Energy Impact of Ventilation and Air Infiltration
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Energy Impact of Ventilation and Dynamic Insulation

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0,35 l/s, m²
↓ all roof surface
$v = 0{,}35$ mm/s (~ 1.2 m/s
$\rho c v = 0{,}42$ W/m²K
$U \sim 0.2 \ldots 0.3$ W/m²K

Synopsis

Dynamic insulation stands for an insulation through which an air flow flows. The air flow is usually the normal ventilation flow. The air can flow in the same or in the opposite direction of the normal heat flow. The dynamic insulation can be arranged as single where only inlet or exhaust air passes the insulation, or as combined where inlet and exhaust air pass one half of the insulation each. Dynamic insulation using exhaust air might result in condensation problems in cold climates.

The normal insulation heat loss is reduced when using dynamic insulation and can be eliminated more or less only if the ventilation heat loss is several times larger than the normal insulation heat loss. The reduction of normal insulation and ventilation heat losses when using dynamic insulation is limited to 0.23 for single and 0.35 for combined dynamic insulation.

Dynamic insulation can be regarded as a ventilation heat recovery system. The equivalent ventilation heat recovery efficiency is limited to 0.5 for single dynamic insulation and to 1 for combined dynamic insulation, and decreases with increasing ventilation flow. An alternative to dynamic insulation in order to obtain the same saving is standard ventilation heat recovery system.

1 Introduction

Dynamic insulation is a notation which is often used. It is however not very descriptive and is far from dynamic in any sense. The notation is used to describe insulation with a constant flow through the insulation in the same or opposite direction of the normal heat flow. The word dynamic is also used for the so called dynamic U value which shows how the normal insulation U value decreases to zero with increasing flow through the insulation. Better notations that sometimes are used are co-flow insulation and counter-flow insulation.

The flow through the insulation is assumed to be the normal ventilation flow of a room or a building. The flow velocity is only in the range of a few m/h or even less than a mm/s.

The benefit with flow insulation is that the total heat loss for the insulation and the ventilation flow is less than the heat loss for the same normal insulation and the ventilation flow added. The decrease is however limited to the normal insulation heat loss and this occurs only if the ventilation flow heat loss is several times the normal insulation heat loss. The decrease is also limited to the ventilation flow heat loss when the ventilation flow heat loss is small compared with the normal insulation heat loss and when both co-flow and counter-flow insulation are used. Only half the decrease can be obtained when using only co-flow or counter-flow insulation.

The flow insulation can be regarded as normal insulation with ventilation heat recovery. The equivalent ventilation heat recovery efficiency decreases with increasing flow from 1 for combined co-flow and counter-flow insulation and from 0.5 for only co-flow or counter-flow insulation.

The ventilation heat loss can however be eliminated completely even for large flows if periodic switching between two parts of flow insulation is used. One part is in the co-flow mode and the other is in the counter-flow mode. The two parts of flow insulation can be regarded as two halves of a rotary heat exchanger wheel which is rotated half a revolution each time. The large heat capacity of the insulation material makes this heat exchanger incredibly oversized and that is why the efficiency becomes close to 1.

The aims of this paper, described in the following sections, are

- to derive simple expressions for total heat loss for single and combined co-flow and counter-flow insulations

- to compare total heat loss for single and combined co-flow and counter-flow insulations as a function of the quotient between ventilation heat loss and normal insulation heat loss or as a function of insulation thickness for a given ventilation need

- to show that the normal insulation heat loss is only saved when using flow insulation and when the normal insulation heat loss is much smaller than the ventilation heat loss

- to show that the possible reduction in total heat loss for different flow insulations compared with the sum of normal insulation heat loss and ventilation heat loss is limited

- to show that the heat loss reduction for flow insulation can be regarded as a ventilation heat recovery and that the equivalent ventilation heat recovery efficiency decreases from 1 for combined flow insulation and from 0.5 for single flow insulation with increasing flow

- to show that the heat savings when using flow insulation can easily be obtained with standard ventilation heat recovery techniques

2 A simple flow insulation model

An insulation with an area of 1 m^2, a thickness of d (m) and a conductivity of λ (W/mK) is studied. The temperature of the air flow and the insulation material is assumed to be the same, given by T(x) (K) where x is the normalized and dimensionless position in the insulation block. The air flow is assumed to move in the x direction with the properties velocity v (m/s), density ρ (kg/m^3) and specific heat capacity c (J/kgK).

The boundary conditions are given by the inlet and outlet temperatures as

$$T(0) = T_i \qquad \text{(K)} \qquad (2.1)$$
$$T(1) = T_o \qquad \text{(K)} \qquad (2.2)$$

The surface heat transfer coefficients are assumed to be infinite at both ending surfaces.

The sum of the heat transferred in the x direction by conduction and by flow must be constant for all x which gives

$$-\frac{\lambda}{d}\frac{dT}{dx}(x) + \rho c v \, T(x) = \text{constant} \qquad (\text{W/m}^2) \qquad (2.3)$$

The differential equation (2.3) can be solved and the solution is given by

$$T(x) = A\,e^{ax} + B \qquad \text{(K)} \qquad (2.4)$$

where the parameter a is the quotient between the ventilation heat loss and the normal (non-flow) insulation heat loss

$$a = \rho c v \,/\, \overbrace{(\lambda \,/\, d)}^{\rightarrow\ 0.04/0.10 = 0.4} \qquad (-) \qquad (2.5)$$

1.2 × 1000 × 0.01 = 12

The two parameters A and B are given by the boundary conditions (2.1) and (2.2). Simple calculations give

$$A = (T_o - T_i) \,/\, (e^a - 1) \qquad \text{(K)} \qquad (2.6)$$
$$B = T_i - A \qquad \text{(K)} \qquad (2.7)$$

Note that the indices i and o stand for inlet and outlet and not indoor and outdoor or inside and outside.

The temperature profile T(x) in the flow insulation is shown in Figure 2.1 for a = 0, 1, 2, 5 and 10, and boundary temperatures T(0) = 0 and T(1) = 1. The case a = 0 corresponds to the normal insulation case.

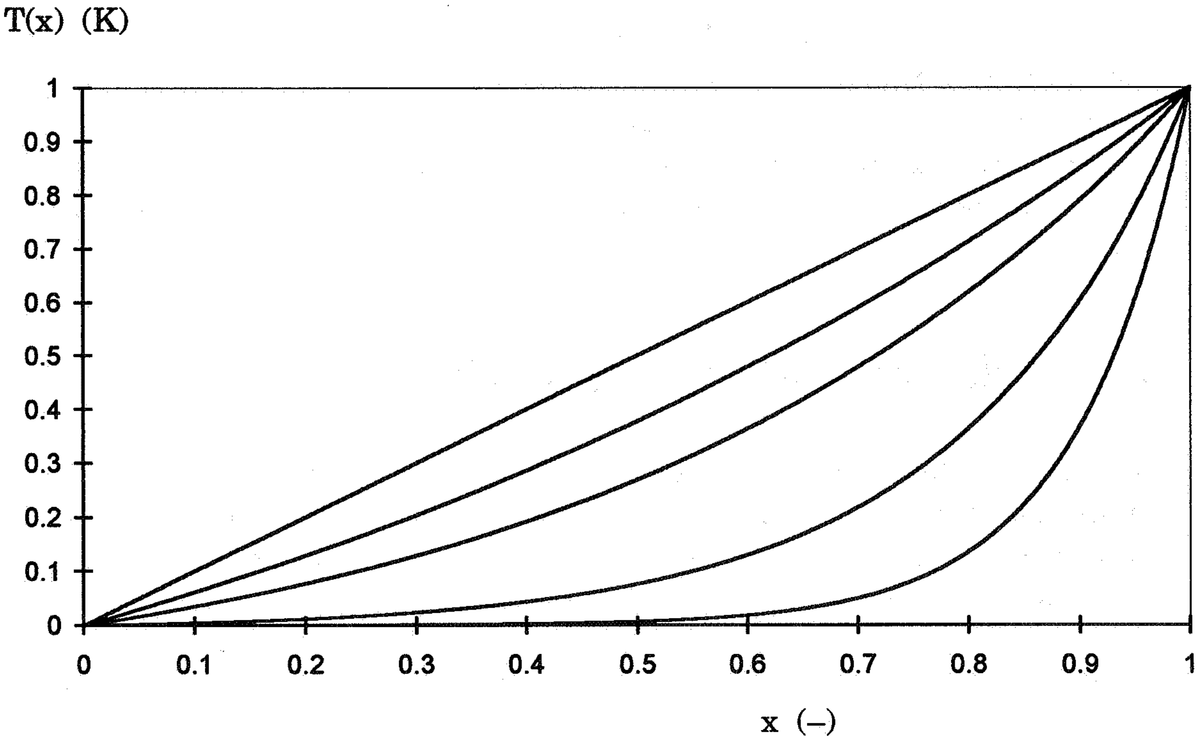

Figure 2.1 Temperature profile T(x) in flow insulation with T(0)=0 and T(1)=1, and for a = 0, 1, 2, 5 and 10 (curves ordered from above)

The total heat loss for the flow insulation looked upon from the outlet side is given as

$$P_o = \frac{\lambda}{d}\frac{dT}{dx}(1) \qquad (W/m^2) \qquad (2.8)$$

and after using the solutions the heat loss becomes

$$P_o = \rho c v\,(T_o - T_i) / (1 - e^{-a}) \qquad (W/m^2) \qquad (2.9)$$

The total heat loss for the flow insulation looked upon from the inlet side is given by

$$P_i = \frac{\lambda}{d}\frac{dT}{dx}(0) \qquad (W/m^2) \qquad (2.10)$$

and after simple calculations the heat loss becomes

$$P_i = \rho c v\,(T_o - T_i) / (e^{a} - 1) \qquad (W/m^2) \qquad (2.11)$$

The difference $P_o - P_i$ corresponds to the ventilation heat loss

$$P_v = P_o - P_i = \rho c v\,(T_o - T_i) \qquad (W/m^2) \qquad (2.12)$$

The choice of inlet and outlet temperatures T_i and T_o determines whether the flow insulation becomes co-current or counter-current flow insulation where flow and heat flow coincide or are opposite.

This paper is mainly based on my own reports (Jensen, 1982, 1986 and 1988). A more complete treatment of flow insulation is found in Anderlind and Johansson (1983).

3 Relative heat loss comparison

Two cases of flow insulation and one case with normal insulation and ventilation heat recovery are normalized to the normal insulation heat loss and compared as a function of the parameter a. The simplified normal insulation heat loss is given by

①
$$P_n = (\lambda / d)(T_i - T_o) \qquad (\mathrm{W/m^2}) \qquad (3.1)$$

where $T_i - T_o$ in this case is the indoor-outdoor temperature difference.

The relative heat loss for single flow insulation (counter-current or co-current) is given by (2.9) divided by (3.1) which becomes

②
$$p_s = P_s / P_n = a / (1 - e^{-a}) \qquad (-) \qquad (3.2)$$

Note that the ventilation heat loss due to the flow is included regardless of the flow direction.

③ Assume that half the insulation is counter-current and the other half is co-current. This means that the flow velocity is doubled compared with single flow insulation using the same insulation area of 1 m^2. The total heat loss can be written as

$$P_c = (2\,\rho c v / (1 - e^{-2a}) + 2\,\rho c v / (e^{2a} - 1))(T_i - T_o) / 2 \qquad (\mathrm{W/m^2}) \qquad (3.3)$$

which is the mean of P_o and P_i from (2.9) and (2.11) regarding that the velocity is doubled. After simplification the relative heat loss, that is (3.3) divided by (3.1), becomes

$$p_c = P_c / P_n = a\,(1 + e^{-2a}) / (1 - e^{-2a}) \qquad (-) \qquad (3.4)$$

Note that the ventilation heat loss is only included in the counter-current part and excluded in the co-current part.

④ The heat loss for normal insulation and ventilation with heat recovery is given by

$$P_r = (\lambda / d + \rho c v\,(1 - e))\,(T_i - T_o) \qquad (\mathrm{W/m^2}) \qquad (3.5)$$

where e is the ventilation heat recovery efficiency, and the relative heat loss becomes

$$p_r = P_r / P_n = 1 + (1 - e)\,a \qquad (\text{–}) \qquad (3.6)$$

The different heat losses p_s, p_c and p_r are given in Figure 3.1 as a function of the parameter a, the quotient between specific ventilation heat loss and normal (non-flow) insulation heat loss. The relative normal insulation heat loss $p_n = 1$ and the relative ventilation heat loss $p_v = a$ are also shown in Figure 3.1.

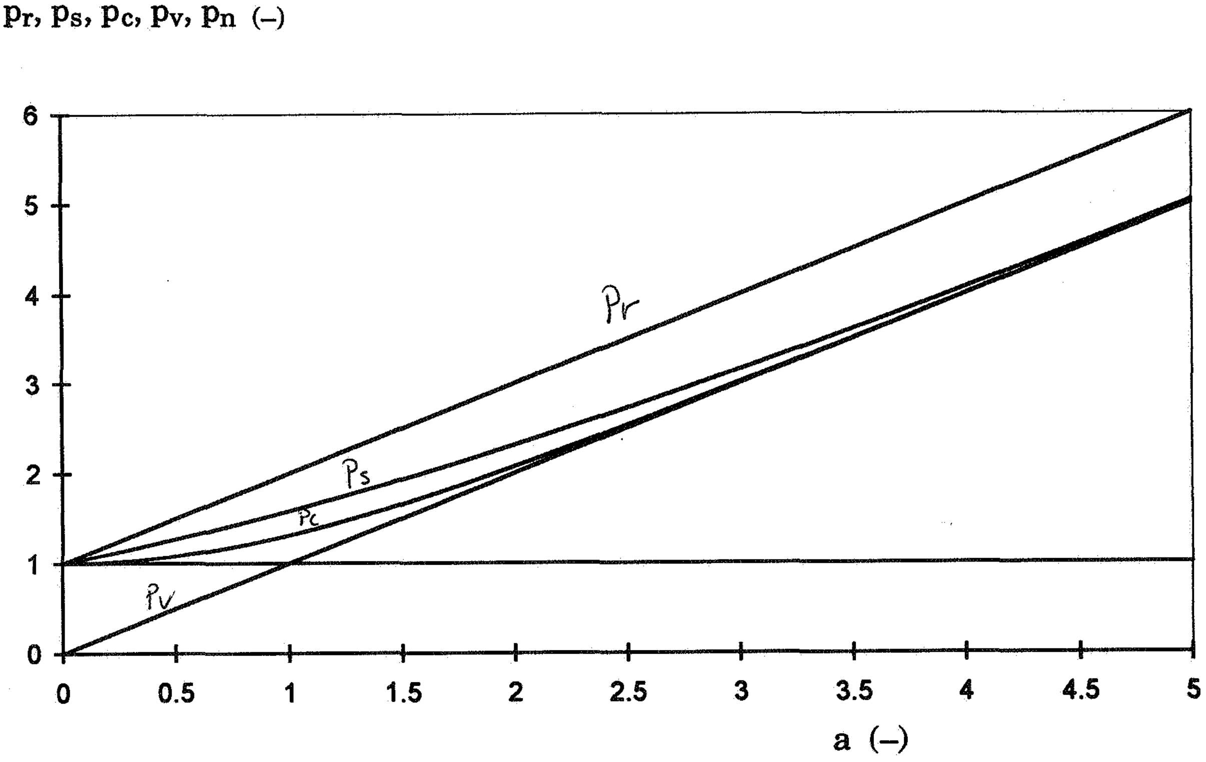

Figure 3.1 Relative heat losses p_r, p_s, p_c and p_v ordered from above, and $p_n = 1$ as a function of the parameter a.

The curves for p_s and p_c show that the saving in heat loss is always less than the minor of the two, the normal (non-flow) heat loss λ / d and the ventilation heat loss $\rho c v$.

The parameter a can also be looked upon as thickness of insulation if the ventilation is fixed. The nominal air flow in residential buildings in Sweden is 0.35 $\mathrm{l/sm^2}$ floor area corresponding to 0.5 air changes per hour. The specific ventilation need is given by ρcv and with $\rho c = 1200$ J/Km^3 and $v = 0.00035$ m/s it becomes 0.42 W/Km^2. If the insulation material conductivity is set to suitable figures 0.042 W/mK then the relation between a and d becomes very simple $a = 10\ d$. The parameter a can also be looked upon as thickness given in units of dm (0.1 m).

4 Relative heat loss reduction

The relative heat loss reduction is calculated relative to normal insulation and ventilation without heat recovery given by (3.6) with $e = 0$ for both single and combined flow insulation as

$$r_s = (p_r - p_s) / p_r \qquad (–) \qquad (4.1)$$

and

$$r_c = (p_r - p_c) / p_r \qquad (–) \qquad (4.2)$$

The two quantities r_s and r_c are shown in Figure 4.1 as a function of the parameter a.

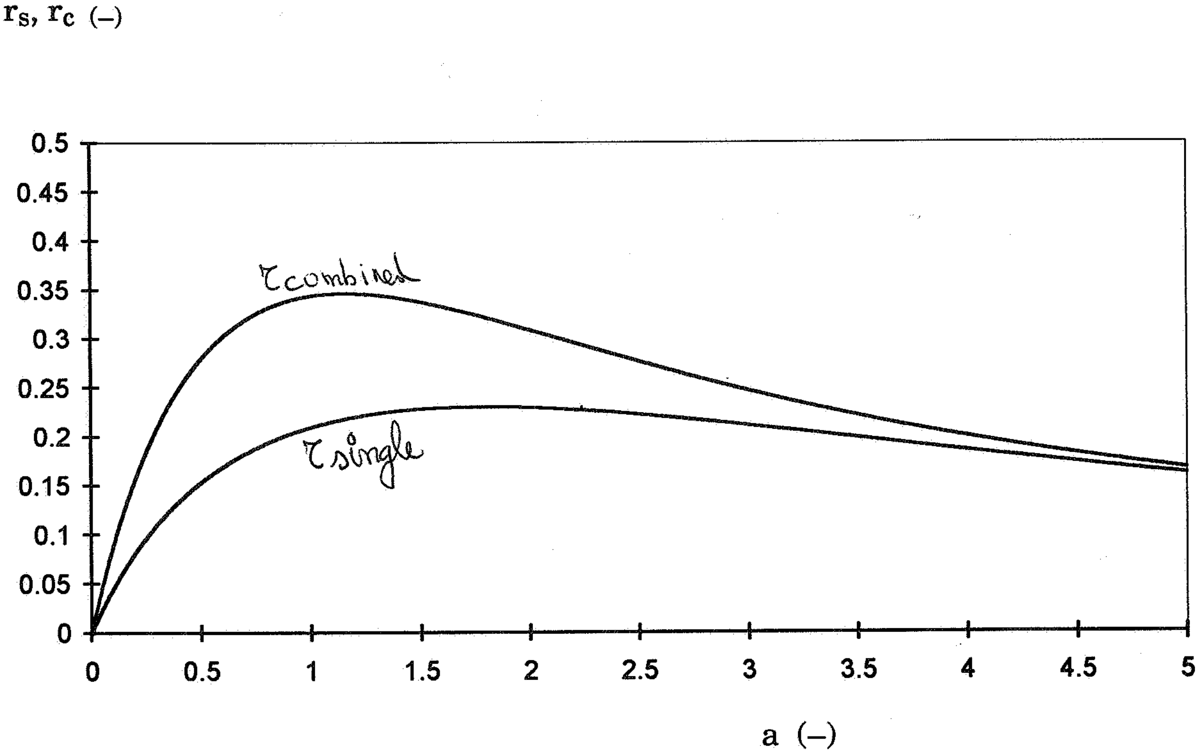

Figure 4.1 Relative heat loss reduction r_s (below) and r_c (above) as a function of the parameter a.

Both curves in Figure 4.1 show that the reduction has got a maximum for a specific value of the parameter a as follows

case	a	r
single	1.79	0.23
combined	1.15	0.35

Note however that the absolute reduction increases up to the normal (non-flow) insulation heat loss with increasing parameter a. Note also that the total reduction for a given building will be even less because of heat losses from other building parts.

5 Equivalent ventilation heat recovery efficiency

The reduced heat loss for both single and combined flow insulation can be described as ventilation heat recovery. The equivalent ventilation heat recovery efficiency can be found by putting $p_s = p_r$ and solving for e which gives

$$e_s = 1 + 1 / a - 1 / (1 - e^{-a}) \qquad (-) \qquad (5.1)$$

The efficiency e can be simplified to 1 / a for large values of the parameter a. The efficiency e is decreasing with increasing parameter a. Small relative ventilation needs or small parameter a values close to zero give e = 0.5. This means that only counter-current or only co-current insulation never can reduce the total heat losses more than a case with normal insulation and ventilation system with a heat recovery efficiency of 0.5.

The case with combined co-current and counter-current insulation gives an equivalent ventilation heat recovery efficiency e by putting $p_c = p_r$ and solving for e gives

$$e_c = 1 + 1 / a - (1 + e^{-2a}) / (1 - e^{-2a}) \qquad (-) \qquad (5.2)$$

This efficiency e is also decreasing with increasing parameter a and is equal to 1 for a = 0, and is close to 1 / a for large values of the parameter a. This means that combined flow insulation can correspond to a ventilation heat recovery efficiency close to 1. The two efficiency functions e_s and e_c are given in Figure 5.1 as a function of the parameter a together with the simplified function 1 / a for a > 1.

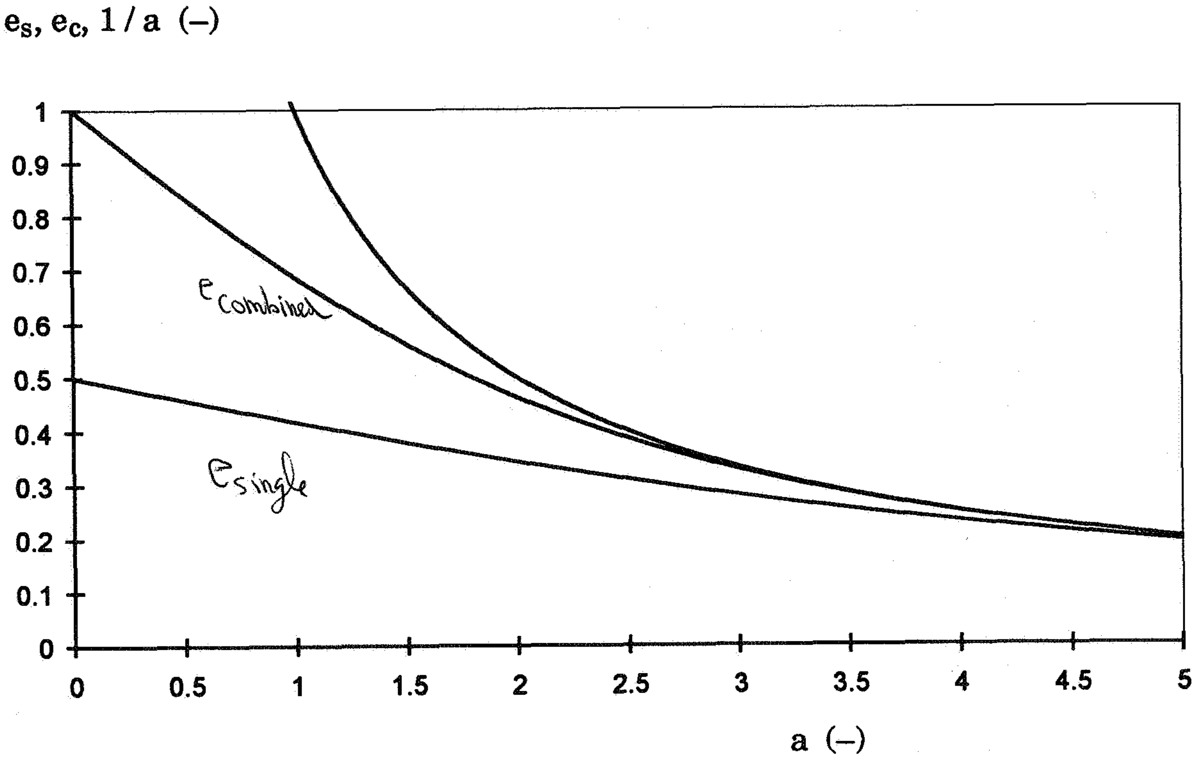

Figure 5.1 Equivalent ventilation heat recovery efficiency e_S (below) and e_C (middle), and the simplified function 1 / a (above) as a function of the parameter a.

6 References

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