ALGORITHM FOR THE REFERENCE TEMPERATURE CALCULATION IN BUILDINGS

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Abstract

In the paper an algorithm for the reference temperature calculation in building rooms is presented. Algorithm works in such a way to changes the reference temperatures and start times for cooling or heating of the rooms when they are not occupied and before the occupancy. Algorithm is tested on the simulated building model by using the well-known TRNSYS software. The building model consists of six thermally coupled rooms with different occupancy and considers the most important thermal characteristics. Simulations are performed for the cooling and heating of the rooms using the weather data of the city of Portorož. Results obtained with the proposed algorithm are also compared with the results that are achieved with the constant reference temperature changes and start times. Comparison is made with regard to the energy consumption for cooling and heating of the rooms and according to the violations of the maximal temperature rise time and occupancy times. Results show that the main advantage of the proposed algorithm is its ability to automatically adjust the reference temperatures and start times to the optimal values in contrast to the manual setting, which is hard to perform in practice.

Keywords: Buildings, Simulation, Temperature control, Energy consumption, Thermal comfort.

Presenting Author's biography

Darko Vrečko is a postdoctoral associate at Jozef Stefan Institute, Department of Systems and Control. He received a B.Sc. degree in 1998 and Ph.D. degree in 2003, all at University of Ljubljana, Faculty of electrical engineering. Since 1998 he is employed at Jozef Stefan Institute. His expertise includes modelling and simulation of wastewater treatment processes, feedforward-feedback control, Smith predictor, model predictive control, benchmark simulation model. Recently he has been involved in projects dealing with scheduling of batches in a production process and control design for energy savings in buildings. He participated in COST 624 and 5th Framework project SMAC. Within European Community's Human Potential Programme WWT&SYSENG project he spent six months at Lund University of Technology as a postdoctoral researcher. He is author or co-author of 12 papers in international scientific journals.

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1 Introduction

In the last decay the computer aided HVAC (Heating, Ventilation and Air Conditioning) systems are being installed in the buildings to provide the adequate thermal comfort of the occupants with efficient energy consumption. Operation of the modern HVAC systems is at the lower level mainly automatic although it is usually not optimal with respect to the energy use and desired thermal comfort in the building.

Operation of the HVAC systems can be optimized at the higher level with the adequate supervisory algorithm that can provide desired thermal comfort at the lowest energy consumption for cooling and heating. Efficient supervisory algorithm can be elegantly developed by using the simulated model of the building, which considers the most important thermal characteristics, such as building orientation, geometry, ambient air temperature, solar radiation, thermal conductions of the walls, models of the HVAC systems, etc.

In the paper, supervisory algorithm for the calculation of the reference temperatures of the HVAC systems is proposed. Algorithm was developed on the simulated building model by using TRNSYS (TRaNsient SYstem Simulation program) software [1]. Algorithm works in such a way to adjust the reference temperatures in the building rooms when they are not occupied [2] according to the thermal conditions in the building and desired comfort. In such a way energy consumption needed for cooling and heating of the building rooms can be reduced and at the same time desired thermal comfort can be preserved.

In the first section of the paper the simulated model of the building is presented. Algorithm for calculation of the reference temperatures in the building is described next. After that results of testing the algorithm on the simulated building model are shown. At the end the most important conclusions are given.

2 Simulated building model

The building model was designed by using the TRNSYS software [1]. TRNSYS is one of the best environments for modeling and dynamic simulation of the various systems such as buildings, heat exchangers, renewable energy systems etc. Working interface in the TRNSYS software is shown in Fig. 1. Ground plan of the building together with building orientation and room numbers is shown in Fig. 2.

Our building consists of six rooms with the size of 5.2m x 4.2m x 3m [3]. Rooms are thermally lumped and below and above connected to the rest of the building.

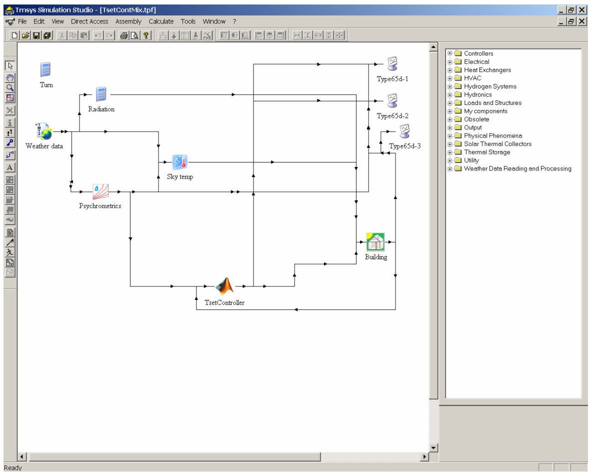

Fig. 1 Working interface in TRNSYS

Thermal conductivity (u-value) of the inner walls are set to 1.6 W/m^2K and outer walls to 0.6 W/m^2K. Each room has a window with the size of 7.5m^2, with the thermal conductivity of 1.4 W/m^2K and with the heat losses (g-value) of 0.6.

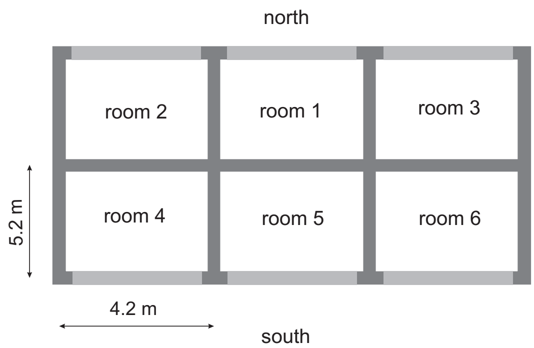

Fig. 2 Building ground plan

Heat capacitance of the rooms was set to 790.9 kJ/K, which is 12 times bigger value

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than the room volume. With such a capacitance it was considered that the rooms are not empty but they are filled with furniture. Shading of the building was not considered in our study and infiltration in the rooms was set to 0.2 per hour. Additional heating of the rooms due to the people that are present in the rooms was also considered.

The power of the HVAC systems for cooling and heating was set to 1 kW, which was proven to be high enough to maintain building temperatures at the desired values. In each room the temperature was controlled by the local on-off controller that trigger cooling or heating of the room according to the difference between the reference and measured room temperature.

Weather data for the different cities in the world are available in the TRNSYS software. These data include ambient air temperature, solar radiation, pressure, wind speed, etc. In our case the weather data from the first 25 days of July and the first 25 days of January from the city of Portorož in the year of 1995 were chosen. The data for the ambient air temperature from those periods are given in Fig. 3. The summer data were used for testing the cooling and the winter data for testing the heating of the rooms.

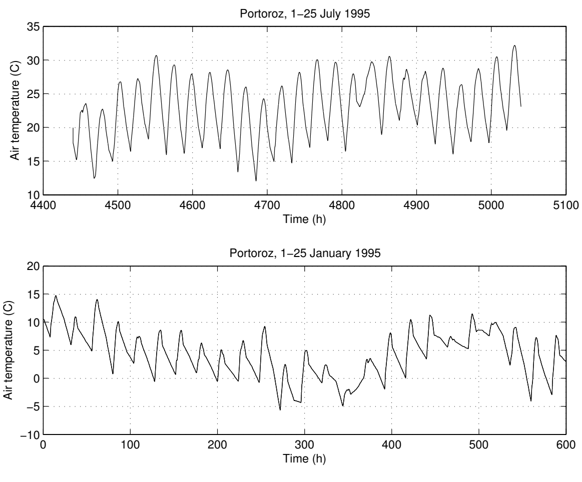

Fig. 3 Ambient air temperature

Different occupancy regime was chosen in different building rooms. Occupancy in rooms 1, 4 and 6 is typical for the hotel rooms, when the guest is already checked in to the hotel. Rooms are occupied between the 10 pm and 9 am and between the 5 pm and 7 pm. In those rooms only one guest is checked in. Room 2 represents a dining room, which is occupied every day between the 11 am and 2 pm. During the occupancy six persons are present in the room. Room 3 represents a hotel room, but with the different occupancy than in the previous hotel rooms. Two persons are present in the room between the 10 pm and 10 am, between the 1 pm in 4 am and between the 7 pm and 8 pm. Room 5 is the working office for one person and it is occupied only during the working days (from Monday to Friday) between the 8 am and 6 pm. Occupancy for all the rooms for 25 days is given in Fig. 4.

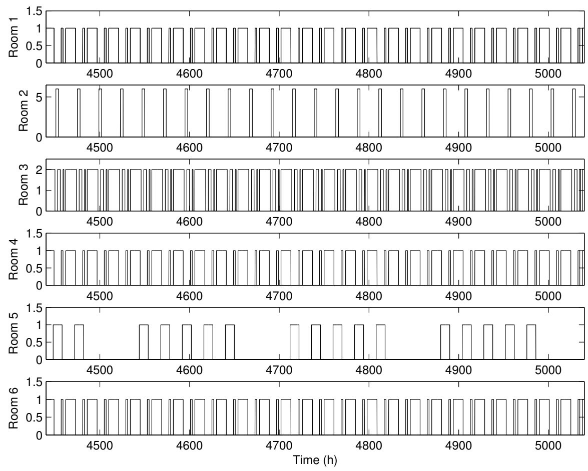

Fig. 4 Occupancy of the rooms

Occupancy in the rooms is bigger then 0 when the guests occupy the rooms and 0 when they are not in the rooms. It was chosen that the occupancy in the rooms 1, 3, 4 and 6 is not known in advance in contrast to the occupancy in the rooms 2 (dining room) and 5 (office), which is chosen to be known in advance.

3 Algorithm for the reference temperatures calculation

An algorithm for the calculation of the reference temperatures in building rooms is only qualitatively described in order to protect intellectual property rights of the project result owners. A control scheme of the room temperature control that was used in our study is shown in Fig. 5. An algorithm represents a supervisory system for the controllers at the lower (local) level that control the HVAC systems.

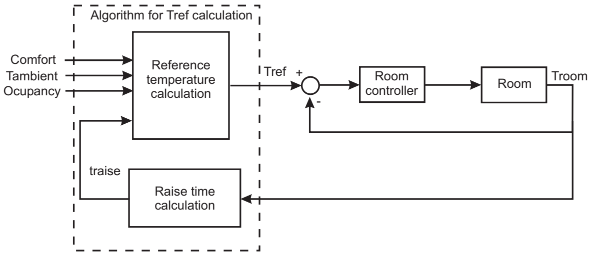

Fig. 5 Control scheme of the room temperature control

Guest comfort was in our study defined with the maximal rise time of the room temperature. In the rooms where the occupancy is known in advance (rooms 1, 3, 4 and 6) the rise time was defined as the time that is needed for the room temperature to reach the reference temperature after the guest enters into the room. In the rooms where the occupancy is not known in advance (rooms 2 and 5) the rise time is defined as the time before the room occupancy until which the room temperature reaches the reference temperature.

An algorithm can calculate the reference temperatures in two ways. In the rooms, where the occupancy is not known in advance the algorithm properly changes the reference temperatures when the guests leave the rooms. When the guests enter the rooms the room temperature should reach the reference temperature inside of the maximal rise time interval. In the rooms, where the occupancy is known in advance the algorithm properly changes the reference temperature during the non-occupancy period and in the proper time starts the cooling or heating, so that the room temperature reaches the reference temperature before the occupancy. With such changes of the reference temperatures energy consumption needed for heating and cooling of the rooms can be reduced and at the same time guest comfort in the rooms can be preserved.

An algorithm for the reference temperature calculation in buildings, which is appropriate for practical use, was developed by using the simulation experiments. In the rooms where it is not known in advance when they are going to be occupied (rooms 1, 3 and 4) the algorithm increases reference temperature change for the next period of non-occupancy, if the last measured rise time is smaller than the maximal one. On the contrary, if the last measured rise time is bigger than the maximal rise time then the algorithm decreases the temperature reference change for the next period of the room non-occupancy. In order to prevent oscillations of the reference temperatures the maximal change of the reference temperature is limited. In the rooms where it is known in advance when they are going to be occupied (rooms 2 and 5) the algorithm calculates how long before the room occupancy should start cooling or heating of the room and calculates the reference temperature for the next period of the room non-occupancy. In case that the reference temperature in the room was achieved before the occupancy the algorithm decreases the start time of the cooling or heating before the next occupancy and increases the reference change for the next period of the non-occupancy. On the contrary, if the reference temperature is not reached before the occupancy the algorithm increases the start time of the cooling or heating before the next occupancy and decreases the temperature reference change for the next period of the non-occupancy. Similar as before the maximal start time change and temperature reference change are limited in order to prevent reference temperature oscillations.

4 Results of testing the algorithm

Proposed algorithm for the reference temperature calculation was tested by means of simulations for cooling and heating of the building rooms. When the guests are present in the rooms the reference temperature was defined to be 25 ^{o}C for cooling and 22 ^{o}C for heating of the rooms. Maximal rise time when the guest enters into the room was set to 30 minutes, initial reference temperature change for the period of the non-occupancy was set to 2 ^{o}C and the initial start time for cooling and heating of the rooms was set to

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30 minutes before the room occupancy. Results of testing the algorithm for the reference temperature calculation are shown in Fig. 6 to Fig. 11.

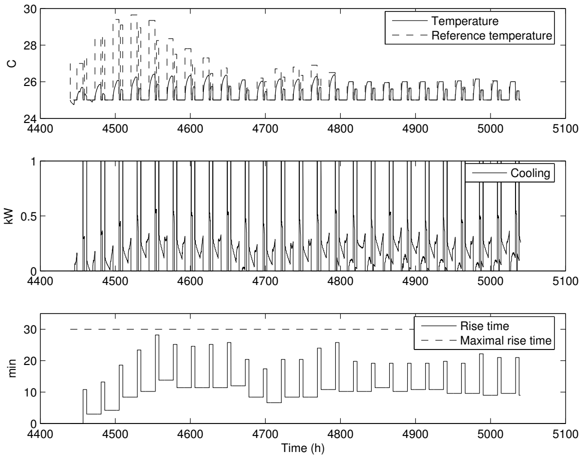

Fig. 6 Reference temperature changes during the cooling of the room 1

Proposed algorithm adjusts the reference temperature in the room 1 according to the ambient air temperature. Reference temperatures in the room 1 are high during the low ambient temperatures and low during the high ambient temperatures. The power of the HVAC system, which is shown in figures, is changing between 0 in 1 kW. The power shown in the figure is calculated from the energy that is needed for cooling or heating of the rooms and it is not equal to the temporary power of the HVAC system.

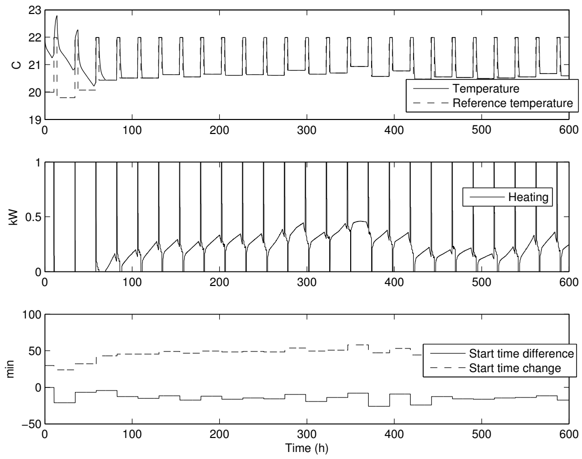

Fig. 7 Reference temperature and start time changes during the heating of the room 2

The temperature rise time after the guest enters into the room is around 15 minutes and always smaller than the maximal rise time of 30 minutes.

In the room 2 the algorithm changes reference temperature and the start time for cooling and heating before the room occupancy without any higher disturbances. This room is oriented to the north and therefore has to be extensively heated. The temperature rise time in the room 2 is around -15 minutes and always smaller than 0. This means that the temperature in the room reaches reference value around 15 minutes before the occupancy and always before the occupancy.

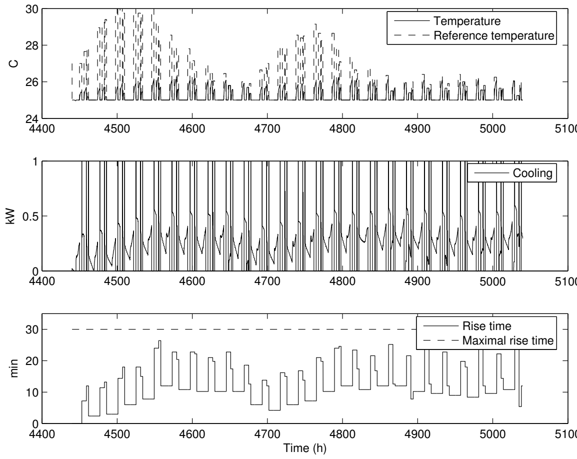

Fig. 8 Reference temperature changes during the cooling of the room 3

During the cooling of the room 3 the reference temperature is adjusting to the thermal conditions in the building, when the room is not occupied.

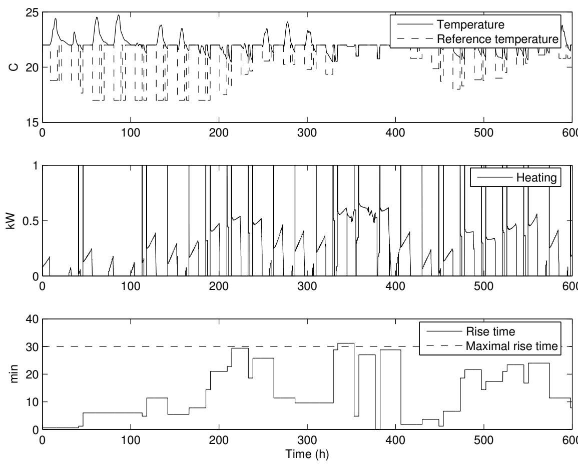

Fig. 9 Reference temperature changes during the heating of the room 4

At the low ambient air temperatures the reference temperature is increased and decreased at the high ambient air temperatures.

During the heating of the room 4 the reference temperature can be decreased significantly when it is not occupied. This is so, because the room is located at the south side of the building and it does not have to be heated so much.

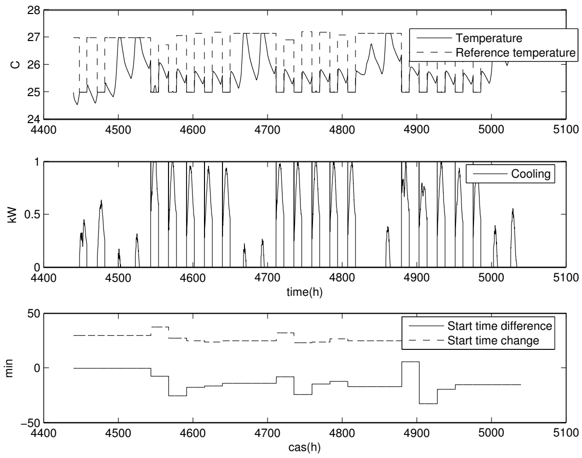

Fig. 10 Reference temperature and start time changes during the cooling of the room 5

In the room 5 the occupancy time until which the temperature in the room should reach the reference was violated twice (the start time difference is bigger than 0). This means that the reference temperature was reached after it has been occupied.

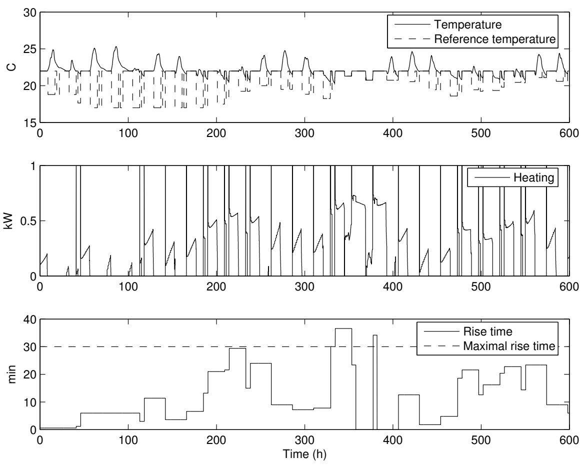

Fig. 11 Reference temperature changes during the heating of the room 6

In those situations the start time for cooling or heating of the room before the room occupancy is increased significantly in order to prevent further violations.

In the room 6 one big violation of the rise time is obtained. The reason for this violation is the sudden decrease of the ambient air temperature. It can be concluded that the algorithm adjust the reference temperature only to the slow ambient air temperature changes.

Results obtained with the proposed algorithm were also compared with the results that were obtained with the constant and manually tuned reference temperatures and start times for cooling and heating. Different constant values of the reference temperature changes during the non-occupancy (0 ^{o}C, 1 ^{o}C and 2 ^{o}C) and different constant start times before the room occupancy (30 minutes and 15 minutes) were tested.

Comparison of the results obtained with the proposed algorithm and with the constant manually selected changes of the reference temperatures and start times is given in Table 1. Comparison was made according to the energy consumption that is needed for cooling and heating of the rooms and according to the violations of the maximal rise time and room occupancy time.

Tab. 1 Comparison of the results obtained with the proposed algorithm and manually chosen reference temperatures and start times

	Proposed algorithm	ΔT_{ref}=0^{o}C,	ΔT_{ref}=1^{o}C, *ts*=30min	ΔT_{ref}=2^{o}C, *ts*=15min
Energy consumption (kWh)	1465(-17%)	1761	1496(-15%)	1375(-22%)
Maximal rise time violation (min)	51	0	8.4	1126
Occupancy time violation (min)	55	0	1.2	716

Results show that with the proposed algorithm around 17 % of the energy for cooling or heating of the rooms can be saved in comparison with the case where the reference temperature is not changed during the non-occupancy. When the reference temperature in the rooms was changed for 1 ^{o}C during the non-occupancy and the start time for cooling or heating was 30 minutes before the room occupancy then similar results were obtained as with the proposed algorithm. When the reference temperature in the rooms is changed for 2 ^{o}C during the non-occupancy and the start time for cooling or heating is 15 minutes before the room occupancy, energy needed for cooling and heating of the rooms can be decreased for additional 5 %, however violations of the maximal rise time and occupancy time are in this case significantly too large.

It can be concluded that for the periods of one month it is possible to achieve similar results with the constant reference temperature changes as with the proposed algorithm, but those constant values are very hard to choose because the thermal conditions in the building are changing all the time. Therefore, the main advantage of the proposed algorithm is its ability to automatically set the reference temperatures and start times for cooling or heating of the rooms to the optimal values.

5 Conclusions

In the paper an algorithm for the reference temperature calculation in the building rooms is presented. Algorithm works in such a way to changes the reference temperatures and start times for cooling and heating of the rooms when they are not occupied and before the occupancy. Algorithm was tested on the simulated building model by using the TRNSYS software. The building model consists of six thermally coupled rooms with different occupancy. Simulations were performed for the cooling and for the heating of the rooms. Results that were obtained with the proposed algorithm were compared with the results that were achieved with the constant reference temperature changes and start times. Comparison was made with regard to the energy consumption for cooling and heating of the rooms and according to violations of the maximal rise time and occupancy times. Results have shown that the main advantage of the proposed algorithm is its ability to automatically adjust the reference temperatures to the optimal values in contrast to the manual setting, which is hard to perform in practice.

Acknowledgement

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