HEAT, MOISTURE AND AIR TRANSPORT IN CRAWL SPACES

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INTRODUCTION

In the Netherlands it is common to build houses with a crawl space below the ground floor. Until now little attention has been paid to potential moisture problems associated with crawl spaces. Most houses are built at places where the ground water level is only few decimeters below the ground level and in general crawl spaces have a very humid climate. A relative air humidity of 95% and an excess water vapour concentration of 6 g/m3 with respect to outdoor air are quite normal. Up to now no special attention was paid to the air tightness of ground floors. The infiltration of moist air from the crawl space to the living areas have led to severe moisture problems in many cases. Another aspect, associated with potential moisture problems, is the presence of thermal bridges at the floor foundation. In recent years, the potential risks of humid crawl spaces have been recognized and since that time many remedial measures have been considered. At TNO several investigations were done with respect to crawl space problems. Research work was directed to investigations in the field as well to the development of models describing HMA (Heat, Moisture and Air) transport mechanisms in crawl spaces. In this paper a brief presentation will be given about work on modelling of crawl spaces.

A COMPLEX CRAWL SPACE MODEL

Below a description will be given of the thermal conduction model TH3DR. In this model some combined HMA features have been implemented, which makes it suitable for a crawl space model. The TH3DR program is an extended version of thermal model TH3D, which was originally developed as a general purpose thermal program to solve 3-D steady state and transient heat conduction problems. The purpose of the extended TH3DR model is to enable the combined modeling of the heat, moisture and ventilation phenomena in crawl spaces. To achieve this some subroutines were added to the TH3D program. Using these subroutines, an internal space is defined inside a 2-D or 3-D distributed solid structure. The internal space is confined by the surface elements of the thermal conduction model. The temperature and humidity of the internal air are considered to be uniform. A subroutine is added to calculate the heat, moisture and air balance of the internal space.

The heat balance includes:
- radiative heat exchange between surface elements
- convective heat exchange between each surface element and the internal air
- the heat loss by ventilation
- latent heat exchange by condensation or evaporation at the surface elements

The moisture balance incudes:
- moisture production
- condensation or evaporation on surface elements
- moisture removal by ventilation

To solve the combined HMA equations in the TH3DR model an iterative procedure of two nested iteration steps is followed. In the first iteration step the temperatures in the solid domain are computed. This yields estimated surface temperatures that are used in the second iteration step to solve the heat balance and moisture balance equations for the internal space. From these equations the internal air temperature and humidity are computed. The heat fluxes for surface elements are also computed and these are used as boundary conditions for the first iteration step. This process is repeated until the desired accuracy is achieved.
An example of a calculation result is given in figure 1.

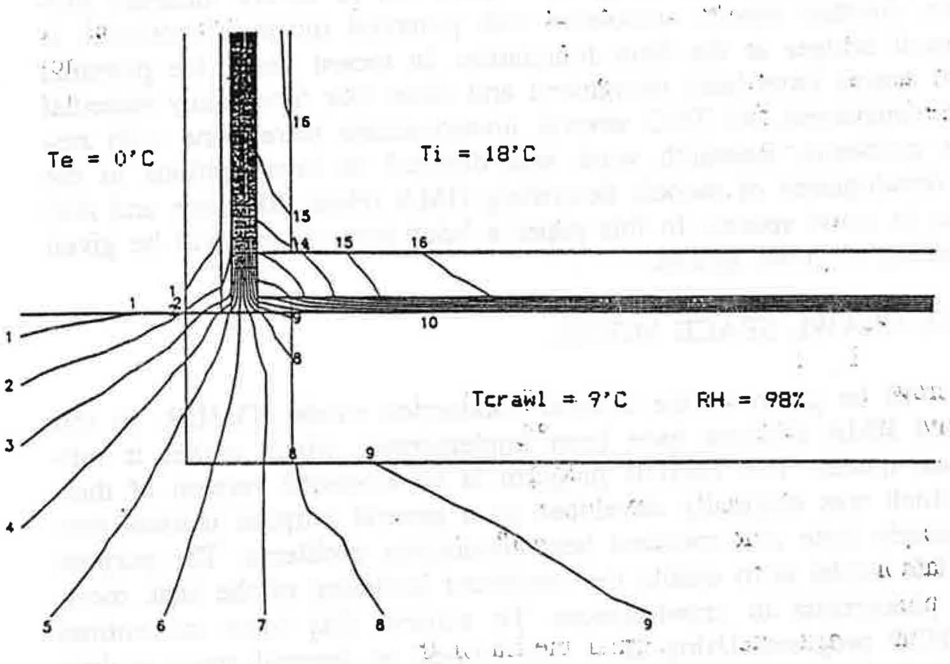

FIGURE 1 Example of a temperature isotherm plot for a crawl space as computes by the TH3DR model. The most relevant input data are:
- 5 cm under floor insulation
- crawl space air change rate 0.5 h^{-1}
- no vapour barrier on crawl space bottom
- steady state conditions
- external temperature Te = 0 °C.
- internal temperature Ti = 18 ° C.

The crawl space air temperature and air humidity are computed by the TH3DR model.

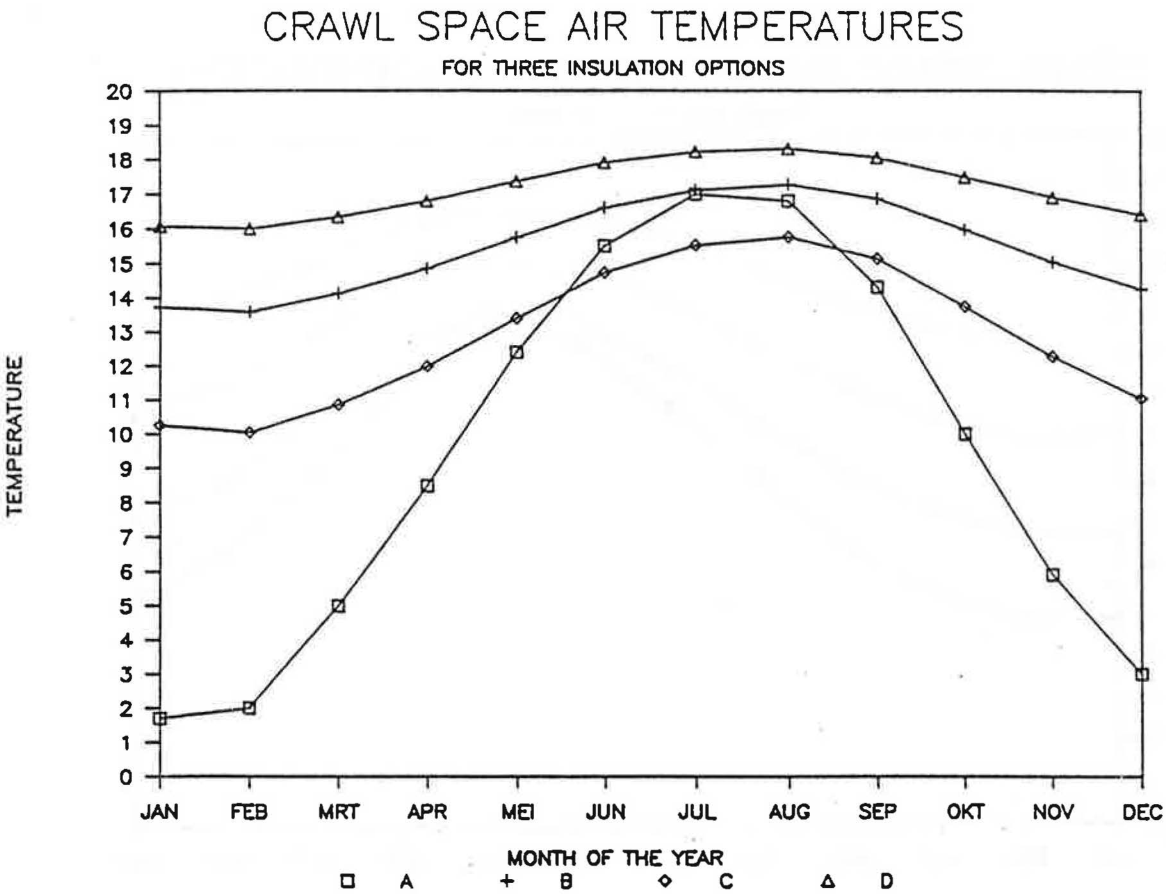

FIGURE 2 Crawl space temperatures as computed by the simplified spreadsheet model.
A: Monthly outdoor temperature.
Crawl space air temperatures are shown for three options:
B: no insulation
C: 5 cm insulation at the ground floor
D: 10 cm insulation including a vapour barrier on the crawl space bottom

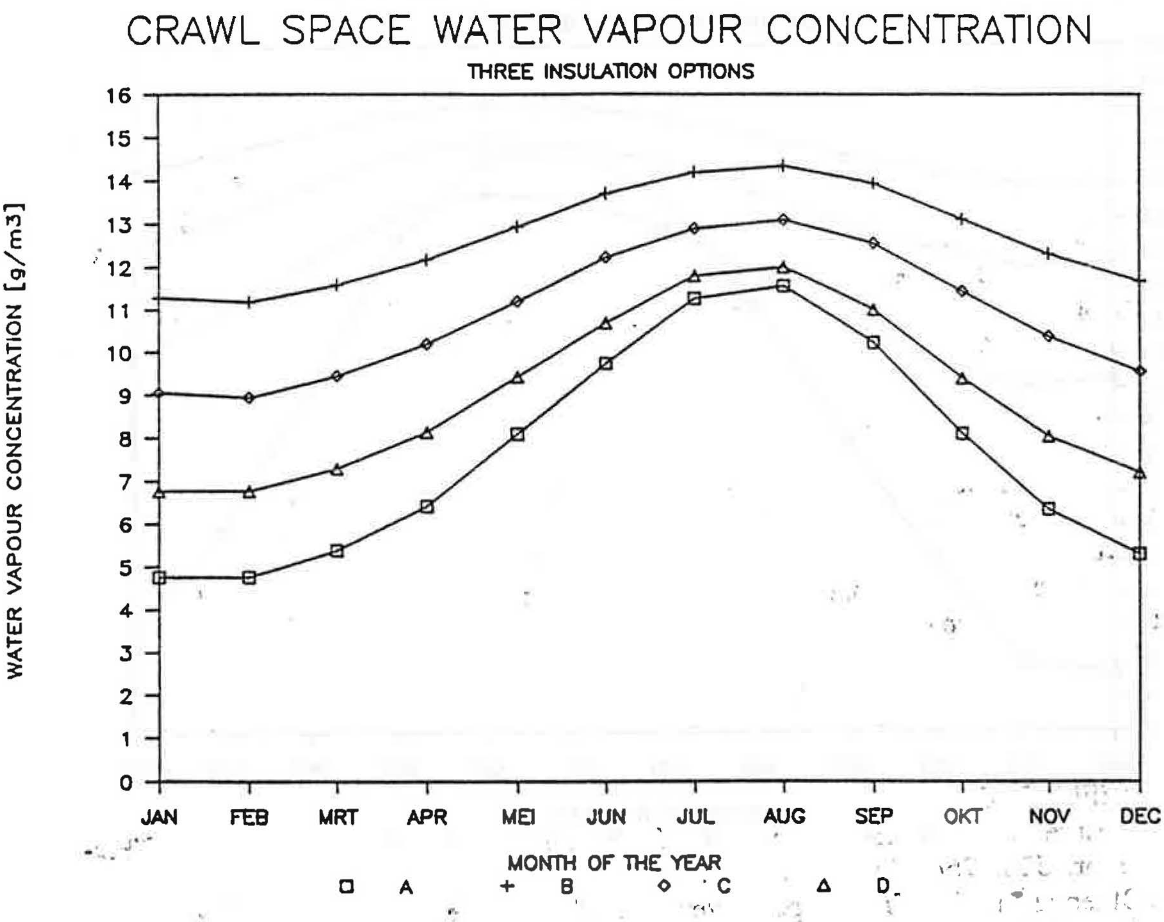

FIGURE 3 Crawl space water vapour concentrations as computed by the simplified spreadsheet model.
A: Monthly outdoor water vapour concentration.
Crawl space vapour concentrations are shown for three options:
B: no insulation
C: 5 cm insulation at the ground floor
D: 10 cm insulation including a vapour barrier on the crawl space bottom

AIRBORNE MOISTURE TRANSPORT FROM CRAWL SPACES

Airborne moisture transport from the crawl space can lead to a severe moisture load for the living zones. Due to thermal stack effects the dwelling will have in general an underpressure with respect to the crawl space. Hence, humid air from the crawl space is easily transported through ground floor air leakages to the rooms on the ground floor. Influencing factors are

- crawl space ventilation
- air tightness of the ground floor
- air tightness of the building envelope
- (mechanical) ventilation systems
- wind pressures
- temperature differences

To study the influence of these factors a multi-zone ventilation and air infiltration model has been used (2). One of the conclusions is that the ratio (air leakage of ground floor) / (air leakage of the facades) is the an important factor. Or in other words: the more airtight the building facades the higher the risk of moisture penetration from crawl spaces, unless one pays a special attention to create airtight floor constructions. In principle there are two approaches to eliminate the moisture infiltration from the crawl space: a. improve he airtightness of the ground floor b. create a dry crawl space climate. The second option requires vapour barrier at crawl space bottom to prevent moisture penetration.

CONCLUDING REMARKS

In the Netherlands new building regulations, aiming at the elimination of crawl space associated moisture problems, are in preparation. Two basic requirements will play a role: an airtightness requirement for the ground floor construction and a thermal quality requirement for thermal bridges. Standard test and calculation methods for the evaluation of these aspects are also in preparation.

REFERENCES

(1) Westgeest, W.F and Oldengarm, J, "Results of crawl space model", TPD-report 526.026/4, In Dutch, Dec. 1987.

(2) Oldengarm, J, "Crawl space ventilation", TPD-report 526.026/3, In Dutch, Dec 1987

The TH3DR model has been used to study the dynamic thermo-hygric behaviour of different types of crawl spaces (1). The purpose of this study was to compare the energy and moisture performance for different concepts of crawl space configurations. Several technical options were taken into consideration, like floor insulation, insulation of the foundation elements and vapour retarders on the crawl space bottom. The aim was to evaluate three important aspects:

a. the air humidity in the crawl space
b. the heat loss through the floor
c. the thermal bridge effect near to the facade

The study resulted also in the development of a more simplified crawl space model as described in the next paragraphs.

SIMPLIFIED CRAWL SPACE MODEL

Simulation results from the complex TH3DR-model have been used to derive simplified equations for the heat, moisture and air balance of the crawl space. These equations are implemented as an utility for the spreadsheet program Lotus 123. The purpose of the spreadsheet model is to provide an easy to use tool to practitioners in evaluating different type of measures to solve crawl moisture problems. The spreadsheet model allows the evaluation of remedial measures like crawl space ventilation, insulation retrofitting, vapour retarders on the crawl space bottom and possible combinations of these measures. One of the critical aspects is the modeling of the heat loss to the ground. In the complex model the ground is divided into a large number of cells for which monthly temperatures and heat flows are computed, taking into account the large thermal inertia of the ground. In the simplified model the monthly heat flow through the bottom surface is computed by the equations

$$Q[t] = (Tk[t] - Tgr[t]) / Req$$
$$Tgr[t] = Tann + a \cdot (Tann - Te[t-t'])$$

where:

Q = averaged heat flux to the ground [W/m2]
Tk = crawl space air temperature [°C]
Tgr = equivalent ground temperature [°C]
Req = equivalent heat resistance of the ground [m2K/W]
Tann = annual mean outdoor temperature [°C]
Te(t)= monthly mean outdoor temperature [°C]
a = damping factor [-]
t = time [in months]
t' = time phase shift due to thermal inertia of the ground

In the simplified model the parameters Req,a, and t' are assumed to be constant. The values for these parameters are estimated from results of the detailed model using regression techniques. In figures 2 and 3 the some of the output is shown. These figures show the monthly temperature and humidity for three crawl space insulation options.