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XIV International Congress of
Refrigeration, Moskow 1975

The Counterflow Wall

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Le mur à contre-courant

MEDDELELSE NR. 59

Résumé

L'article présente la construction d'un mur extérieur d'un nouveau type: le mur à contre-courant. Ce mur a été étudié en vue d'économiser de l'énergie au cours du chauffage des pièces. Un climat intérieur agréable ne dépend pas seulement de la température de la pièce, mais aussi de la qualité de l'air qui est normalement assurée par une ventilation naturelle ou artificielle d'air frais. On a besoin d'énergie à la fois pour réchauffer l'air frais à la température de la pièce et pour compenser les pertes de chaleur à travers les parois de la pièce. Le mur à contre-courant, dont le coeur est rempli d'un matériau isolant poreux, est construit de manière à ce que l'air frais entrant soit distribué d'une manière uniforme au niveau de la surface isolante et circule à contre-courant du flux des pertes de chaleur. Ainsi, la chaleur perdue sert au préchauffage de l'air frais.

On peut aussi utiliser le mur à contre-courant pour économiser de l'énergie au cours du refroidissement d'une pièce en inversant le courant d'air.

Introduction

A good indoor climate depends not only on a suitable room temperature but also on good air quality. The latter is usually achieved by means of appropriate fresh air ventilation.

In order to meet these demands it is necessary to use energy for a large part of the year, partly to cover transmission loss through the surfaces of the room and partly to heat the fresh air. There are several ways in which the expenditure of energy for this purpose can be reduced.

The transmission loss can be reduced by better insulation.

The energy used for heating fresh air can be reduced significantly by means of heat recovery plants.

As long as energy consumption is not subjected to restrictions, it will be the cost of the energy which determines to what extent it is advantageous to insulate and how much should be expended on heat recovery.

A new procedure will be described below, which can be used to reduce energy expenditure on the heating of houses.

The principle of the system is that the outer walls, etc. are designed in such a way that heat transmission through them is used to preheat the fresh air taken in through the wall's porous insulation.

Outer walls, ceilings and possibly floors, which are designed according to this principle, will be termed counterflow walls.

Before the used air is expelled it is cooled to the outdoor temperature by means of a heat pump. The heat obtained through this process is used to heat the house.

Counterflow wall

The principle in the construction of a counterflow wall is illustrated in fig. 1. Between two airtight sheets, porous insulating material is placed in such a way that there is a space on either side of it. Fresh air is blown into the outer space so that the air is evenly distributed and flows through the insulating material to the inner space from where it enters the house through inlets.

The counterflow wall theory

If the insulating material is inserted in a coordinate system, as shown in fig. 2, and subjected to a temperature difference and an air flow contrary to the heat flow, the following differential equation can be derived for the determination of the course of the temperature through the insulating material under stationary conditions.

$$\frac{\partial^2 t}{\partial x^2} - \frac{v L}{\lambda} \frac{\partial t}{\partial x} = 0$$

where v is the air velocity

L is the specific heat of the air

λ is the heat conductance capacity of the insulating material

The solution of the differential equation is:

$$t = C \left(\exp\left(\frac{v L}{\lambda} x\right) - 1 \right) + t_0$$

$$\text{where } C = \frac{t_0 - t_E}{1 - \exp\left(\frac{v L}{\lambda} E\right)}$$

where E is the thickness of the insulating material.

The temperature gradient is expressed as follows:

$$\text{grad } t = \frac{v L}{\lambda} C \exp\left(\frac{v L}{\lambda} x\right) \quad \text{for } v \neq 0$$

$$\text{For } v = 0, \frac{\partial^2 t}{\partial x^2} = 0, \text{ or } \text{grad } t = \text{constant} = \frac{t_E - t_0}{E}$$

For the warm side, $x = 0$, we obtain:

$$\text{grad } t_0^v = \frac{v L}{\lambda} C$$

For the cold side, $x = E$, we obtain:

$$\text{grad } t_E^v = \frac{v L}{\lambda} C \exp\left(\frac{v L}{\lambda} E\right)$$

The amount of heat which flows in through the side $x = 0$ is:

$$\lambda \text{ grad } t_0^v$$

The amount of heat which flows out through the side $x = E$ is:

$$\lambda \text{ grad } t_E^v$$

The difference between these two amounts goes toward heating the air flowing through the insulating material:

$$q_1 = L v (t_o - t_E)$$

$$\lambda (\text{grad } t_o^v - \text{grad } t_E^v) = L v (t_o - t_E)$$

The unused heat loss through the inner side of the wall is as follows:

$$\lambda \text{ grad } t_o^v - L v (t_o - t_E) = \lambda \text{ grad } t_E^v$$

Without air flow, $v = 0$, the heat loss through the wall is:

$$\lambda \text{ grad } t_x^o = \lambda \frac{t_E - t_o}{E}$$

As a clear expression of how much the counterflow principle improves the insulating capacity of the wall, the concept "equivalent insulating thickness" is inserted which can be defined as the thickness which the insulating layer should have in order to give the same heat loss through the wall without air flow ($v = 0$).

$$E_{\text{equ}} = (t_E - t_o) \text{ grad}^{-1} t_E^v = \left(\frac{v L}{\lambda}\right)^{-1} (1 - \exp^{-1}(\frac{v L}{\lambda} E))$$

For a typical counterflow wall with mineral wool insulation, the following values can be reckoned with:

$$L = 0.35 \text{ W hm}^{-3} \text{ C}^{-1}, \quad \lambda = 0.035 \text{ W m}^{-1} \text{ C}^{-1}$$

For various values of v the equivalent insulating thickness, independent of the actual insulating thickness, can be seen in fig. 3.

Heat balance for a house

Heat loss = heat addition

Heat loss can be divided into the following components:

Ventilation heat loss	Q_1^-
Transmission loss through outer walls and ceiling	Q_2^-
Transmission loss through floor	Q_3^-
Transmission loss through windows and doors	Q_4^-

Heat addition can be divided into the following components:

Heat addition from solar radiation through windows	Q_5^+
Heat addition from people	Q_6^+
Heat addition from housekeeping	Q_7^+
Heat addition from heating plants	Q_8^+

Heat balance

$$Q_1^- + Q_2^- + Q_3^- + Q_4^- = Q_5^+ + Q_6^+ + Q_7^+ + Q_8^+$$

The following example will show that it is a realistic possibility to build a house in such a way that Q_8^+ is negative, i.e. there is excess heat which by means of a heat pump can be used to heat the household water supply.

Heat balance for a zero energy house

Data of the house:

Floor area	$8 \times 15 \text{ m} = 120 \text{ m}^2$
Ceiling height	2.5 m
Room volume	300 m^3
Window area	20 m^2
Ceiling + outer walls	200 m^2

Ventilation

The following fresh air ventilation is reckoned with:

8 evening hours (4 persons in the house)	$200 \text{ m}^3 \text{ h}^{-1} \sim 0.67 \text{ h}^{-1}$
8 night hours (4 persons sleeping)	120 - ~ 0.4 -
8 day hours (1 person working)	120 - ~ 0.4 -

The corresponding ventilation heat loss is $q_1 = 51 \text{ W C}^{-1}$

Transmission loss

The ceiling and outer walls are constructed as counterflow walls with mineral wool insulation of 0.20 m. The amounts of fresh air indicated, namely 200 and $120 \text{ m}^3 \text{ h}^{-1}$, correspond to air velocities through the insulation of 1 m h^{-1} and 0.6 m h^{-1} respectively. From fig. 3 it will be seen that this corresponds to equivalent insulating thicknesses of 0.64 and 0.39 m respectively.

The corresponding transmission loss is $q_2 = 16 \text{ W C}^{-1}$, disregarding the surface resistance.

The floors are built with 0.40 m mineral wool without the counterflow principle, the corresponding transmission loss being $q_3 = 11 \text{ W C}^{-1}$.

The windows and outer doors are built with three layers of glass and insulated outer shutters which are used at night so that the transmission loss is $q_4 = 20 \text{ W C}^{-1}$.

Total heat loss

$$q_1 + q_2 + q_3 + q_4 = 98 \text{ W C}^{-1}$$

For a normal Danish heating season with a degree day number of 3000, the heat consumption is:

$$Q_1 + Q_2 + Q_3 + Q_4 \sim 7100 \text{ kWh}$$

Heat addition

In a normal Danish heating season there can be a usable solar heat addition through the windows of $Q_5 = 2800 \text{ kWh}$.

From a household comprising 4 persons one can reckon with a heat addition of $Q_6 = 2400 \text{ kWh}$, and from normal housekeeping, a usable heat addition of $Q_7 = 2400 \text{ kWh}$.

$$Q_5 + Q_6 + Q_7 = 7600 \text{ kWh}$$

Heat balance

$$Q_8 = 7100 - 7600 = -500 \text{ kWh}$$

For a whole heating season the heat addition thus exceeds the heat loss by 500 kWh.

The heating plant

Even though there is in this way a balance between heat addition and heat loss over the whole heating season, there will at certain periods be a heat requirement which must be met by means of a heating plant. The necessary amount of heat for this purpose is stored in a heat accumulator, e.g. a water tank, with the aid of a heat pump in those periods when the heat addition is greater than the heat loss.

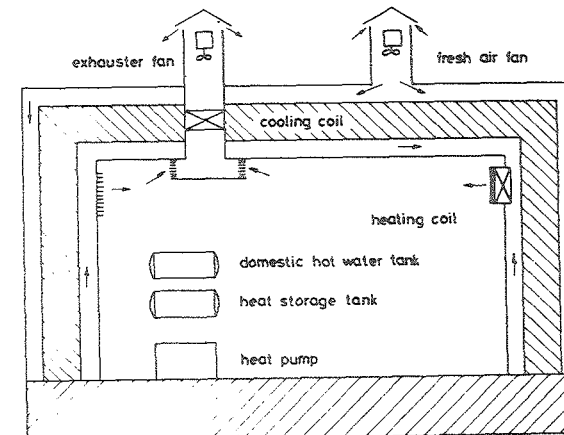
Hot water supply

The amount of heat rejected with the ventilation air

$$Q_1 = 3672 \text{ kWh} + Q_8 = 500 \text{ kWh} = 4172 \text{ kWh}$$

can be used for heating the water supply by means of the heat

pump which cools the used air from room temperature to outdoor air temperature. If an effect factor of 3 is reckoned with from the heat pump, the current needed for this will be 1390 kWh. (The amount of hot water used by a typical Danish family corresponds to a heat consumption of 3000 kWh).



Principle sketch of zero-energy house

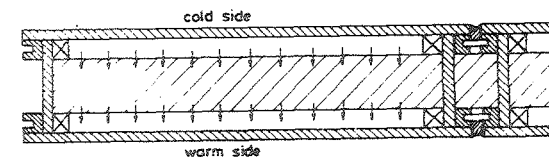
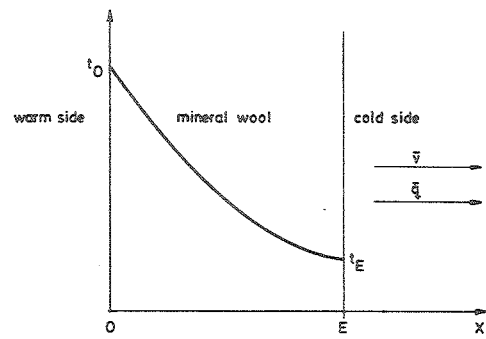


Fig. 1



Temperature distribution in a counterflow wall Fig.2

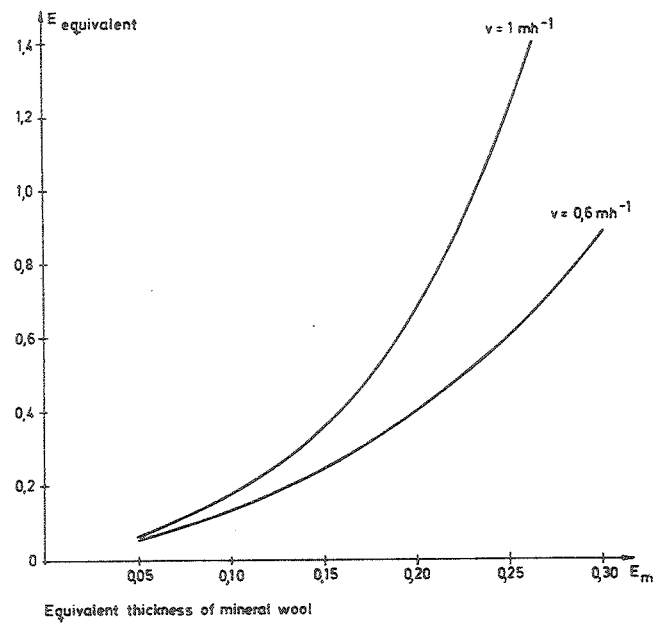


Fig.3

Типография ВТИ. Заказ № 4780

Внешторгиздат. Заказ № 64759