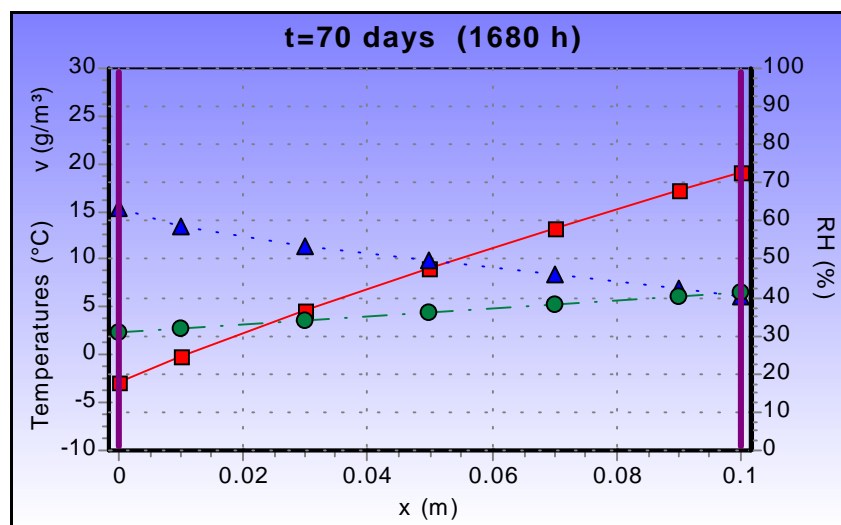# 1D-HAM

Coupled Heat, Air and Moisture Transport

in Multi-layered Wall Structures.

Manual with brief theory and an example.

Version 2.0

October 23, 2000

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1. Introduction

1.1 Overview

The PC-program **1D-HAM** solves the problem of coupled heat, air and moisture transport in a multi-layered porous wall. The program is based on the finite difference technique with explicit forward differences in time. Analytical solutions for the coupling between the computational cells for a given air flow through the construction are used. Moisture is transferred by diffusion and convection in vapor phase. No liquid water transport occurs. Heat is transferred by conduction, convection and latent heat. Climatic data are supplied through a data file with a maximum resolution of values per hour over the year. The program accounts for surface absorption of solar radiation.

1.2 System requirements and installation

1D-HAM requires Windows 95/98/NT/2000. A PC with a Pentium processor and 16 MB RAM is recommended.

Before using the installation diskette, it is recommended to make a backup copy. To install **1D-HAM** run the SETUP.EXE program from Windows. **1D-HAM** will be installed in directory *1D-HAM* by default. The following steps describe this process in detail:

1. Start the setup program (SETUP.EXE)
2. Follow the instructions on the screen

The following files will be installed:

- **1D-HAM.EXE** is the main program
- Files with extension CLI are climate files used by **1D-HAM**
- **MTRL1DHAM.TXT** is a file with thermal properties that may be edited
- Files with extension DAT are input data files

1.3 Technical support

Questions and comments can be sent by email to hagentoft@buildphys.chalmers.se. See update info on www.blocon.com.

2. Mathematical description

2.1 Governing differential equations

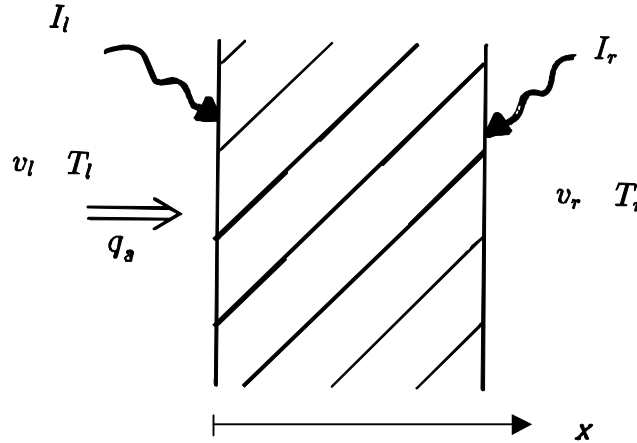Figure 2.1 shows the problem considered:

Figure 2.1: Air flow through a porous wall. Boundary values of the temperature, humidity by volume, and solar radiation are shown.

Air can flow through the structure. The air flow rate in the positive x-direction is denoted by q_a (m$^3_{air}$/(m^2·s)). The boundary air temperature at the left side is T_l and at the right side it is T_r. The solar radiation absorbed at the boundary surfaces is denoted by I_l (W/m^2) and I_r respectively. The humidity by volume v (kg/m^3) in the surrounding air is denoted by v_l on the left hand side and v_r on the right one.

The humidity by volume v is used as the governing potential for moisture transfer. The temperature T (℃) is used in the heat transfer equation. The two transport processes are coupled through the transfer of latent heat and the temperature dependence of the humidity at saturation v_{sat}, which together with the actual relative humidity determines the humidity by volume. The relative humidity φ (-) is determined by the water content in the material through the sorption isotherm.

The governing equation for the temperature T is:

$$-\frac{\partial}{\partial x}\left(-\lambda\frac{\partial T}{\partial x}+q_a\rho c_a \cdot T\right)+r\frac{\partial w}{\partial t}=\rho c\frac{\partial T}{\partial t}$$

The thermal conductivity of the wall material is denoted by λ (W/m·K), the density is ρ (kg/m^3), and the heat capacity is c (J/kg·K). The volumetric heat capacity of the air is denoted by ρc_a (J/(m^3·K)). The latent heat of evaporation is denoted by r (J/kg).

4

The governing equation for the humidity by volume is:

$$-\frac{\partial}{\partial x}\left(-\delta_v \frac{\partial v}{\partial x} + q_a \cdot v\right) = \frac{\partial w}{\partial t}$$

Here, w (kg/m^3), denotes the water content of the material considered. The vapor diffusion coefficient is denoted by δ_v (m^2/s).

2.2 Boundary conditions

A fictitious surface film is used to account for the surface resistances. The film is simulated as a material layer, fully transparent for solar radiation and with no additional air flow resistance. The surface thermal resistance and the surface vapor resistance for the left and right hand side film layer (without air flow) are given as input.

3. Numerical model

3.1 Numerical technique

The numerical model is based on finite difference technique with explicit forward differences in time. The coupling between neighboring computation cells are based on analytical solutions for the coupled processes of air flow through two layers of different materials in contact with each other. Details are given in [Hagentoft, 92].

The structure is divided into a number of layers, a maximum of 20 can be used. Each layer can be divided into computational cells, a maximum of 50 cells can be used in each layer. All together a number of N cells are used. This number must be less or equal than 100. The transport coefficients of each layer are constant.

3.2 Moisture storage model

The transfer of moisture to and from the cells are governed by the humidity by volumes in the cells and the humidity at the boundary. The increase of the moisture content, w (kg/m^3), of cell number i, with the width Δx_i due to the net flow rate of moisture Δg_i ((kg/m^2·s)), is given by:

$$\Delta w_i = \Delta t \cdot \frac{\Delta g_i}{\Delta x_i}$$

Here Δt (s) is the time step considered.

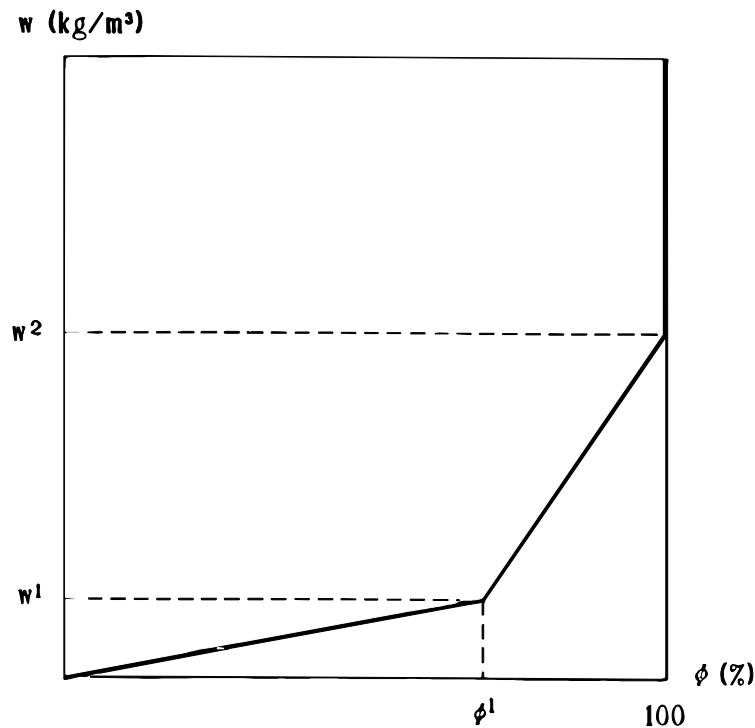Figure 3.1 shows the used simplified sorption isotherm.

Figure 3.1: Simplified sorption isotherm.

The sorption isotherm is approximated by three straight lines. These should be chosen in order to fit the true sorption isotherm as good as possible. The level w^2 corresponds to the upper limit of the hygroscopic region. Together with w^1, and φ^1 it specify the sorption isotherm. In the computational model there will be no limit for the amount of stored water in a material.

3.3 Air flow model

The air flow rate through the structure is the same everywhere. The constant flow resistance R_p (Pa/(m^3_{air}/($m^{2 \cdot}$s))) together with the pressure difference over the structure determines the air flow rate:

$$q_a = \frac{\Delta P}{R_p}$$

The air flow rate can vary in time. The flow resistance can be negative, in order to allow for a changed direction of the air flow. However the absolute value of R_p must be greater than 0.001 MPa/(m^3_{air}/($m^{2 \cdot}$s)), i.e. 1000 Pa/(m^3_{air}/($m^{2 \cdot}$s)). A positive value of the pressure difference and the flow resistance results in a air flow in the positive x-direction.

3.4 Stable time step

The stable time step is determined automatically by the program. It is updated at each time step. The expressions for the stable time step can be found in [Hagentoft, 1992]. The stable time step for the thermal process has been altered in this version of the program to account for the transfer of latent heat.

3.5 Climatic data

The input data to the are supplied through a text file (*.CLI). The climate data i.e. boundary temperatures, solar radiation, humidity by volume, and pressure difference over the wall are given for arbitrary time differences down to hourly values. The boundary values, used in the calculations, are taken as discrete step-wise constant values.

3.6 Algorithm

The simulation of the combined air-, moisture- and thermal flow processes is described by the following algorithm. The time step Δt is the stable time step.

1. Start ($t=t_{start}$)
2. Input of start values for temperatures and moisture (w, T)
3. Insert the actual boundary conditions (T, I, v, q_a)
4. Determine the conductances
5. Calculate the stable time step (Δt)
6. Calculate the relative humidity (φ (w))
7. Calculate the humidity by volume ($v = \varphi \cdot v_{sat}$)
8. Calculate the change in moisture content (Δw)
9. Calculate the change in temperature (ΔT)
10. Update the time ($t_{new}=t_{old}+\Delta t$)
11. Update the moisture content ($w_{new}=w_{old}+\Delta w$)
12. Update the temperature ($T_{new}=T_{old}+\Delta T$)
13. Repeat step 3 to 12 until the stop time is reached
14. Stop

4. Working with 1D-HAM

4.1 Material data

Material properties can be obtained from a material data bank or the data can be inserted direct by the user, see Figure 4.1.

Moisture and thermal data

Laye	Length [m]	Cell	Material name (<=resize=>)	Dv [mm²/s]	Phi [%]	w1 [kg/m²]	w2 [kg/m²]	w(start) [kg/m²]	Lambda [W/(m·K)]	Capacity [MJ/(m²·K)]	Tstart [°C]
1	0.08000	2	Brick 4	4.000	88.00	8.00000	17.00000	8.00000	0.6000	1.2000	10.00
2	0.05000	2	Concrete,vct 0.4	0.500	80.00	60.00000	120.00000	60.00000	1.7000	2.0700	10.00
3	0.20000	5	Mineral wool,150	8.000	90.00	0.90000	1.00000	0.50000	0.0360	0.1200	10.00
4	0.02000	1	Part-b.wood,690	0.400	80.00	105.0000	200.00000	50.00000	0.1400	1.0000	10.00
5	0.01300	1	Gypsum board	5.000	90.00	8.00000	25.00000	10.00000	0.2200	0.6400	10.00

N=11   Close

> Figure 4.1: Menu for the determination of material properties, start conditions, and the number of computational cells per layer.

The material data bank, written in the file Mtrl1dham.txt, can be edited by the user. The first 30 positions are recommended for the material name, and the following 30 positions should be used for the material data. The structure should be as follows:

Material name $\delta_v \; \varphi^1 \; w^1 \; w^2 \; \lambda \; \rho c$

The units should be:
  For δ_v : in mm²/s i.e., take the value in m²/s and divide with 10^{-6}
  For φ^1 : in % i.e., take the value of φ^1 (0-1) and multiply with 100
  For w^1 : in kg/m³
  For w^2 : in kg/m³
  For λ : in W/(m·K)
  For ρc : in MJ/(m³·K) i.e., take the value in J/(m³·K) and divide with 10^6

4.2 Boundary condition

The climatic data files (*.CLI) have the following structure:
The first line must contain the number, $N_{climate}$, of climate data sets (lines) that follows. This must not exceed the number of 8 762. This number is larger than the number of hours of the year (8 760). The data set, in total $N_{climate \; lines}$, has the following structure:

t^1 $T_l \; T_r \; I_l/\alpha_{sol} \; I_r/\alpha_{sol} \; v_l \; v_r \; \Delta P$

....

$t^{Nclimate}$ $T_l \; T_r \; I_l/\alpha_{sol} \; I_r/\alpha_{sol} \; v_l \; v_r \; \Delta P$

Each number must be separated by blank characters. Here, I_l (W/m^2) and I_r represent the net in flow of heat due to radiation. In the climate files we have I_l/α_{sol} which represents the total incident solar radiation before any reflection or absorption take place.

The data can be inspected through the menu item *Input*, both as text files and as charts.

The time *t* should be considered as the time of the year in seconds. Simulation can be performed with annual cycles by using a complete weather data year, and activating the *Annual cyclic climate* switch (Switch=1).

The index l refers to the left side and the index r refers to the right one. Normally, the left hand side of the structure should be considered as the external one. The times given must be in an increasing series. The time intervals may vary.

The following restrictions must be followed:

$0 < t_{start} < 1$ year $= 3.1536 \cdot 10^7$ s

$t_{stop} < t^{Nclimate}$ when Switch=0

$t^{Nclimate} > 3.15359 \cdot 10^7$ s   when Switch=1

$t^1 < 100$ s   when Switch=1

$t_{start} > t^1$

It is often required to prescribe the interior humidity, as the exterior one plus a moisture source. In the Input menu *Moisture Supply* we have the following options, see Figure 4.2.
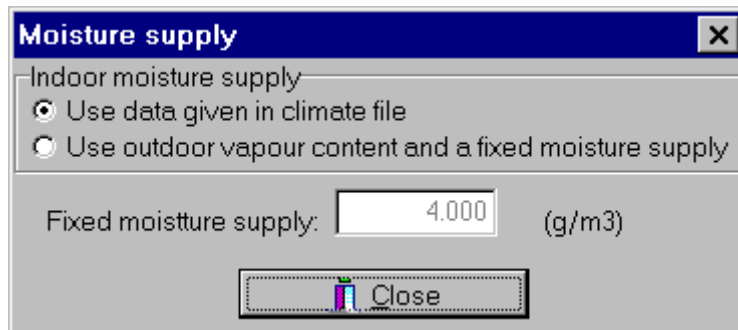

Figure 4.2: Determination of the indoor humidity by volume.

If the first option is chosen the right hand side (interior) humidity is taken directly from the climatic file. If the second option is chosen the right hand side humidity is given by the exterior one (left hand side) plus the given moisture supply. The indoor humidity by volume will be limited by the saturation level.

4.3 Input data file

The format in the input data file is as follows;

1. Name of output files, without extension
2. Program version
3. Name of climatic data file
4. Start time of simulation (s)
5. Stop time of simulation (s)
6. Time for first output (s)
7. Printing interval (s)
8. Number of different layers in the wall
9. Width of each layer, from left to right (m)
10. Number of computational cells in each layer
11. Thermal conductivity, λ, for each layer, from left to right (W/m·K)
12. Volumetric heat capacity, ρc, of each layer, from left to right (J/m^3·K)
13. Start temperature of each layer, from left to right (℃)
14. Vapor permeability, δ_v, for each layer (m^2/s)
15. Value of φ^1 of each layer, from left to right (%)
16. Value of w^{1}of each layer, from left to right (kg/m^3)
17. Value of w^{2}of each layer, from left to right (kg/m^3)
18. Start moisture content of each layer, from left to right (kg/m^3)
19. Thickness of fictitious surface film layer, always 0.001 0.001 (m)
20. Thermal conductivity of fictitious surface film layer. Together with the thickness it defines the surface resistance, (W/m·K).
21. Vapor permeability of fictitious surface film layer. Together with the thickness it defines the surface resistance, (s/m).
22. Reference temperature (℃) for convective heat flow (and further three arbitrary numbers, set to 1 1 1 not used for the moment)
23. Absorption factors (-) for solar radiation at the left and right hand side, and the flow resistance R_p (Pa/(m$^3_{air}$/(m^2·s))) of the wall
24. Switch, Equal to 1 if annual cyclic values of the climatic data should be used, else 0
25. Indoor moisture supply (g/m^3). If values for v_r directly taken from the climatic file use the value -1 here.

As the last lines, copies of the material data properties used in the Mesh and properties submenu (of Input) are written. These lines are used basically to couple material names with the data. However, if new material data has been introduced, they can be transferred to the data bank file Mtrl1dham.txt, by copy and paste routines.

4.4 Solver

As option under the Solve menu, the calculations can be done using graphics to follow the process or without. Figure 4.3 shows the graphical output, which gives the distribution of the temperature, the humidity by volume and the relative humidity, for the print-out times.

4.5 Output data

The results of the calculation can be seen on the screen. The generated diagrams can be saved to files or to the clip board. Results are also written into a number of text files:
A parameter PN (print number) is introduced. It is given by:

PN=integer part of($(t-t_{\text{first print time}})/t_{\text{print interval}}$)

At each print time, (PN), a number of average values are written into the output files. The average values are calculated for the period:
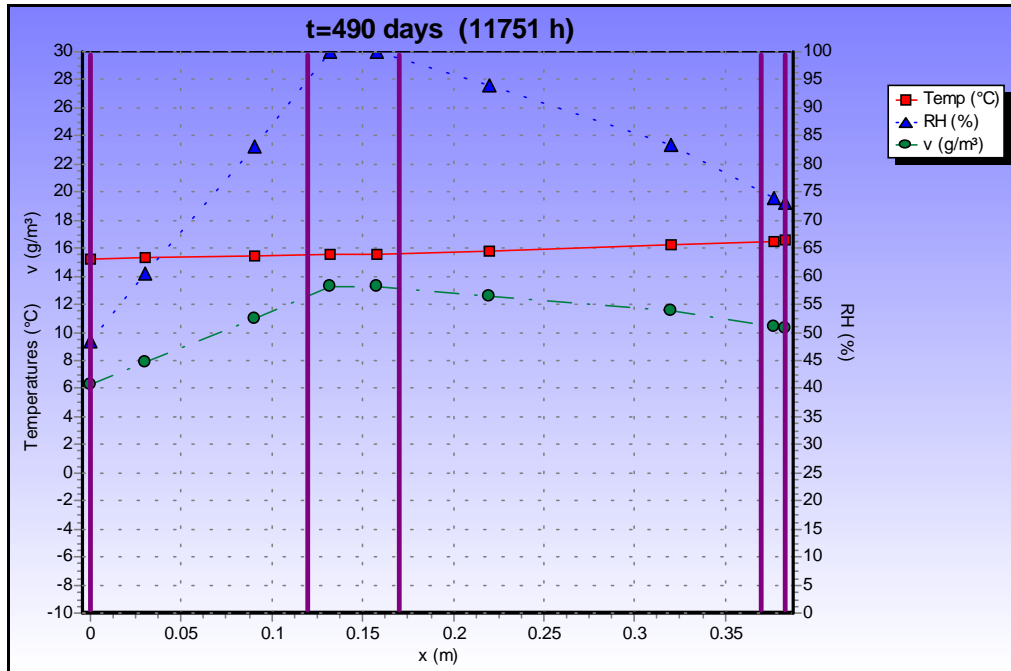
t- t$_{print interval}$ to t

Figure 4.3: Distribution of the temperature, the humidity by volume and the relative humidity.

The (*.MOI)-file contains the average moisture content (kg/m^3) of each layer. Figure 4.4 shows how this can be edited:

The (*.RH)-file contains the average relative humidity of each layer (%), based on the average moisture content and the sorption isotherm.

The (*.TEM)-file contains the average convective and conductive heat flow (W/m^2) flowing into the right hand side of the wall. The following definitions are used:

$$q_{cond}^r = \lambda \frac{\partial T}{\partial x}$$

$$q_{conv}^r = -q_a \rho c_a \cdot (T - T_{ref})$$

The output data have the following structure:

$$q_{cond}^r \quad q_{conv}^r \quad q_{cond}^r + q_{conv}^r$$

The (*.BND)-file contains the average values of the boundary temperatures, the boundary relative humidity by volume, the total incident solar radiation into the left boundary, and the air flow rate.

T_l T_r v_l v_r I_l/α_{sol} q_a

The direction of the flows are chosen so that they are positive when flowing from the right to the left.
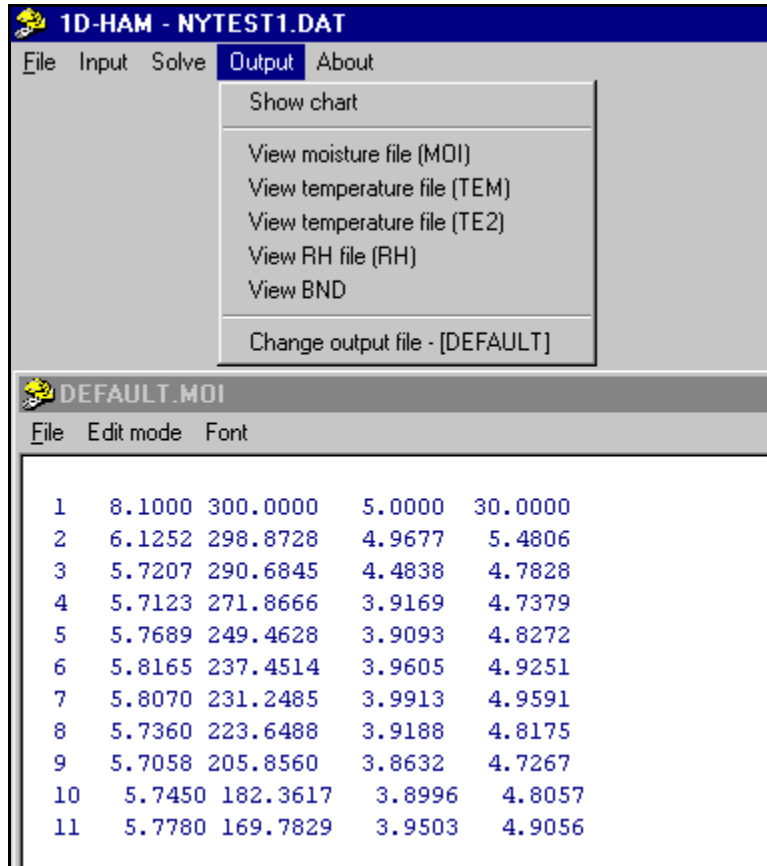

Figure 4.4: Inspection of the *.MOI output file.

The (*.TE2)-file contains the actual temperature distribution (not averaged over time) at the time of out print. The top lines of the file also give the total number of computational cells and the distance (from left to right) to the node points representing the temperatures. The files also gives the actual times of each print-out.

References

Hagentoft, C-E, 1992. Simplified analysis of combined heat, moisture and air transport for one-dimensional cases. Report T1-S-92/04. IEA/Annex 24, working paper October 1992. Dept. of Building Physics, Lund University. Report TVBH-7146, 1993.

Hagentoft, C-E, 1993. PC-program: 1D-HAM. Notes on heat transfer 5-93. Dept. of Building Physics, Lund University. Report TVBH-7147, 1993.