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Ventilation, Heat and Moisture Conditions in Attic Spaces.

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1 Summary

Due to the complexity in describing the simultaneous effects of a number of factors that influence the climate of an attic space it has proven to be difficult to make simulations of it.

This report deals with the problem of using different computer programs for ventilation, heat and moisture balance in an integrated way so that a proper description of the expected attic climate can be achieved.

A general overview of attic space climate and the factors affecting it will be given and it will be described how the simulation packet works. Results from a simulation will be given and commented upon.

2 Attic space climate

2.1 General

The most important parameters for describing the attic climate as far as the hygro-thermal behaviour of the attic space is concerned are relative humidity values and temperatures for the air in the attic space itself and at the surface of materials exposed to the attic space. Knowing these parameters and their variations quite a lot of conclusions can be drawn regarding the expected durability of the materials, the energy performance etc.

The attic space climate is determined by a number of factors such as ventilation rate, outdoor climate, moisture exchange by convection between the attic space and the heated part of the building, insulation degree of the attic floor, solar radiation on the roof, radiative and convective heat exchange in the attic space, moisture and other properties of materials used etc.

2.2 Ventilation

The purposes of ventilating an attic space is to remove moisture and to decrease the temperature in the attic space. In most cases purpose provided ventilation devices are installed in order to ventilate the attic space naturally, by means of wind and sometimes stack forces. The most simple and perhaps also most common way to provide these vent devices is to leave a slot open (10-30 mm wide) at the eaves of the roof. In this case the ventilation of the attic space is depending on the prevailing wind conditions around the building.

Every attempt to predict the heat and moisture conditions of an attic space must involve a calculation or at least an estimation of the ventilation flow, otherwise calculations cannot be undertaken.

The most severe problem in calculating or estimating the ventilation is to determine what the wind close to the building really is like (speed and direction). Even if the wind is known there is a problem to select reliable pressure coefficients for the intake and outlet openings. Furthermore, you must know the geometry of the flow paths of the ventilation openings.

The wind-driven ventilation of the attic also influences the pressure difference between the attic space and the heated part of the building, thus affecting the convective moisture exchange.

2.3 Heat balance

The heat balance of the attic space is governed by a large number of factors such as the outdoor climate (including solar radiation), the indoor climate and the insulation level of the attic floor, convective heat exchange, radiative heat exchange etc. and again the ventilation. If condensation / evaporation takes place at some surface(s) this will also influence the heat conditions.

2.4 Moisture balance

The moisture conditions of an attic space are governed by the outdoor climate, the convective moisture exchange between the attic and the heated part of the building and the moisture exchange between the attic space and the materials in it, (absorption or desorption). If the relative humidity should be considered, also the temperatures of the air and at surfaces must be taken into account.

3 Simulation package

3.1 General layout

A ventilation program provides the heat balace and the moisture balance programs with an algorithm for the ventilation rate of the attic as a function of wind velocity and direction. There is also an algorithm for the convective moisture and heat exchange betweeen the attic and the heated part of the building.

For the ventilation as well as the other calculations performed a data file of outdoor climatic data is used (Malmö, Sweden, 1971 - a widely used natural reference year for energy calculations in Sweden).
The ventilation algorithms are used in the heat balance program, describing all the convective parts of the heat balance. The heat balance program then performs traditional calculation on heat transfer due to conduction and radiation coming up with a set of temperatures for the attic air and surface temperatures.

The data produced until now is used in the moisture balance program taking into account sorption and desorption in materials, thus producing final data on humidity in the attic space.

3.2 Software

3.2.1 MLNBS

The MLNBS code was originally developed by G Walton at the NBS in US, WALTON (1982), and further developed by M Liddament at the AIVC in UK (unpublished). It is essentially a multi-zone infiltration and ventilation program.In this work a two zone simulation is performed, one zone being the attic space and the other the heated part of the building. As a result of running the program all air flow rates of interest are calculated as a function of the wind velocity and the temperature difference between the attic and the heated part of the building.

The calculations are performed for different levels of airtightness of the walls of the building and the bottom floor in the attic. The calculation results for a building specified in part 4.1 of this report are shown in figures 3.2.1.a - 3.2.1.f. For all the calculations the wind velocity used is the local wind velocity at roof top level.

The pressure coefficients used originate from the AIVC Air Infiltration Calculation Techniques Guide, (Liddament, 1986)

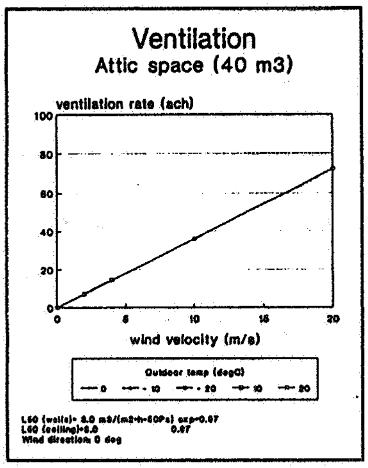

Figure 3.2.1a

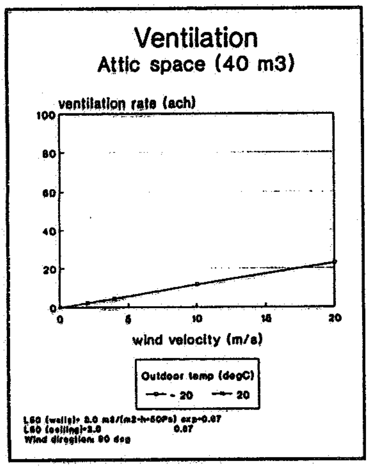

Figure 3.2.1b

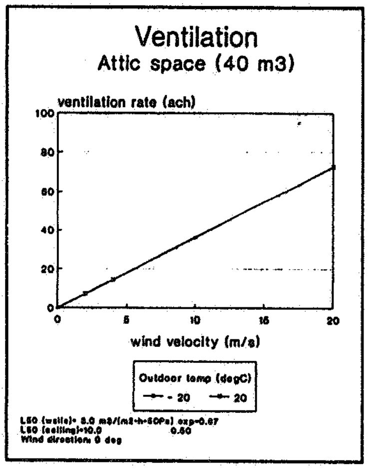

Figure 3.2.1c

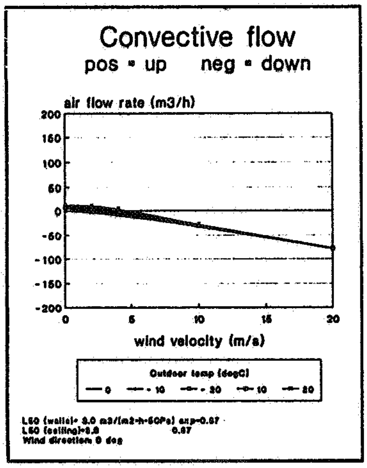

Figure 3.2.1d

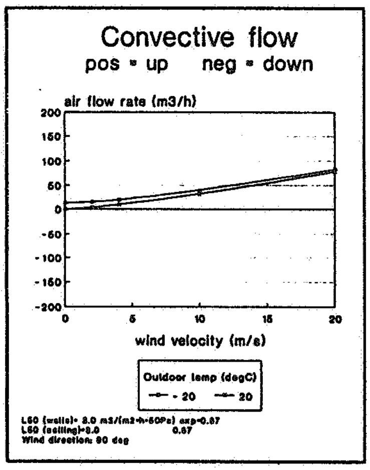

Figure 3.2.1e

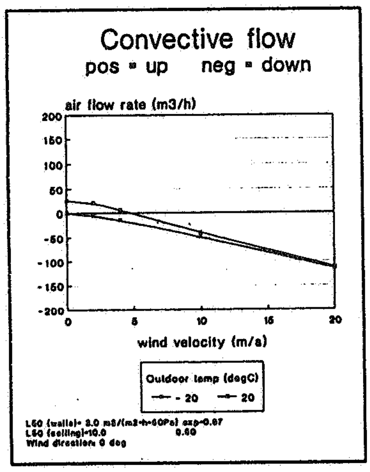

Figure 3.2.1f

3.2.2 DEROB-LTH

DEROB or Dynamic Energy Response of Buildings is a computer program in Standard-Fortran with generalized algorithms for the calculation of temperatures and energy in arbitrarily designed buildings. The program was originally developed by F.N. Arumi at the School of Architecture, University of Texas, Austin, US, (Arumi & Wysocki, 1979 and Arumi, 1979). The work with the development of the program was started in 1971. The program has been further developed at the department of Building Science, Lund University. The version used for the calculations is called DEROB-LTH.

3.2.3 PIVIND

Moisture absorption and desorption at surfaces exposed to the attic atmosphere is calculated by using the moisture transfer equation

$$g = ð\ \text{delta} * \text{grad}\ v$$

where
g = density of moisture flow rate
delta = vapour permeability
v = vapour concentration

and the boundary condition

$$g = \text{beta} * (v_{sur}\ ð\ v_{attic})$$

where
beta = surface coefficient of vapour transfer
v_{sur} = v at material's surface
v_{attic} = v in the surrounding attic air

The surface temperatures of the various building elements surrounding the attic are taken from the DEROB simulation. The temperature distribution between the surfaces is considered linear, thus disregarding all effects of heat capacity.

To carry out the calculations it is necessary to know the vapour permeability as a function of the moisture content and the hygroscopic sorption curve (relation between moisture content and relative humidity).

A simple forward difference method is used to solve the equations and for each time step the evaporation from the surrounding surfaces (gevap) to the attic is calculated.

For each time step a new attic vapour concentration is then calculated:

$$v_{attic,new} = v_{attic,old} + R_{out}*dt/V*(v_{out}\ ð\ v_{attic,old}) + \\ +R_{in}*(v_{in}\ ð\ v_{attic,old})*dt/V + dt/V*gevap$$

where
$v_{attic,new}$ = new vapour concentration in the attic air
$v_{attic,old}$ = old vapour concentration in the attic air

Rout = air flow to the attic from the outside
Rin = air flow to the attic from the inside
dt = time step
V = attic volume
vout = outdoor air vapour concentration
vin = indoor air vapour concentration
gevap = density of evaporation flow rate

4 Simulation application

4.1 General input data

The calculations have been performed for a building by the size of 7.4 m * 7.2 m with a height to the eaves of 2.5 m. The building has a roof with a ridge height of 0.75 m.

The roof of the house consists of a 22 mm thick wooden panel and a roof felt. The roof is supported by trusses (45 mm * 145 mm). The attic floor is insulated with 200 mm of mineral wool (lambda = 0.04 W/mK). The indoor moisture supply (in the heated part of the building) is 0.003 kg/m^3.

The wind pressure coefficients used are shown in figure 4.1.a.

	Wind pressure coefficient	
Surface	Wind acting on long side (dir A)	Wind acting on gable side (dir B)
1	0.3	-0.3
2	0.4	-0.3
3	-0.5	-0.3
4	-0.5	-0.3
5	-0.3	0.3
6	-0.3	0.4
7	-0.3	-0.3
8	-0.3	-0.3
9	0.4	-0.4
10	0.4	-0.3
11	-0.5	-0.4
12	-0.5	-0.3

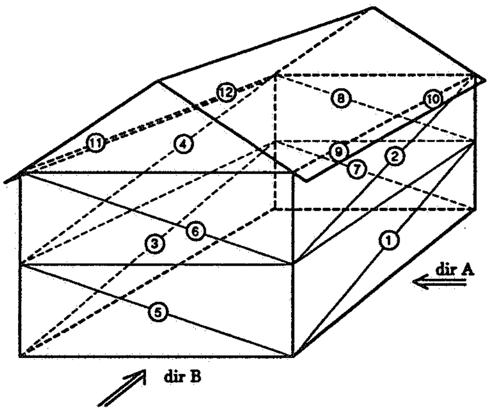

Figure 4.1.a Wind pressure coefficients used in the simulations

The ventilation of the attic space is provided by a 20 mm wide slot at each roof eave along the longer side of the building.

The results of the ventilation and convection calculations performed by means of the MLNBS program were generalised for introduction as algorithms in the DEROB-BKL and the PIVIND programs in the following way

Ventilation of attic space with outdoor air

For wind direction perpendicular to the eaves (0 deg)

$q = 0.04\ u$

where

q = ventilation flow rate (m3/s)
u = wind velocity at roof top (m/s)

For wind direction perpendicular to the gables (90 deg)

$q = 0.01\ u$

Convection from (positive) or to (negative)
the heated part of the building into/from the attic space

L50 = 3 m^3/m^2h ('normal' airtightness)

For 0 deg $q = 0.0060 - 0.0014\ u$
For 90 deg $q = 0.0014 + 0.0010\ u$

L50 = 10 m^3/m^2h (leaky)

For 0 deg $q = 0.0060 - 0.0020\ u$
For 90 deg $q = 0.0014 + 0.0020\ u$

4.2 Output data with comments

In this section results from a simulation will be presented and commented upon. The mere intent of this is to demonstrate the possibilities of the program packet rather than giving a detailed description of the results for a longer period. The month chosen is October and the reason behind the choice is that empirically we know that this may be a month with an outdoor climate giving rise to rather severeimpactson the moisture levels in the attic space.

The simulation is performed for wind perpendicular to the eaves during the whole period and with 'normal' airtightness of the attic floor (see above in section 4.1). The outdoor conditions are determined by the climatic conditions in Malmö, Sweden in 1971.

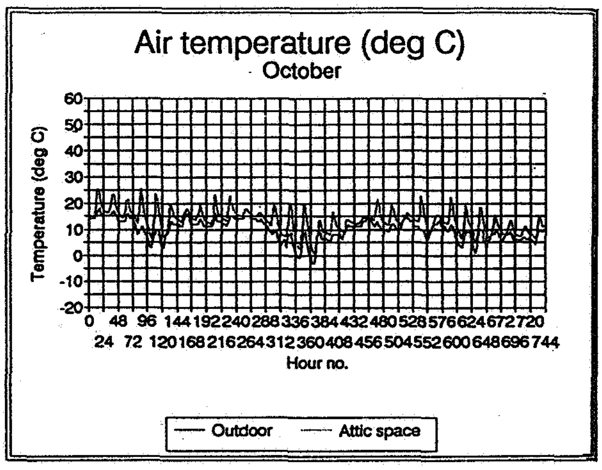

Figure 4.2.a

The figure shows the air temperatures outdoors and in the attic space. It can be seen that the attic air temperature always exceeds the outdoor air temperature. The difference can be up to around 10 deg C, probably on sunny days.

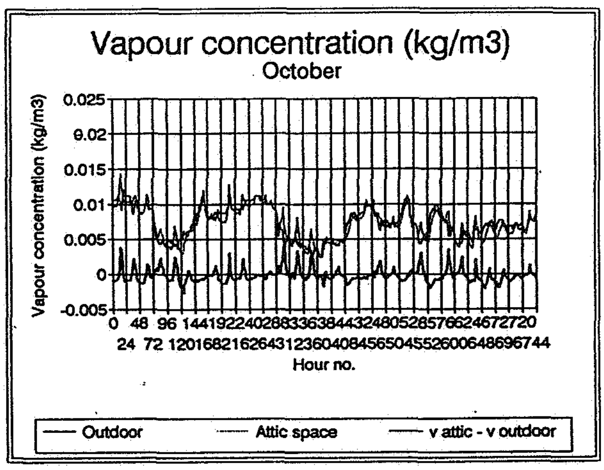

Figure 4.2.b

The figure shows the vapour concentration outdoors and in the attic space, as well as the difference between them. For a number of days a periodical behaviour of the vapour concentration in the attic space can be traced, while in most cases this is not seen for the outdoor condition. This is more easily seen in the graph for the difference in vapour concentration. The main reason for these variations is probably the moisture exchange between the materials in the attic and the attic air. This could be studied more specifically in figure 4.2.d.

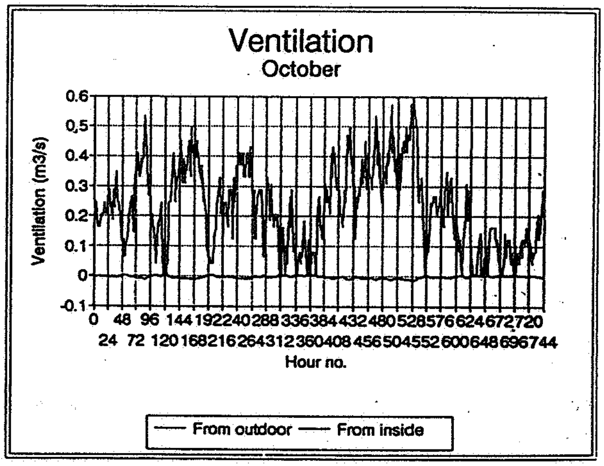

Figure 4.2.c

The figure shows the ventilation with outdoor air of the attic space as well as the convective exchange between the attic and the heated part of the building.First of all it can be seen that, compared to the ventilation, the convective exchange is small. This is probably due to the fact that the simulated case is the most 'favourable' (normal airtightness of the attic floor and wind hitting the long-facade of the house; see section 4.1 for details!). The ventilation rate however varies considerably due to different wind velocities during the period. For the period studied there seems to be a peak in ventilation during daytime. The attic has a volume of 40 m^3 so the ventilation rate of 0.2 m^3/s e.g. corresponds to 0.2*3600/40 = 18 ach. This seems to be a proper estimation of the average during the period.

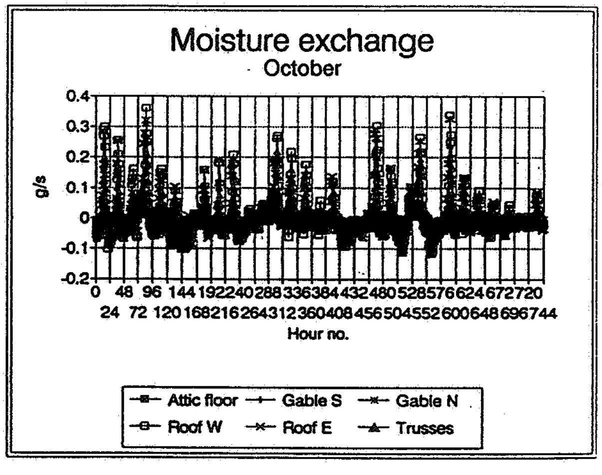

Figure 4.2.d

The figure shows the moisture exchange between the different parts of the envelope of the attic and the attic air. Most surfaces seem to have a relatively modest exchange (close to 0 g/s) while others give relatively large contributions (Roof W, roof E and the trusses especially). By comparing this figure with figure 4.2.a it can be seen that large desorptionof moisture is closely connected to sunny days, while,on the opposite, sorption takes place on cold nights.

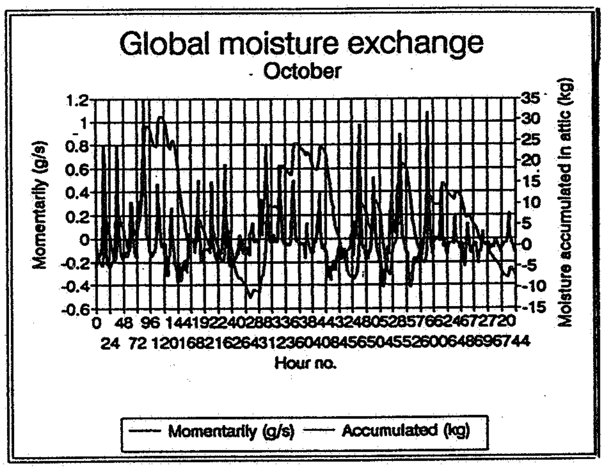

Figure 4.2.e

The figure shows the global moisture exchange for the attic space as a whole, both momentarily and accumulated for the whole month. The peaks for the momentarily case, also seen in the last picture, are still there. The accumulation graph shows that during this month there is a drying out of the attic with appr. 7 kg water, with variations in accumulation between 30 kg and - 15 kg.

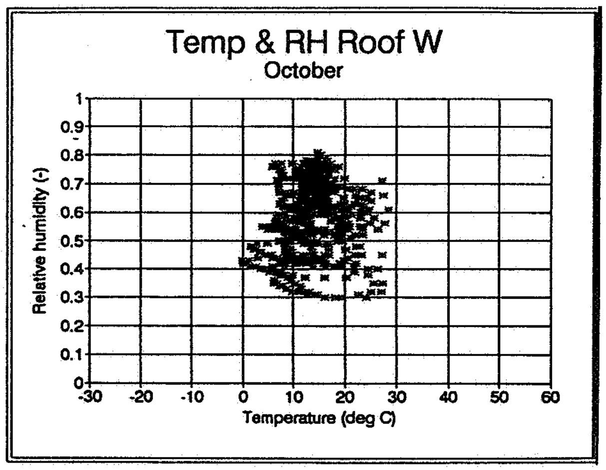

Figure 4.2.f

The figure is a XY-plot of relative humidity at a surface (roof W) against surface temperature. As can be seen there seems to be a concentration of dots around appr 15 degC and RH around 60 per cent. The variations are however large. There is a potential with this kind of plots for predicting the risk for mould growth on surfaces in an attic space since certain combinations of temperature and RH represent different risk levels for mould growth (Nevander & Elmarsson, 1991).

5 Literature

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