enjoy & understand ANTHERM
http://www.kornicki.at/

AnTherm

the software system for
Analysis of **Therm**al
behaviour of building constructions
with thermal bridges

http://antherm.eu/

PRACTICAL IMPLEMENTATION OF A HARMONIC CONDUCTANCE MODEL IN THERMAL SIMULATION SOFTWARE

Calculation and visualization of thermal heat bridges by tracing the heat- and vapour stream. Examples and capabilities available for such calculations by using the three dimensional simulation software AnTherm

T.Kornicki, Vienna

Tomasz Kornicki

- Physicist and computer scientist
- “IT Services” in Vienna, 23°
- Scientific and Management Consultancy since more then 25 years
- Software Tools for Building Physics
- Reliable partner for high performance simulation, supercomputing and (not only scientific) visualisation
- Lecturer at TU-Vienna, Danube-Univ. ,…
- International Building Performance Simulation Association

Decades of Transient Behaviour

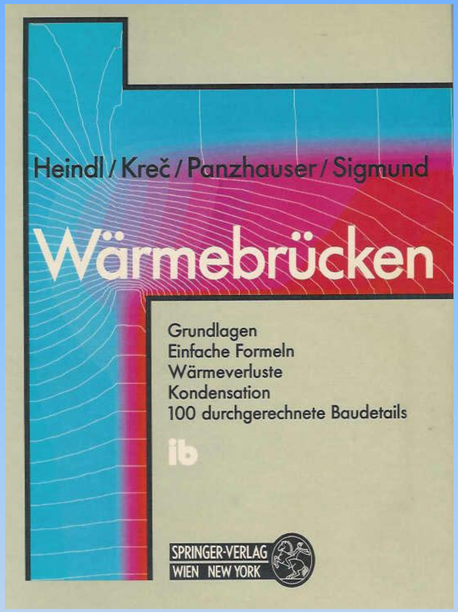
- “Periodic heat flow – homogenous walls and roofs”
  1944, Mackey C.O., Wrigth L.T.
- “Conduction of heat in solids”
  1959, Carslaw H.S., Jaeger J.C.
- “Heat storage in walls and ceilings”
  1974, Heindl W.
- “Wärmebrücken”
  1987, Heindl W. Krec K., Panzhauser E., Sigmund A.
- “Heat loss to the ground from a building”
  1988, Hagentoft CE., 1991, Claesson J., Hagentoft CE.
- “Heat storage in building constructions”…
  1993…, Krec K.,
- …

Concept of thermal conductances

- Well suited for modelling dynamic thermal behaviour under periodic boundary conditions
- Straight forward method for implementing in simulation software
- Employed in international norms and standards
- Multidimensional heat transfer mechanisms involving thermal storage
- Applicable in the field of dynamic simulation of time-dependant, transient thermal building behaviour
- Its practicality and efficiency of the harmonic approach often demonstrated

Concept of thermal conductances

- Introduced in „Wärmebrücken“ (Heindl1987) (thermal conductances and base solutions, g-values)
- Starting point for practical software implementations related to thermal bridges while assessing the risk of surface condensation in 2- and 3-dimensions
- Generalisations of earlier concepts towards dynamic heat transfer mechanisms involving thermal storage within buildings (Krec1993)
- Subsequently extended to include consideration of power sources (Krec1993), ventilation a.s.o.
- Practicality and Efficiency demonstrated in everyday use



Periodic development

$$f(t) = \sum_{n=-\infty}^{+\infty} \hat{f}_n \cdot e^{-j\cdot\omega_n\cdot t}$$

$$\omega_n = n \cdot \frac{2\cdot\pi}{T}$$

- any time dependant periodic entity can be developed by a *Fourier* series
- harmonic *n*
- complex amplitude of f_n

Heat loss

- the heat loss of a space *i* is given by integrating the heat flow density (heat flux) at the boundary of this space
- with Fourier's law applied

$$\hat{\Phi}_i^h = -\iint_{\mathfrak{R}_i} (\lambda \cdot \operatorname{grad} \hat{T}^h) \cdot d\vec{a}$$

- complex amplitude of the heat loss Φi
- boundary surface of the space Ri
- λ thermal conductivity
- surface element oriented towards the space da,
  <u>oriented from the space toward the building component</u>

Base solutions

$$\hat{T}^{h}(x,y,z) = \sum_{j} \tilde{g}_{j}^{h}(x,y,z) \cdot \hat{\Theta}_{j}^{h}$$

- T complex amplitude of the h-th harmonic of the temperature oscillation in or at the component
- space number j
- complex base solution g_j („temperature weighting factor“)
- complex amplitude of air temperature θ_j

Harmonic Thermal Conductance

$$\hat{\Phi}_i^h = -\sum_j \hat{\Theta}_j^h \cdot \iint_{\Re_i} (\lambda \cdot \mathrm{grad}\, \tilde{g}_j^h) \cdot d\vec{a}$$

$$\boxed{\tilde{L}_{i,j}^h = \iint_{\Re_i} (\lambda \cdot \mathrm{grad}\, \tilde{g}_j^h) \cdot d\vec{a}}$$

$$\hat{\Phi}_i^h = -\sum_j \tilde{L}_{i,j}^h \cdot \hat{\Theta}_j^h$$

important note: the summation in *j* runs for all spaces (<u>including *i*</u>)

Periodic boundary conditions

The (yearly) mean value of heat losses of space i (steady state)

$$\bar{\Phi}_i = -\sum_{j=1}^{N} L_{i,j} \cdot \bar{\Theta}_j$$

The (yearly) oscillation of heat losses of space i (transient period of one year)

$$\hat{\Phi}_i = -\sum_{j=1}^{N} \tilde{L}_{i,j} \cdot \hat{\Theta}_j$$

important: The summation is to be executed through all N spaces connected to the model – this also includes the space i .

The time dependant distribution of heat losses during the year can be determined by a Fourier synthesis of the results for the entire building

Standardisation, EN ISO Norms

- concepts have been incorporated in the “thermal bridge standard” EN ISO 12011

- additional standards (e.g., EN ISO 6946, 13370, etc.) made direct use of these concepts during the late 1990s

- generalisation of the concept to describe dynamic transmission processes involving heat capacity consideration under periodic boundary conditions established within EN ISO 13768.

Special Case – single zone

- all interior spaces share the same temperature (1 zone)
- the exterior space is considered isotherm too

$$\bar{\Phi}_1 = -L_{1,0} \cdot \bar{\Theta}_0 - L_{1,1} \cdot \bar{\Theta}_1 = L_{1,0} \cdot (\bar{\Theta}_1 - \bar{\Theta}_0)$$

$$\hat{\Phi}_1 = -\tilde{L}_{1,0} \cdot \hat{\Theta}_0 - \tilde{L}_{1,1} \cdot \hat{\Theta}_1$$

Fourier synthesis yields:

$$\Phi_1(t) = L_{1,0} \cdot (\bar{\Theta}_1 - \bar{\Theta}_0) + \left|\tilde{L}_{1,0}\right| \cdot \left|\hat{\Theta}_0\right| \cdot \cos(\omega \cdot t + \varphi) + \left|\tilde{L}_{1,1}\right| \cdot \left|\hat{\Theta}_1\right| \cdot \cos(\omega \cdot t + \psi)$$

and by comparison with EN ISO 13370:2008-4 :

$$H_g = L_{1,0} \qquad H_{pe} = \left|\tilde{L}_{1,0}\right| \qquad H_{pi} = \left|\tilde{L}_{1,1}\right|$$

AnTherm simulation

- AnTherm stands for a powerful innovative software application for the building physics
- integrates new visualisation capabilities, which have their origins in supercomputing and in the scientific visualisation of large sets of physical data, in the daily life of a civil engineer
- features unavailable to building physicists only a short time ago are provided in AnTherm in an intuitively graspable way.
- employs extensive automation of the numerical models
- calculation results are (almost) immediately assessable
- high quality visualisations can be transferred directly into the reports

Implementation requirements of a simulation application

- thermal conductances (the matrix of thermal coupling) calculated directly without the need to specify any boundary conditions
- Standard conformant presentation of results, easily transferable to other simulation systems by a few simple manual calculations at most
- efficiently support evaluation of two- and three dimensional problems
- immersive 2D and 3D visualisations
- numerical stability of the method sufficient for most tasks (various levels of model detail like ground, foils, spaces)

Implementation requirements of a simulation application

- integrated implementation for effective execution after a short learning period to ensure conscious control of the tool without specialised knowledge
- the tool should integrate itself into the everyday work process of an engineer, architect, building specialist or assessment expert
- address seldom, rare, occasional use
- seconds or, at most, a few minutes of computation when executed on typical office hardware

Implementation requirements of a simulation application

- conformity to standards can be easily verified by the users themselves for each and every simulation
- application of advanced simulation and visualisation techniques
- enhances the enjoyment of exploring the thermal performance of buildings
- encourages the user to create optimised component variations
- support and facilitate insightful learning when used in the classroom

Numerical Solution

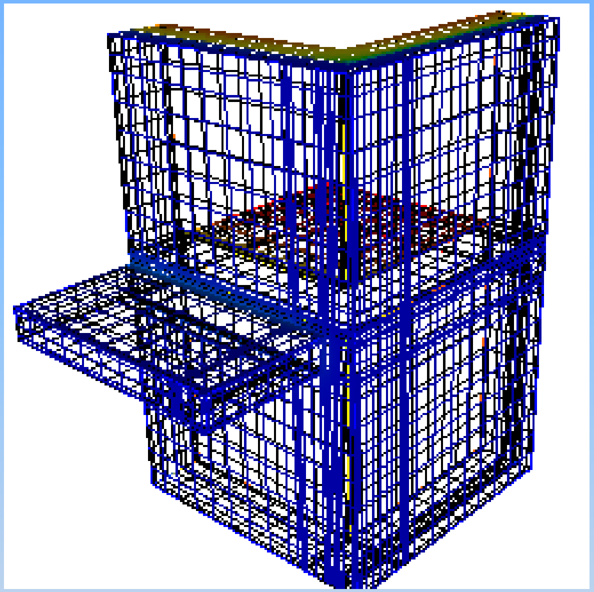
- finite difference model - linear system of equations derived from the heat transfer equation for the harmonic periodic model in the discrete space and represented by complex numbers
- linear system of several hundred thousand to a few millions of equations
- the solution vectors of base solutions for every period length contain the weighting factors (g-values) of respective cells (complex numbers as well)
- convergence assured by property “A” of the Jacobi matrix (iterative over-relaxation following Gauß-Seidl with varied relaxation factor) – related to symmetry and significantly dominant diagonal

Numerical Solution

- only material cells taking part in the heat transmission included
  (instead of the whole volume)
- Number of evaluated nodes is multiple of that:
  - 2D: cells x 4 = evaluated nodes
    - cell center, corners, mid-sides
  - 3D: cells x 8 = evaluated nodes
    - cell center, corners, mid-sides and mid-edges

  20.000.000 equations = cells in 3D

  ➔ more than 160.000.000 nodes



Harmonic thermal coupling coefficients and the phase lag between the oscillation of the temperature and the resulting variation of heat losses

- calculated directly
- independent of boundary conditions (no need to know them)
- shown as complex number and as the amplitude and phase lag

Thermal Coupling Coefficients [W / K]

Space\Space	Room 0	Room 1	Room 2
Room 0		2,116365	15,705269
Room 1	2,116364		10,089766
Room 2	15,705270	10,089766	

Harmonic Thermal Condactance for the period of 31536000 s Year

Space\Space	Room 0 Re	Room 0 Im	Room 1 Re	Room 1 Im	Room 2 Re	Room 2 Im
Room 0	-372,1741	-343,2399	2,1133	-0,0619	7,2899	-2,9619
Room 1	2,1130	-0,0616	-12,2096	-0,4732	10,0850	-0,2123
Room 2	7,2866	-2,9647	10,0853	-0,2123	-28,3451	-6,3106

Space\Space	Room 0 Amplitude [W/K]	Room 0 Phase [months]	Room 1 Amplitude [W/K]	Room 1 Phase [months]	Room 2 Amplitude [W/K]	Room 2 Phase [months]
Room 0	506,2876	-4,5772	2,1143	-0,0559	7,8686	-0,7371
Room 1	2,1139	-0,0557	12,2187	-5,9260	10,0872	-0,0402
Room 2	7,8666	-0,7380	10,0876	-0,0402	29,0391	-5,5816

Steady state coefficient heat loss factor

harmonic coefficient heat loss factor

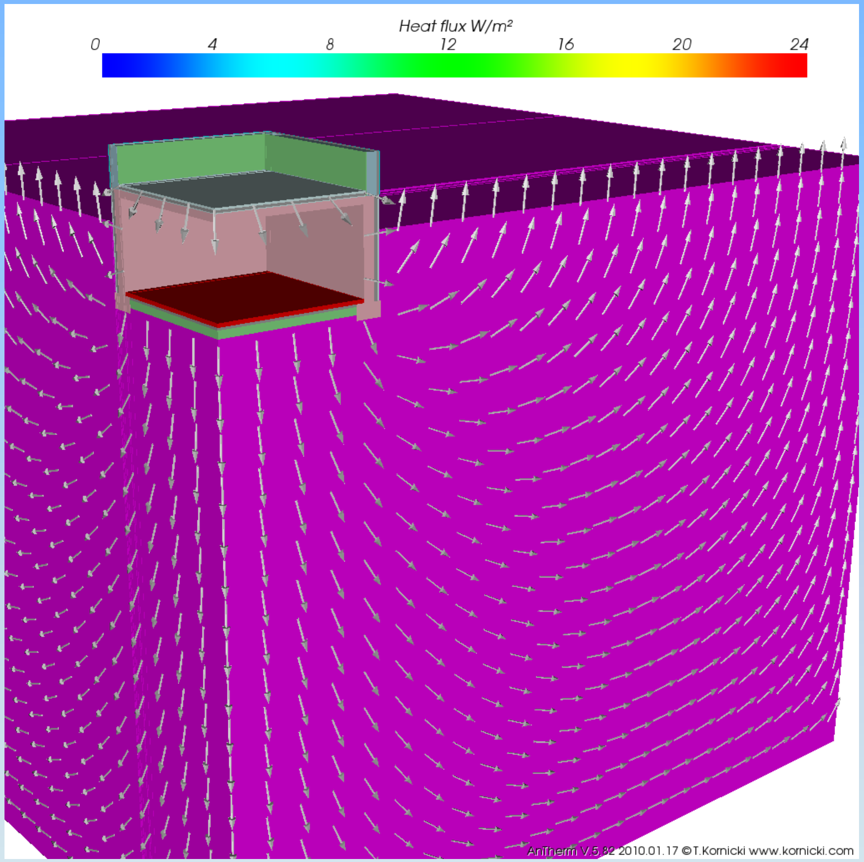
Amplitude

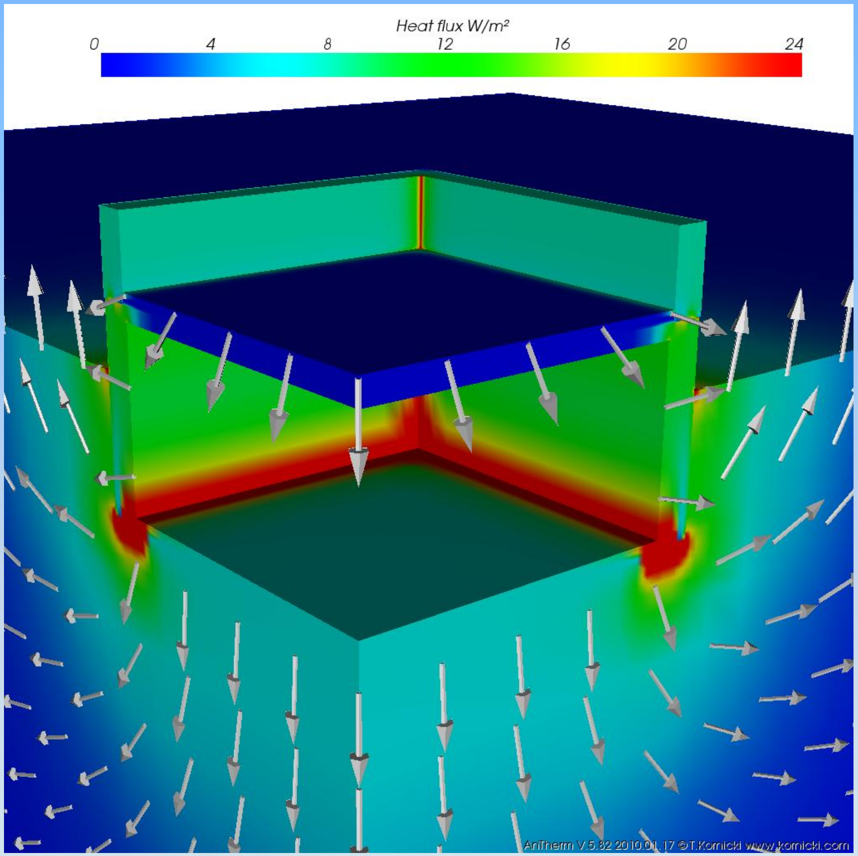
Phase-Lag

Interactive 2D and 3D visualizations

- support better understanding of thermal processes
- can easily be used as planning or component optimisation support
- research or education
- “If houses could talk …”
- state of the art computer-aided visualisation methods
- heat flow processes are easily “made perceivable”
- integrated in the highest quality to the desktops of building physics experts
- thermal bridges can be explored and examined in an almost playful, enjoyable manner

Foundation deep in ground
dynamic transient problem
Harmonic simulation in 3D





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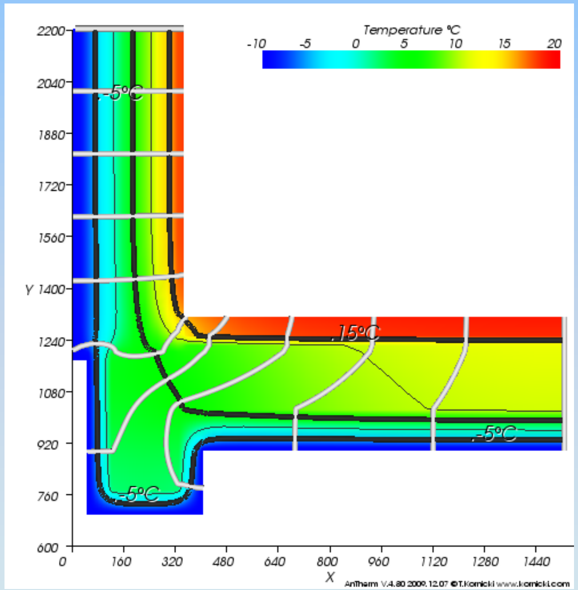
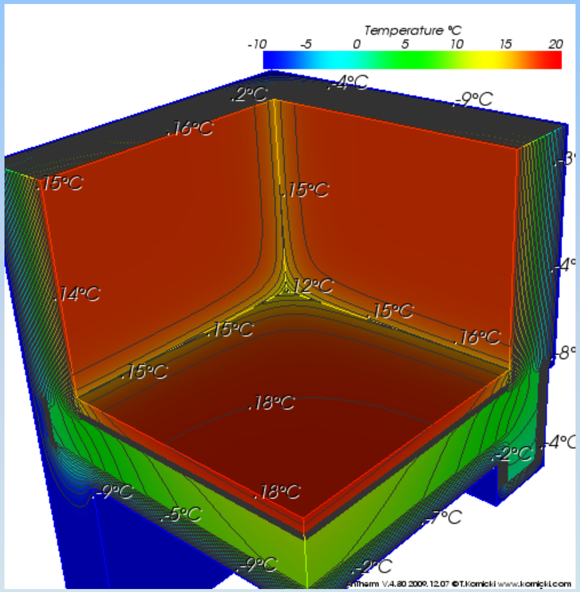
Slab over carport
Localising thermal bridges
Simulation in 2D and 3D
with
AnTherm





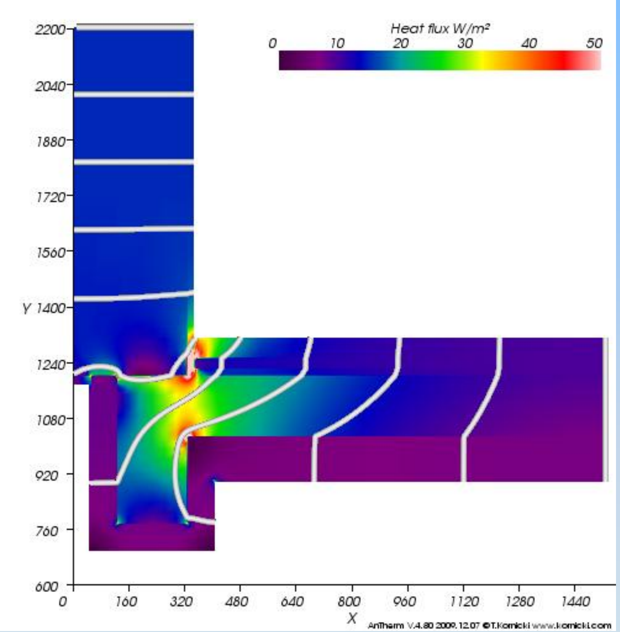
- 2D calculated result :

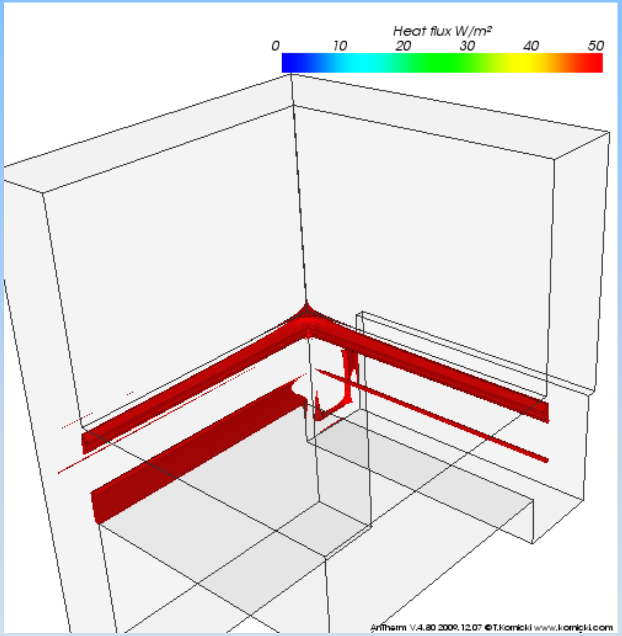
  T* = 15,22°C, fRsi = 0.84

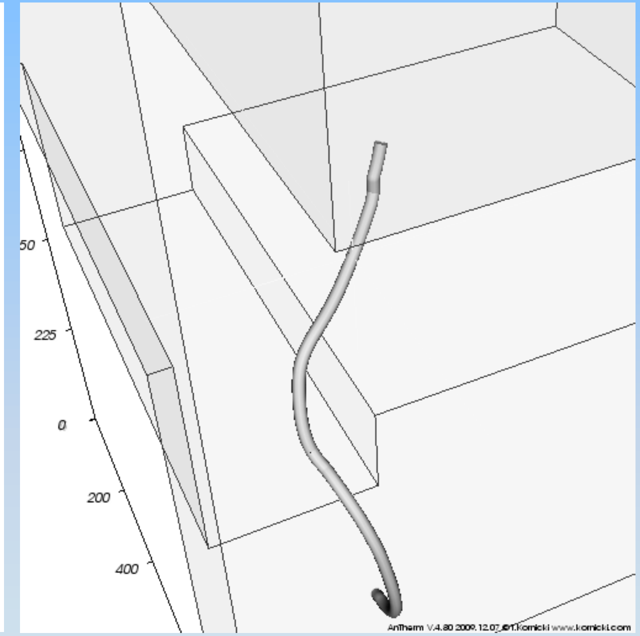
but

- 3D calculation leads to :

  T* = 11.08°C, fRsi = 0,70 !

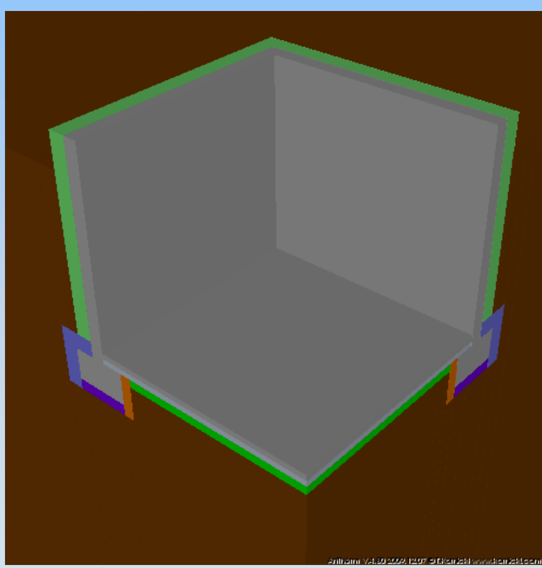


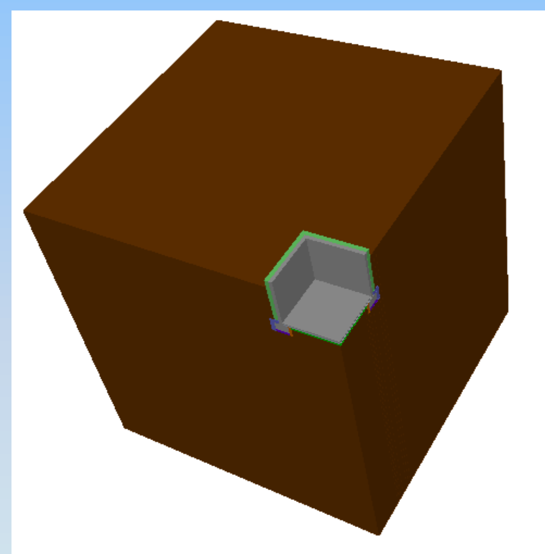


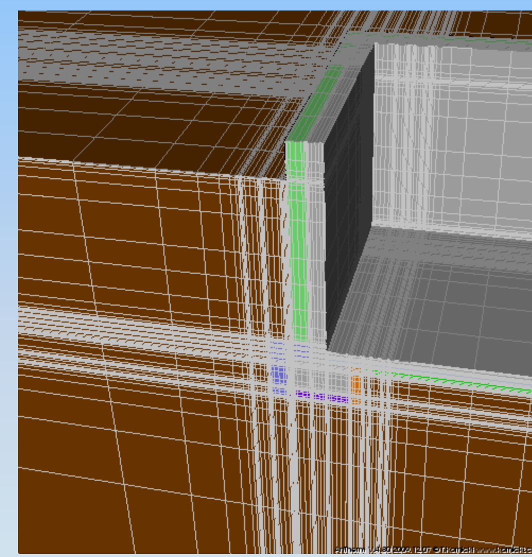


Groundwork

Simulation in 3D
mit
AnTherm







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AnTherm (WALTER/UDO)
Version 4.80 2009.12.07

File: D:\Entw\01 Forum Passivhaus Poznan\Pyszczek\STOPA FUNDAMENTOWA-01_tko.antherm

Number of evaluated cells: 538272 (Nodes > 4306176)

Boundary conditions and resulting Surface Temperatures / Condensing Humidity

	Air temperature [°C]	min.temperature [°C]	max.temperature [°C]	Condensing.H. [%]	f^*_{Rsi}
INDOOR	16,00	11,35	15,56	73,90 %	0,87
OUTDOOR	-20,00	-20,00	-19,51	100,00 %	

Boundary conditions

Extremes and surface condensation

Weigting factors for coldest surface point of each room

	INDOOR	OUTDOOR
g(INDOOR)	0,870846	0,000098
g(OUTDOOR)	0,129154	0,999902

Weighting factors (g-values)

Coordinates (x,y,z) for coldest surface point of each room

	x	y	z	Temp.[°C]	f^*_{Rsi}
INDOOR	-125,0000	-125,0000	800,0000	11,35	0,87
OUTDOOR	20000,0000	20000,0000	3700,0000	-20,00	

Critical locations

Thermal Coupling Coefficients [W / K]

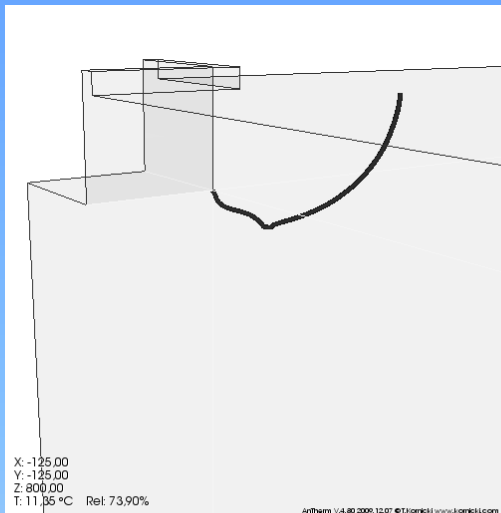
Room\Room	INDOOR	OUTDOOR
INDOOR		6,741698
OUTDOOR	6,741750	

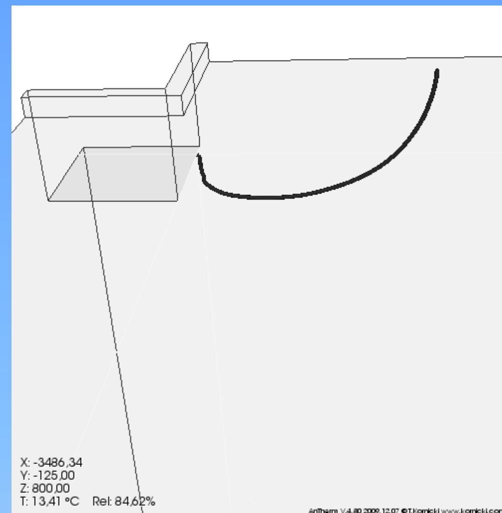
Coupling Coefficients (Thermal Heat Loss Factors)

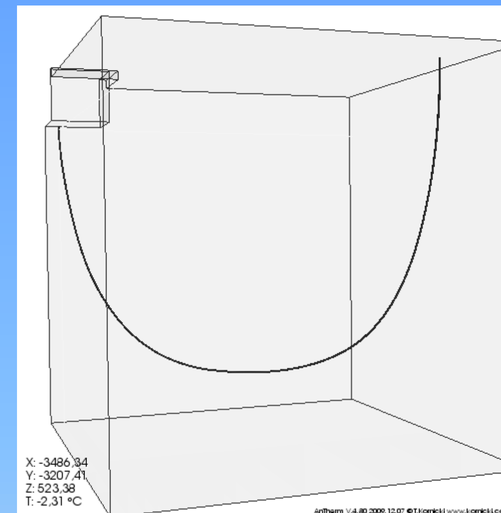
Precision information

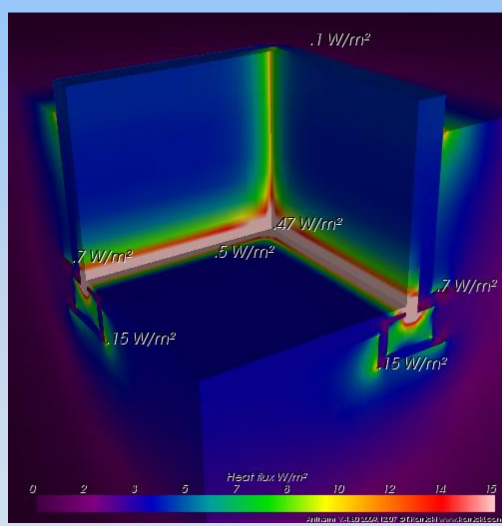
	Close-up error [W / K]	Coeff. sum [W / K]	Relative close-up error
INDOOR	5,29186e-005	6,741750	7,84938e-006
OUTDOOR	-5,29186e-005	6,741698	-7,84944e-006

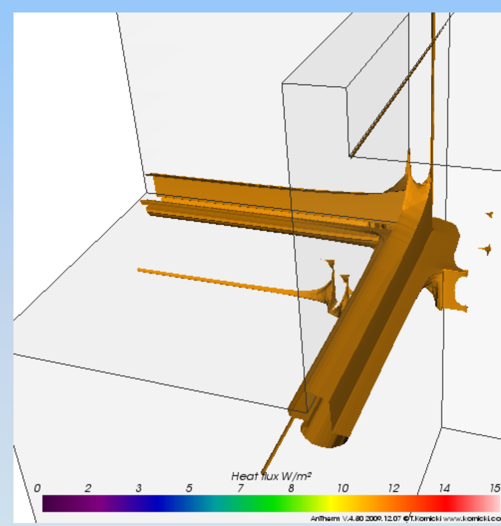
Precision information (error estimates)

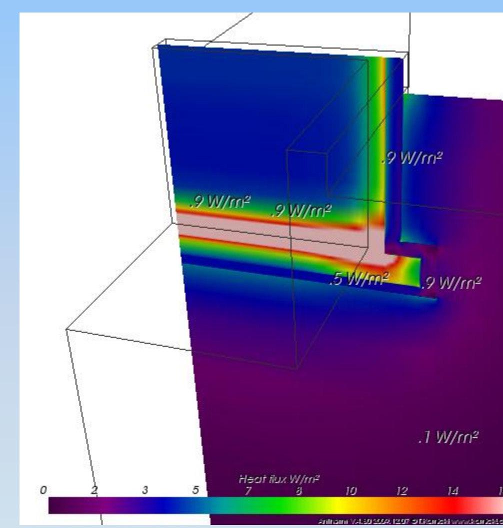

X: -125,00
Y: -125,00
Z: 800,00
T: 11,35 °C Rel: 73,90%


X: -3486,34
Y: -125,00
Z: 800,00
T: 13,41 °C Rel: 84,62%


X: -3486,34
Y: -3207,41
Z: 523,38
T: -2,31 °C


.1 W/m²
.47 W/m²
.7 W/m²
.5 W/m²
.7 W/m²
.15 W/m²
.15 W/m²
Heat flux W/m²
0 2 3 5 7 8 10 12 14 15


Heat flux W/m²
0 2 3 5 7 8 10 12 14 15


.9 W/m²
.9 W/m²
.9 W/m²
.5 W/m²
.9 W/m²
.1 W/m²
Heat flux W/m²
0 2 3 5 7 8 10 12 14 15

Future work

- further efficiency improvement of the harmonic- periodic transient calculation model
- extension of the visualisation techniques
- supplemental extensions of calculation, evaluation, and visualisation; deployment on massively parallel systems
- continuing to respect the currently typical equipment of engineering bureaus
- 4D visualisation of time-dependant simulation results in immersive virtual environments is within reach

AnTherm

- AnTherm = the hymn (anthem)

  In memoriam of **Dr. Walter Heindl** (†1994), author of the concept of **Base Solutions** and the **Thermal Coupling Coefficients (Leitwerte)**

- The kernel of these theoretical concepts have been directly adopted into the „**Thermal Bridge Standards“ EN ISO 10211**, thus stringent **conformity to the standard** is easily and automatically provided by **AnTherm**!

Trial instead of elaboration

- Fee demo version:

  http://www.antherm.eu/
- Registration required (contact data)

- Example videos on YouTube:

  http://www.youtube.com/user/tkornicki
- Imagery created with AnTherm on PicasaWeb:

  http://www.picasaweb.com/antherm
- User Guide, Theory, Learning materials, Tutorials:

  http://help.antherm.eu/

AnTherm

the software system for
Analysis of **Therm**al behaviour
in building constructions with thermal bridges

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