Application of simulation in design and operation of refurbished buildings and heating systems

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ABSTRACT

This paper gives an introduction into the simulation of the thermic behaviour of a modernized building including the calculation of both single and two pipe heating by a new TYPE57 for simulation of heating pipe systems within the program TRNSYS. The data simulated are compared with measurements. The occupancy behaviour and the kind of decentral control have a decisive influence on heat consumption within a building.

INTRODUCTION

The building used here is a five-storey block of flats built in 1968. That type of buildings was built from the mid-sixties to the mid-seventies and represents a typical specimen of the industrial house-building in the former GDR.

Figure 1: View of the building

The block of flats consists of 4 segments which are connected with one another and have separate entrances. Each segment hosts 10 flats of equal size. The floor space of the 3-room flats amounts to 58.5 m² (Figure 2). One of the two outer segments is adjacent to the neighbouring block of flats with its gable-end. The gable-end of the other outside segment borders on the outside air (Figure 3).
Concerning the heating system the building is subdivided into two parts. Hot water is supplied from district heating stations via pipelines. Those pipelines including the local house station and the individual convection heaters work without heat exchangers. The building used had a single pipe system. The adaptation of the flow temperature or of the mass flow rate on the load variation was not given.

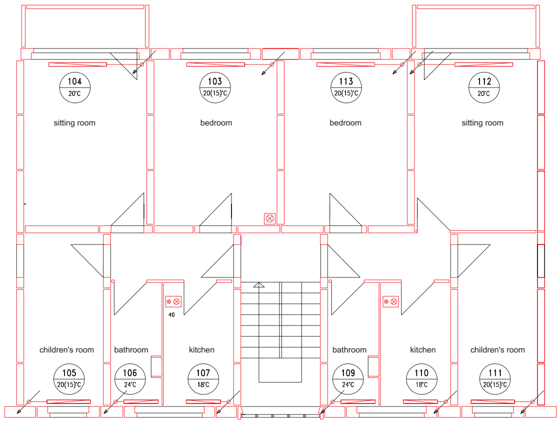

Figure 2: Ground plan of flats

The heat output of the convection heaters could be influenced by a manual air dumper adjustment to a certain degree.

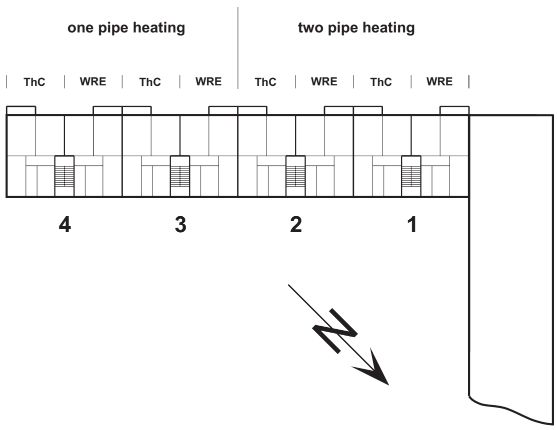

Figure 3: Site plan of the test building with entrances 1-4

On the complete outside cover of the building polystyrene foam flats (6cm thick) were installed but, however, not in the basement. The arithmetical thermal conductivity for this material is λ_{ar}=0.040 W/mK. That way the theoretical k-value of the external wall is improving from k=0.97 W/m²K to k=0.41 W/m²K. A 40 mm thick rigid plastic foam heat insulation with λ_{ar}=0.057 W/mK was installed between basement and first floor. The number of windows with k≈2.5W/m²K was reduced, since in the sitting rooms, in the staircase and in the cellars windows with k=2.0W/m²K were built in. The modernization of the central heating stations was carried out under retention of the direct heating connection. The district heating supply was designed for a heat requirement of 89 kW and 91 kW. The reason for the difference is the gable-end bordering on the outside air.

system parameter

-primary circuit

heating medium	:	warm water from district heating system
load adaptation	:	the same inlet temperature for the housing estate, dependent on the ambient temperature
medium temp.	:	$\vartheta_{i,max}$ =105 °C

-secondary circuit

heating medium	:	warm water from district heating system
load adaptation	:	flow temperature dependent on ambient temperature, flow temperature control with entrain return water
medium temp.	:	$\vartheta_f / \vartheta_r$=90/55 °C at ϑ_{amb} =-16 °C

The heating system was separately modernized in the two distribution systems. The two substations located in the basement were equipped with controllers and heat meters. One heating system is linked to a single pipe system, the other to a two pipe system. In both systems the upper distribution pipes, the collector pipes in the cellars as well as the risers remained unchanged. Within the flats the heating installation was completely renewed. The pipes, however, were not insulated. Radiant panels in compact design were installed to heat the flats. The distribution pipes and the collector pipes of the two-pipe heating were laid in the same way like in the case of the single pipe heating. All 5 types of rooms of the same kind (sitting-room, bathroom, children's room, kitchen, bedroom) are supplied by separate rising pipes. In the flats on the left there is an additional radiant panel in the cellar rooms connected to the pipes supplying the sitting rooms and the bedrooms. Each of the heating networks has 20 rising pipes for 104 radiant panels (Figure 4).

Both substations have been equipped with an electronic monitoring system (WRE). The system mentioned has the task both of a datalogger and a controlling device. Data from all flats of the building are collected via the WRE-system. The single pipe heating as well as the two-pipe heating, however, have been equipped with two different types of control units. One part of the building has ordinary thermostat controllers (ThC), whereas in the other part the WRE-system does the job of controlling and monitoring. The WRE-system records room temperatures, flow and return temperatures as well as energy consumption. Each occupancy can program any desired value for room temperatures in a week schedule.

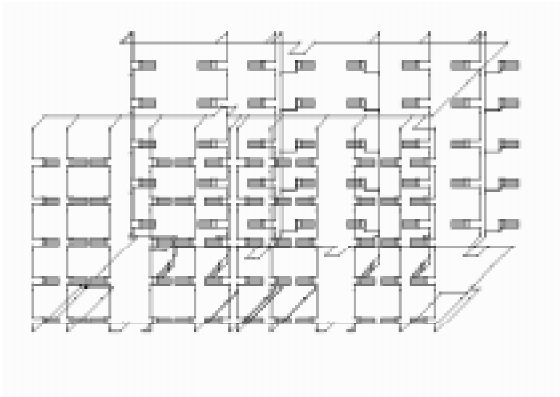

Figure 4: Pipe network of the single pipe heating

SIMULATION

TRNSYS-TYPE57 for the heating system

The mathematical model used here is a new subroutine for TRNSYS to simulate a heating system. It is not new concerning the approach. Is new, however, the complex application within a coupled heating-building-user-system.

The new TYPE57 has the characteristics:

- general use (the hydraulic model allows simulations for single pipe and two pipe heating systems)
- coupling of thermal and hydraulic behavior (TYPE57 includes the behavior for pump, pipe, radiator, controller)
- modular structure
- simple use
- problem orientated data input

Figure 5 shows the programming flowchart for the the heating system TRNSYS-TYPE57.

The program has the following working process:

1. Read network data
2. meshes search (with meshes generator)
3. calculation of mass flow
4. calculation of heat output (pipe,radiator), return temperature and drag coefficient
5. calculation of thermodynamic circulation presure
6. calculation of value position

For that purpose, the heating network is subdivided into single sections.

The two pipe heating system in houses 1 and 2 consists of 999 sections with altogether 897 knots and 104 meshes.

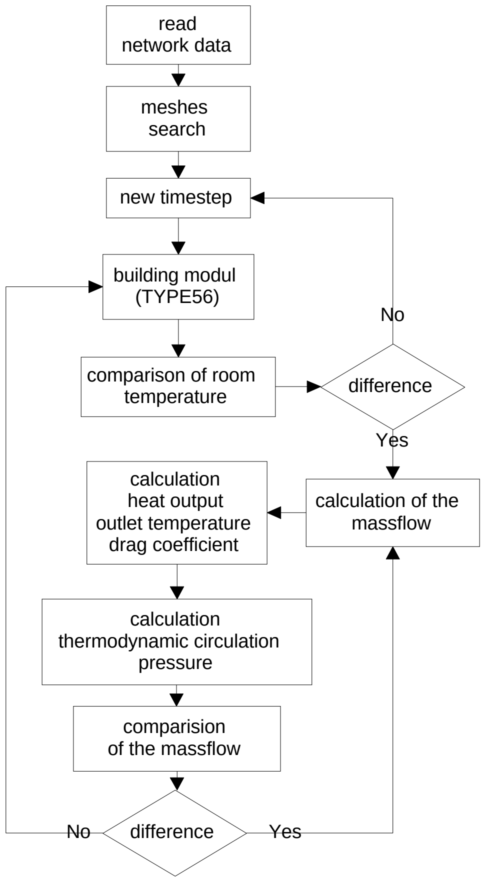

Figure 5: programming flowchart for the the heating system TRNSYS-TYPE57

The single pipe heating system is divided into 1111 sections, 989 knots and consequently 124 meshes.
With the help of a special input instruction the sections of the network are related to the corresponding 164 heated zones of the building, and the valves with the controllers belonging to them are defined.
The method used is applicable to any type of network. The disadvantage is the equation system the solution of which requires a lot of time. The model is only applicable to larger heating systems to a certain degree. Since the solver has already optimally been adjusted to the problem, the speed of calculation has been optimized by an automated division of sections. Therefore the whole system is split up into a main network (distributor network) and 20 subnetworks (cords). The calculation algorithm has been changed. Now, in each iteration step the distribution of the mass flow rate in the main network has to be calculated first. For that reason, fictitious part sections (helping part sections), which are calculated as a replacement for the cords in the main network, have been defined. The only thing that is unknown for those part sections is their hydraulic resistance. It can be determined with the help of the laws of parallel and series circuitry connections. In case of the two-pipe heating system in question the determination of the resistance of the part networks is only indirectly possible. A fictitious pump pressure for the part network is chosen (in case of a current calculation it is the cord difference pressure from the previous calculation). With its help and the current hydraulic resistances of the part sections you get the distribution of the mass flow rate for that pump pressure and consequently the overall resistance of the part network. When you have found out the distribution of the mass flow rate in the main network, the fictitious pump pressures of the part networks can be iteratively approached by using the calculated mass flow rate of the part sections and the overall resistances.

ANALYSIS

By means of the heat consumption measured the occupancy were classified into three groups ‘saver’, ‘standard consumer’, ‘intensive consumer’. Figure 6 illustrates the distribution of these groups at the building.

Loft of House 4		Loft of House 3	
Intensive Consumer Apartment A20	Standard Consumer Apartment A15	**Save** r Apartment A010	Standard Consumer Apartment A05
Standard Consumer Apartment A19	Standard Consumer Apartment A14	Standard Consumer Apartment A09	Standard Consumer Apartment A04
Intensive Consumer Apartment A19	**Saver** Apartment A13	**Saver** Apartment A08	**Save** r Apartment A03
Standard Consumer Apartment A17	Standard Consumer Apartment A12	Standard Consumer Apartment A07	**Intensiv** e Consumer Apartment A02
Standard Consumer Apartment A16	**Intensiv** e Consumer Apartment A11	Standard Consumer Apartment A06	Standard Consumer Apartment A01
left	right	left	right

Figure 6: Distribution of occupancies

The real system is modelled by the multi-zone building module of simulation program TRNSYS. Inner gains and infiltrations (compare Table 1) are fixed by identical schedules for all apartments since the simulated heat consumption will be controlled by nominal room temperature data.

Table 1 : Schedule for airchange

Room	time in h	airchange in 1/h
sitting room	0.00 am - 5.00 am	0.5
	5.00 am - 6.00 am	1.0
	6.00 am - 2.30 pm	0.5
	2.30 pm - 3.30 pm	0.8
	3.30 pm - 12.00 pm	0.5
bedroom children’s room	0.00 am - 8.00 am	1.7
	8.00 am - 8.30 pm	0.5
	8.30 pm - 12.00 pm	1.7
kitchen	0.00 am - 7.30 am	0.5
	7.30 am - 10.30 am	0.8
	10.30 am - 12.00 am	0.5
	12.00 am - 1.30 pm	0.8
	1.30 pm - 12.00 pm	0.5
bathroom	0.00 am - 9.00 pm	0.5
	9.00 pm - 10.00 pm	1.6
	10.0 pm - 12.00 pm	0.5

The simulation is intended to give some findings about the influence of

- heating curve,
- night setback,
- occupancy behaviour,
- control systems
- building structure,

on heat consumption and comfort.

The simulation covers the time period from December 5, 1994 to January 31, 1995 but analysis is restricted to January. The two pipe heating system is partly simulated in the same building like the single pipe heating to make a comparison of both systems possible. The actual installed controllers, i. e. thermostatic valves in the left apartments and single room controllers (WRE) in the right apartments of the building are simulated.

The first goal was to copy measured data by simulation results. This is not possible completely since some boundaries are inaccurate, missing or cannot be simulated. Knowing this there is a finding about precision of the mathematical simulation model.

The measured heat consumption in January 1995 is 93.1 GJ for the single pipe heating and 88.7 GJ for the two pipe heating. The simulation comes to 87.62 GJ for single pipe heating and 85.59 GJ for two pipe heating. These values are references for the following analysis.

Table 2: Heat consumption of all apartments January 1995, Single pipe heating

	House 4	House 4	House 3	House 3
Floor	left	right	left	right
4	5.586 GJ	4.192 GJ	3.310 GJ	4.213 GJ
3	2.959 GJ	3.815 GJ	3.236 GJ	3.793 GJ
2	5.319 GJ	2.101 GJ	3.031 GJ	2.086 GJ
1	3.308 GJ	3.624 GJ	3.040 GJ	5.064 GJ
ground	3.836 GJ	5.450 GJ	3.066 GJ	3.559 GJ
Sum	21.008 GJ	19.183 GJ	15.682 GJ	18.715 GJ

I. Influence of heating curve

The heating curve of the reference simulation

$$\vartheta_f = -1.94\left(\vartheta_{a,d} - 20^\circ C\right) + 32.0^\circ C \quad (1)$$

with $\vartheta_{a,d}$ .... softened ambient temperature

was changed at single pipe heating to

$$\vartheta_f = -1.72\left(\vartheta_{a,d} - 20^\circ C\right) + 29.9^\circ C$$

get the influence of the heating curve on heat consumption of the building. The simulated consumption amounts to 86.54 GJ so that with this lower heating curve just minimal savings (-1.3%) are reachable.

II. Influence of night setback

The flow temperature of simulation reference version was reduced by 20 K from 10 pm to 7 am on workdays and from 11 pm to 7 am on weekends. Depending on the ambient temperature and the reduced flow temperature the duration of night setback was changed, too. To get the influence of night setback now the flow temperature is only evaluated as (1).

Single pipe heating. The building heat consumption amounts to 88.68 GJ (+1.2%). At night the heat output of the uninsulated pipes increases and consequently there is a lower heat requirement in the morning.

Two pipe heating. The total heat consumption amounts to 86.18 GJ (+0.6%). Since in contrast to the single pipe heating there is a lower heat output of pipes the higher flow temperature at night has a lower influence on the heat consumption.

Summary. The night setback leads to small heat savings without affecting the temperature comfort.

III. Influence of occupancy behaviour

To determine the influence of occupancy behaviour on the heat consumption the set temperatures of **all** apartments were fixed to both ‘savers’ and ‘intensive consumers’.

Single pipe heating - saver. The building heat consumption amounts to 80.13 GJ (-8.6 %). The heat ouput of the radiators decreases by 23%. The heat consumption of apartment A03, where the occupancy behaviour has been unchanged, increases by 41.5 %. This big difference is caused by the occupancy behaviour of the apartment A02 underneath, which was defined as ‘intensive consumer’ before and served the cooler apartment of the ‘saver’ as heat source. On the other hand the heat consumption of apartment A08, where the occupancy behaviour has been unchanged, too, increases by only 10.6 %. This smaller difference is caused by the lower heat gains of the adjacent apartments, which were defined only as ‘standard consumer’ before. The heat consumption of the several apartments is shown in Table 3.

Table 3 : Heat consumption of all apartments January 1995, single pipe heating, ‘savers’

	House 4	House 4	House 3	House 3
Floor	left	right	left	right
4	4.154 GJ	3.338 GJ	3.860 GJ	3.502 GJ
3	3.649 GJ	2.831 GJ	3.348 GJ	2.986 GJ
2	3.645 GJ	2.792 GJ	3.350 GJ	2.950 GJ
1	3.647 GJ	2.799 GJ	3.357 GJ	2.942 GJ
ground	3.891 GJ	3.016 GJ	3.577 GJ	3.066 GJ
Sum	18.986 GJ	14.777 GJ	17.492 GJ	15.446 GJ

Single pipe heating - intensive consumer. The building heat consumption amounts to 95.97 GJ (+9.5 %). The heat ouput of the radiators increases by 21%. The heat consumption of apartment A02, where the occupancy behaviour has been unchanged, **decreases** by 24.3 %. This effect is caused by higher air temperatures of the adjacent apartments, which heat consumptions increase by 19.3 % ('standard consumer', ground floor) up to 83.3 % ('saver', second floor). The heat consumption of the several apartments is shown in Table 4.

Table 4 : Heat consumption of all apartments January 1995, single pipe heating, 'intensive consumers'

Floor	House 4 left	House 4 right	House 3 left	House 3 right
4	4.961 GJ	4.524 GJ	4.454 GJ	4.588 GJ
3	4.299 GJ	3.775 GJ	3.813 GJ	3.843 GJ
2	4.299 GJ	3.735 GJ	3.828 GJ	3.821 GJ
1	4.338 GJ	3.768 GJ	3.853 GJ	3.832 GJ
ground	4.799 GJ	4.275 GJ	4.275 GJ	4.247 GJ
Sum	22.696 GJ	20.077 GJ	15.682 GJ	20.332 GJ

Two pipe heating. The total building heat consumption amounts to 76.69 GJ (-10.4 %) for a occupancy behaviour 'saver' and it amounts to 94.14 GJ (+10.0 %) for the 'intensive consumers'.

IV. Influence of control systems

The energy conservation potential of a programmable high-low control system is determined by comparison with a conventional thermostat. For that the set room temperatures of apartments equipped with WRE-system are controlled by schedules whereas the appartments equiped with thermostatic valves show constant set temperatures. To minimize the influence of the building structure one simulation for each control system (WRE, thermostat controllers) was done. The subdivision into the different occupancy groups is retained.

Single pipe heating. The heat consumption for the building completely equipped with WRE-system amounts to 85.28 GJ. The simulation of the building equipped with thermostatic valves gets a heat consumption of 93.23 GJ. That means an energy conservation of 8.5 % in favour of the single room WRE-system. The heat output of the radiators is reduced by 19.9 %. Thus the maximum conservation of about 20 % is equalized by a higher heat output of pipes. The discussed results are not general but only valid in combination with defined boundaries.

Figure 7 shows the daily range of air temperature of a reference apartment equipped with WRE-system. The temperature range of the same apartment equipped with thermostatic valves is shown in Figure 8.

Two pipe heating. The heat consumption for the WRE equiped building amounts to 84.65 GJ. For the thermostatic controled two pipe heating the heat consumption amounts to 92.04 GJ. Thus the energy conservation is 8.0 %.

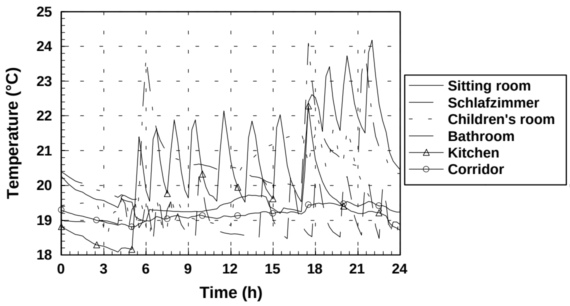

Figure 7 : Daily range of air temperature, apartment A20, single pipe heating with WRE

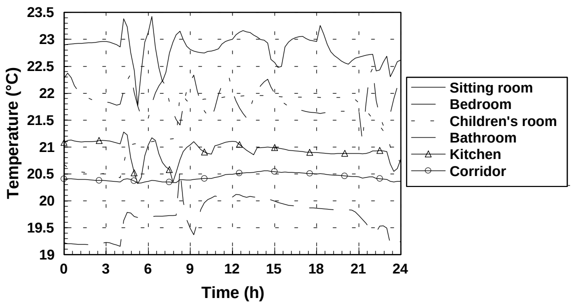

Figure 8 : Daily range of air temperature, apartment A20, single pipe heating with thermostat

V. Influence of building structure

a) Stationary analysis. The influence of characteristic building parameters like staircase, cellar, loft or gable to the heat consumption has to be determined. The building of the single pipe heating has a heat requirement of 79.6 kW. For the building of the two pipe heating the heat requirement amounts to 77.6 kW.

Single pipe heating. The heat requirement at the gable increases by 9.7 %. Due to the heat losses to the loft the heat requirement of the apartments on the fourth floor increases by 14.4 % compared with apartments on the second floor. Owing to the bathrooms adjacent to the staircase and controlled at 24°C the heat requirement increases by 4 %. The heating of some cellar rooms decreases the heat requirement of apartments above them by 2 %.

Two pipe heating. Due to the missing gable the heat requirement of the building decreases by 2.5 %. The heat requirement of the apartments on the ground floor increases by 9-11 % because of the cellar.

b) Instationary analysis. The simulation was done with ideal controllers.

Single pipe heating. The simulated heat consumption of the building in January, 1995 amounts to 93.7 GJ. The consumption at the gable increases by 17.6 %. Due to the heat losses to the cellar the heat consumption of the apartments on the ground floor increases by 11-12 % in comparison to the apartments on the second floor. Owing to the fact that th bathrooms adjacent to the staircase and controlled at 24°C the heat consumption increases by 16.9 %. The heating of some cellar rooms decreases the heat requirement of apartments above them by 1 %.

Two pipe heating. The simulated heat consumption of the building amounts to 93.0 GJ. The heat requirement of the apartments on the ground floor increases by 9-11 % because of the losses to the unheated cellar. Due to the heat losses to the cellar the heat consumption of the appartments on the ground floor increases by 17-21 % compared with apartments on the second floor. The heating of some cellar rooms decreases the heat requirement of apartments above them by 3.5 %.

Conclusion. The influence of gable to the building heat requirement is small (2.5 %) but looking at the instationary anaylsis the heat consumption for the apartments at the gable is increased by 17.6 %. The heat consumption of the apartments on the ground floor increases by 10-16 % because of the cellar. The heating of some cellar rooms decreases the heat requirement of apartments above them by 2-5 %.

VI. Thermal output

Figure 9 shows a comparison of the average thermal output of the single pipe heating plant for measurement and simulation.

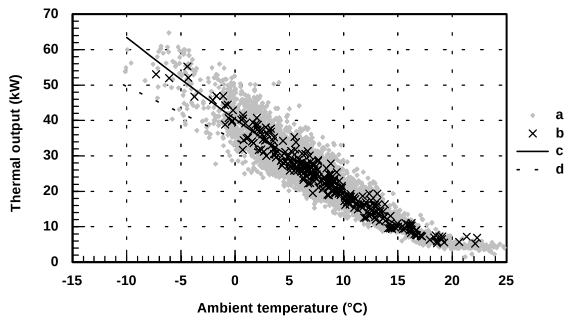

Figure 9: Average thermal ouput of single pipe heating as function of ambient temperature
a: Hourly means b: Daily means
c: Line of measurement d: Line of Simulation

CONCLUSION

The characteristical criterion for operation of a heating plant is the occupancy behaviour. For heat consumption the influence of the occupancy is dominant compared with all other influences. Big temperature differences between adjacent rooms make heat gains to intensive consumer's disadvantage possible. It is too difficult to measure these heat gains to take them into heating costs consideration. The schedule-controlled air temperature level improves the heat input corresponding to heat requirement.

It is possible to optimize the heating plant by exact radiator sizes with regard to its control.

Comparison of single and two pipe heating. The heat consumption of the single pipe heating exceeds the consumption of the two pipe heating by 2.4 %. Due to the higher heat output of pipes the average air temperature of the building equipped with single pipe heating is higher, too. The unrecorded heat output of the single pipe heating amounts to 53.3 % whereas this value amounts to 36.9 % for the two pipe heating

SUPPLEMENTARY VIEWS OF SIMULATION AND IMPROVEMENTS OF THE TRNSYS-TYPE56

The simulation of the test building with the TRNSYS Version 14.1 demonstrates the difficulties to match measured data with simulation results. Looking at the heat consumption of the building there are differences up to 10 %.

The TRNSYS version 14.2 differs between convective and radiant heat transfer coefficient at exterior surfaces (external walls , windows). To screen the quality of the model a validation of the entire calculation method according to the E DIN 4108 p.20 was done. Here the maximum, minimum and average value of a quasi-staionary operative temperature curve should be within a tolerance of ±1 K to the given nominated data. As figure 10 shows the simulated temperatures considerable deviate from this nominated data.

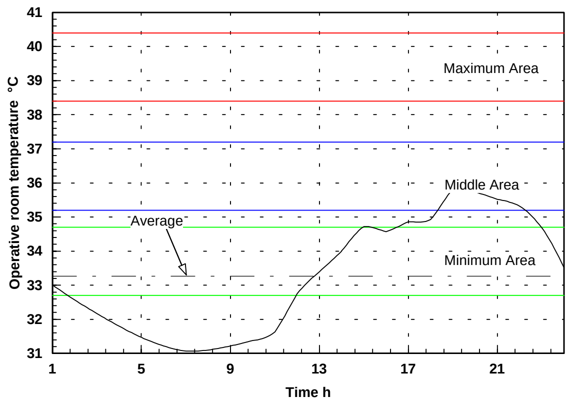

Figure 10: Operative room temperature calculated with 2-node-model

One reason for these differences could be the simplified appoximation of longwave radiation exchange using a star network. This 2-node model is characterized by a so called star node.and an air temperature node for each zone. The conduction heat fluxes from the walls at the inside surfaces to the star temperature node are a combination of radiant and convective heat fluxes.[2]

For an improvement of the 2-node-model to calculate the inside heat transfer the radiant heat exchange between surfaces has to be calculated exactly and with consideration of the room geometry. Only the convective heat is balanced at the air temperature node. The radiant heat exchange happens directly between the surface temperature nodes. The calculation of a star temperature is replaced by balance the heat fluxes at all the inside surfaces of a zone and the calculation of the corresponding surface temperatures. Because the star node is not in use this model could be called a 1-node-model.

It is possible to arrange different modi at each zone of a building to calculate the longwave radiation heat exchange. In dependence on the calculation mode it is necessary either to define the radiant heat transfer coefficients or the emission coefficients for longwave radiation. By the indication of the view factors it is also possible to simulate non-cubic room structures.

The calculation of the temperatures at the air node and at the surface nodes is realized by a solution of a heat balance system. For the air node the balance is

$$\dot{Q}_i = \dot{Q}_{surf,i} + \dot{Q}_{inf,i} + \dot{Q}_{v,i} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i}$$

with

$$\dot{Q}_i = \frac{2C_i\left(\overline{\vartheta}_{air} - \overline{\vartheta}_{air,\tau-\Delta t}\right)}{\Delta t}$$

The consideration of inner long wave radiation exchange requieres the calculation of the single surface temperatures. Then the convective heat flux at the inner surfaces is

$$\dot{Q}_{surf,i} = \sum^{N_{surfs}} h_{s,i} A_{s,i}\left(\vartheta_{s,i} - \overline{\vartheta}_{air}\right)$$

The radiant heat transfer coefficient between two surfaces as used with the 1-node-model is

$$\alpha_r = C_{1,2} 10^{-8}\left[\left(\vartheta_{s,1} + \vartheta_{s,2}\right)\left(\vartheta_{s,1}^2 + \vartheta_{s,2}^2\right)\right]$$

For two surfaces the exchange coefficient for radiation is

$$C_{1,2} = \frac{C_S}{\frac{1}{\varepsilon_1} - 1 + \frac{1}{\varphi_{1,2}} + \left(\frac{1}{\varepsilon_2 - 1}\right)\frac{A_1}{A_2}}$$

with the radiant coefficient of a black radiator

$$C_S = 5.670 \frac{W}{m^2 K^4}$$

The surface temperatures needed to calculate the heat transfer coefficients result from the last simulation timestep to avoid an iterative calculation. The influence of the temperature difference on the radiant heat transfer coefficient is shown in figure 11.

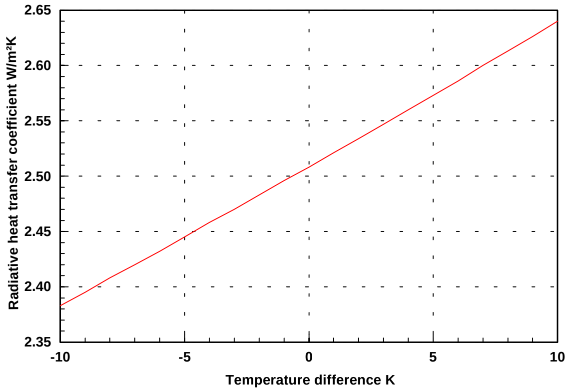

Figure 11: Radiant heat transfer coefficient in dependence on the temperature difference of two surfaces
A_1=7.5 m² ; A_2=5 m²
φ_1=0.5; φ_2=0.75
ε_1=0.9; ε_2=0.9
$\vartheta_{s,1}$=20°C; $\vartheta_{s,2}$=10...30°C

To calculate the radiant heat exchange the 2-node-model works with an average constant temperature for all surfaces.

To demonstrate the usability of the new 1-node-model the validation of E DIN 4108 p.20 was re-done. The simulation result for the 1-node-model by means of the DIN-test A.1 with the airchange variation a) is shown in figure 12. The temperature curve is within the demanded tolerance. A comparison with figure 10 stresses the deviations between both models.

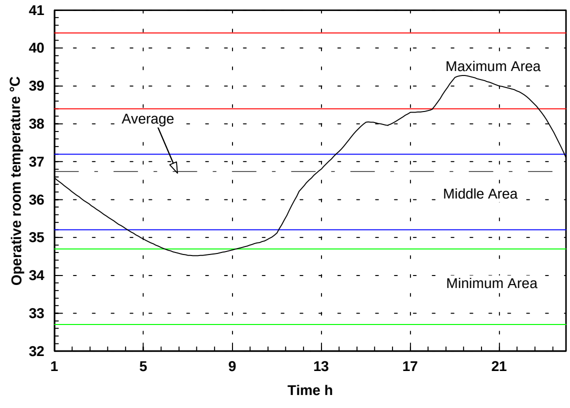

Figure 12: Operative room temperature calculated with 1-node-model

Once again it is to say that the only difference between both models is the different way to calculate inside radiant heat exchange and the consideration of the room's geometry. The conditions outside are identical in both cases. The temperature oscillation

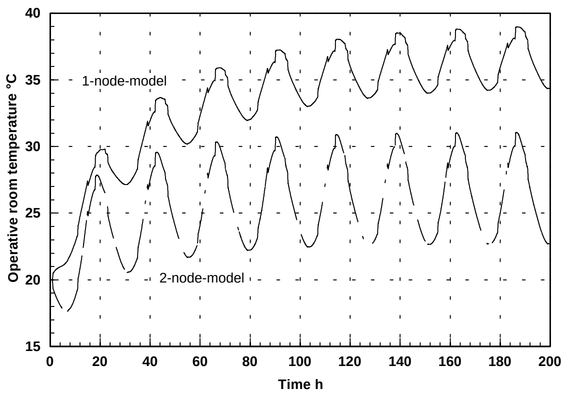

Figure 13: Oscillation of operating room temperature

due to a different longwave radiation model is shown in figure 13.

In all there is a decisive improvement of simulation results achievable with TRNSYS-Type56.

With the multizone building model Type56 in TRNSYS it is also possible to determine the sensible energy demand for a zone using an idealized heating equipment. If the required power is lower than a maximum the air temperature is hold at a set point. As figure 14 shows in dependence on the used radiant heat exchange model the outputs of energy demand differ.

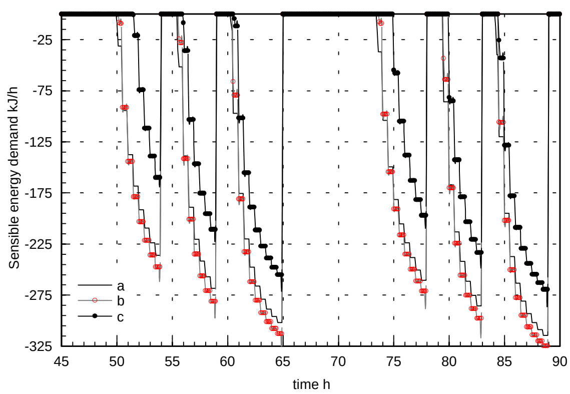

Figure 14: Sensible energy demand calculated with idealized Heating
a: 1-node-model; 100 % Convective heat
b: 1-node-model; 70 % Convective heat
c: 2-node-model; 100 % Convective heat

The human temperature sensation not only depends on air temperature. Also the radiant temperature of surfaces is important. That is why the idealized heating and cooling equipment was supplemented to determine the energy requirement for a fixed operative room temperature which is defined as

$$\vartheta_{o,i} = a\overline{\vartheta}_{air} + (1-a)\overline{\vartheta}_{surf,i}$$

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NOMENCLATURE

$\dot{Q}_i$	Heat flux to air node	W
$\dot{Q}_{surf,i}$	Heat flux from walls	W
$\dot{Q}_{inf,i}$	Heat flux due to infiltration	W
$\dot{Q}_{v,i}$	Heat flux due to ventilation	W
$\dot{Q}_{g,c,i}$	Heat flux due to gains	W
$\dot{Q}_{cplg,i}$	Heat flux due to zone coupling	W
$h_{s,i}$	Convective heat transfer coefficient	W/m^2K
$A_{s,i}$	Surface area	m^2
α_r	Radiant heat transfer coefficient	W/m^2K
$C_{1,2}$	Radiant exchange coefficient	W/m^2K^4
a	Wheighting factor	-
$\overline{\vartheta}_{surf,i}$	Average surface temperature	°C
C_i	Capacitance of zone	kJ/K
Δt	Simulation time step	h
τ	Time	h
$\varphi_{1,2}$	View factor	-
$\varepsilon_{1,2}$	Emission coefficient	-
ϑamb	Ambient temperature	°C
$\vartheta_{s,i}$	Surface temperature	°C
$\overline{\vartheta}_{air}$	Air temperature	°C
ϑi	Inlet temperature	°C
ϑf	Flow temperature	°C
ϑr	Return temperature	°C
$\vartheta_{o,i}$	Operative room temperature	°C