PREDICTION OF THE IMPACT OF BUILDING DESIGN PARAMETERS ON THE THERMAL BEHAVIOUR OF A BUILDING IN THE EARLY DESIGN STAGE

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ABSTRACT

The thermal performance of a building depends on a number of building design parameters. Development of 'energy efficient building concepts' therefore requires insight in the here mentioned interrelation.

In the recent past many advanced simulation tools have been developed for prediction of temperatures and energy flows in buildings. However in spite of their potentialities, the use of these tools during the building design process still is limited. Based on an ongoing Ph.D.-project it has become clear that in general no (advanced) simulation tools are used to support selection of promising energy saving building concepts [de Wilde et al (2001)].

At least two different approaches can be distinguished to support early building design decisions by means of computational models. The first involves the 'early design stage adapted' use of advanced simulation tools. The second approach aims at development of tools that give in a more general way a reliable insight in the impact of building design parameters [van der Voorden et al (1999)]

In this paper the last mentioned approach, based on the differential equation of Fourier, will be discussed and demonstrated by means of an example.

KEYWORDS

Building construction elements, thermal behaviour, design tools, early design stage

INTRODUCTION

In the early design stage the following two questions may arise with respect to the thermal performance of buildings:

– To which extent will outdoor temperature fluctuations penetrate in construction elements of the building envelope?
– What is the effect of incoming solar irradiation on the thermal performance of the building?

In this paper an analytical based method will be discussed that can be used in the early design stage to answer before mentioned questions.

APPROACH

Description of the analytical based method

The analytical method is based on the Fourier equation. In case of periodical boundary conditions based on this equation a set of equations can be derived for layered constructions, describing the relation between air temperatures and heat fluxes on both sides of the construction element [Carslaw et al (1959)]. When for instance a construction element consists of two layers A (outer layer) and B (inner layer) (see figure 1), the following matrix equation can be found (see eqn. 1):

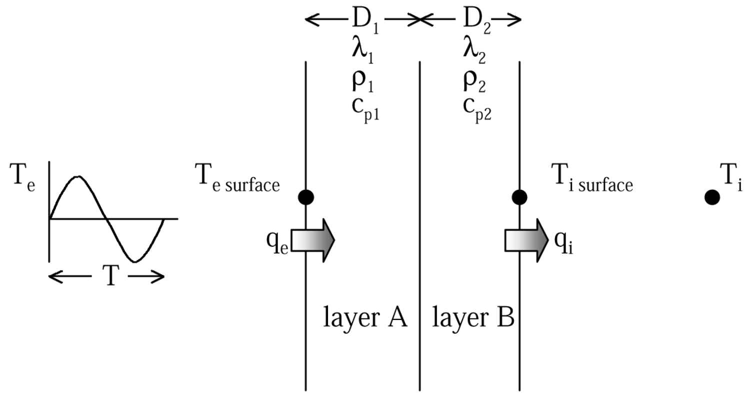

Figure 1: Example of layered construction with temperatures and heat fluxes

$$\begin{pmatrix} T_i \\ q_i \end{pmatrix} = \begin{pmatrix} 1 & -\frac{1}{\alpha_i} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} 1 & -\frac{1}{\alpha_e} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} T_e \\ q_e \end{pmatrix} \qquad \text{[eqn. 1]}$$

In which:
T_e: external air temperature [°C]
T_i: internal air temperature [°C]
q_e: external heat flux [W/m^2]
q_i: internal heat flux [W/m^2]
α_e: external heat exchange coefficient [W/m^{2}K]
α_i: internal heat exchange coefficient [W/m^{2}K]

$$a_{11} = a_{22} = \cos kD \cdot \cosh kD + i \cdot \sin kD \cdot \sinh kD$$
$$a_{12} = \frac{1}{2\lambda k}(-\cos kD \cdot \sinh kD - \sin kD \cdot \cosh kD + i \cdot (\cos kD \cdot \sinh kD - \sin kD \cdot \cosh kD))$$
$$a_{21} = -\lambda k(\cos kD \cdot \sinh kD - \sin kD \cdot \cosh kD + i \cdot (\cos kD \cdot \sinh kD + \sin kD \cdot \cosh kD))$$

$$k = \sqrt{\frac{\pi \rho c_p}{\lambda T}}$$

D: thickness of the layer [m]
_: heat conduction coefficient [W/mK]
_: density [kg/m^3]
c_p: specific heat [J/kgK]
T: duration of one temperature fluctuation [hr]

The matrix elements b_{ij} can be calculated in the same way using the material properties and dimensions of the inner layer B.

The method also enables computation of temperatures and heat fluxes inside the construction element. For construction elements that consist of more than two layers the method also is applicable.

For periodical boundary conditions q_e, q_i, T_e and T_i the set of equations can be solved when 2 of the 4 boundary conditions are known.

Verification of obtained computational results

To verify the reliability of the above described method, obtained results have been compared with numerical results for similar construction elements and similar boundary conditions. The numerical program CAPSOL [P.Standaert] has been used in order to carry out this verification.

Application of characterizing numbers for non-stationary heat flows

In order to gain insight in the thermal behaviour of building construction elements and to compare the thermal behaviour for various construction element variants, representative numbers are required. The following existing characterizing numbers for non-stationary heat flows have been applied: damping, time delay and heat storage capacity. These numbers will be explained later on.

Sol-air temperature

Based on an energy balance at the surface of any construction element, periodical functions for air temperature and solar irradiation can be transformed into the so-called sol-air temperature T_s. The here mentioned sol-air temperature will be used as a reference temperature for the characteristic numbers damping and time delay.

Investigated situations

Several building design situations have been investigated during the project, using the here-discussed method. Here the following situation will be discussed in detail. See figure 2.

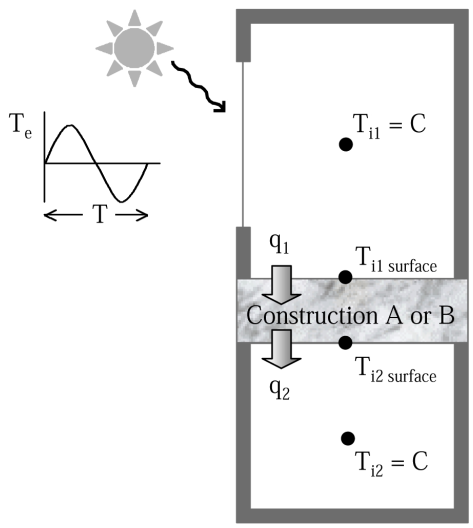

Figure 2: thermal behaviour of a separation wall between two adjacent rooms

In an office building two adjacent rooms, both with an indoor air temperature of 20 ^{0}C, have been considered. In only one of the rooms fluctuating incoming solar irradiation, with an average value $q_{s,average}$ = 200 W/m^2 and an amplitude $q_{s,ampl}$ = 200 W/m^2, reaches the floor and the inner walls.

Fluctuating solar irradiation and a constant inner temperature together have been transformed into the sol-air temperature $T_{sol\text{-}air}$, with an average value $T_{sol\text{-}air,average}$ = 45°C and an amplitude $T_{sol\text{-}air,ampl}$ = 25°C. $T_{sol\text{-}air}$ reaches its maximum value at 12:00 hours.

In this study, the thermal behaviour of the wall between the two considered rooms has been investigated, using the before mentioned numbers damping, time delay and heat storage. Here these numbers are defined as:

$$\text{Damping} = \frac{T_{sol-air,ampl}}{T_{i1 surface,ampl}} \qquad \text{[eqn. 2]}$$

Time delay is defined as the time between a maximum sol-air temperature and a maximum surface temperature.

Heat storage capacity of the wall is defined as the maximum amount of energy that is stored in the wall during one time cycle T.

Construction element variants

To get insight in the impact of layer dimensions and layer sequences, during the study various wall construction variants have been considered. The following variants will be discussed here:

– Variant A: 5 cm concrete & 15 cm insulation material
– Variant B: 5 cm insulation material & 15 cm concrete

Assumed material properties are shown in table 1.

TABLE 1
Material properties

	Concrete	Insulation material
λ [W/mK]	0.9	0.05
ρ [kg/m^3]	1900	50
c_p [J/kgK]	840	1470

RESULTS

Characteristic numbers for the separation wall

The characteristic numbers, shown in table 2, clearly demonstrate which differences in thermal behaviour of both construction variants can be expected.

TABLE 2
Damping and time-delay, heat storage

Variant	Damping [-]	Time delay [hr]	Heat Storage [J/m^2]
A	1.3	2.2	$3.0 \cdot 10^6$
B	1.1	0.1	$5.8 \cdot 10^5$

Temperatures and heat fluxes as a function of time

In figure 3, the sol-air temperature in the room as well as surface temperatures on both sides of the separation wall are given as a function of time for both construction variants.

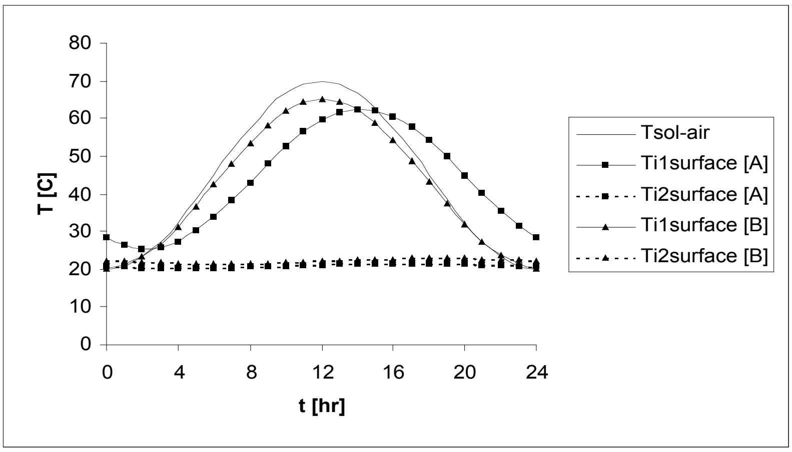

Figure 3: Sol-air temperature and construction element temperatures

In figure 4, heat fluxes at both surfaces of the construction element are given as a function of time.

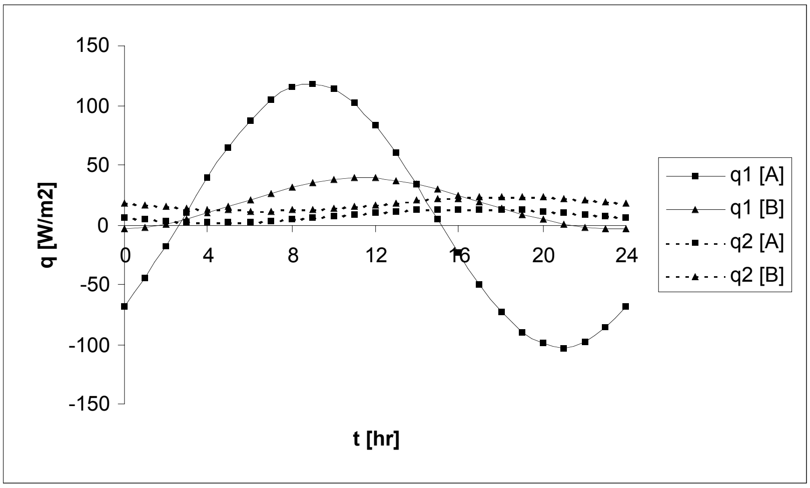

Figure 4: Heat fluxes

Comparison with numerical computation results

In all the compared cases, the differences between the analytical method and the CAPSOL calculations were smaller than 3 percent.

DISCUSSION AND CONCLUSION

- For periodical temperature and solar irradiation fluctuations and constant indoor air temperatures the thermal behaviour of layered construction elements can be simulated in a highly accurate way, using the here discussed analytical based computational model.
- Without time consuming and expertise requiring modelling efforts insight in the impact of relevant design parameters on occurring heat flows and temperatures can be obtained.
- If necessary also non-stationary effects can be accurately quantified, using well known characteristic numbers.
- The here discussed approach has been applied for situations with constant indoor temperatures. However the method can be extended in order to gain insight in the passive behaviour of a building.

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