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IEA- EXCO Energy Conservation in Buildings and Community Systems

ANNEX 24 HAMTIE: Heat- Air- Moisture Transfer in New and Retrofitted Insulated Envelope Parts

Energy transport due to heat conduction and mass transfer. A study of magnitudes.

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1 Introduction

The energy transport through a building construction part is caused by conduction, mass transfer or radiation. In this small study we will look at the effect due to conduction and mass transfer only. In the case of mass transfer we will look at vapor diffusion and air movements caused by forced and natural convection. The examples given below are supposed to give the magnitude of the various heat transfer mechanisms.

2 Heat conduction for the basic case

As a basic construction part we choose a homogeneous wall consisting of mineral wool only. For simplicity we neglect surface resistances.

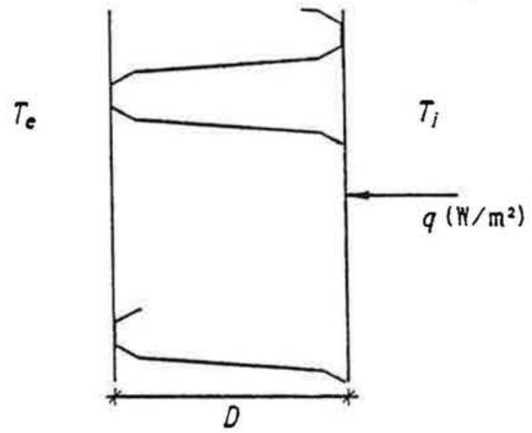

Figure 1: Heat conduction in a homogeneous wall.

The thermal conductivity is denoted by λ (W/mK). The thickness of the wall is D (m). The interior temperature is denoted by T_i and the external one is denoted by T_e (°C). The heat loss through the inner wall surface is denoted by q (W/m^2).

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The formula for the heat loss is:

$$q = \frac{T_i - T_e}{R} \tag{1}$$

$$R = \int_0^D \frac{ds}{\lambda(s)} \tag{2}$$

Here we have defined R ($\mathrm{m^2K/W}$) which is the total thermal resistance of the wall from the interior to the exterior side of the wall. We integrate over the width D in order to take variations of the lambda value, for instance caused by variations in moisture content, into consideration.

Example 1:

$$D = 0.3 \text{ m} \quad \lambda = 0.04 \text{ W/mK}$$
$$T_i = 20 \text{ °C} \quad T_e = -5 \text{ °C}$$

Formulas (1) and (2) give:

$$R = \frac{0.3}{0.04} = 7.5 \text{ m}^2\text{K/W}$$

$$q = \frac{25}{7.5} = 3.3 \text{ W/m}^2$$

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3 Extra heat transfer due to vapor diffusion without evaporation

Now we will try to estimate the maximum magnitude of the heat transfer caused by vapor diffusion.

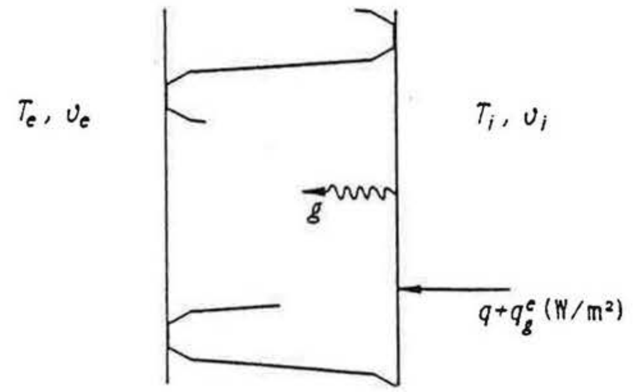


Figure 2: Moisture diffusion through a homogeneous wall.

The density of moisture flow rate g (kg/m²s) through the wall becomes:

$$g = \frac{\vartheta_i - \vartheta_e}{Z} \text{ (kg/m}^2\text{s)} \quad (3)$$

$$Z = \int_0^D \frac{ds}{\delta(s)} \text{ (s/m)} \quad (4)$$

Here Z (s/m) is the moisture resistance of the wall, ϑ_i and ϑ_e (kg/m^3) is the humidity by volume at the inner and other boundary.

We have denoted the extra heat transfer due to the vapor diffusion by q_g^e. This is the extra heat loss that should be added to the heat loss due to heat conduction only.

Let us assume that the relative humidity at the inner surface is very high ≈ 100 %, but still less than 100 %. We will not have any condensed water on the inner side, but almost as high relative humidity as possible. We assume that the relative humidity is 50 % outside the building. The moisture flow rate through the wall becomes:

$$g = \frac{\vartheta_{i,sat}(T_i) - 0.5 \cdot \vartheta_{e,sat}(T_e)}{Z} \text{ (kg/m}^2\text{s)} \quad (5)$$

Here we have used the index *sat* in order to note that it is the humidity by volume at saturation at a certain temperature level.

The vapor is transporting energy due to its heat capacity, c=1 860 J/kg °C. The vapor will release its heat on its way out through the wall. Assuming small water transports (normal case), half of the released heat will flow back through the inner wall and the other half will flow out through the outer one. We have:

$$q_g^e \approx -\frac{1}{2} \cdot g \cdot c \cdot (T_i - T_e) \text{ (W/m}^2\text{)} \quad (6)$$

In an energy balance for the building, one should of course take into account that the energy content of the vapor has been supplied by the building in its earlier history. However, this has to do with the global energy balance of the building. In this study we focus only on the wall itself. Furthermore we have not consider any counter effects due to air pressure differences caused by the difference in vapor pressure, which might be the case when equal total pressure at both sides of the wall is assumed.

Example 2:

$$D = 0.3 \text{ m} \quad \delta = 24 \cdot 10^{-6} \text{ m}^2\text{/s}$$
$$T_i = 20 \text{ °C} \quad T_e = -5 \text{ °C}$$

$$Z = \frac{0.3}{24 \cdot 10^{-6}} = 1.25 \cdot 10^4 \text{ s/m}$$

$$g = \frac{\vartheta_{i,sat}(20) - 0.5 \cdot \vartheta_{e,sat}(-5)}{1.25 \cdot 10^4} = \frac{(17.28 - 0.5 \cdot 3.24) \cdot 10^{-3}}{1.25 \cdot 10^4} =$$
$$= 1.25 \cdot 10^{-6} \text{ kg/m}^2\text{s} = 0.4 \text{ g/m}^2\text{h} = 10.8 \text{ g/m}^2\text{24h}$$

$$q_g^e \approx 3 \cdot 10^{-3} \text{ W/m}^2$$

The energy effect due to water vapor diffusion is around 1000 times less than the one caused by heat conduction only.

It must be stressed that the considered wall is extremely permeable for vapor diffusion, and it has a very good thermal resistance. A plastic foil increases the vapor resistance with a factor of 100, and 10 cm of concrete increases the resistance by a factor of around 10. For the example it should result in a ratio between heat conduction and moisture energy transfer of 10 000 to 100 000.

4 Extra heat transfer due to vapour diffusion considering evaporation and condensation.

Let us assume that we have condensed water at the inner surface of the wall. The vapor that is transferred into the wall originates from evaporation of the inner wall surface water. The energy for evaporation is taken from the wall surface. We get the following energy rate:

$$q^e_{ev} = r \cdot g \text{ (W/m}^2\text{)} \tag{7}$$

Here r is the condensation energy, $r = 2.5 \cdot 10^6$ J/kg, and g is the rate of evaporated water at the wall surface. This is also equal to the moisture flow rate through the wall. If the water is condensing in the inner of the wall the energy rate (7) is released. For the case when it is released in the middle of the wall, half of the energy will flow back to the inner wall surface.

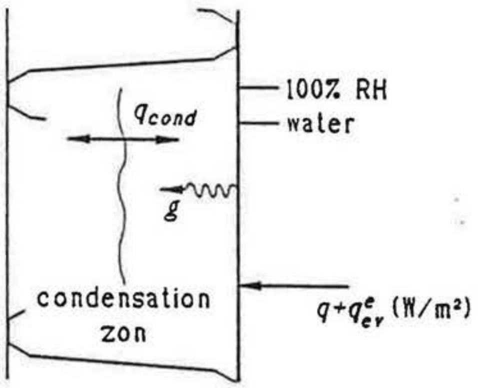


Figure 3: Evaporated and condensed water together with its associated energy transfers.

The net extra energy effect for the inner wall due to the moisture transport becomes:

$$q^e_{ev} - \frac{1}{2} \cdot q^e_{cond} \approx \frac{1}{2} r \cdot g \tag{8}$$

Example 3:

Using the same data as in Example 2 we get the following net extra hea: through the inner wall:

$$q^{e}_{ev} - \frac{1}{2} \cdot q^{e}_{cond} \approx \frac{1}{2} \cdot 2.5 \cdot 10^{6} \cdot 1.25 \cdot 10^{-6} = 1.56 \text{ W/m}^2$$

For lower indoor relative humidities than say 80 % there will be no condensa. at all.

The example shows that the energy rate due to evaporation and condensation the same order of magnitude as heat conduction. However, keep in mind that we a high relative humidity at the inner surface, and a wall that is very permeab vapor diffusion. The heat transfer in Example 3 demands accessibility of water a inner surface.

In normal walls the moisture transfer g is around 100 times less than the one in the example. This means that the numbers for the extra heat loss in the exa will decrease with a factor of 100.

5 Air movements in cracks

5.1 Heat transfer due to water carried by the air.

The heat capacity of the air and vapor is:

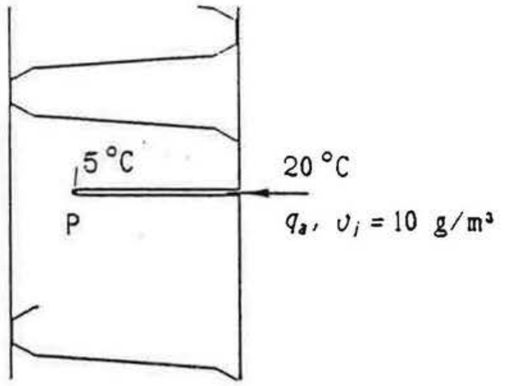
$$C_{air} = 1\ 290 \text{ J/m}^3\text{K}$$

$$C_{vapor} = c \cdot \vartheta \approx 1860 \cdot 10 \cdot 10^{-3} \approx 18.6 \text{ J/m}^3\text{K}$$

Here we have assumed a humidity by volume equal to around $10 \cdot 10^{-3}$ kg/m can see that the heat capacity due to the water content is around 1-2 % of the capacity of the air. It can therefore be neglected if there is no phase change water. This is shown in the following example:

Example 4:

Assume that air is flowing from the interior wall to a point P in the constru according to the figure below. At this point water is condensing.



The air flow rate is denoted by q_a (m^3/s). The total amount of heat transferred to the point due to the heat capacity of the air is:

$$q_a \cdot (20 - 5) \cdot 1290 = q_a \cdot 19\,350 \text{ (W)}$$

The corresponding heat due to condensation becomes:

$$q_a \cdot (\vartheta_i - \vartheta_{sat}(5)) \cdot r \approx q_a \cdot (10 - 6.79) \cdot 10^{-3} \cdot 2.5 \cdot 10^6 \approx q_a \cdot 8\,025 \text{ (W)}$$

For this case the two components of the heat transfer are of the same magnitude.

5.2 Forced convection in a crack

First we will study the case of forced convection in a straight crack in a wall. This is shown in Figure 4.

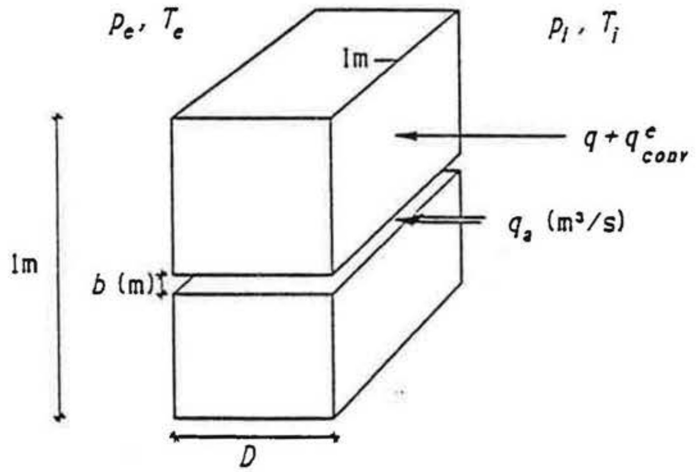


Figure 4: Forced convection in a crack through a wall.

We have denoted the pressure at the interior of the wall by p_i and the pressure at the exterior by p_e (Pa). The width of the wall is D and the crack height is b (m). The pressure difference induces the air flow q_a (m^3/s) in the crack. The excess heat loss through the wall due to air convection is denoted by q^e_{conv} (W/m^2).

Example 5:

We have the following data:

$\lambda = 0.04$ W/mK $D = 0.3$ m
$T_i = 20$ °C $T_e = -5$ °C
$p_i - p_e = 10$ Pa

The following table gives the excess heat loss for varying air gap heights b:

b (10^{-3} m)	q^e_{conv} (W/m^2)
0.1	0.0025
0.2	0.02
0.5	0.32
0.8	1.3
1.0	2.2

The calculations have bene done with the PC-program AHConp developed at our department.

5.3 Natural convection in the interior of a wall

We will study the case of natural convection in the interior of a wall. This is shown in Figure 5.

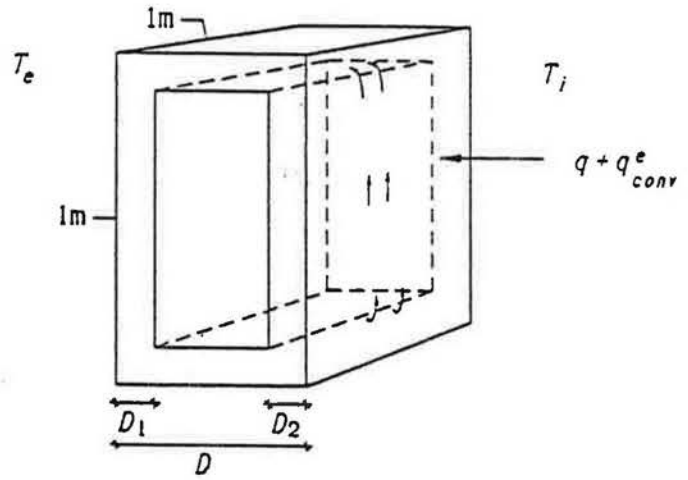


Figure 5: Natural convection in the interior of a wall.

The various widths describing the crack distribution in the wall are D, D_1, D_2 and the crack height is b (m). The stack effect induces the air flow q_a (m^3/s) in the crack. The excess heat loss through the wall due to the air movement is denoted by q^e_{conv} (W/m^2).

Example 6:

We have the following data:

$D = 0.3$ m $\quad D_1 = 0.05$ m
$D_2 = 0.02$ m $\quad \lambda = 0.04$ W/mK
$T_i = 20$ °C $\quad T_e = -5$ °C

The following table gives the excess heat loss for varying air gap heights b:

b (10^{-3} m)	q^e_{conv} (W/m^2)
0.5	0.00013
0.8	0.0006
1.0	0.0019
2.0	0.028
3.0	0.14
3.5	0.28
4	0.51

The calculations have been done with the PC-program ANHConp developed at our department.

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6 Conclusions

The most important heat flow component is caused by heat conduction. Moisture diffusion might be important for the energy flow in the case of evaporation or condensation in very vapor permeable constructions. For these cases water must be accessible. For normal cases the moisture gives heat flows that is less than one thousandth of the one obtained from heat conduction only.

In the case of cracks that are going through the construction or air that can circulate in cracks inside the construction, we obtain heat losses that are between 1 to 100 % of the heat conduction heat loss for air gap heights around 0.5-2 mm.

2.2 Task 2: Environmental conditions (leading country: UK)

The UK turned around a form on environmental conditions. The answers received were summarised in a first, short summary report. Also 2 provocative papers are introduced, both of mayor interest for the further evolution of the work: see add 2.