Insulated roof

HAMSTAD: Benchmark no: 1,TUE: Eindhoven University of Tech.

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TOOL: COMSOL

EQUATIONS:

$$C_T \frac{\partial T}{\partial t} = div(K_{11}\nabla T + K_{12}\nabla LPc)$$

$$C_{LPc} \frac{\partial LPc}{\partial t} = div(K_{21}\nabla T + K_{22}\nabla LPc)$$

$$LPc = {}^{10}\log(Pc)$$

Coefficients for materials

$$C_T = \rho \cdot c$$

$$K_{11} = \lambda$$

$$K_{12} = -l_{lv} \cdot \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho RT},$$

$$C_{LPc} = \frac{\partial w}{\partial Pc} \cdot \frac{\partial Pc}{\partial LPc}$$

$$K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho RT},$$

$$K_{21} = \delta_p \cdot \phi \cdot \frac{\partial Psat}{\partial T},$$

Corresponding MatLab & COMSOL functions:

C_T(LPc,T) for material A: CTa

C_T(LPc,T) for material B: CTb

K_{11}(LPc,T) for material A: K11a

Etc.

Boundary conditions

internal (connected with material B):

$$q = \alpha_i \cdot (T_i - T) + l_{lv} \cdot \beta \cdot (p_i - p),$$
$$g = \beta \cdot (p_i - p)$$

external (connected with material A):

$$q = \alpha_e \cdot (T_e - T)$$
$$g = 0$$

Corresponding MatLab & COMSOL functions:

T_i(t): tit

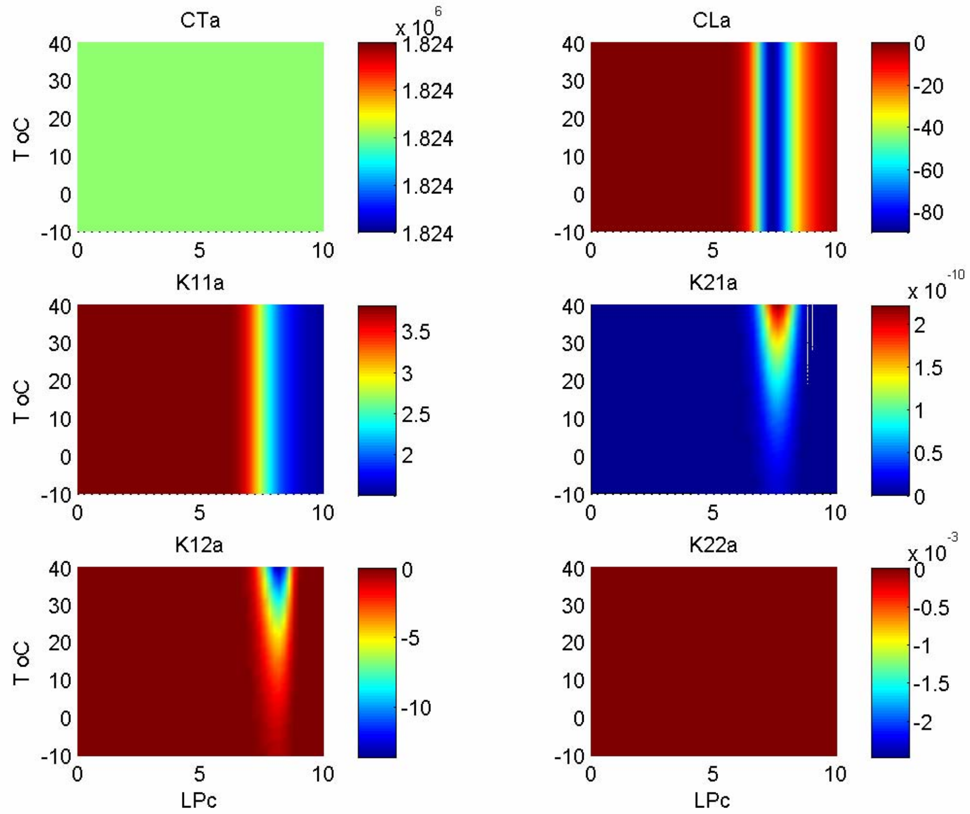
T_e(t): tet

p_i(t) : pvit

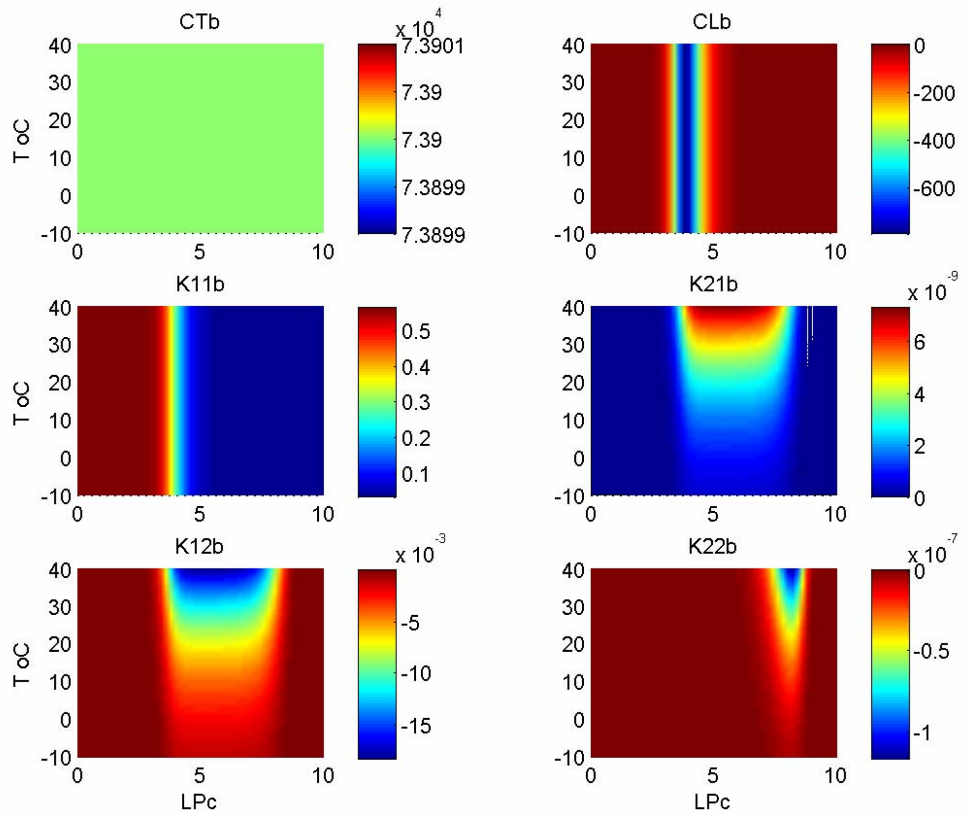
p_e(t) : pvet

p(LPc, T) on boundary of B: Pvb

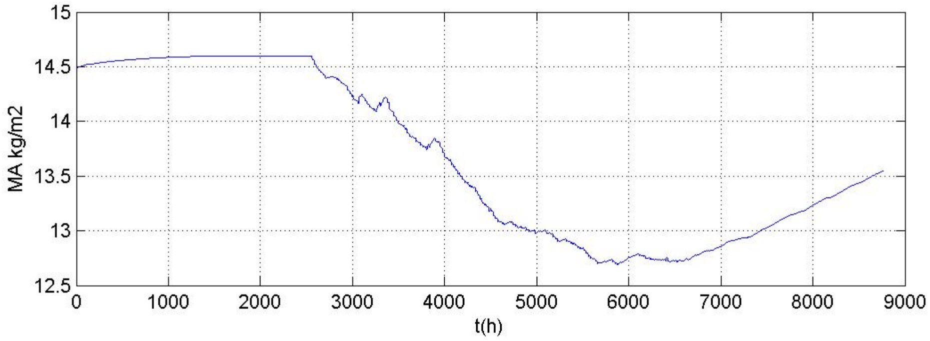
Material A properties:

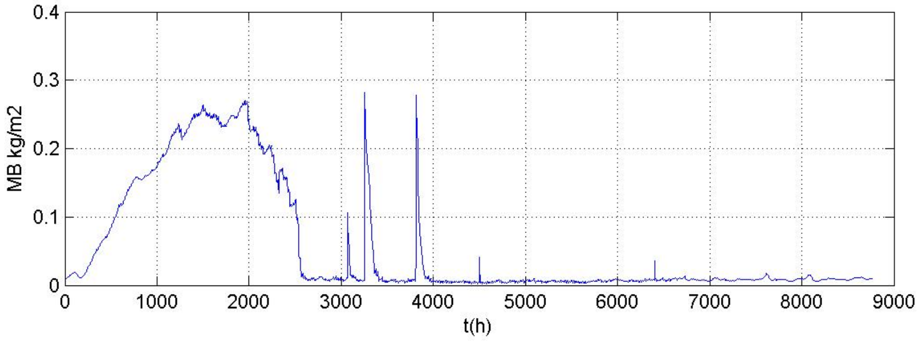


Material B properties:

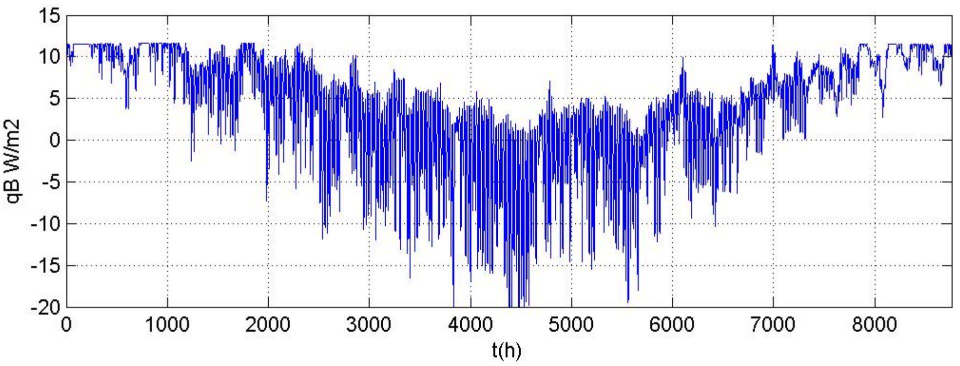


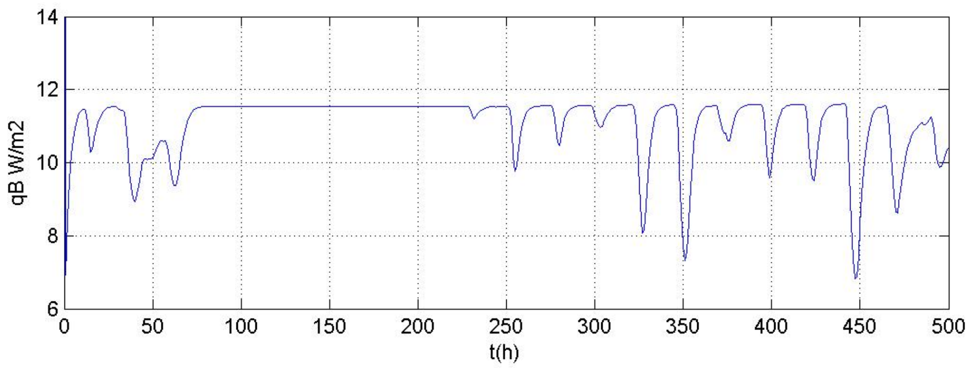
Results





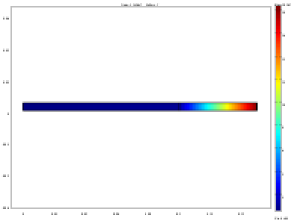
Top: Fig 3.1.1. Bottom: Fig. 3.1.2





Top: Fig 3.1.3. Bottom: Fig. 3.1.4

COMSOL Model Report



1. Table of Contents

2. Model Properties

Property	Value
Model name	
Author	
Company	
Department	
Reference	
URL	
Saved date	Feb 15, 2008 2:32:44 PM
Creation date	Feb 6, 2008 2:54:17 PM
COMSOL version	COMSOL 3.4.0.248

File name: D:\COMSOL34\HAMSTADT\Bench1\ben1b.mph

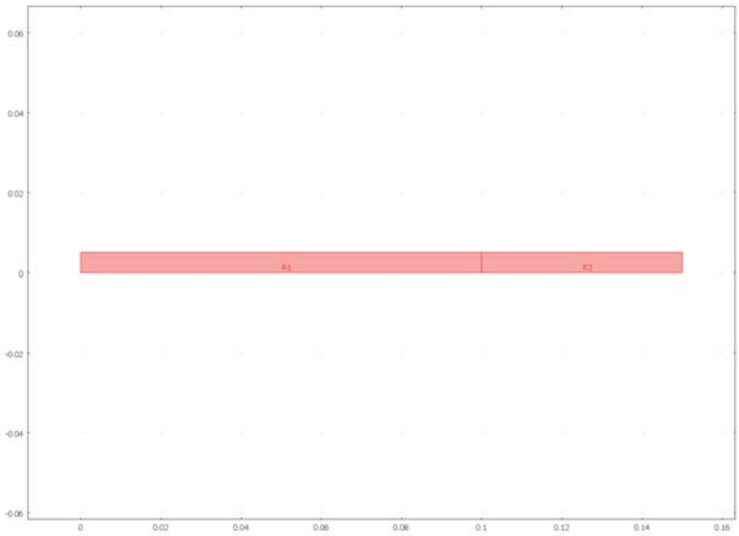
Application modes and modules used in this model:

- Geom1 (2D)
  - PDE, Coefficient Form

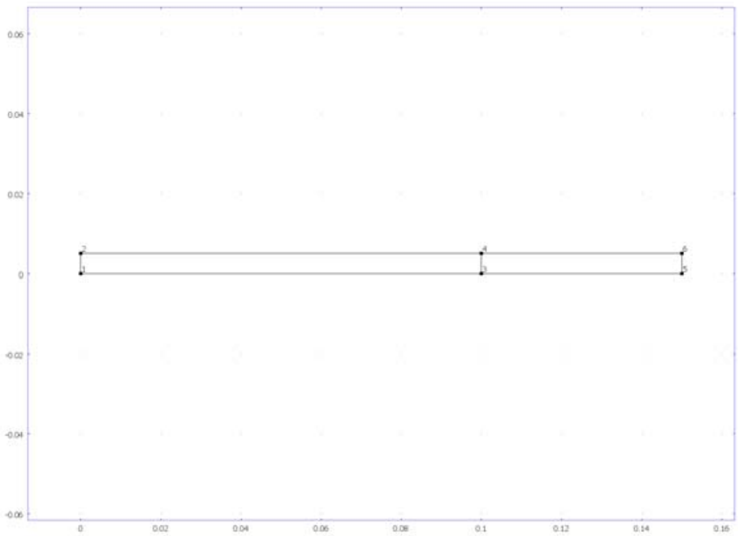
3. Geometry

Number of geometries: 1

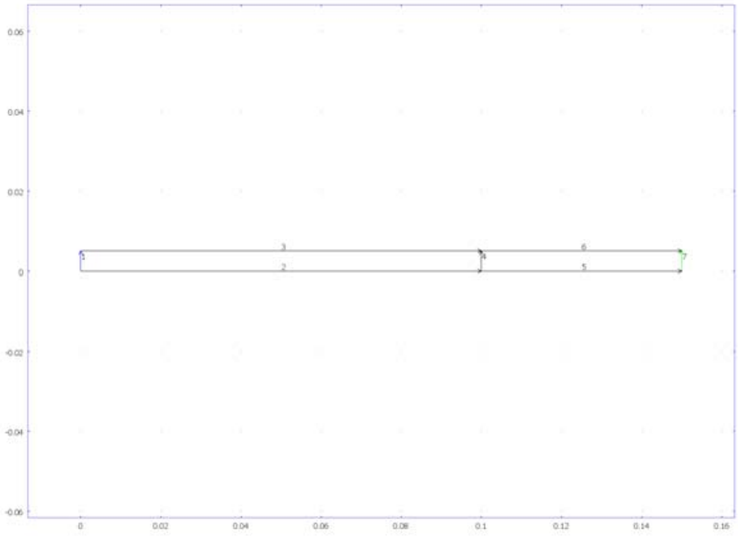
3.1. Geom1



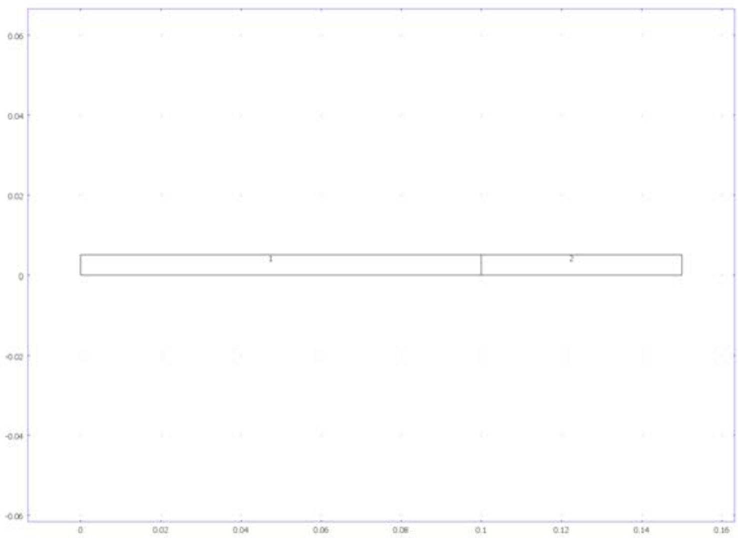
3.1.1. Point mode



3.1.2. Boundary mode



3.1.3. Subdomain mode



4. Geom1

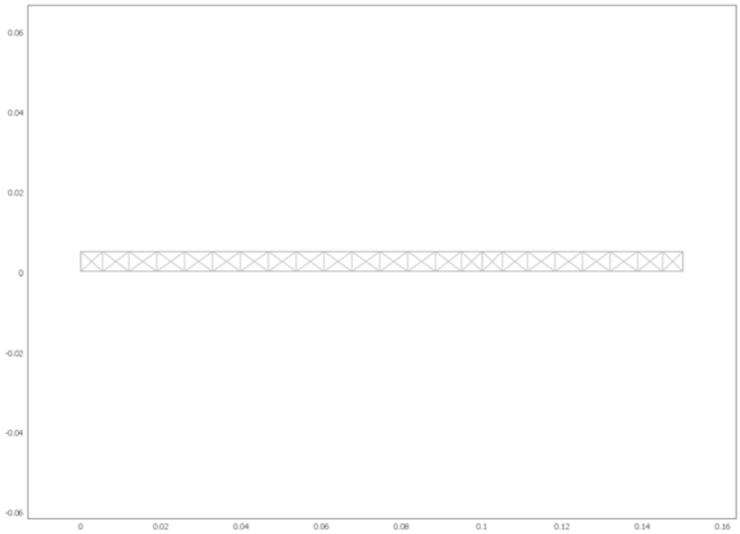
Space dimensions: 2D
Independent variables: x, y, z

4.1. Mesh

4.1.1. Mesh Statistics

Number of degrees of freedom	466
Number of mesh points	71
Number of elements	92

Triangular	92
Quadrilateral	0
Number of boundary elements	49
Number of vertex elements	6
Minimum element quality	0.709
Element area ratio	0.726



4.2. Application Mode: PDE, Coefficient Form (c)

Application mode type: PDE, Coefficient Form

Application mode name: c

4.2.1. Application Mode Properties

Property	**Value**
Default element type	Lagrange - Quadratic
Wave extension	Off
Frame	Frame (ref)
Weak constraints	Off

4.2.2. Variables

Dependent variables: T, LPc, T_t, LPc_t

Shape functions: shlag(2,'T'), shlag(2,'LPc')

Interior boundaries not active

4.2.3. Boundary Settings

Boundary	2-3, 5-6	1	7
Type	Neumann boundary	Neumann boundary	Neumann boundary

	condition	condition	condition
(g)	{0;0}	**{25*(tetfun(t)-T);0}**	**{7*(titfun(t)-T); 2e-8*(pvitfun(t)-Pvbfun(LPc,T))}**

4.2.4. Subdomain Settings

Subdomain	1	2
Diffusion coefficient (c)	**{K11afun(LPc,T), K12afun(LPc,T); K21afun(LPc,T), K22afun(LPc,T)}**	**{K11bfun(LPc,T), K12bfun(LPc,T); K21bfun(LPc,T), K22bfun(LPc,T)}**
Source term (f)	**{0;0}**	**{0;0}**
Damping/Mass coefficient (da)	**{CTafun(LPc,T),0; 0,CLafun(LPc,T)}**	**{CTbfun(LPc,T),0; 0,CLbfun(LPc,T)}**

Subdomain initial value	1	2
T	10	10
LPc	6.0138	7.8403

5. Solver Settings

Solve using a script: off

Auto select solver	On
Solver	Time dependent
Solution form	Automatic
Symmetric	auto
Adaption	Off

5.1. Direct (UMFPACK)

Solver type: Linear system solver

Parameter	**Value**
Pivot threshold	0.1
Memory allocation factor	0.7

5.2. Time Stepping

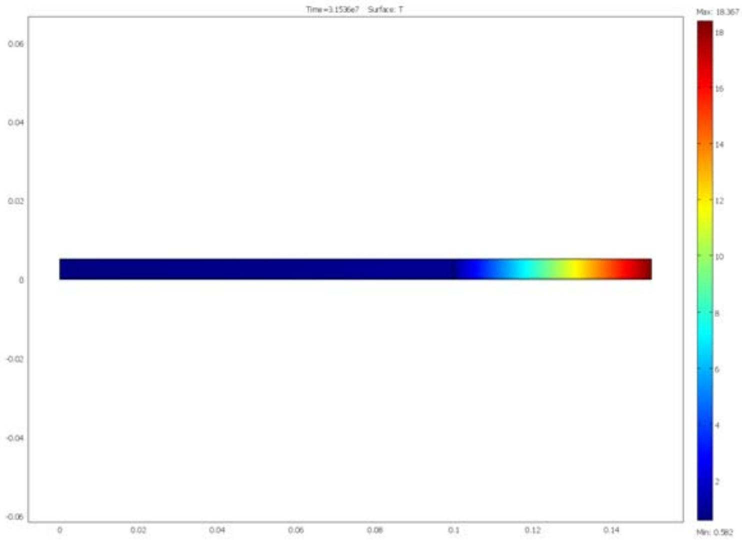
Parameter	**Value**
Times	0:3600:365*24*3600

Relative tolerance	0.01
Absolute tolerance	0.0010
Times to store in output	Specified times
Time steps taken by solver	Free
Manual tuning of step size	On
Initial time step	0.0010
Maximum time step	3600
Maximum BDF order	5
Singular mass matrix	Maybe
Consistent initialization of DAE systems	Backward Euler
Error estimation strategy	Include algebraic
Allow complex numbers	Off

5.3. Advanced

Parameter	**Value**
Constraint handling method	Elimination
Null-space function	Automatic
Assembly block size	5000
Use Hermitian transpose of constraint matrix and in symmetry detection	Off
Use complex functions with real input	Off
Stop if error due to undefined operation	On
Store solution on file	Off
Type of scaling	Automatic
Manual scaling	
Row equilibration	On
Manual control of reassembly	Off
Load constant	On
Constraint constant	On
Mass constant	On
Damping (mass) constant	On
Jacobian constant	On
Constraint Jacobian constant	On

6. Postprocessing



7. Variables

7.1. Subdomain

Name	Description	Unit	Expression
absTx_c	|grad(T)|		sqrt(Tx^2+Ty^2)
abscu1x_c	|c*grad(T)|		sqrt(cu1x^2+cu1y^2)
absLPcx_c	|grad(LPc)|		sqrt(LPcx^2+LPcy^2)
abscu2x_c	|c*grad(LPc)|		sqrt(cu2x^2+cu2y^2)

3.1 Benchmark one: ***'Insulated roof'***

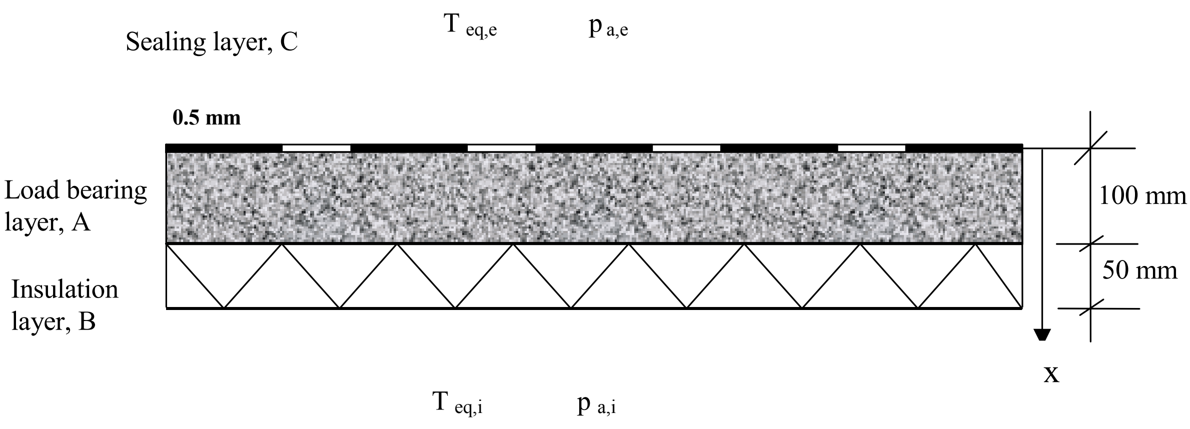
Insulated roof

HAMSTAD: Benchmark no: 1

Initiated by Chalmers University of Technology (CTH)

An insulated roof structure is analysed in one dimensions. The thermal insulation is facing the interior and there is a moisture barrier facing the exterior. The structure is perfectly airtight.

Structure



Properties of layers

1 General data:

$T = T_{ref} = 293.15$ K, ρ_w=1000 kg/m^3, R=8.314 J/(mol,K), M_w=0.018 kg/mol
$\ell_{\ell v}$ =2.5 · 10^6 J/kg

2 Material properties:

A. Load bearing material

-Water retention curve: $$w = \frac{146}{(1+(8\cdot 10^{-8}\cdot P_{suc})^{1.6})^{0.375}} \quad (\text{kg/m}^3)$$

$$P_{suc} = 0.125\cdot 10^8((\frac{146}{w})^{\frac{1}{0.375}} - 1)^{0.625} \quad (\text{Pa})$$

- Sorption isotherm: $$w = \frac{146}{(1+(-8\cdot 10^{-8}\cdot \frac{RT\rho_w}{M_w}\ln(\phi))^{1.6})^{0.375}} \quad (\text{kg/m}^3)$$

$$\phi = \exp(-\frac{M_w}{RT\rho_w}0.125\cdot 10^8((\frac{146}{w})^{\frac{1}{0.375}} - 1)^{0.625}) \quad (-)$$

- Vapour diffusion: $$\delta_p = \frac{M_w}{RT}\cdot\frac{26.1\cdot 10^{-6}}{200}\cdot\frac{1-\frac{w}{146}}{0.503\cdot(1-\frac{w}{146})^2 + 0.497} \quad (\text{s})$$

- Liquid water permeability:

$$K = \exp(-39.2619 + 0.0704\cdot(w-73) - 1.7420\cdot 10^{-4}\cdot(w-73)^2 - 2.7953\cdot 10^{-6}\cdot(w-73)^3 - 1.1566\cdot 10^{-7}\cdot(w-73)^4 + 2.5969\cdot 10^{-9}\cdot(w-73)^5) \quad (\text{s})$$

- Thermal conductivity: $$\lambda = 1.5 + \frac{15.8}{1000}w \quad (\text{W/mK})$$

- Specific heat capacity: c_p=800 (J/kgK)

- Density: ρ_0= 2280 (kg/m^3)

B. Insulation material

-Water retention curve: $$w = \frac{900}{(1+(2\cdot 10^{-4}\cdot P_{suc})^2)^{0.5}} \quad (\text{kg/m}^3)$$

$$P_{suc} = 0.5 \cdot 10^4 ((\frac{900}{w})^2 - 1)^{0.5} \text{ (Pa)}$$

- Sorption isotherm: $$w = \frac{900}{(1 + (-2 \cdot 10^{-4} \cdot \frac{RT\rho_w}{M_w} \ln(\phi))^2)^{0.5}} \text{ (kg/m}^3\text{)}$$

$$\phi = \exp(-\frac{M_w}{RT\rho_w} 0.5 \cdot 10^4 ((\frac{900}{w})^2 - 1)^{0.5}) \text{ (-)}$$

- Vapour diffusion: $$\delta_p = \frac{M_w}{RT} \cdot \frac{26.1 \cdot 10^{-6}}{9.6} \cdot \frac{1 - \frac{w}{900}}{0.503 \cdot (1 - \frac{w}{900})^2 + 0.497} \text{ (s)}$$

- Liquid water permeability: $K = 0$ s

- Thermal conductivity: $\lambda = 0.033 + \frac{0.59}{1000} w$ (W/mK)

- Specific heat capacity: c_p=1000 (J/kgK)

- Density: ρ_0= 73.9 (kg/m^3)

C. Sealing layer

$Z_p = 1 \cdot 10^{12}$ m/s, K=0 s, R=0 m^{2}K/W, moisture and heat capacity negligible.

3 Dimensions:

A.	Load bearing layer:	0.1 m
B.	Insulation layer:	0.05 m
C.	Sealing layer:	0.0005 m

Boundary conditions

1 Thermal and humidity conditions:

According to attached climate data file: *ClimateBench1.txt.*
Hourly values covering one year. Interpolated values for intermediate times.

Repeated values for ensuing (subsequent) years shall be used.
Equivalent temperatures accounts for both ambient air temperature and radiation exchange.

Climate data are structured as:

Column 1	Column 2	Column 3	Column 4	Column5
time (s)	$T_{eq,e}$ (ºC)	$T_{eq,i}$ (ºC)	$p_{a,e}$ (Pa)	$p_{a,i}$ (Pa)

2 Pressure conditions: no air pressure difference

3 Surface transfer coefficients:

$\alpha_{e,e}$ = 25 W/m^{2}K, $\alpha_{e,i}$ =7 W/m^{2}K, $\beta_{p,e}$ = 0 s/m , $\beta_{p,i}$ =2 · 10^{-8} s/m

Initial conditions

A. Load bearing material: w=145 kg/m^3, T=10 ºC
B. Insulation layer material: w=0.065 kg/m^3, T=10 ºC

Output

Output file has ASCII format. Each line represents a given time (h). Data are separated by a space. Each year is represented by in total 8761 lines. The start of the year is 0 h and the last hour is 8760.

1. **Simulation time: 5 years**

2. **Requested output:**

Moisture content $w(x)$ (kg/m^3) in space and time for the load bearing material, A and the insulation material, B, at the depth x (m) from the top of the load bearing material.

w(0167) w(0.05) w(0.0834) w(0.125)

Output file structure: files no. 1-5: (one file for each year!), in ASCII format

Column 1	Column 2	Column 3	Column 4	Column 5
time	w(0.0167)	w(0.05)	w(0.0834)	w(0.125)
0	145	145	145	0.065
1	…	…	…	…
2	…	…	…	…
…	…	…	…	…
8760	…	…	…	…

Integrated mass of moisture M (kg/m^2) in each layer, and heat flow into the structure from the interior q (W/m^2).

M_A M_B q

Output file structure: files no. 6-10: (one file for each year!), in ASCII format

Column 1	Column 2	Column 3	Column 4
time	M_A	M_B	q
0	14.5	14.5	0.00325
1	…	…	…
2	…	…	…
…	…	…	…
8760	…	…	…

3 Name of data files:

The output files should be named as: 'University/Institute'+ Bench1+'Output file no.' + .txt, e.g. files from Chalmers (CTH):

CTHBench11.txt
CTHBench12.txt
…
CTHBench110.txt

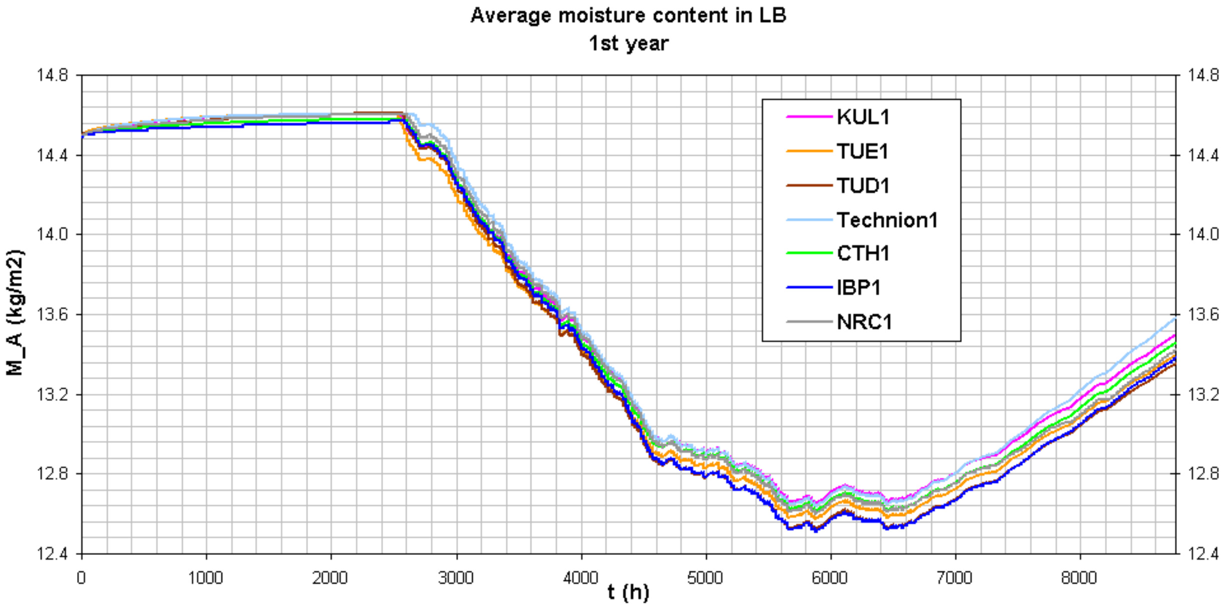


Figure 3.1.1

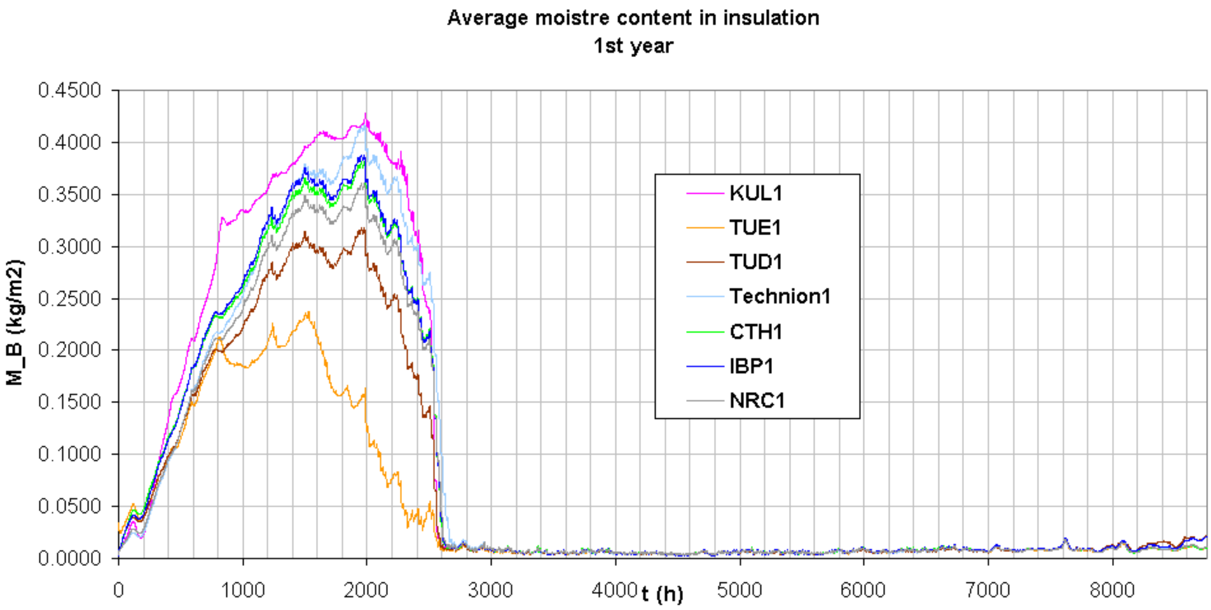


Figure 3.1.2

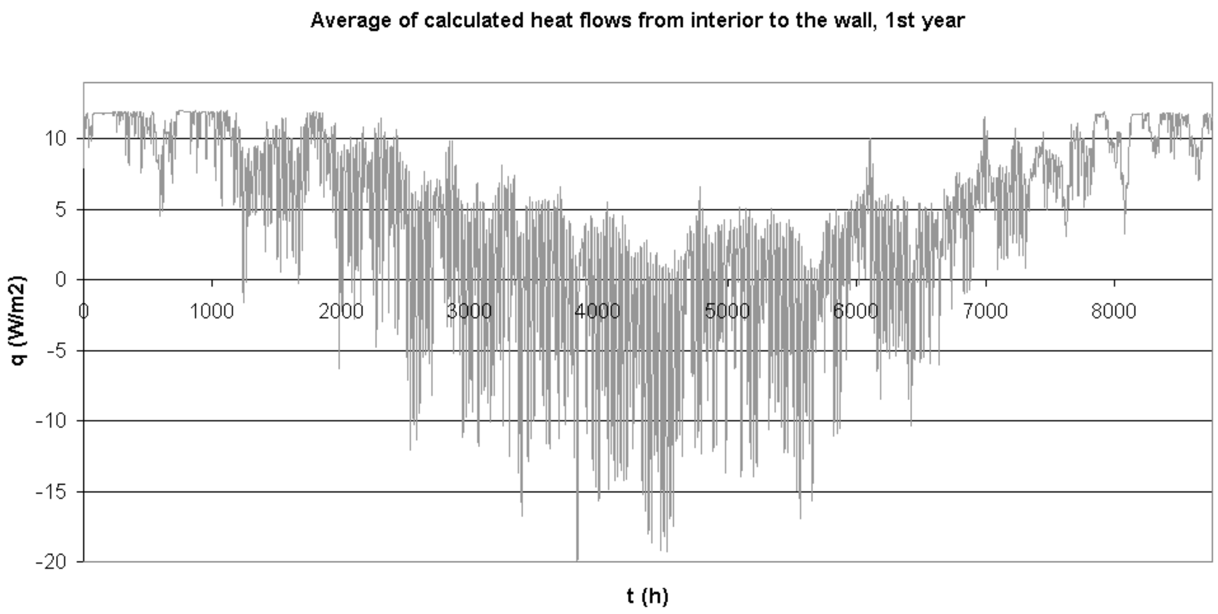


Figure 3.1.3

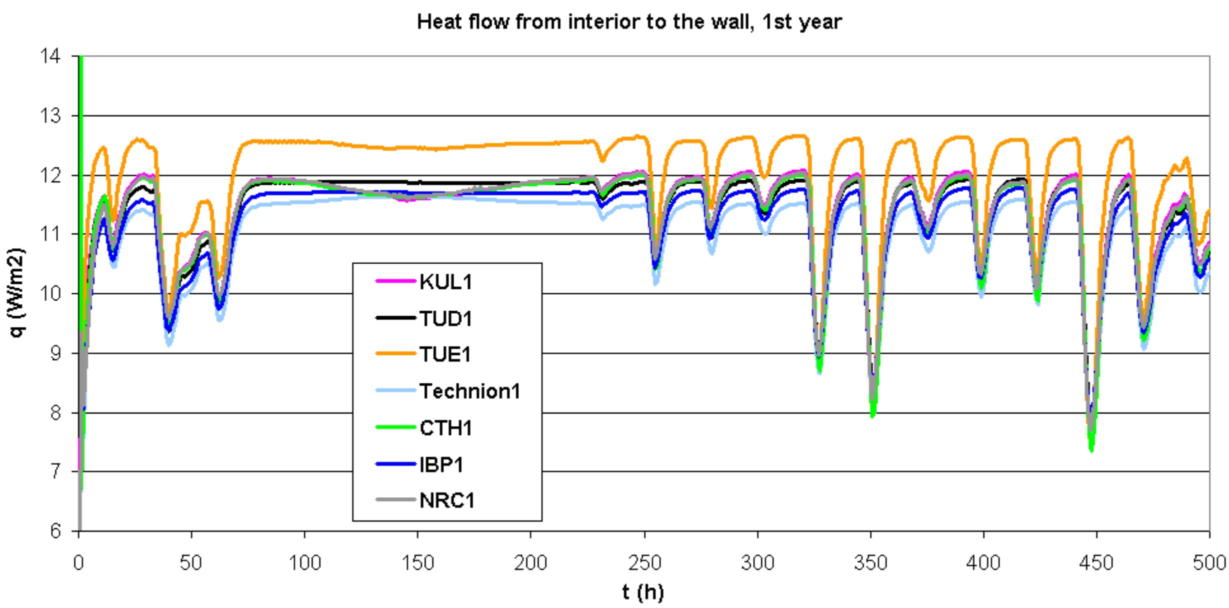


Figure 3.1.4