THERMAL BUILDING SIMULATION WITH MAPLESIM

Adhi Susilo and Martin Bauer
Faculty of Architecture and Civil Engineering
Hochschule Augsburg, Germany

ABSTRACT

This work is based on a systematic approach in construction process. The idea is to break down the building into its basic part and then we model the basic part and finally we rearrange that components to build the system and do the simulation. With that idea and using a computational tool, MapleSim, we build the model.

MapleSim is one of simulation tools that is able to work on both approaches; causal and acausal. This new development in simulation tool can be used to build a custom thermal building simulation for our purpose.

We took VDI 6020 as a benchmark to evaluate a developed room model. The model is built from basic components provided by MapleSim library. However, some bugs exist in this version of software.

ZUSAMMENFASSUNG

Zur Unterstützung von Konstruktionsvorgängen beim methodischen Konstruieren wird ein graphenbasiertes Simulationssystem aufbereitet.

Hierzu wird in Analogie eines Vorgehensmodells für die Baukonstruktion auf Basis des kommerziell verfügbaren Simulationswerkzeuges MapleSim eine Raumsimulation aufgebaut.

Aus Basiskomponenten heraus werden Konstruktionsteilsysteme für die Simulation gebildet. Die Kombination der Teilsysteme ergibt das Gesamtsystem.

Zur Validierung der Simulation wird die VDI-Richtlinie 6020 herangezogen.

INTRODUCTION

This section gives short explanation about systematic in construction process. The systematic process is base of this work.

Systematic Engineering Design

A construction as a technical system is developed in seven basic working steps, from abstract to detail, as shown in Figure 1 (Pahl et al., 2007). The working steps are associated with construction phases. Those phases are defined as :

1. Planning and task clarification
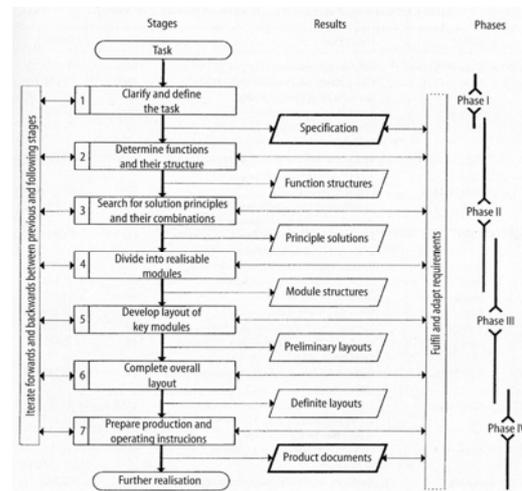2. Conceptual design
3. Embodiment design
4. Detail design

Figure 1 General construction process (Pahl et al., 2007)

Formalizing Building Construction Process

With the construction point of view, we are going to synthesis a system, from abstract to detail (Figure 2).

Figure 2 Synthesizing construction

The construction and its behavior can be modeled as a formal system represented by graphs (Bauer, 2000), as depicted on Figure 3.
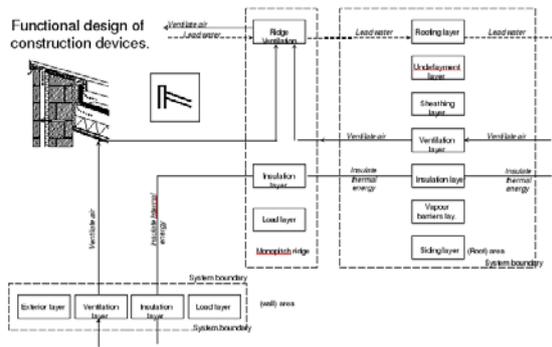
Figure 3 Graph method of construction (Bauer 2000, 2008)

This work focuses on the energetic behavior of the building system and its thermal functions. The objective is to formalize simulation as a graph based method as analogy to systematic design. At the end simulation should follow the phases in construction process in different levels of detail.

The plan is simulating a model from VDI 6020 test. In this work, as our concept, we only consider energy transfer from zone to environment (or boundary to system). In systematic model, it can be represented as Figure 4. The model complies with conceptual design model.

It shows a single zone which has a periodic internal gain, a constant temperature side (at 22°C) and adiabatic condition on the other sides. Heat travels by convection only, and it is assumed that there is no radiation.
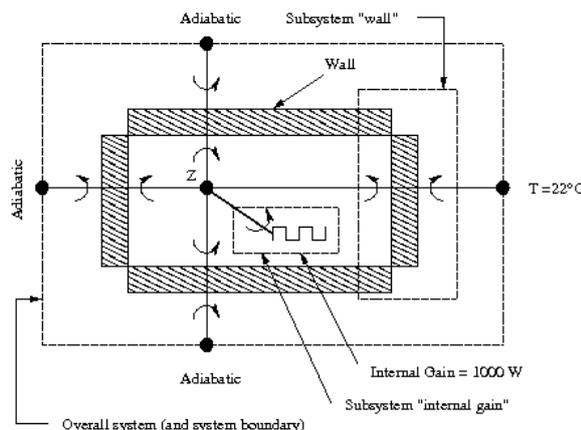

Figure 4 The system, a single zone model

Then that concept is embodied. The system enclosed by walls (ceiling and floor) and window. Energy

moves in 1D direction through those surfaces. For further analyzing, the surfaces consist of layer or layers. The system elements can be associated with simulation properties.

It is defined that layer may behave as conductor and capacitor. However, there is component, such as air, that uses radiation and convection mechanism to transmit the heat.

Finally, the detail design breaks down the construction into single component, we use MapleSim to build this basic component, and then we synthesize the component to simulate a complex system. The following section will explain the synthesizing further.

MODELICA AND MAPLESIM

Many components in MapleSim are taken from the Modelica standard library (Maplesoft homepage). Modelica is a non proprietary, object-oriented, equation based language to conveniently model complex physical systems containing, e.g., mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process oriented subcomponents (Modelica homepage). As mentioned before, the equation based language, or called an acausal system, makes simulating complex physical system easier. In acausal system it can be written $x = y + C$, although there are unknown variables on both sides. On the contrary, a causal system demands value on the right side, that is an assignment statement, i.e $x := y + C$, where y and C must be solved before reaching this line.

With this ability, man can build a model without worrying direction of input and output. The complex model can be built from simple components that are provided in standard library. Following decribes some papers that show Modelica availabilty. Felger et. al. built their model with Modelica. Their building simulation can handle weather data, heating, and controller with fuzzy logic method (Felgner et al., 2002). Hoh, et. al. also built their model with Modelica. Their model includes internal gains, solar gains, and air exchange (Hoh et al., 2005). Another example of using Modelica in building simulation is shown by Wetter's work. His model even includes humidity gains and CO2 gains (Wetter, 2006).

This paper is also discussing on the usage of this acausal method in solving thermal problems, especially on the thermal building system. However, instead of using Modelica, we build the model with MapleSim (MapleSim3). MapleSim library contains more than 300 modelling components, including electrical, mechanical, and thermal devices; sensors and sources; and signal blocks (Maplesoft, 2001-2009).

Following is thermal library components in MapleSim, that isl be used by our model:

- Boundary Condition Controls
  - Fixed Temperature
- Heat Transfer Components
  - Body Radiation
  - Convection
  - Heat Capacitor
  - Thermal Conductor
  - Prescribed Heat Flow

With those components we build a model to simulate a thermal building. In this paper, we are going to take one of VDI 6020 tests as a bench mark.

BASIC MODEL

VDI 6020

We use VDI 6020 Example 1 as a bench mark for the simulation (VDI Richtlinie 6020, 2001) and we choose Room type S only for this work. Before discussing the construction, we would like to show the surounding of the model. The environment or boundary condition of the room is set in these following tables, i.e. Table 1 and 2 respectively, and other parameters of the building which are not included in Table 2 are assumed as zero.

Table 1
The convective heat transfer coefficients

BUILDING COMPONENTS	INTERNAL W/(M^{2}K)	EXTERNAL W/(M^{2}K)
External wall	2.70	20.00
Internal wall	2.70	2.70
Door	2.70	2.70
Floor	1.67	1.67
Ceiling	1.67	1.67
Window	2.70	20.00

Table 2
The boundary conditions

PARAMETER	UNIT	VALUE
Outside temperature	^{o}C	22
Internal gain (from machine)	Watt	1000
Operating time (the machine)	hour	6-18
All adjacent rooms	^{o}C	adiabatic

The material properties of the construction are shown in the next tables. However, the materials of the window are not mentioned clearly on the text; in this work we are using Natronglas (Hohmann et al.,

2004) for clear glass layer, as shown on Table 3 and 4, respectively.

Building element

The Room type S is a 'box shoe' room with dimension *3.5m x 5.0m x 3.0m*. The surfaces are categorised into four types, i.e. ceiling and floor, internal walls, internal door, and external wall. The internal walls or internal door has one layer only. The ceiling and floor consist of four layers. The external surface has two parts, an external wall that consists of three layers and a window that also consists of three layers.

A solid layer is simulated with two thermal conductors and a heat capacitor and convection component for both sides. Example 1 of VDI 6020 does not take account the short-wave and long-wave radiation, so in this paper we assume heat travels through conductors and convection flows. Figure 5 shows typical layer of the system. It also shows the components for convection on the both sides. The internal gain is the only heat source for this system, so convection is the important variable for this test (Van Treeck, 2010).
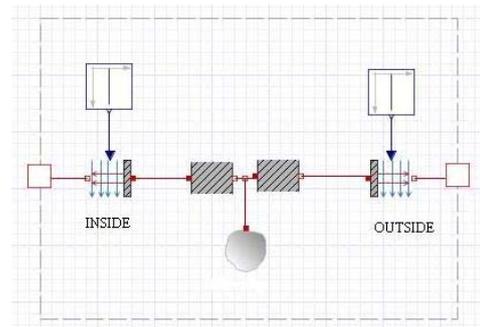

Figure 5 Typical layer

If a wall consists of many layers, then we put those additional layers between convention components, as depicted on Figure 6. This figure represents a detailed wall as a graph.
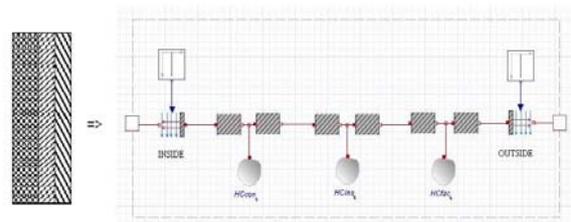

Figure 6 A wall with three layers

Table 3
Material properties of the Room type S (VDI Richtlinie 6020, 2001)

TYPE	CONSTRUCTION	THICKNESS m	λ W/(mK)	ρ kg/m3	C J/(kgK)
Ceiling and floor	PVC covering	0.002	0.210	1300	1470
	Screed	0.045	1.400	2200	1050
	Rock wool	0.012	0.060	50	840
	Concrete	0.150	2.035	2400	1050
Internal walls	Cavity blocks	0.240	0.560	1300	1050
Internal door	Beech, solid	0.040	0.210	700	2520
External wall	Concrete	0.240	2.035	2100	920
	Insulation	0.062	0.047	75	840
	Façade slab	0.025	0.450	1300	1050

Table 4
Material properties of the window, two-panes glazing

TYPE	CONSTRUCTION	THICKNESS m	λ W/(mK)	ρ kg/m3	C J/(kgK)
Window	Clear glass	0.006	1.000	2500	750
	Air	0.012		1.205	1.005
	Clear glass	0.006	1.000	2500	750

The window is two-panes glazing that contains air, so we have to treat this layer differently because conductance of air is zero. Therefore, instead of a thermal conductor we replace this component with body radiation component and convection component, as shown on Figure 7.
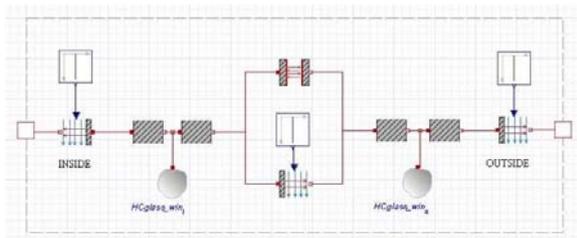

Figure 7 Air in window is simulated by body radiation and convection component

The next step is computing the parameter of each component. For detail explanation can be found on the Modelica Standard Library (Modelica Association, 2008).

The heat capacitor needs parameter *C*, heat capacity, that is defined as

$$C = cp \times m \qquad (1)$$

where *cp* is specific heat capacity and *m* is the mass. The constant thermal conductance, *G*, is needed by thermal conductor and computed as

$$G = k \times \frac{A}{d} \qquad (2)$$

where *k* is thermal conductivity, *A* is area, and *d* is thickness.

Next parameter is *Gc*, the convective thermal conductance, which is defined as

$$Gc = A \times h \qquad (3)$$

where *A* is convection area, *h* is heat transfer coeffcient which equals to 12 W/(m²K) for free convection and equals to 7.8 x V^{0.78} W/(m²K) and *V* is air velocity (m/s). The last parameter, which is needed to simulate the window, is *Gr*, the net radiation conductance between two surfaces. *Gr* of two parallel plates is stated as

$$Gr = \frac{A}{\frac{1}{e_1} + \frac{1}{e_2} - 1} \qquad (4)$$

Table 5
Computed parameters of the layers

COMPONENT	MATERIAL	W(x) m	D(y) m	H(z) m	A m²	Vol m³	C J/K	G(0.5d) W/K	Gc_in W/K	Gc_out W/K
Top / Bottom	PVC covering	3.5	0.002	5.0	17.5	0.035	66885	3675.00	29.225	29.225
	Screed	3.5	0.045	5.0	17.5	0.787	1819125	1188.89		
	Rock wool	3.5	0.012	5.0	17.5	0.210	8820	175.00		
	Concrete (I)	3.5	0.150	5.0	17.5	2.625	6615000	474833.33		
Wall-east	Cavity blocks	3.0	0.240	5.0	15.0	3.600	4914000	70.00	40.5	40.5
Wall-west	Cavity blocks	3.0	0.240	5.0	15.0	3.600	4914000	70.00	40.5	40.5
Wall-north	Cavity blocks	3.0	0.240	3.5	8.5	2.040	2784600	39.67	22.95	22.95
Door	Beech, solid	1.0	0.040	2.0	2.0	0.080	141120	10.50	5.4	5.4
Wall-south	Concrete (II)	3.5	0.240	3.0	3.5	0.084	1622880	59354.17	9.45	70
	Insulation	3.5	0.062	3.0	3.5	0.217	13671	5.31		
	Façade slab	3.5	0.025	3.0	3.5	0.087	119437.5	126.00		
Window	Clear glass		0.006		7.0	0.042	78750	2333.33	18.9	140
	Air		0.012		7.0	0.084				
	Clear glass		0.006		7.0	0.042	78750	2333.33		
Room	Air	3.5	5.000	3.0		52.5	63.5			

where *A* is area of plate, e_1 is emission value of plate 1 (from 0 to 1), and e_2 is emission value of plate 2 (from 0 to 1). With the emission of glass 0.91, a free convection between glasses, and area of window 7 m², we get *Gr* and *Gc* for air layer are 5.8440 m² and 84 W/K respectively. Computed parameters of other layers are shown in Table 5.

ROOM MODEL AND HEAT GAIN

This is one zone simple room which has 6 walls. With those heat transfer components we build the wall. There are 8 surfaces (floor, ceiling, north wall, east wall, south wall, west wall, door, and window). The outside temperature of external surfaces (south wall and window) is constant, 22°C. Other surfaces are bounded with zero heat flux (adiabatic).

MapleSim works in SI unit, second is default for time and Kelvin is default for temperature, therefore we have to adjust the unit for both input and output data according to the defaults. After all wall is set and putting required boundary conditions, we build the model as depicted on Figure 8.

The system has internal heat gain, which is a 1000 watt machine and operates everyday from 6.00 to 18.00. MapleSim has pulse function in signal blocks library, but unfortunately at the moment (the time the paper is written), there is bug in MapleSim (in this case MapleSim3) which makes this program can not generate the pulse function that has long span, the 12
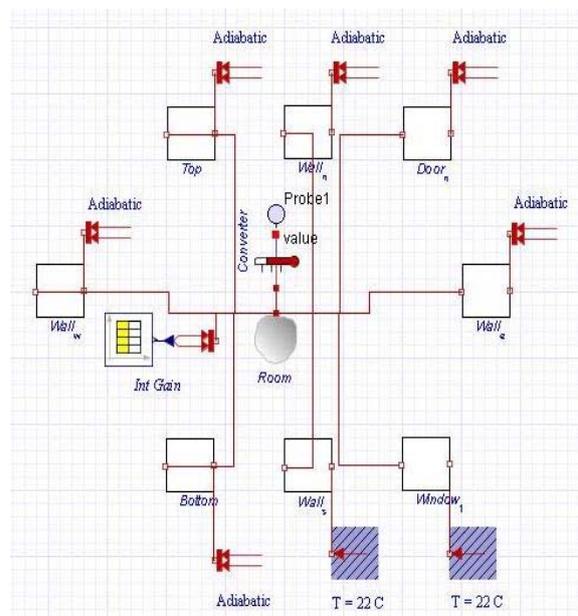
hours is beyond MapleSim pulse function (at the moment, the pulse function works well in unit second or less). Therefore we have to feed this internal gain with an external file, a spreadsheet that contains two columns, time in second and magnitude of the gain in watt respectively.

Figure 8 The room model, the overall system

However, the data from spreadsheet is discrete, and MapleSim will change it into continuous data, then the continued signal will overshoot or undershoot on the corners as shown on Figure 9.
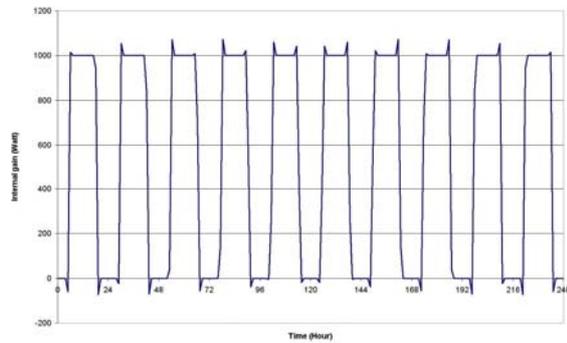

Figure 9 An example of internal gain within ten days

RESULTS IN SIMULATION

The simulation is run for 60 days with boundary condition as mention on Table 4. This is similar to the Example 1 of VDI 6020 test. VDI 6020 test used seven different simulation tools, but we just pick up one of the simulation results for the comparison. The results of first day, 10th day, 60th day, and 60 day simulation are plotted, as shown on Figure 10, 11, 12, and Figure 13 respectively.

Results from the MapleSim are little bit different from VDI results. Temperatures on starting/finishing internal gain also experience undershooting and overshooting. VDI simulation shows that the room temperature reaches steady states faster than MapleSim simulation as shown on the result of day 10th. In this work, the gain is generated discretely in hourly interval, then we have to use hourly time step. It is possible that time step influences the computation, therefore MapleSim result is slower to get steady state. A small time step computation may give a better achievement. However, in general MapleSim results show a good trend as VDI test.
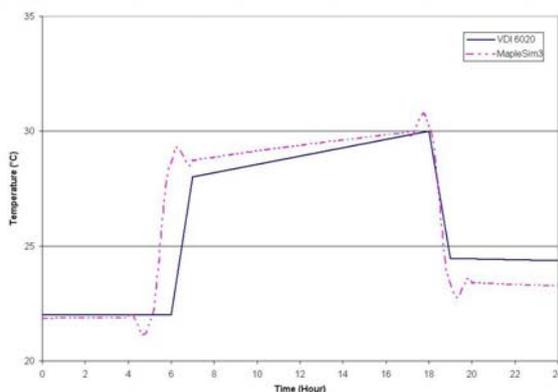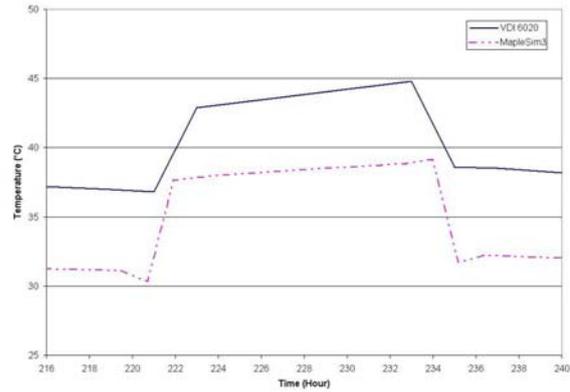

Figure 10 Simulation result on day 1

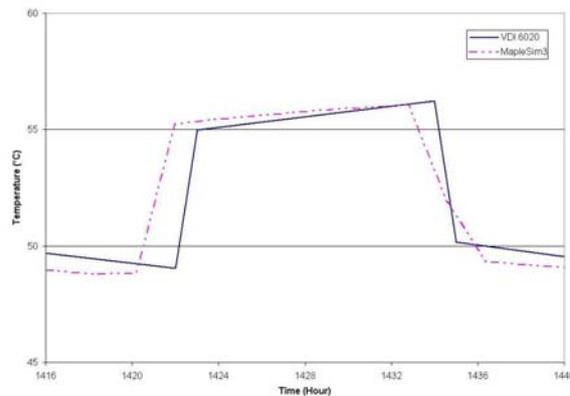*Figure 11 Simulation result on day 10*
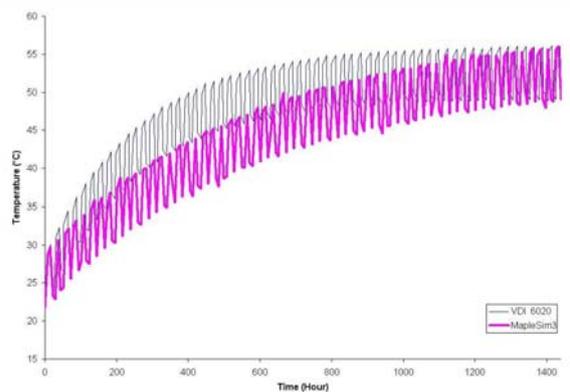

Figure 12 Simulation result on day 60

Figure 13 Simulation result for 60 days

CONCLUSIONS AND FURTHER WORK

It is shown that simulation model can be prepared like a systematic approach in construction process. It can help developing construction design in different level of detail. For that a complex system is broken down into basic components. After that we rearrange

and sythesize the basic component to simulate the overall system.

This model is one-dimensional heat transfer with lumped elements method. The results show that the model can simulate the dynamic energy flow in thermal building system. Though the gradient of the steady state of both results is different, but both simulations reach steady state at around day 60.

This work also shows that MapleSim can be used as an alternative tool to simulate the thermal building. Though MapleSim is relatively slow, especially for complex system, this tool (with its basic components in the library) is suitable for users with less computation background.

There are two aims for further work. First, before bugs fixed, we have to create input (in this case is internal gain) with combination of other functions, for example combining sine function and on-off function. Secondly, we extend this model to accommodate a multizone building.

ACKNOWLEDGEMENT

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