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DYNAMIC INSULATION COMBINED WITH HEAT STORAGE

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1. Introduction

Dynamic insulation or breathing building constructions is not a new concept. We find elements of this technique in our oldest buildings. This technique has, however, been developed for use in modern buildings the last 10-15 years in Scandinavia. Today dynamic insulation normally means that fresh air for the building is passed through the insulation in the roof and/or the walls.

This paper describes a further development of a roof construction where dynamic insulation is combined with a system for electrical heating and heat storage. This enables storage of heat during night, thus reducing the daytime power peak. The transmission loss through the roof is reduced with more than 70 % . The system may also be run as a cooling system when needed by ventilating the construction with cold air at night.

This concept is based on several laboratory tests together with theoretical developments, prototype field experiments and plans for use in commercial buildings. The project is sponsored by private and governmental sources.

2. The Constructions

A dynamic insulation roof consists in principle of a closed top roof, an open airspace and a layer with airpermeable insulation material. The construction has no vapour barrier. Adjustable fans blow outdoor air into the open airspace and through the permeable insulation material. The system requires a minimum airflow of about 1 m^3/m^2h. The normal maximum for use in offices are 7 m^3/m^2h. The airflow may be increased if necessary for extra cooling or ventilation. Normally the total pressure difference through the insulation will be from 1-2 Pa (at minimum airflow) up to 5-7 Pa. The ventilation is normally balanced with an extractor fan.

In our project we have been working with a construction as shown in figure 1. It consists of 2 layers of insulation material with different density and heat capacity. The difference from the earlier types of constructions is that an electrical heating element is put between the two layers. This allows us to preheat the ventilation-air and to use the roof

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as a heating system for the room. This type of structure has been tested with different combinations of materials and layer-thickness, with varying temperature conditions, heat input and ventilation rates.

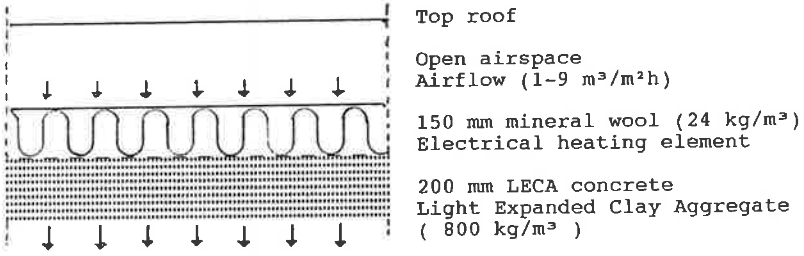


Fig. 1. Cross-section through the roof construction.

3. Analytical model

Under steady state conditions the temperature distribution in an insulation layer with air flow (fig. 2) can be found from the differential equation:

$$\lambda \cdot \frac{d^2T}{d^2x} - v \cdot C_a \cdot \frac{dT}{dx} = 0 \qquad (1)$$

where: λ = thermal conductivity of the insulation (W/mK)
v = air velocity (m/s) = (m³/m²s)
C_a = thermal capacity of air (at constant pressure) (J/m³K)
$T(x)$ = temperature distribution (K)

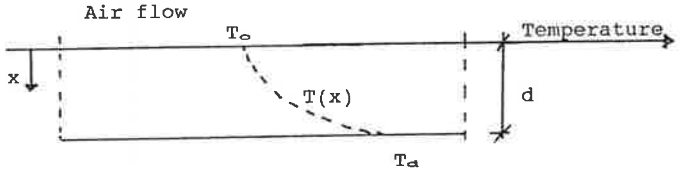


Fig 2. Single layer model

Here the assumption is made that the air velocity is so low that air temperature is equal to the insulation temperature at any x. The general solution of eqation (1) is :

$$T(x) = A \cdot e^{F \cdot x} + B \ , \qquad F = \frac{v \cdot C_a}{\lambda} \qquad (2)$$

where the constants A and B are depending on boundary conditions. Expressions for heat fluxes and dynamic U-value can be derived from (2). In multilayer structures the solutions for neighbouring layers may be linked together by the common interface temperature.

When boundary conditions and air flow are time dependent, the thermal regime may be described by the transient differential equation :

$$\lambda \cdot \frac{\partial^2 T}{\partial x^2} - v(t) \cdot C_a \cdot \frac{T}{x} + q(x,t) = C_M \cdot \frac{\partial T}{\partial t} \qquad (3)$$

where : t = time (s)
$q(x,t)$ = power input (W/m²)
C_M = thermal capacity of insulation (J/m³K)

Equation (3) has no general analytical solution, but can be solved numerically for defined boundary conditions, using for example difference methods.
In our project the analytical models (2) and (3) have been tested against measurements on laboratory models. (1,2). In the actual range of air velocities we have found reasonable agreement between calculations and measurements. We have also developed a simulation model for multilayer structures, based on euation (3). By this model we can optimize the regulation strategy in different types of buildings under different climatic conditions.

4. Laboratory experiments

Laboratory tests have been made with several different structures. As the upper layer of the structure we have used glasswool with low thermal conductivity and capacity. In the lower layer with high thermal capacity, we have used expanded clay aggregate concrete (LECA) or sand. The thickness of the light-weight concrete slab has varied from 60 to 250 mm. The glasswool layer has normally been 150 mm thick. Three types of electrical heating elements have been tried. They all functioned well.

In one test glasswool was used in both layers. This system functioned good for preheating the ventilation air and gave fast response to changes in the room heat load. Electric power, of course, had to be added during the day because the structure had very low thermal capacity.

The heat loss through the roof is reduced to about 30 % of what a conventional system would have had. The dynamic U-value for three thicknesses of mineral wool are shown in fig. 3. The reduction of the U-value is proportional with the reduction of the gradient of temperature near the outer surface of the insulation. The measured gradients are equal to the theoretical.

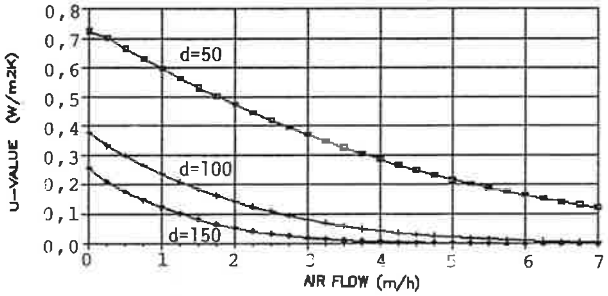


Fig. 3 The dynamic U-value of mineral wool as function of thickness, d (mm) and air flow (m/h).

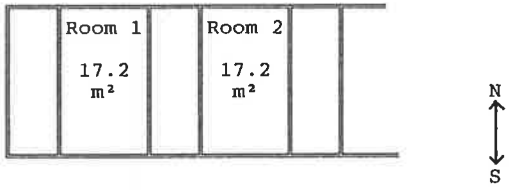
The measured inside surface heat transfer resistance varied from 0.30 to 0.15 m²K/W for ventilation speed 1.0 to 4.0 m/h.

For use in Norway with minimum outdoor temperature at -20 °C we have found a solution with 200 mm thick light-weight concrete slab and 150 mm mineral-wool to be optimal. In the construction we install a load of 100-150 W/m² using electrical heating.

5. The field prototype tests.

While working in the laboratory we focused on the thermal performance of the roof structure separately. On moving to the test house the purpose was to find out how the system would perform together with the rest of the building in a real climate situation.

The test house: The building has one storey and no basement . The testrooms are separated by narrow buffer-cells. In these cells the temperature are kept at 20 °C. See fig. 4.



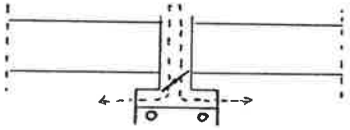
The area of the windows are each 1.2 m².

Fig. 4 The plan of the testhouse.

The testhouse was run uninhabited simulating an office situation. During daytime, from 7.00 am until 5.00 pm the required ventilation rate is 5 m³/m²h and the room temperature are allowed fluctuating within the range 19 - 23 °C. During the evening and night ventilation is 1.0 m³/m²h and the minimum room temperature 15 °C. At 6.00 pm the system (an Olivetti M-24 PC with digital output ports) calculates the necessary heat storage time depending on the mean outdoor temperature this day. The status of the system is logged every 10 minutes and checked for necessary changes.

5.1 Cold weather conditions

On running a system with heat accumulation during the night, a prediction must be made for the outside temperature the succeeding day.If this estimate is too low, there might be a heat surplus stored and overheating may occure in the room during the day. To allow a temperature reduction of the ventilation air in such cases there were mounted two by-pass vents in each test roof. They were made of tubes with diameter 100 mm and fitted with automatically controlled open/close valves. The by-pass air are led into a volume on top of the light fittings and blown horizontally into the room, thus mixing with heated air and eliminating any draught problems. (See fig 5). This also enables a fast response to variations in internal heat load in the room.



The permeable roof

The light-fitting with perforated top

Fig. 5 The by-pass vents (section).

When these vents are opened the pressure difference is reduced with about 40 %. Then nearly half of the ventilation air flows directly into the room. The total volume of air is not changed as the flow resistance is mainly in the fan and ducts.

If there has been stored too little heat, the power will not be turned off at 4.00 am as normally. Depending of how much the outdoor temperature has fallen the loading will continue.

In fig.6 the whole system of regulation and temperature development in the building for one cold day can be studied. As shown by the diagrams, the indoor temperature is effectively reduced when the by-pass vents are opened. The heat storage then lasts longer and the time for loading for the next day is reduced. The computer takes care of this.

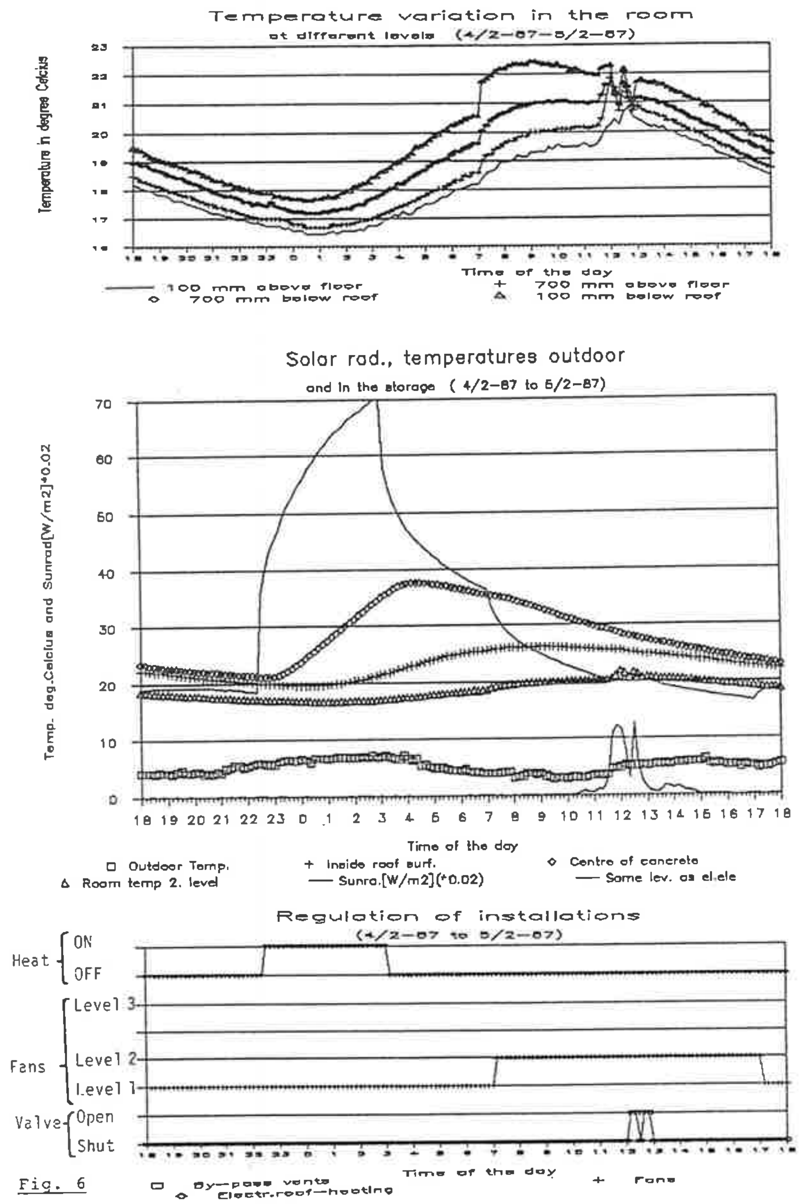


Fig. 6

5.2 Hot weather conditions.

If the outdoor temperature is so high that there is no need for extra heating, the system is run for hot weather conditions. The problem then is to keep the morning room temperature above 18 °C and, at the same time, the storage cold enough to cool the ventilation air during the day. This implies that the construction can not be cooled down uncontrolled. The maximum air flow from the fan on level 3 is 9 m³/m²h. The necessary cooling is calculated the same way as the heating during the winter.

Changes in the outdoor temperature during the night can make it necessary to start heating the storage. In this situation the thermal capacity of the storage makes it impossible to get any heat out of the construction the first 3-4 hours. Thus it may be necessary to turn on some internal heating in the room. The light system might be enough to increase the temperature the few degrees necessary.

It is possible to reduce the temperature of the ventilation air several degrees during the day even in very warm periods. In norwegian climate the outdoor temperature during the night often is so low that the construction makes it possible to cool off the heat produced in the building as well as cooling the ventilation air.

6. Final remarks.

This type of structure needs a minimum airflow of 1 m³/m²h to work properly. If the air flow is reversed, condensation problems may occur and dust/smoke particles may deposit on the surface. Although short periods of reversed ventilation is not harmful, the permeability of the insulation must be chosen low enough to secure the minimum ventilation regardless of pressure variation caused by thermal or wind effects. The tested horizontal structure has performed well with a pressure drop of 0.8 -1.0 Pa at minimum ventilation. If used in a sloping roof or even walls, this pressure drop should be increased to 3 - 5 Pa, which is obtainable with a denser glass wool.

The thermal capacity of the construction may cause problems when the outdoor temperature changes rapidly. Some direct heat input to the room will solve this and assure the required morning temperature level. When the internal heat gains are big during the day, it is preferable not to use the roof heating, but add the necessary heat directly to the room. The cooling effect during summer will still be fully effective.

So far our tests indicate that this type of combined structure will be an interesting alternative for reducing daytime power peaks and total energy demands, especially for one-storey buildings. In 1987 we will continue testing of this system in different climatic conditions and with different regulation strategies.

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