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Energy — insulation

The influence of natural convection on the thermal quality of insulated cavity construction

RESULTS OF EXPERIMENTAL RESEARCH AND COMPUTER SIMULATION

Jan Lecompte

Correct application of insulation within a cavity is vital if heat transfer is not to be increased by natural convection, argues dr.ir. Jan Lecompte, formerly of the Laboratory of Building Physics at the University of Leuven.

La mise en oeuvre correcte de l'isolation dans un mur creux est essentielle si l'on ne veut éviter que la convection naturelle augmente les transferts de chaleur. C'est ce qu'affirme le Dr Jan Lecompte, ancien directeur du Laboratoire de Physique du Bâtiment à l'Université de Louvin.

Introduction

When thermal insulation is placed in a cavity construction, special attention must be paid to the air permeability of the insulation layer and to the absence of residual cavities, otherwise a considerable increase of the heat transfer can be expected, due to air flows around and through the insulation layer, caused by natural convection (ref. 1–8).

The use of insulation boards introduces the problem of the joints between the boards themselves and between the boards and other components, coupled with the (inevitable) presence of small cavities on both sides of the insulation layer. The air gaps in both insulation and cavities leads to air flow around the insulation (Fig. 1a). The insulation material itself has no major influence on this phenomenon.

The use of air permeable insulation boards (mineral wool) leads to additional requirements concerning the minimal density, since permeability and density are coupled. The combination of low density mineral wool and cavities on both sides of the insulation layer, can cause air flows through the insulation (Fig. 1b). The resulting increase of heat transfer is of less importance than when there are air gaps in the insulation layer.

When the outer wall and the inner wall of the cavity construction are considered as airtight, there is no air flow through the construction. As shown in Figures 1 and 2 there is only an internal air flow in the cavity, which is not influenced by external pressure differences.

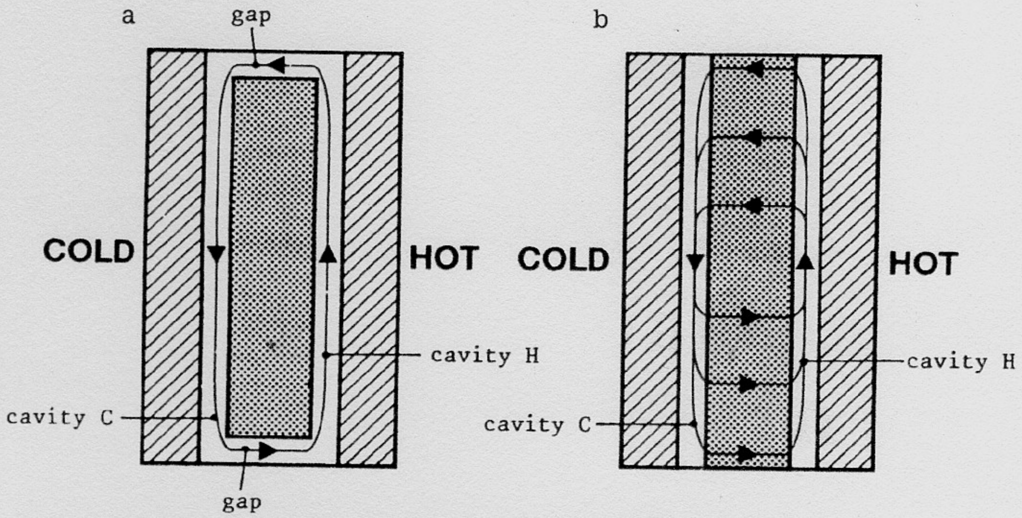

Fig. 1. Air flow (a) around insulation and (b) through insulation

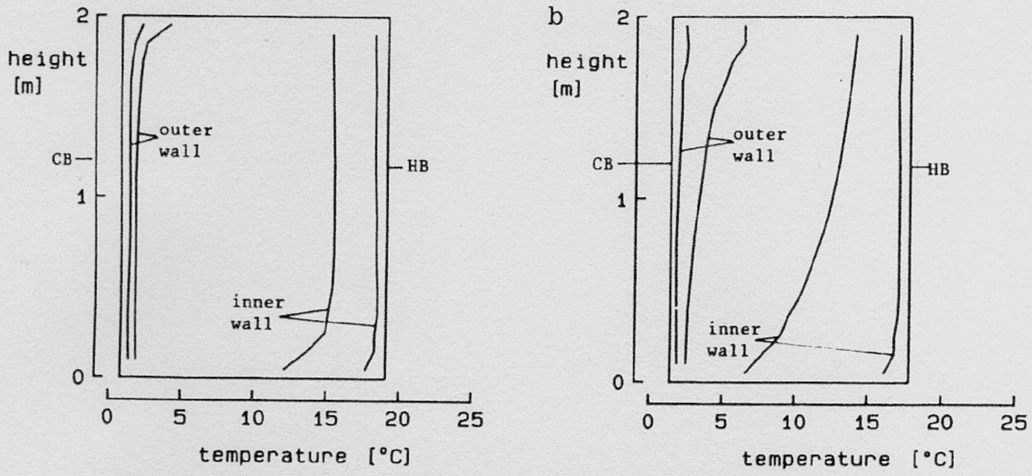

Fig. 2. Measured temperature profiles, gaps at top and bottom: (a) gaps = 0 mm; (b) gaps = 10 mm

It must be stressed that these problems are mainly a result of inadequate workmanship in the application of the insulation materials, not of the materials themselves.

Air flows around the insulation

Experimental research

Measurement Set-Up A 5 cm measure of extruded polystyrene was placed in the cavity of a wall with an inner leaf of 9 cm cellular concrete, plastered on both sides, and an outer leaf of 1.2 cm plywood. The height of the wall was 2 m. This test wall was placed in a calibrated Hot Box–Cold Box. More than 100 measurements were taken with different combinations of gaps in the insulation layer and widths of the cavitites on both sides of the insulation.

Example of results The cavity on the cold side of the insulation was 4 cm, that on the warm side 1 cm. There was an air gap at the top and one at the bottom of the insulation. The theoretical U-value of the test wall, calculated from the measured thermal conductivities of the used materials, was 0.34 W/(m² . K), (=100%). Table 1 gives the measured heat transfer. Figures 2 and

Table 1. Measured heat transfer, gaps at top and bottom

	Temperature difference HB – CB, °C	Width top gap mm	Width bottom gap mm	Measured heat transfer W/(m² . K)
(1.1)	18.3	0	0	0.34 (101%)
(1.2)	17.0	3	3	0.54 (158%)
(1.3)	16.1	10	10	0.65 (193%)

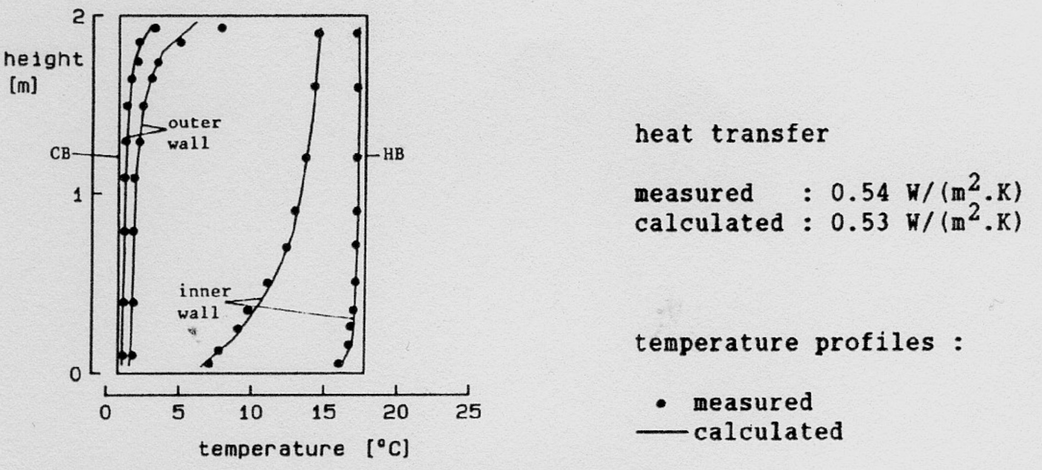

Fig. 3. Measured and calculated temperature profiles

3 give the measured surface temperatures on both sides of the outer wall and the inner wall as a function of the height. The temperature difference between the Hot Box and the Cold Box varied between 16 and 22°C.

Numerical simulation

Calculation model A computer model has been developed to simulate the influence of natural convection on the heat transfer through insulated cavity constructions. For the calculation of the two-dimensional, steady state air and heat transport, the method described in Lecompte (1989) and Kronvall (1982) (refs 7, 9) is used. A construction is transformed in a network, and in each node the laws of mass and energy conservation are applied. The two coupled sets of equations are solved through repeated measurements. Figure 3 gives a comparison between the measured and calculated heat transfer and temperature profiles from measurement (1.2) (Table 1, gaps 3 mm).

Application A cavity construction (height 2 m) with an outer and an inner wall of 1.8 cm plywood is prepared. A depth of 5 cm insulation (λ=0.025 W/(m . K)) is placed in a cavity of 8 cm. Figure 4 gives the ratio of the calculated heat transfer, and the theoretical U-value, U=0.40 W/(m^2 . K) (at 100%), as a function of the width of the top and bottom gap, with both gaps taken as equal. The width of the cavities on both sides of the insulation is taken as a parameter. The temperature difference across the wall is 20°C, h_e=23 W/(m^2 . K), h_i=8 W/(m^2 . K).

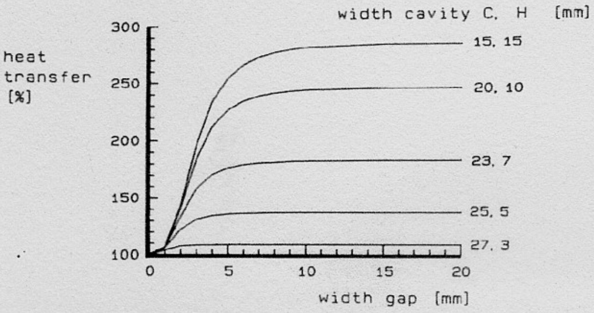

Fig. 4. Influence of gaps and cavities on the heat transfer

Air flows through the insulation

Experimental research

The cavity of the test wall, described earlier, is partially filled with 5 cm mineral wool. Various combinations of cavity widths and mineral wool densities are measured. There are no air gaps in the insulation layer.

Example of results The mineral wool (glass wool) has a density of 21 kg/m^3 and an air permeability of 1.5 E−3 m^3/(N . s). The cavity on both sides of the insulation is 2.5 cm. The theoretical U-value of the test wall, calculated from the measured thermal conductivities of the used materials, is 0.39 W/(m^2 . K),)(=100%). In measurement (2.1) one side of the insulation is made airtight. Table 2 gives the measured heat transfer. Figure 5 gives the measured temperatures on both sides of the inner wall and the outer wall, as a function of the height.

Numerical simulation

Application A cavity construction (height 2 m) with an outer and an inner wall of 1.8 cm plywood is prepared. A depth of 5 cm insulation (λ=0.35 W(m . K)) is placed in a cavity of 8 cm. Figure 6 gives the ratio of the calculated heat transfer, and the theoretical U-value, U=0.40 W/(m^2 . K) (=100%) as a function of the permeability of the insulation; there are no air gaps. The width of the cavities on both sides of the insulation is taken as a parameter. The temperature difference across the wall is 20°C, h_e=23 W/(m^2 . K), h_i=8 W/(m^2 . K).

Table 2. Heat transfer, air permeable insulation

	Temperature difference °C	Measured heat transfer W/(m^2 . K)
(2.1) impermeable (painted)	22.1	0.39 (100%)
(2.2) permeable	20.0	0.43 (111%)

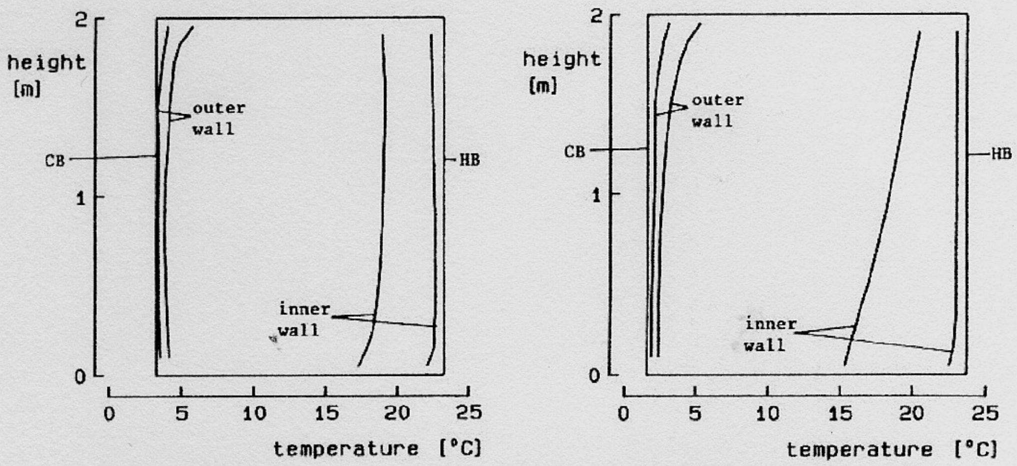

Fig. 5. Measured temperature profiles, glass wool insulation: impermeable

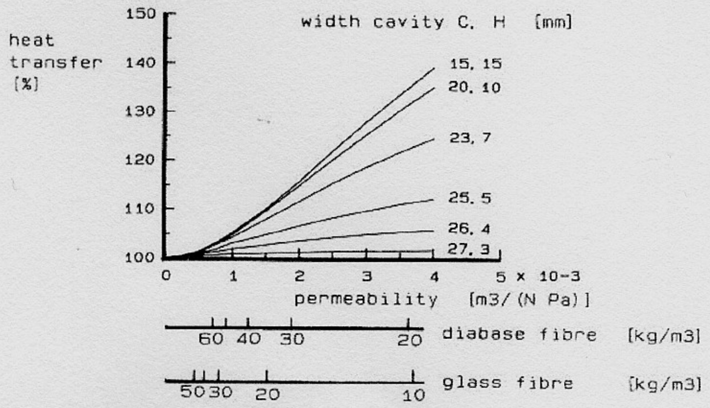

Fig. 6. Influence of the permeability

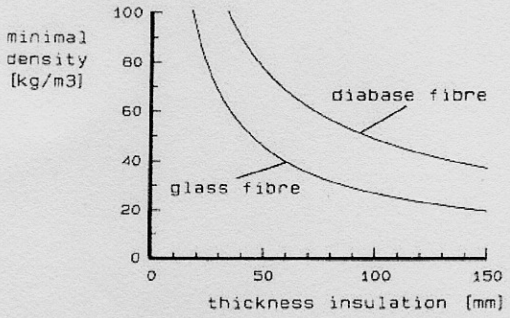

Fig. 7. Lower limit for the density of mineral wool as function of the insulation thickness

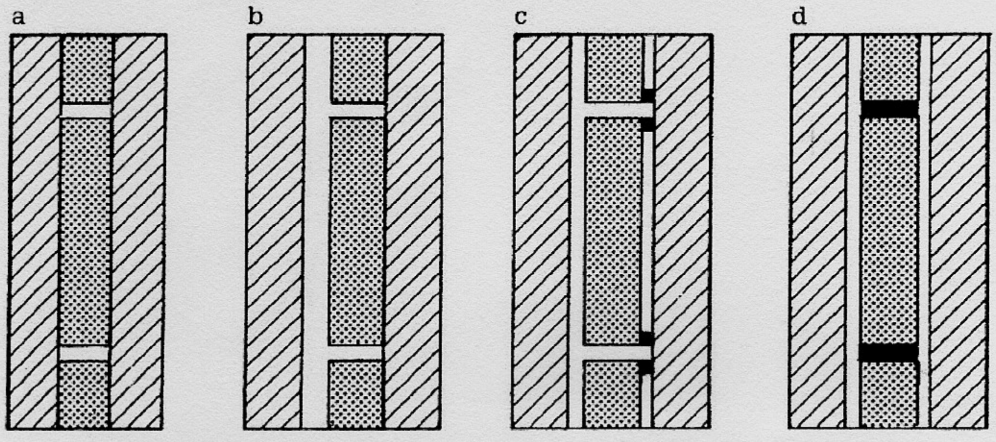

Fig. 8. Measured temperature profiles, glass wool insulation: permeable. (a) Eliminate both cavities; (b) Eliminate one cavity; (c) seal a cavity; (d) seal all joints

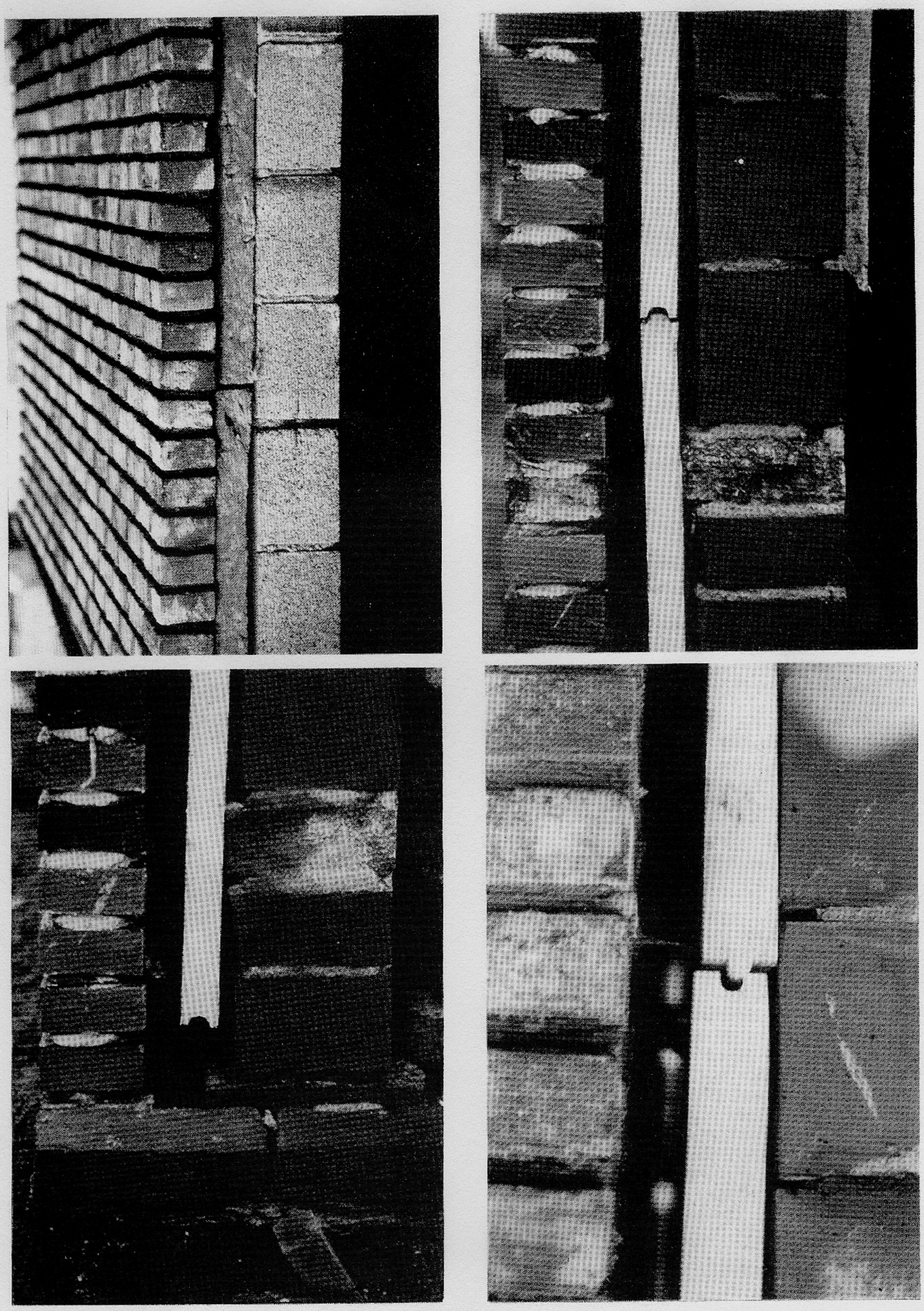

Fig. 9.

Since permeability and density are coupled, from Fig. 9 we conclude that the use of mineral wool of higher density is to be recommended, when the mineral wool boards cannot be fixed against a surface of the cavity. In the case of air flow perpendicular to the fibres, the relationship density–permeability can be approximated by:

permeability$=a\rho^{b}/d$

where d the thickness of the insulation [m], ρ the density [kg/m^3], a, b are constants for a specific mineral wool product: type of wool (glass or diabase fibre), type of fibre (diameter, etc.) and fibre-structure. Typical values for cavity insulation are:

glass fibre: $3.6\ 10^{-3}\ \rho^{-1.3}/\mathrm{d}\quad \mathrm{m}^3/(\mathrm{N}\cdot\mathrm{s})$
diabase fibre: $1.7\ 10^{-2}\ \rho^{-1.5}/\mathrm{d}\quad \mathrm{m}^3/(\mathrm{N}\ .\ \mathrm{s})$

If we propose 5.10^{-4} m^3/(N . s) as the upper limit for the permeability, the lower limit for the density of the mineral wool can be calculated, as a function of the insulation thickness (Fig. 7). These requirements are only applicable in cases where small cavities exist on both sides of the mineral wool insulation.

Conclusions

From this research it can be concluded that stringent requirements must be formulated concerning the application of insulation in cavity construction, since the presence of small air leaks and residual cavities can cause a substantial increase in heat transfer.

A first solution to the problems described is to fill the cavity construction completely, eliminating both residual cavities (Fig. 8a). This is only possible when the surfaces of the inner and outer walls are very smooth, or if the insulation is sufficiently compressible (mineral wool). The same applies to the second solution, where one cavity is eliminated by fixing the insulation against the inner wall (Fig. 8b). A third solution is to seal the cavity on one side of the insulation (Fig. 8c). A last solution is to seal the joints between the insulation boards themselves and between the insulation boards and other construction parts (Fig. 8d). In the last two cases, boards of higher density are required, when mineral wool is used.

It is clear that good workmanship is a major priority in obtaining an insulated cavity construction of high thermal quality.

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