results. Both the heat flow down through the floor and the temperature distribution in the cavities was measured, first with the cavities filled with mineral wool, with thermal conductivity 0.035 W/mK, and thereafter with eight different combinations, variants, of cold edge insulation and reflective foils. The positions of reflective foils, with total emissivity of 0.032, are marked with red lines in the figures 4 to 6.

The overall size of the test floor structure was 3.0 m x 3.0 m and the metering area of the hot-box is 2.46 m x 2.46 m. Fans were used to apply forced convection at both the cold and hot surface of the test specimen. The air speeds were adjusted to provide surface heat transfer resistances of 0.04 and 0.11 m²K/W at the cold and hot sides respectively.

In a real house the floor structure is exposed to exterior temperature conditions both on the underside and at the edges of the floor. To study the risk of convection in the cavities at the external edges of the floor structure we had to establish realistic temperature conditions also in the hot-box set up. This was achieved by use of heat sinks of 5 mm thick aluminum plates mounted on the exterior side of the edge beams. The aluminum plates were exposed to the air in the cold box, as shown in Figure 3.

The same nine variants has also been simulated using a program for 2-dimensional heat flow, COMSOL Multiphysics® 5.2a. (https://www.comsol.com/). The modeling domain covers the entire cross section, including parts of the hot-box. The 2D-model includes heat transfer by conduction, convection and radiation which is implemented as described in [7]. Laminar flow is assumed in the cavities. In the Comsol models direction-dependent values of thermal conductivity of wood and plywood was used. The thermal conductivity in the fibre direction is estimated to twice the measured value perpendicular to the fibre direction.

Fig. 1. Photo showing the timber frame test section under construction with a reflective foil at the hot side of the cavities and thermocouples mounted for measuring temperatures inside the cavities. Edge insulation partly mounted, (right).

Fig. 2. Photo showing the pivotal hot-box (left). The test floor specimen was mounted between the cold room and the metering chamber/guard room and was in horizontal position during the tests. The timber frame test section variant V7 under rebuilding (right).

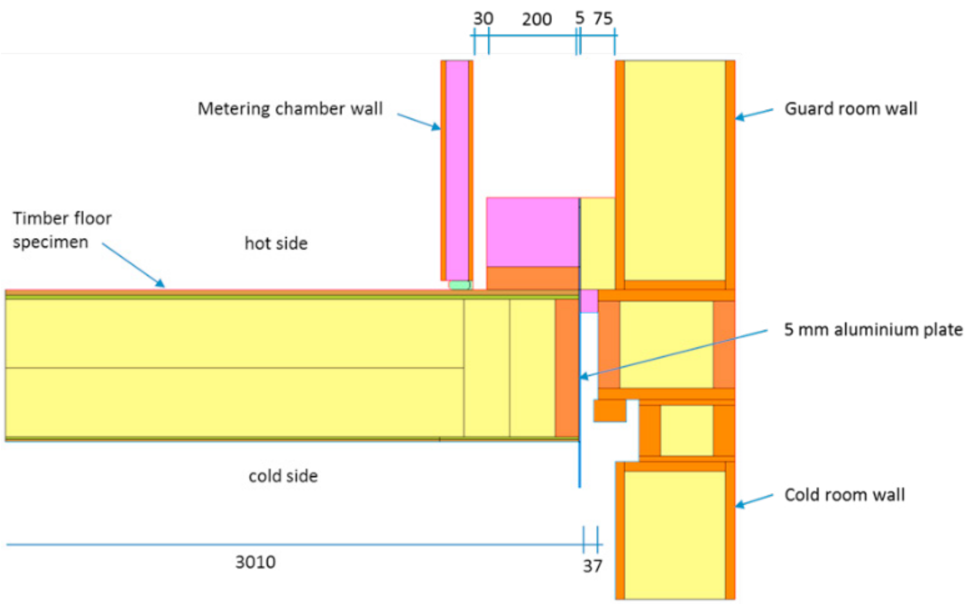


Fig. 3. Vertical section, parallel to the joists, showing part of the test floor, Variant 1, and part of the measuring equipment. Dimensions in millimeters. Aluminum plates mounted on the exterior edges of the test floor served as heat sinks to achieve outdoor temperature at the edge beams. Sills and insulation (pink) on the warm side of the floor simulates the lower part of external walls in order to achieve approximately normal temperature distribution in the whole floor structure.

3. Results

Equivalent U-values of the test floor variants, including edge losses, has been calculated by dividing the measured heat flow, W, by the metering area, m², of the hot box and the environmental temperature difference, °C, between the hot and cold sides of the floor specimen. The main results are shown in the figures 4 and 5 where the measured results are compared with calculated results. An example of measured and calculated temperature distributions in one of the floor cavities are shown in Figure 6.

Fig. 4. Diagram showing measured and calculated equivalent "U-values" of six timber frame floor variants with various number and positions of reflective foils, marked with red lines. All these variants had 200 mm edge beam insulation. The temperature was +20 °C at the hot side and 0 °C at the cold side of the test floor during the measurements.

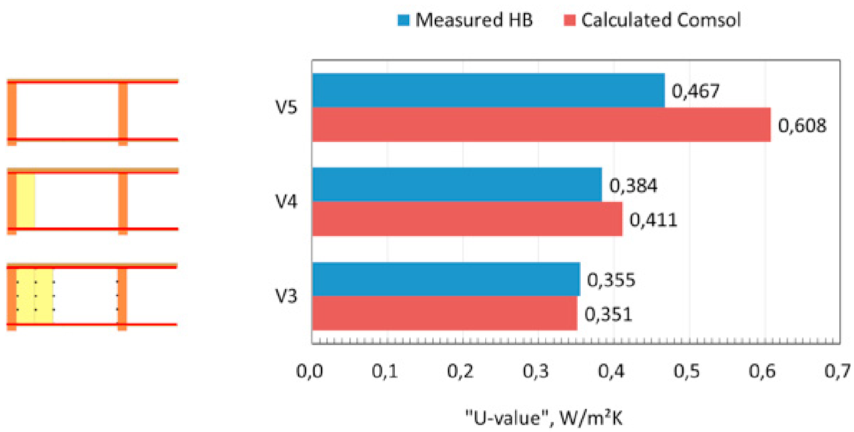
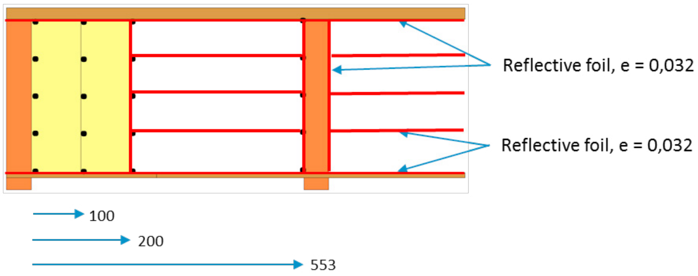


Fig. 5. Diagram showing measured and calculated equivalent "U-values" of three floor variants with varies edge beam insulation. The temperature was +20 °C at the hot side and 0 °C at the cold side of the test floor during the measurements.



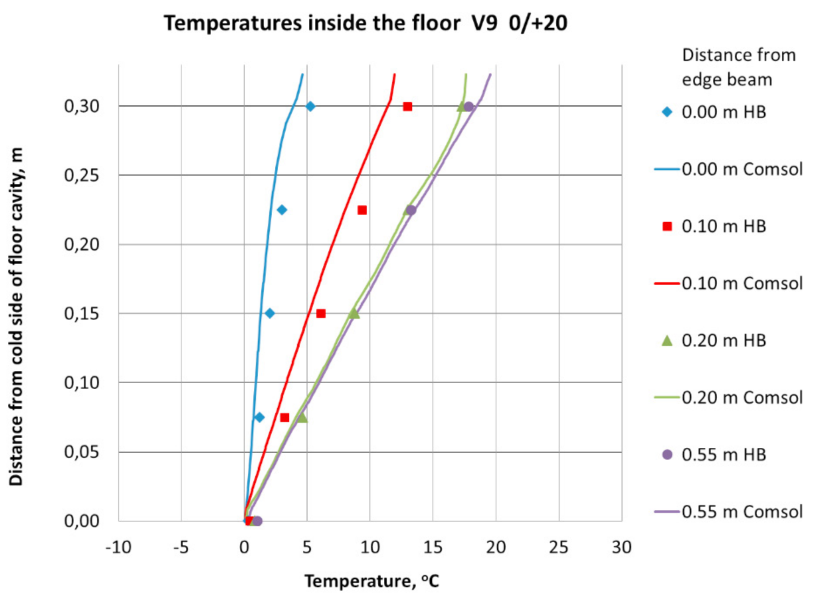


Fig. 6. Diagram showing measured and calculated temperature distribution in floor Variant 9, at the following distances from the edge beam: blue 0 mm, red 100 mm, green 200 mm and purple 550 mm. The full lines are Comsol values and point markers are measured values (HB). The location of mineral wool and thermocouples in the test section is shown by black dots in the drawing above the diagram.

4. Discussion

Both the hot-box measurements and the calculations show that timber frame floors with no ordinary thermal insulation, but air and reflective foils in the cavities, can achieve nearly the same thermal resistance and U-value as floors filled with mineral wool. Measured equivalent U-value, including edge heat losses, for the reference floor variant V1 was 0.160 W/(m²K). For variant V9, with 200 mm edge beam insulation, and air filled cavities with reflective foils on all surfaces, the measured equivalent U-value was 0.185 W/(m²K). The tested floor is small and the edge heat losses have a relatively large influence on the equivalent U-value. For floors of normal size the U-values will be lower.

Measured and calculated results show good agreement for most of the tested timber floor variants, see figures 4 and 5. The deviation between equivalent U-values measured by hot-box and values calculated with COMSOL Multiphysics® 5.2a was less than 2 % for the reference floor, variant V1 filled with mineral wool, and for the variant V9 fully insulated with reflective foils. For the other variants with edge beam insulation the deviation between calculated and measured equivalent U-values was less than +/- 8 %. We have not estimated the absolute uncertainty of these hot box measurements, but the very god agreement between measured and calculated results for the reference floor, variant V1 filled with mineral wool, indicates an uncertainty of a few %.

The importance of edge beam insulation to reduce the heat losses by natural convection is shown in Figure 5. Using 200 mm edge beam insulation, variant V3, reduces the equivalent U-value by 24 % compared with no edge beam insulation, variant V5. For variant V5 with no edge beam insulation the calculated value was 30 % higher than the measured value, which clearly indicates that COMSOL Multiphysics® 5.2a overestimates the convection at a cold edge beam.

The study show that it is effective to apply reflective foils also on the vertical surfaces bonding the cavities in order to reduce the radiation heat transfer. With reflective foils on all cavity surfaces, variant V7, the equivalent U-value was reduced by 29 % compared with variant V3 with reflective foils only on the horizontal surfaces.

There was good agreement between measured and calculated temperature distributions in the cavities for all variants. See example for variant V9 in Figure 6, where the temperature distribution is linear at the space borders indicating minimal convection. For the variants V2, V3 and V7 with no foils dividing the floor spaces, both measured and calculated temperatures showed a non-linear "S-formed" distribution [6], as expected in cavities with natural convection. Relative low CO_2 footprint is assumed to be an advantage with insulation system of air filled cavities enclosed by reflective foils compared to mineral wool, but the difference has not been estimated yet.

For the tested timber floor variants with 200 mm edge beam insulation and air filled cavities with one or several reflective surfaces, COMSOL Multiphysics® 5.2a give reliable results both for heat transfer and temperature distribution at the edge zone.

5. Conclusion

The test results show that reflective foil systems can be a real alternative to traditional mineral wool insulation in timber frame floors. Both the hot-box measurements and the calculations show that timber frame floors with no ordinary thermal insulation, but air and reflective foils in the cavities, can achieve nearly the same thermal resistance and U-value as floors filled with mineral wool.

With reliable measurements and verified numerical models, improved ways of using reflective foils as an alternative to conventional insulation in floor cavities can be developed by calculations.

Before reflective foils can be practical and economic alternatives, multi-layer systems for prefabrication has to be developed. The systems must be easy and quick to assemble in floor elements in factory or on a building site.

6. Acknowledgements

The research described in this paper has been carried out within the Research Centre on Zero Emission Buildings (ZEB). The authors gratefully acknowledge the support from The Research Council of Norway and the partners in the ZEB Centre.

7. References

[1] Uvsløkk S, Arnesen H. Thermal insulation performance of reflective material layers in well-insulated timber frame structures. Proceedings of the 8th Symposium on Building Physics in the Nordic Countries, p1-8. Copenhagen 2008

[2] Jelle BP, Kalneæs SE, Gao T. Low-emissivity materials for building applications: A state-of-the-art review and future research perspectives, Energy and Buildings 96 (2015) 329-356.

[3] Tenpierik MJ, Hasselaar E. Reflective multi-foil insulations for buildings: A review, Energy and Buildings 56 (2013) 233-243

[4] Saber HH. Practical correlations for the thermal resistance of vertical enclosed airspaces for building applications, Building and Environment 59 (2013) 379-396.

[5] Harris DJ. Use of Metallic Foils as Radiant Barriers to Reduce Heat Losses from Buildings, Applied Energy 52 (1995) 331-39.

[6] Uvsløkk S, Schlemminger C, Asphaug S. Thermal insulation performance of reflective foils in floor cavities - Hot box measurements and calculations. Project report to be published within the Research Centre on Zero Emission Buildings, 2017, Trondheim 2017.

[7] Comsol. COMSOL 5.2a Heat Transfer Module User's Guide. COMSOL 5.2a Documentation. 2016