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PREVENTION OF MOISTURE DAMAGE BY VENTILATION OF THE FOUNDATION

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1. SYNOPSIS

Rising moisture from the ground has caused quite a lot of damage on foundations of Swedish buildings, in particular for the type concrete slab on the ground. Some of these constructions may be repaired by mechanical ventilation, for example below the floor or below the concrete slab , if there is an air-permeable layer below the slab.

Summarized results from a few field studies and tests, which have been going on for a period of 2-3 years, are reported. Different methods with mechanical ventilation systems have been found to work quite well so far, i.e. under two and a half years of experience, provided that the air flow is well distributed over the whole area exposed to the ground.

The temperatures immediatly below the slab is an important factor for the condensation. The time-dependent, two-dimensional thermal process in the ground, coupled to the convective heat transfer in the air-permeable layer, is simulated by a computer model. Preliminary results from the field measurements showed that it was necessary to take into account the heat of evaporation in order to get better agreement between calculations and field measurements.

A few results from parameter studies are reported. The influence of air flow intensity, inlet air temperature, climate, thermal insulation thickness, thermal properties of the ground and moisture supply to the inside air and from the ground is discussed.

2. LIST OF SYMBOLS

L= length of the house, m
B= width of the house, m
λ= thermal conductivity of the soil, W/m°C
ρc= volumetric heat capacity of the soil, J/m^3°C
T_o^{mean}= annual outdoor mean temperature, °C
T_o^{amp}= amplitude of outdoor temperature, °C
λ_{ec}= thermal conductivity of the insulation, W/m°C
d_{ec}= thickness of thermal insulation, m
Q_a= air flow intensity from mechanical ventilation, m^3/h
T_i= indoor temperature, °C
T_a= air flow temperature, °C
v_o^{max}= maximum outdoor vapour concentration, kg/m^3
v_o^{min}= minimum outdoor vapour concentration, kg/m^3
Δv_i^{max}= maximum moisture supply to the inside air, kg/m^3
Δv_i^{min}= minumum moisture supply to the inside air, kg/m^3
Z= resistance to water vapour migration, s/m

3. EXPERIENCE FROM FIELD MEASUREMENTS

A lot of relatively new Swedish buildings, founded with concrete slab on the ground, suffer from moisture damages. Therefore, a lot of different repairing methods have been developed in recent years. In many of these methods, mechanical ventilation in some form is an important factor.

3.1 Mechanical ventilation below the concrete slab

In order to ventilate an air-permeable layer below a concrete slab, different kinds of system have been developed. In many of these, holes are drilled through the concrete slab at the central part of the building. Fans are installed in connection to the holes. They force air through the air-permeable layer below the concrete slab. This air flow will prevent rising moisture from the ground to enter the concrete slab. In some of these systems, the fans are installed to give a positive pressure in the layer. As the fans are installed at the central parts of the building, the air is forced to move to the foundation walls, where it leakes out through drilled holes to the outdoor air. Other mechanical systems of this type creates a negative pressure in the permeable layer below the concrete slab. Indoor air is sucted into the air-permeable layer through holes which have been drilled through the concrete slab near the outer walls of the building. In a one-family residential house, it is usually sufficient to install a single fan at the center of the house. See Figure 1. The Swedish National Testing Institute has performed some field measurements on this type of system.

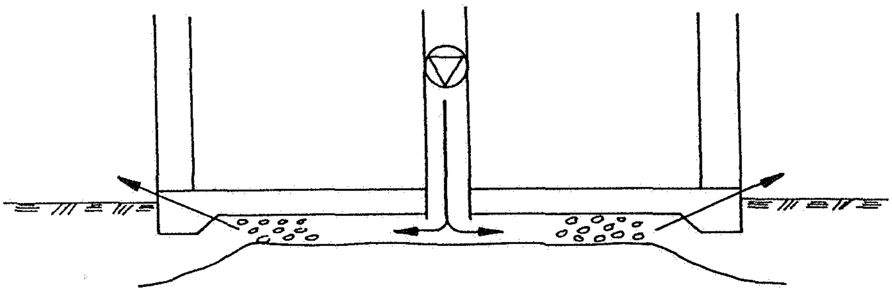

Figure 1: Ventilation under the slab with air flowing from the center to the sides.

Another system, with holes along two opposing sides is shown in Figure 2. The air flow in the air-permeable layer below the concrete slab is one-dimensional. We have followed such a system since its installation in June,1986. Indoor air from different parts of the building is pumped into the layer of lightweight expanded clay aggregate below the concrete slab at one gable end of the building and sucked out from the other gable end. In order to obtain a reasonably even distribution of the air stream below the concrete slab, evenly spred holes have been drilled through the foundation walls at the gable ends. Outside these holes there is a thermally insulated air channel which is connected to a fan at each gable end. Temperature measuring points have been installed in the upper- and lower parts of the ventilated layer below the spine wall. These temperature measurements, combinded with other measurements, are used in order to test the numerical model described below.

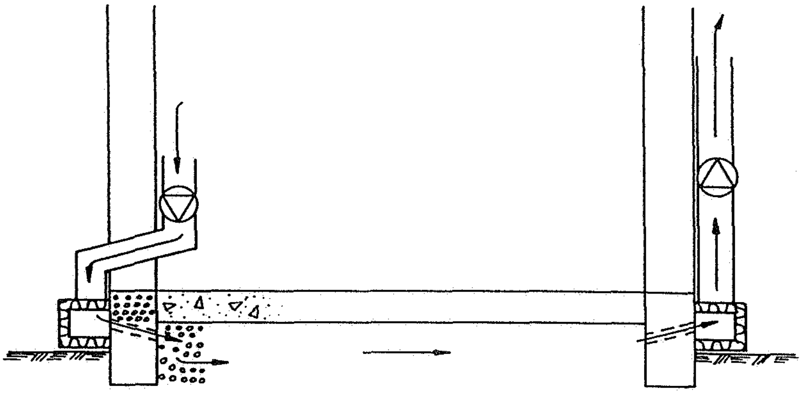

Figure 2: Ventilation under the slab with one-dimensional air flow from side to side

The measurements have just been finished, and no final conclusion regarding the installation has been reached. At this time, the experiences can be summarized in the following way:

- The relative humidity has decreased considerably in the lightweight expanded clay aggregate layer below the whole building. The concrete slab has also dried out, both near the gable ends and in the central part of the house.
- An advantage of this system compared to many other similar systemes, is that it should give an even distribution of the air flow below the whole concrete slab, provided that the foundation walls are fairly airtight.

3.2 Mechanical ventilation above the concrete slab

Methods of ventilating the space between a concrete slab and a joist floor construction in order to dry out wooden parts of the floor have been used in many Swedish houses during the last years. It is a comparably cheap method that has shown more positive effects than were expected only a few years ago.

We have made measurements for two one-family residential houses with joist floor on concrete slab in the south of Sweden. A centrally placed exhaust air fan has been installed in the houses combined with air supply devices at the outer corners. See Figure 3. The inlet to the exhaust air fan tube is placed immediatly above the concrete slab in the joist floor and the outlet is placed in the roof of the building.

In both of the houses, the mechanical ventilation system has caused a drying of the wooden parts of the floor. The effect has varied somewhat due to the fact that different parts of the floor are ventilated to lesser or greater degree. The surface of the concrete slab has also dried out.

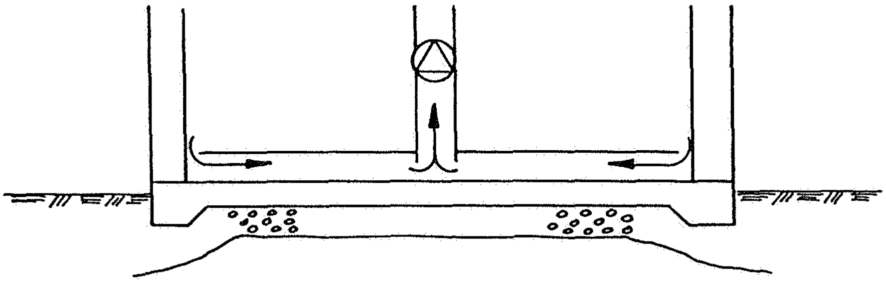

Figure 3: Ventilation above the concrete slab with air flowing from the sides to the center.

Mathematically this system can be described in exactly the same way as the systems with a centrally placed fan for ventilation of an air-permeable layer below the concrete slab.

3.3 Conclusions

The experiences this far indicate that, in many situations, mechanical ventilation is a succesful way to repair concrete slab foundations with moisture problem caused by rising moisture from the ground.

A disadvantage is that it is impossible to get full control of the air flow pattern.

It is a relatively cheap method. It can be installed in a short time and with small disturbance to the inhabitants.

Ventilation of the layer below the concrete slab is practically impossible, if the layer is to air tight.

Sewer pipes and other installations that have been placed in the ventilated layer will disturb the air flow pattern in a negative way.

The mechanical ventilation of the foundation must always be in use.

The mechanical ventilation should improve the quality of the indoor climate for a house with natural ventilation only.

There remains risks for condensation in the ventilated layer, if the indoor air has a high relative humidity, if there is a considerable temperature fall near the foundation walls, or if the moisture supply from the underlying ground is very big combined with low ventilation intensity.

4. NUMERICAL MODEL

The heat flow in the ground, below and around a building is three-dimensional and time-varying. The model described here concerns the two-dimensional case for a vertical cross-section. The heat flow in the ground is simulated using conventional explicit forward differences. The mesh size increases outwards and downwards to adiabatic boundaries far away. The outdoor temperature at the ground surface, the outdoor vapour concentration and the moisture supply to the indoor air varies during the year.

The vertical space below the house becomes, in the two-dimensional case, a channel along the x-axis. Let T_a(x,t) be the air temperature along the channel. The convective-diffusive heat balance for the air is:

$$K_+ (T_+ - T_a) + K_- (T_- - T_a) - \rho_a c_a q_a \frac{\partial T_a}{\partial x} = 0 \tag{1}$$

Here K_+ (W/m°C) is the conductance between the indoor temperature T_+ and the air, and K_- the conductance to the centre of the first cell in the ground with the temperature T_-(x,t). The air flow rate is q_a(t) (m_a^3/ms). We neglect horizontal heat conduction in the air and the capacity term ($\rho_a c_a \frac{\partial T_a}{\partial t}$). There is evaporation or condensation of moisture, which is determined by the difference between the moisture content in the air and at the ground surface. In the model we assume that the ground is saturated and that the resistance to water vapour migration Z (s/m) between the ground surface and the air in the ventilated layer is constant. A mass balance along the channel between evaporation/condensation and convective moisture flow gives the evaporation rate $g(x,t)$ (m_w^3/ms). The corresponding latent heat of evaporation must be accounted for in the heat balances. In the model, this heat enters in the balance of the first cell layer, which is exposed to the air channel.

The temperature field in the ground is calculated for time-step after time-step. At each step, equation 1 is solved analytically in the following way. We introduce the average temperatures T_m and the length l:

$$T_m = \frac{K_+ T_+ + K_- T_-}{K_+ + K_-} \tag{2}$$

$$l = \frac{\rho_a c_a q_a}{K_+ + K_-} \tag{3}$$

Equation 1 becomes:

$$\frac{\partial T_a}{\partial x} = -\frac{1}{l}(T_a - T_m) \tag{4}$$

The quantities l and T_m are piece-wise constant for each cell, $x_i \leq x < x_{i+1}$. The temperature along the cell becomes:

$$T_a(x) = T_{m,i} + (T_a(x_i) - T_{m,i})\, e^{-(x-x_i)/l_i} \qquad x_i \leq x \leq x_{i+1} \tag{5}$$

The inlet temperature to the air channel is given. The outlet temperature becomes the inlet temperature to the next cell, and so on.

5. PARAMETER STUDIES

The model is currently used to investigate how different parameters influence the temperature- and moisture distribution in the air-permable layer above or below a concrete slab. The model with its one-dimensional, or linear air flow, is applicable to the field measurement for the case shown in Figure 2.

The other types with a central hole give a more complicated two-dimensional air-flow pattern. We are currently working with this case. The two-dimensional air flow in the ventilated space must first be calculated. Then, there is a convective-diffusive heat balance with a more complicated convective term in equation 1.

Before the results from the parameter study are presented, it should be mentioned that the model that describes the moisture flow and the moisture distribution in the air-permeable layer is rather simple. We assume that the air flow is confined to one distinct level in the air-permeable layer. In most of the calculated cases we assume that this level is situated in the middle of the expanded clay aggregate layer below the concrete slab.

A basic case used in the discussions below, has the following data:

Basic case:

L =15.6 m
λ =1.0 W/m°C
T_o^{mean}=8.0 °C
λ_{ec} =0.12 W/m°C
Q_a=50.0 m^3/h
v_o^{max}=$10.9 \cdot 10^{-3}$ kg/m^3
Δv_i^{max}=$3.0 \cdot 10^{-3}$ kg/m^3
Z=360 s/m

B =8.0 m
ρc =$1 \cdot 10^6$ J/m^3°C
T_o^{amp}=8.6 °C
d_{ec}=0.2 m
T_i=T_a=22.0 °C
v_o^{min}=$3.9 \cdot 10^{-3}$ kg/m^3
Δv_i^{min}=$1.0 \cdot 10^{-3}$ kg/m^3

All cases below are compared at the end of January when the differences between the cases are largest. The differencies can generally be seen during the whole year, but they are not so pronounced in other seasons when the outdoor air temperature is higher.

Figure 4 shows the computed temperature along the air channel in three cases: 1. without ventilation, 2. with ventilation and without evaporation/condensation , 3. with ventilation and evaporation/condensation.

5.1 Temperatures without taking into account evaporation/condensation

Firstly, we will in this section study the thermal behaviour, and, in particular, the air temperature of the ventilated layer, without evaporation/condensation. The parameter studies presented in this section concern variations from the basic case

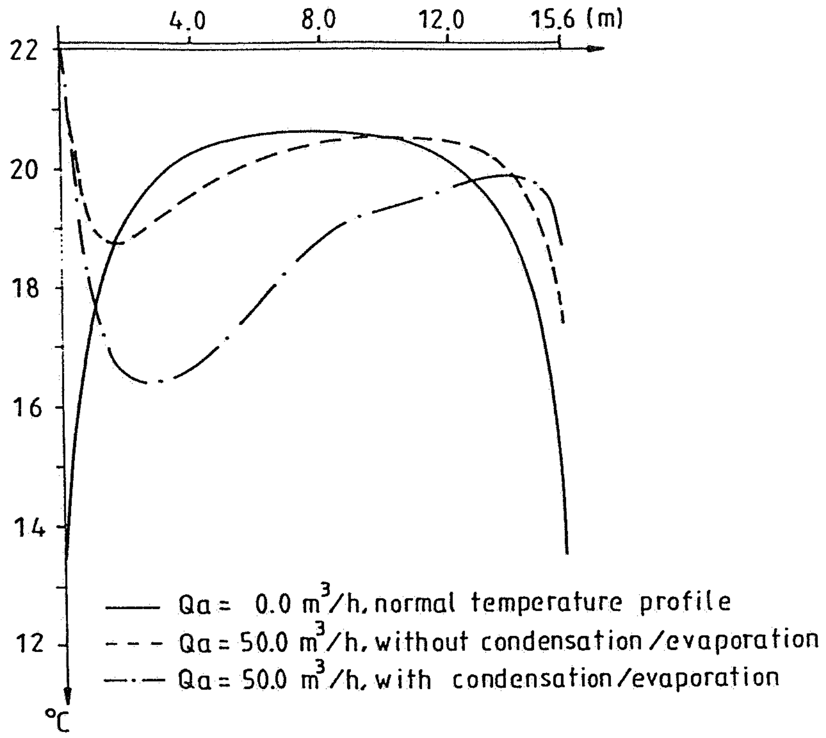

Figure 4: Temperature along the air channel.

without evaporation/condensation.

Basic case compared to natural temperature distribution without air flow
The temperature increase with more than 1 °C in the first 1.5 meter from both gable ends. The largest temperature increase occurs below the foundation walls.

Increased air flow rate (Q_a= 100 m^3/h)
A considerable increase in temperature is obtained near the inlet gable end. A very low air flow rate of 5 m^3/h results in approximately undisturbed conditions.

Increased inlet air temperature (T_a= 32 °C)
This gives a considerable temperature increase from the inlet gable to the middle of the house.

Colder outdoor climate (north of Sweden)
This gives a decrease of 0.5-1.5 °C.

Thicker thermal insulation (d_{ec}= 0.4 m)
The effect is small near the foundation walls. Below the central part of the concrete slab, the temperature decreases by at most 1.3 °C.

Thermal insulation outside the gable ends (width=0.8 m, R=1.0 m^2°C/W)
This gives a rather small increase of the temperature. The maximum increase is of 0.5 °C near the inlet gable end.

Increased thermal conductivity in the ground (λ= 3.5 W/m °C)

This gives a considerable temperature decrease, with a maximum of 2.5 °C. This can be noticed except near the inlet gable end.

Thermal insulation of the foundation walls at the gable ends ($R = 0.5\ m^2{}^\circ C/W$)
The effect on the temperature in the layer, is negligible.

Air flow along the bottom of the air-permeable layer
This means that the air is in direct contact with the ground below, while,in the basic case, the flow is positioned to the middle of the layer. This results in a temperature decrease of several degrees centigrade, about 4 °C near the gable ends.

5.2 Temperatures when evaporation/condensation is taken into account

Basic case including evaporation/condensation
Water from the ground will evaporate near the inlet gable end. This results in a temperature decrease. The temperature gradually approaches the temperatures of the basic case without evaporation/condensation, as the flowing air becomes saturated. Near the outlet gable end, the temperature becomes somewhat higher, compared with the basic case, which means that condensation is taking place. The parameter studies presented in this section concerns variations from this basic case with evaporation/condensation.

Increased air flow rate ($Q_a = 100\ m^3/h$)
If the air flow rate is doubled the temperature decreases near the inlet gable end. The increase in temperature when the saturated air moves towards the outlet gable end is also reduced.

Colder outdoor climate (north of Sweden)
A colder climate results in lower vapour concentration of the outdoor air. In this case we get the same behaviour as in the basic case, but the effect of the latent heat release is larger.

Thicker thermal insulation ($d_{ec} = 0.4\ m$)
The local maximum in temperature near the outlet gable end is decreased with approximately 1 °C.

Higher resistance to water vapour migration from the ground ($Z = 16500\ s/m$)
This will result in lower moisture supply from the underlying soil, and an ensuing smaller influence from the latent heat.

5.3 Vapour concentration in the air-permeable layer

Basic case
The vapour concentration increases continiously until about 2 m from the outlet gable end where it decreases somewhat due to condensation.

Higher heat conductivity of the natural soil (λ=2.0 W/m°C)
Approximately the same form of the vapour concentration curve is obtained but on a lower level due to the lower temperature level.

Increased air flow rate (Q_a= 100 m^3/h)
The vapour concentration increases of a lower rate along the layer, and the decrease near the outlet is reduced.

Colder outdoor climate (north of Sweden)
The only difference from the basic case is that the level of the vapour concentration curve lies about 1.0 g/m^3 lower.

Thicker thermal insulation (d_{ec}= 0.4 m)
The shape of the curve does not change, but the level is 1-2 g/m^3 lower.

5.4 Comparison between field measurements and calculations

The measured temperatures in the air-permeable layer differ somewhat from the calculated ones. The gradients along the flow direction near inlet and outlet become larger in the calculations, and the level is about 1-2°C too high. Part of the differences can probably be explained by uncertainties in the parameter values, in particular for thermal conductivity of the soil, thermal conductivity of the ventilated layer, air flow, outdoor climate and measuring errors. Another uncertainty is the distribution of the air flow in the air-permeable layer. The model assumes a perfectly linear flow, which is evenly distributed over the inlet/outlet gable ends.