Energy cost models for air supported sport hall in cold climates considering energy efficiency

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Abstract

The aim of the study was to develop models for energy planning for air supported sport hall by analyzing different energy efficiency possibilities. This is a very specific building type suitable for sport activities in cold climates. The observed hall was operated when outdoor temperature was under 5°C, while the most common measured indoor air temperature was 8°C during the year. Neither indoor nor outdoor temperature influenced the overpressure. Based on the measurements, the specific annually heating energy use was 75 kWh/m^2*. The results showed that improvement in the hall insulation would not give a significant effect on the heating use. The analysis of energy efficiency measures showed that air recirculation has the greatest effect on total energy use and the air recirculation could give an energy saving of 27 % when 50 % of the indoor air was recirculated. The results might be used to calculate heating energy demand for different operation scenarios in the air supported halls. The results give a simple tool to size the heating coil in the AHU and for energy planning for similar halls. The study gave very specific and unique data on energy use in sport halls in cold climate.*

Keywords: air supported sport hall, energy efficiency, air recirculation, energy planning, cold climate

1. Introduction

Air supported hall is a specific construction where overpressure in the hall has to be kept to maintain the hall height. A sport hall is usually built with a plastic cover and insulation. This type of construction may be used for sport facilities in the cold climates to afford a long training season for outdoor sports such as football, golf, running, or some other activities. In addition to these sport activities, the sport hall could be used for some other activities such as social gathering, a temporary cinema, or military training. These other activities usually requires a higher indoor temperature in the hall than for the sport activities. The air supported hall can afford to people in the cold climates to train outdoor sports all over the year. However, there is a few references on the energy use or operation of these sport facilities. A similar problem regarding insufficient information and lack of consistent data about building energy use in general is pointed out in [1].

Energy use in sports halls can be very different from ordinary buildings such as residential or office buildings. The Norwegian statistics show that the total specific annual energy use in offices and commercial buildings may vary from 200 to 250 kWh/m^2 [2], where the exterior wall U-value might be from 0.18 to 0.5 W/m^{2}K. Energy use in sport facilities may be influenced by many factors that are not directly technical parameters. Therefore, it may not be acceptable to use the basic assumptions of building energy use for these sport buildings. For example, operation time and type of activities may have great influence on energy use in the sport halls. Therefore, it is important to analyze energy use in the sport halls for a proper analysis.

Sport halls in Greece use less than 100 kWh/m^2 per year [3]. However, climate is much warmer in Greece than Norway and it might cause that the sport halls in Greece have much lower heating demand and higher cooling demand. Therefore, it could be concluded that a higher energy use might be expected in the sport halls located in Norway. In the research work of the Centre for Sport Facilities and Technology [4], energy use in the swimming pools in Norway is analyzed. Swimming halls are a very different building type than the air supported sport hall, but their energy use could give a theoretical maximum on energy use in the sport facilities. They found out that the swimming halls may use from 2 000 up to 7 000 kWh/m^{2}ws (water surface) [5]. In the work of Nord and Sjøthun, it was found that two Norwegian sport halls built in 1967 and 2003 have the specific total annual energy use of 1 600 and 230 kWh/m^2, respectively. Both examples show possibility to decrease energy use by 30 % [6]. An air supported sport hall in Trondheim consists of three handball courts and occupied 2 718 m^2 [7]. This hall is covered with two-layer cover with insulation which gives U-value of 3.05 W/m^{2}K [8]. The indoor temperature in this hall is maintained at the minimum of 16°C. The total annual district heating use was 583 324 kWh in 2012. Monthly distribution of the district heating use and monthly average outdoor temperatures are given in Figure 1. Based on the presented facts, the total annual specific heating use was 215 kWh/m^2, while the average annual outdoor temperature was 5°C.

Figure 1. District heating use in the air supported sport hall in Trondheim, Norway

To decrease energy use in the air supported construction, air recirculation might be a good energy efficiency measure. Air recirculation can be calculated in terms of the proportion of return air in the total supplied airflow. Proportions of recirculated air as high as 80 - 90 % are common in North America, whereas, in Finland, they are usually between 30 - 70 % [9]. To get an acceptable living environment, a minimum ventilation rate of 0.5 h^{-1} is recommended in Finland and other EU countries [10]. For example, 70 % recirculated air accompanied by an adequate intake of outdoor air can be used without causing adverse effects [9]. Another study also reported that the potential energy saving of 8.3 – 28.3 % may be achieved with acceptable indoor air quality (IAQ) by increasing recirculated air [11]. One recent study developed a local demand control ventilation solution, which may save 40 – 50 % supply air in the system by using recirculated air [12]. Table 1 gives a summary of energy saving potentials and consequences on IAQ and indoor environment quality (IEQ) by using recirculated air or return air in buildings.

Table 1. Energy saving potentials and consequences on IAQ and IEQ

The above information found in the literature and examples together with the data collected from the observed hall in Mo i Rana, Norway, were useful information to calibrate the simulation model.

To enable easy energy planning, renting, and design, it is necessary to have available tools and methods for energy use prediction based on the driving variables. In that way, a building operator or building owner could budget the energy cost and plan building activities. For example, principle component analysis is used to identify important variables of energy use in low energy office building. In this study the outdoor temperature and heating system operation parameters are identified as important and may be used to describe heating energy use [13]. In the work of Hens, simple linear regressions between daily or monthly heating use and outdoor temperature show good fitting results reliable for a further analysis [14]. In this study, linear regression was used to derive simple tool for energy planning and hall design.

The aim of the study was to analyze different energy efficiency possibilities for the air supported sport hall in Mo i Rana, North Norway. Further, the aim was to analyze possibilities to achieve a higher and more stable hall temperature. The study also estimated energy use when the hall would operate longer and the hall temperature would be higher. Total annually and daily energy use were also calculated considering sensitivity of the results. In addition, the real time indoor environment and energy measurements were analyzed in this study. More than one year of the detail operation data were analyzed in this study. All these data were combined to give suggestions for heat supply sizing and energy planning for the air supported sport hall. Since the air supported hall is a typical construction, the results of this study could be treated as general and could be used in for other similar constructions.

2. Methods

To analyze energy use in the air supported sport hall, documentation from the observed hall, together with the real-time measurements, and simulation were used. *EnergyPlus* was used as a simulation tool. The real-time measurements and documentation were used to calibrate the simulation model. *EnergyPlus* is based on the most popular features and capabilities of BLAST and DOE-2, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems, and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, and photovoltaic systems. *EnergyPlus* has been verified and used for many studies related to energy use.

Modeling of pressure level is based on simplified equations for pressure drop and pressure differences. Nevertheless, the results can still show trends for the pressure level in a hall. These results for pressure levels are not equal to the real hall measurement, but can be still used as guide values to show trends.

The model calibration was performed by using data from the hall documentation and by introducing several operation scenarios.

3. Air supported sport hall

3.1 Sport hall description

In this Section basic information about the hall, the hall operation, and the hall construction are given. Importance and meaning of this information for the simulation model and the analysis are also briefly explained in the text.

Figure 2 and Figure 3 show two photos of the air supported sport hall, which is a full-scale football court and has a ground area of 120 x 95 m. The highest point of the roof is at 28 m above the floor. The hall can be considered as one of the biggest in Europe of this type [8]. The hall has been used for football, golf, and different training activities of the pupils. The stands can receive 650 people. The floor consists of sand and artificial grass over the sand. In addition to the football court, the hall contains changing and storage room. With changing room is meant all the rooms used for changing such as showering and meeting rooms.

Changing room, storage, and other rooms occupied an area of 75 x 12 m. Therefore, an area of 11 400 m^2 was used for the further simulation and result presentation, where the changing room takes 900 m^2.

Figure 2. Interior of the air supported sport hall in Mo i Rana, Norway

Figure 3. Facade of the air supported sport hall in Mo i Rana, Norway

3.2 Energy service system description

The air supported sport hall is connected to the district heating network in Mo i Rana with a heat exchanger of 580 kW. Originally a bigger heat exchanger of 1 300 kW was planned. The idea was that 1 050 kW would be used for heating of the hall and 250 kW for heating of the changing rooms. The hall is warmed up with the ventilation air that was blown directly into the hall. The air is warmed up by a heating coil. Air handling unit (AHU) has one fan that ensured sufficient pressure in the hall. It is necessary to provide sufficient overpressure in the hall so that the hall can stand as planned. An average overpressure in the hall should be about 250 - 310 Pa to keep the hall stand. Practically it is possible to keep the hall stands with the lowest overpressure of approximately 175 Pa and a maximum overpressure of 620 Pa [15].

Floor heating was installed in the changing rooms. Floor heating and showers were also connected to the district heating. The changing rooms had own ventilation plant with 100 % air from the hall. There was no heat recovery for this ventilation plant.

The lighting system in the hall consisted of 144 light points in the roof, where each of them has 1 000 W. The entire lighting system is rarely in use, usually a part of the lighting points were in use. For example, under an usual training during the working day about 30 light points were in use. During the tournaments about 62 % of the all the lighting points were in use. The full lighting implied that about 92 % of the all the lighting points were in use. Base on this information the internal load from the lighting system were modeled.

The AHU for the hall consisted of a supply fan and a heating coil as shown in Figure 4. In the documentation was found that the air flow rate through the fan was 18 m^3/s and installed fan power rate was 22.371 kW. In the AHU there was a possibility for the air recirculation as shown in Figure 4. However, this possibility had not been used. The reason for that was a risk that the overpressure would be low to keep the hall stands. Therefore, within this study energy savings by using heat recovery was analyzed.

Figure 4. Sketch of the air handling unit

3.3 Modelling of the sport hall

Figure 5 shows the geometry of the simulation model. The construction of the hall consisted of the insulation cover that has pockets with the fiber insulation. The hall producer guaranteed the U-value of 0.406 W/m^{2}K. Due to some issues during the construction phase, a lower U-value was achieved of 0, 473 W/m^{2}K [16]. This U-value was used in the simulations. Several cold bridges were introduced at the connection lines between the insulation covers. The simulation models were calibrated with a U-value for the cold bridges of 5.8 W/m^{2}K. The geometry of the simulation model is shown in Figure 5. Cold bridges can be observed as thin lines in the hall roof in Figure 5.

Figure 5. Simulation model

Based on the hall geometry, the model was developed with a covering area of 18 200 m^2. To model that the part of the construction had lack of insulation, it was assumed that 14.2 % of the total cover was without insulation. An U-value of 5.474 W/m^{2}K was assumed for the cover without the insulation. This U-value was obtained when the fiber insulation was removed from the envelope construction.

Data about the operation time of the hall were crucial to model properly the energy use of the hall. On the yearly level, the hall was in operation from November until May. During working days, the hall is open before noon for three hours on Monday, Wednesday, and Friday for the school pupils. About 45 persons were present in the hall before noon. Further, during working days from 3:30 p.m. till 10:30 p.m. the hall was open for training and public. About 100 to 120 people were present in the hall in the afternoon. During weekend, tournaments were organized and the hall was in use from 9 a.m. till 7 p.m. at Saturdays and 10 a.m. till 6 p.m. at Sundays. In total about 650 people might be present in the hall. The above facts were used to develop schedules and models for the internal loads from the occupants in the hall. It was important to make difference between the athletes and the public, because the athletes had light clothes and trained hard, while the public had more cloth and was in a sitting position. Both the athletes and the public were modeled in *EnergyPlus.*

The weather data of the year 2010 for Mosjøen, Norway, were used for the simulation, which was the nearest place with the available data on the Internet in Norway[17]. The data were converted to produce an EPW weather input file for the *EnergyPlus* model. The outdoor temperature used for the simulation is shown in Figure 6, where a line at 5°C is introduced to indicate difference between warmer and colder period.

Figure 6. Outdoor temperature for the simulation model

4. Results

The aims of the study were: to analyze possibilities for energy efficiency in the air supported sport hall, possibilities to increase the indoor temperature, and to define key numbers important for the energy cost models. To provide these, a huge analysis was performed starting from the model calibration till analyzing different energy efficiencies scenarios. In this section, the results on energy and real time measurement, the model calibration, energy efficiency, and effects on the hall energy planning and design are presented.

4.1. Energy use measurements

More than a year of energy measurement data were analyzed. The most important conclusions and key number are presented here. Some additional issues with the energy measurement important for the model calibration are also discussed. Energy measurements on electricity and district heating use were obtained.

The measurements on the electricity use appeared to be too low compared to the installed power rate of the fan and light. For example, the analysis of the electricity use showed a specific annual electricity use of 2.1 kWh/m^2. Comparing that with the installed fan power rate of 22.371 kW operating entire year and assuming an average fan load of 50 %, it appeared that the fan electricity use should be about 98 MWh or 8.6 kWh/m^2. Due to these big difference between the measured electricity use and installed power, the nominal value of the installed fan power rate were used to calibrate the model.

The district heating measurements showed an annual specific heating use of 75 kWh/m^2. Comparing this with the before mentioned air supported sport hall in Trondheim, using 215 kWh/m^2 of district heating, the heating use in the analyze hall was lower. To recall the hall in Trondheim had an indoor temperature of 16°C, while the hall in Mo i Rana had 8°C, see Figure 7. In addition, the hall in Mo i Rana was better insulated with a U-value of 0.473 W/m^{2}K comparing with the U-value of 3.05 W/m^{2}K in the hall in Trondheim. Since the value of the district heating use appeared to correspond well with the values found in other studies, it was used for the model calibration.

4.2. Measured indoor temperature and pressure in the sport hall

The indoor environment and energy measurements in the hall were important for the model calibration. More than one year of the detail operation data were analyzed. Some of the most important measurements and conclusions are presented in this section. The analyzed air supported sport hall had building energy management system (BEMS). Figure 7 shows the temperature measurements over one year period.

Figure 7. Temperature measurements in the hall

The measurements of the indoor temperature shows that the most common indoor temperature was 8°C. Further, these measurements showed that with the increase of the outdoor temperature, the indoor temperature was increasing too. By analyzing BEMS measurement on the air handling unit, it was difficult to find a reliable relation between the supply and indoor air temperature. However, a trend was identified that when the supply temperature is increasing up to 20°C, the indoor temperature was increasing as well. Increasing of the supply temperature up to 50 or 60°C did not give any effect on the increase of the indoor temperature. These high supply air temperatures might be the result of the system dynamic, for example immediately after the heating coil start. These measurements and trends were important for modeling of the air handling unit and control.

Height of the hall was measured at three locations: mid-point, South point, and North point. All the obtained measurements are organized and presented in Figure 8. Results showed that the hall height could be kept in a large range of the overpressure from 300 Pa to 550 Pa. This conclusion from Figure 8 was important for the further study about the air recirculation. If the hall height could be kept in a large range of the overpressure value, than the change in the overpressure due to air recirculation would not influenced a lot the hall height.

Figure 8. Hall height vs. overpressure in the hall

4.3. Energy performance and model calibration

The aim of the model calibration was to find a reference model that could be used in the energy efficiency analysis and for energy planning. Further, the model calibration study could show a possible range on energy use in the analyzed hall. Previously mentioned information on the hall construction, district heating energy use, and operation data were reliable to be used for the calibration. The air heating system of the hall was turned on when the outdoor temperature was lower than 5°C. The calibration was performed by introducing different scenarios where the most unsure parameters were changed. All the calibration scenarios were summarized in Table 2. For Calibration 1 in Table 2, collected data explained in Section 3 were used. This meant that for Calibration 1 a flow rate of 18 m^3/s was assumed. For other calibration scenarios, lower air flow rates were chosen. The air pressure rise over the fan were chosen based on the fan characteristic.

Table 2. Calibration scenarios

A summary of the specific annual heating use for all the calibration scenarios is given in Figure 9. In addition, the annual average indoor temperature in the hall is given in Figure 9.

Figure 9.Calibration summary

The results in Figure 9 showed a trend that was noted by the hall operator, at low air flow rate, 6 m^3/s, the indoor temperature decreased. Further the results showed that a possible heating energy use could be in the range from 53 to 115 kWh/m^2. Comparing these values with the measured district heating of 75 kWh/m^2, it could be concluded that the assumed calibration scenarios in Table 2 were reasonable for the further analysis. Since Calibration 1 was based on the collected data, it was used as a reference scenarios to estimate energy efficiency possibilities in the hall.

4.4. Energy efficiency measure in the sport hall

The following energy efficiency measures were tested for the air supported sport hall: improvement of the hall insulation and recirculation of the indoor air. Table 3 gives a summary of the parameters that could decrease the heating energy use. As part of the hall lacked the insulation cover, this lack was estimated to be about 14.2 % of the total cover area. With the scenario of ‘All insulation’, it was assumed that there was no lack in the insulation. Further models were estimate by including the air recirculation with different percent of the outdoor air such as 80 %, 70 % and 50 %. These values were chosen to avoid decrease of the hall overpressure and to maintain a satisfied IAQ. Similar values were suggested in the literature.

Table 3. Energy efficiency measures

Figure 10 shows the total annual specific district heating use for different energy efficiency measures. Due to uncertainties about the recirculation and supply air temperature control, additional simulations were performed to estimate the uncertainty in the results. The uncertainty in the results on the energy efficiency measures are also shown in Figure 10 as vertical variation lines.

Figure 10. Summary of energy efficiency measures on the district heating demand

The results in Figure 10 showed that the air recirculation gave the biggest reduction in the heating use. Improvement of the insulation that there was no lack in the cover insulation would give barely 1 % in district heating savings. The simulation model was also tested for different insulation possibilities, but improvement in the insulation did not give a significant decrease in the heating use of the hall. The air recirculation gave an energy saving of almost 27 % by circulating 50 % of the indoor air. Similar energy saving possibilities are found in [11, 18, 19]. Similarity between the simulation results and results from the literature gave a high fidelity in the presented results for the further decision making and energy planning, thereby can be treated as general and valid for other studies.

Further analysis on additional simulation results on increase in the indoor temperature and extension of the operation time were also performed. It was interesting to perform this part of the analysis, because the increased indoor air temperature together with the extended operation time would give a possibility to use the hall for other activities. The most important results are brief discussed. The results showed that the extended operation time would increase the average annual indoor temperature for about 0.6 K. Extended operation time and increased indoor temperature could increase the average annual indoor temperature for about 1.2 K. In total, the increase in the indoor air temperature and extended operation time would increase the district heating use for more than 40 % annually. However, if 50 % of the indoor air was recirculated, the specific district heating use would still be lower than with 100 % of the outdoor air and short operation time. This means that the air recirculation and longer operation time are favorable for the indoor air temperature. Further the analysis with introducing a decentralized heating coil of 500 kW was performed too. The results showed that the total specific annual heating energy use including the additional heating coil would be 121 kWh/m^2 with 50 % outdoor air and 198 kWh/m^2 with 100 % outdoor air. These values are higher than with the central air heating through the heating coil in the AHU. The decentralized heating coil could increase the temperature in the hall, but at the same time it would increase the total heating energy use. The reason for this is that the heating coil is decentralized equipment and could be control based on the user needs, not centrally.

4.5. Energy cost model and sport hall design

The aim of this part of the study was to give key numbers that could help for energy planning, renting the hall, and hall design. To develop this tool, all the results from the daily simulation related to the heating use, heating rate, and indoor temperature were organized and analyzed. As shown before, the heating coil in the AHU was using most of the district heating. Therefore, the further results are given considering only heating and heating rate for the heating coil. The results on daily heating demand could be used for energy planning and renting the hall. Figure 11 shows heat demand and heating rate at different outdoor temperatures with a share of 100 % and 50 % outdoor air. When the outdoor temperature was -20°C, the heating rate would be 810 kW. As the hall only had a heat exchanger of 580 kW, which resulted in a low temperature during cold days. The results in Figure 11 and previous discussion proved that the model calibration was correct and that the results could be treated as general and valid for other studies. If the recirculation of the 50 % of the indoor air was implemented, a heating coil of about 413 kW would be necessary to warm up the hall.

Figure 11. Daily heating demand at 100 % and 50 % outdoor air

Figure 12 and Figure 13 show the trends of heat demands and heating rate for different operation scenarios. The functions in Figure 12 show the heat demand in kWh/day, the y-axis is presented with MWh for the effectiveness of the presentation. One may use these functions in combination with the district heating price to estimate the renting cost of the hall. Figure 13 is a simple chart to choose the necessary heating coil in the AHU and the heat exchanger for the connection to the district heating system. Figure 13 may be used as a tool to design similar air supported hall considering different indoor air temperatures and the share of air recirculation.

Figure 12. Daily heat demand at different operation scenarios

Figure 13. Heat rate at different operation scenarios

5. Discussion

As mentioned in Introduction, it was difficult to find reliable data on energy use of air supported sport halls. Therefore, it is necessary to estimate the validity of the presented results. Monthly heating use was available for the air supported hall in Trondheim, see Figure 1. Heating energy use data were available in our study, see Section 4.1. Monthly heating use versus outdoor temperature for different measurements and simulation scenarios are given in Figure 14. The results of this analysis showed that the sport hall in Trondheim had the steepest line, indicating a low U-value and higher indoor temperature than in the analyzed hall. The hall in Mo i Rana was better insulated. This resulted in a less steep line in Figure 14. Introducing the air recovery with a share of 50 % outdoor air would give a less steep line and thereby less dependent heat demand on the outdoor temperature. Calibration 5 gave the lowest heat use in Figure 14 and the less steep line. To recall, Calibration 5 implied only an air flow rate of 6 m^3/s, which induced the lowest indoor air temperature, see Figure 9.

Figure 14. Monthly heating use versus outdoor temperature

Since the comparison of different halls and simulation results in Figure 14 looks soundly, it could be concluded that the presented results in this study are general and valid for other studies.

6. Conclusions

The aim of the study was to develop models for energy planning for air supported sport hall by analyzing different energy efficiency possibilities in cold climate. Further, the aim was to analyze possibilities to achieve a higher and more stable hall temperature.

The observed hall in Mo i Rana had a lower annual specific heating energy use of 75 kWh/m^2, comparing the air supported sport hall in Trondheim that used 215 kWh/m^2 of heating energy. The energy efficiency analysis showed that improvement of the insulation had no significant effect on the district heating use. The air recirculation has the greatest effect on energy efficiency. The 50 % of the air recirculation could result in an energy saving of 27 %. The recirculation of the indoor air would not influence much the overpressure in the hall. However, the recirculation of the indoor air might cause decreasing of the overpressure in the hall.

40 % increase in specific annual district heating use could be expected when indoor temperature and operation time were increased. However, if 50 % of the indoor air is recirculated, the specific district heating use would still be lower than with 100 % of the outdoor air and short operation time. This means that it is worth to combine extended operation time with higher indoor temperature and the recirculation of the indoor air. It is possible to achieve higher and more comfortable indoor temperature with the 50 % indoor air recirculation. Higher indoor temperatures without recirculation would require a twice higher heating energy use. In addition, higher temperature would require almost a twice bigger heating rate to be installed in the hall. The simulation results were similar to the values of energy use and energy savings potential of the sport halls found in [6, 11, 18, 19].

Trends for the heating and heating rate demand were obtained for different operation scenarios. The functions may be used to estimate the heating energy demand with different operation scenarios, which may be useful to calculate the daily energy cost and design the heating system of the hall. This means that the functions are a simple tool to calculate the size of the heating coil in the AHU for similar halls.

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Tables

Table 1. Energy saving potentials and consequences on IAQ and IEQ

References	Portion of the recirculated air	Energy saving potential	IAQ and IEQ
Jaakkola et al. [9]	70 %	-	No (accompanied by an adequate intake of outdoor air)
Chao and Hu [11]	-	8.3 – 28.3%	IAQ is acceptable (>90% occupants)
Naumov et al. [12]	100 m^3/h	40 – 50 % (air saving)	Acceptable microclimate
Aziz et al. [13]	-	70 %	Drying process
Chakroun et al. [14]	40 %	37 %	CO_2 concentration less 600 ppm
Liang et al. [15]	Return air dynamic control	27.8 %	Acceptable room air temperature
Hirunlabh et al. [16]	15 %	24 %	Drying room air

Table 2. Calibration scenarios

Scenario	Parameters
Calibration 1	Air flow rate = 18 m^3/s Air pressure rise over the fan = 900 Pa Air heating period: Oct. 15th till May 10th
Calibration 2	Air flow rate = 18 m^3/s Air pressure rise over the fan = 900 Pa Air heating period: Dec. 1st till May 1st Lower temperature in the changing rooms
Calibration 3	Air flow rate = 10 m^3/s Air pressure rise over the fan = 1 350 Pa Air heating period: Oct. 15th till May 10th
Calibration 4	Air flow rate = 10 m^3/s Air pressure rise over the fan = 1 350 Pa Air heating period: Dec. 1st till May 1st
Calibration 5	Air flow rate = 6 m^3/s Air pressure rise over the fan = 1 500 Pa Air heating period: Oct. 15th till May 10th

Table 3. Energy efficiency measures

Scenario	Parameters
All insulation	All insulation Air flow rate = 18 m^3/s – 100 % outdoor air, no recirculation
All insulation and 80 % outdoor air	All insulation Air flow rate = 18 m^3/s – min 80 % outdoor air, with recirculation
All insulation and 70 % outdoor air	All insulation Air flow rate = 18 m^3/s – min 70 % outdoor air, with recirculation
All insulation and 50 % outdoor air	All insulation Air flow rate = 18 m^3/s – min 50 % outdoor air, with recirculation

Note: Air pressure rise over the fan = 900 Pa; Air heating period: Oct. 15th till May 10th; Set temperature for the recirculation was equal as the supply air temperature 20°C in the changing rooms

Figure 1

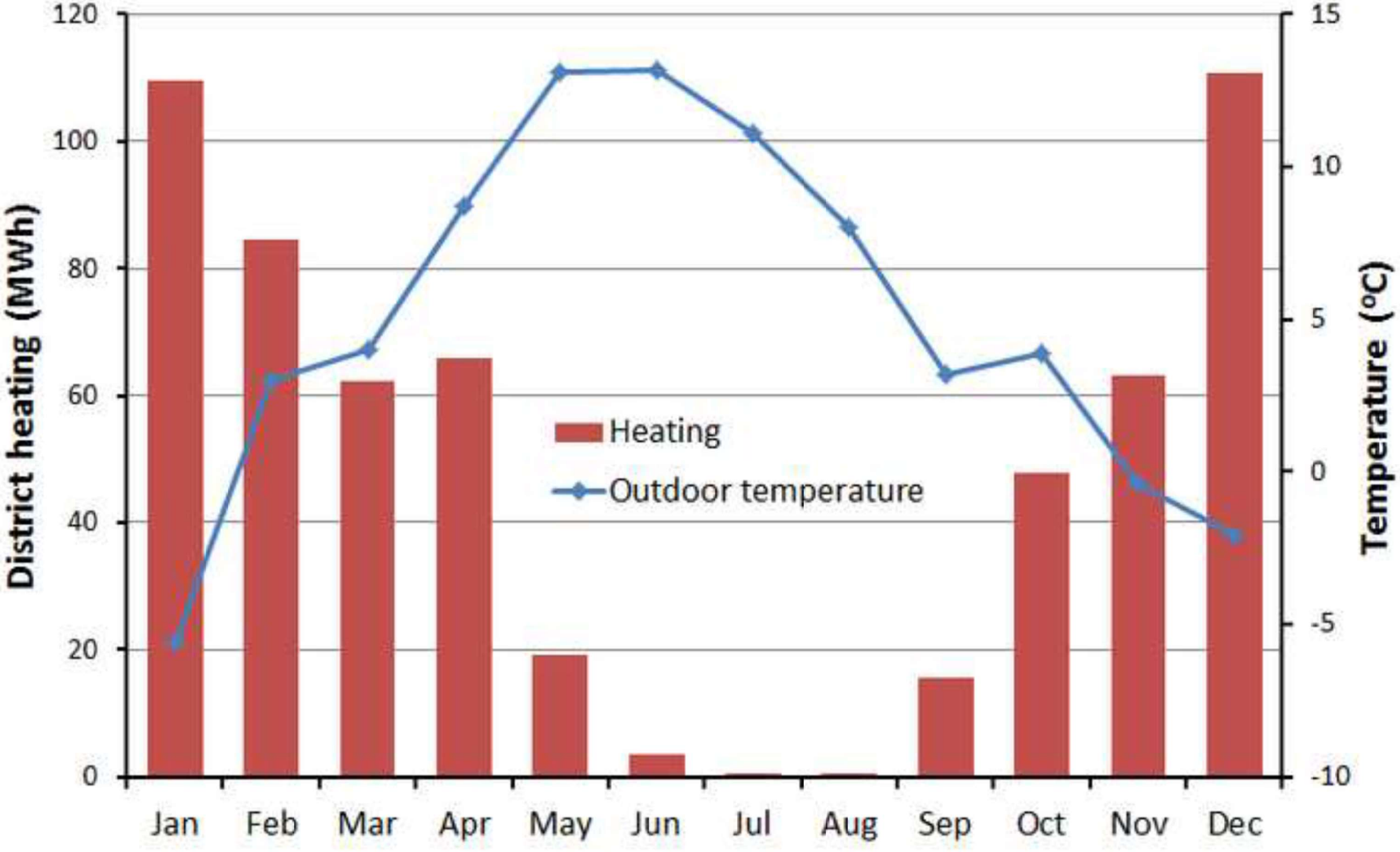
District heating (MWh)
120
100
80
60
40
20
0
Temperature (ºC)
15
10
5
0
-5
-10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Heating
Outdoor temperature

Figure 2

Figure 3

Figure 4

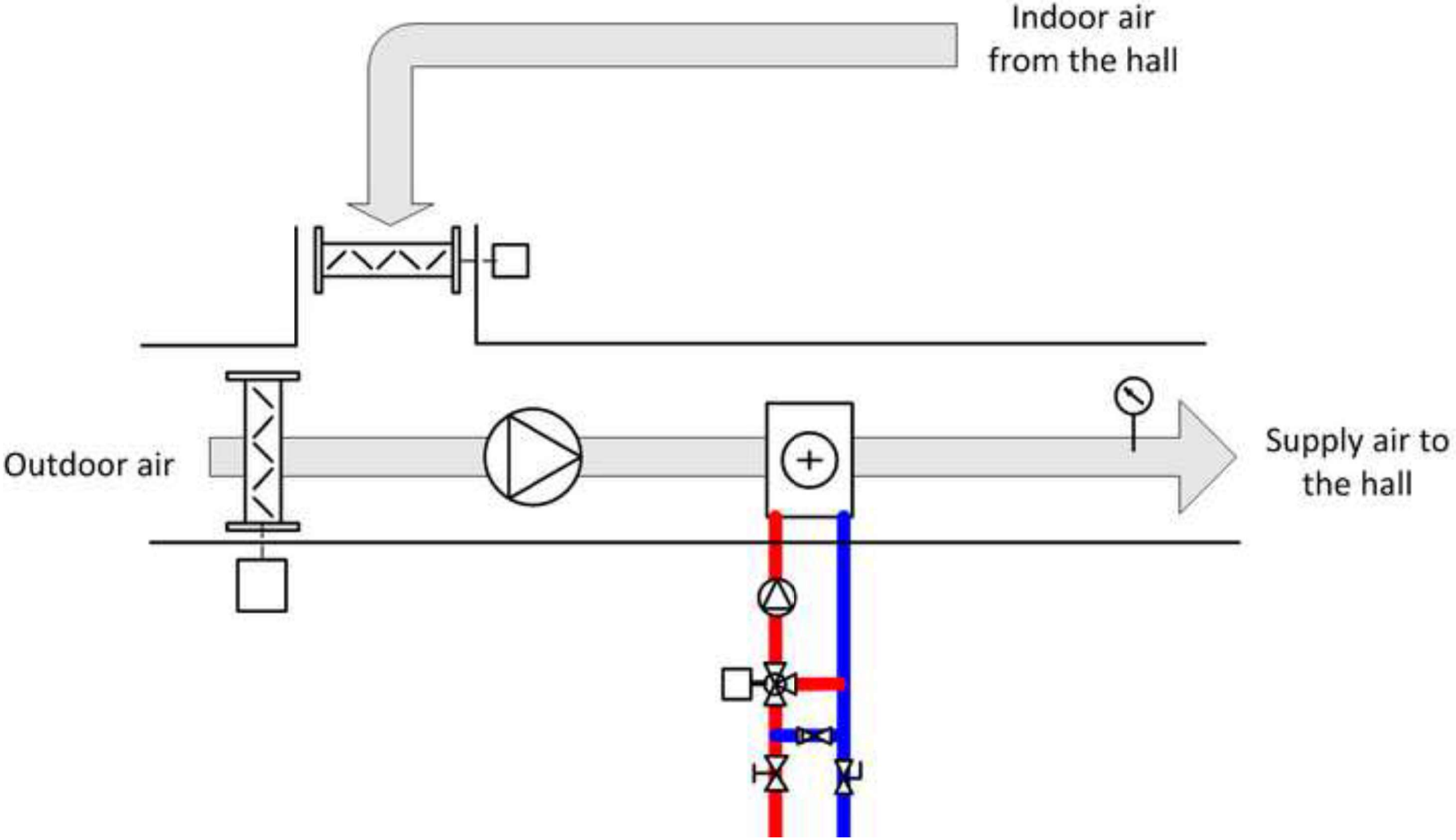

Figure 5

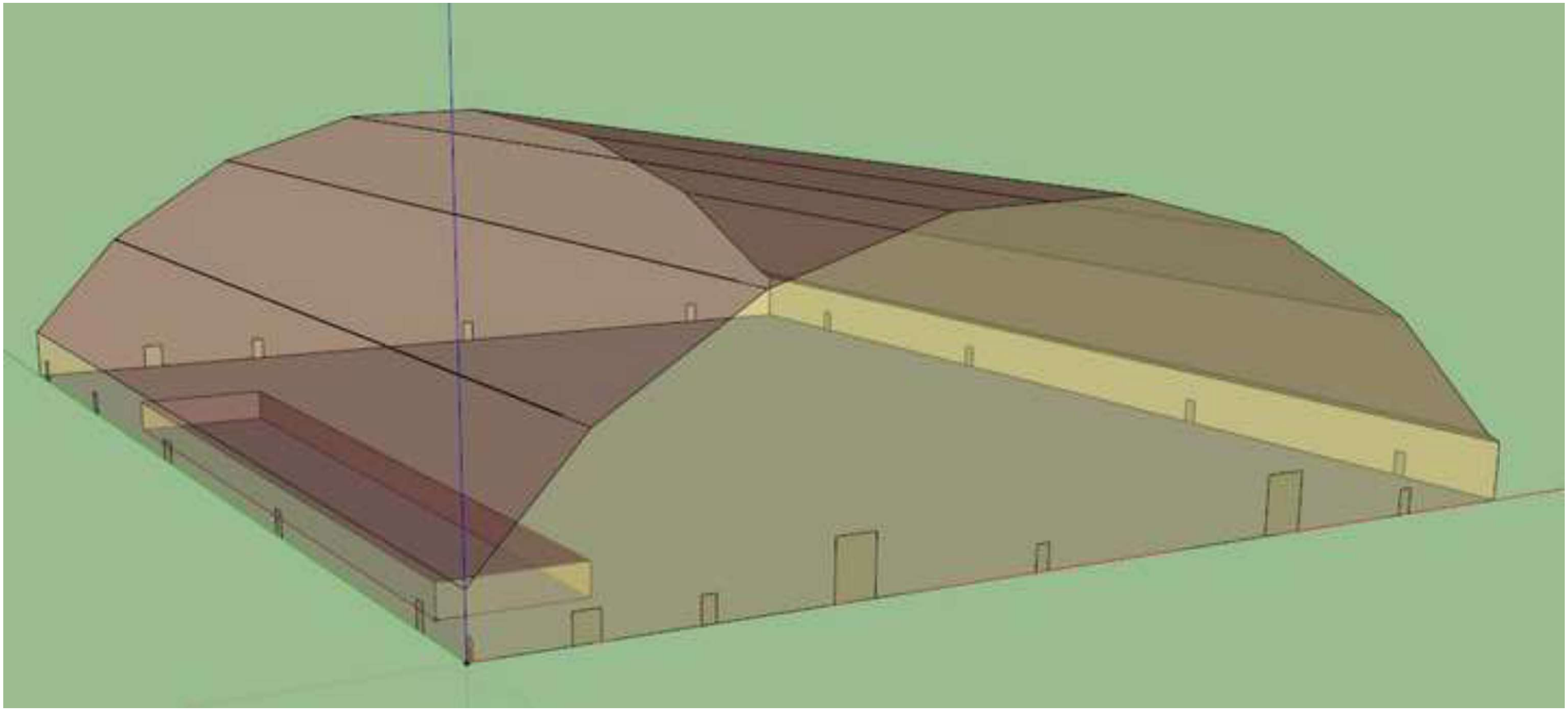

Figure 6

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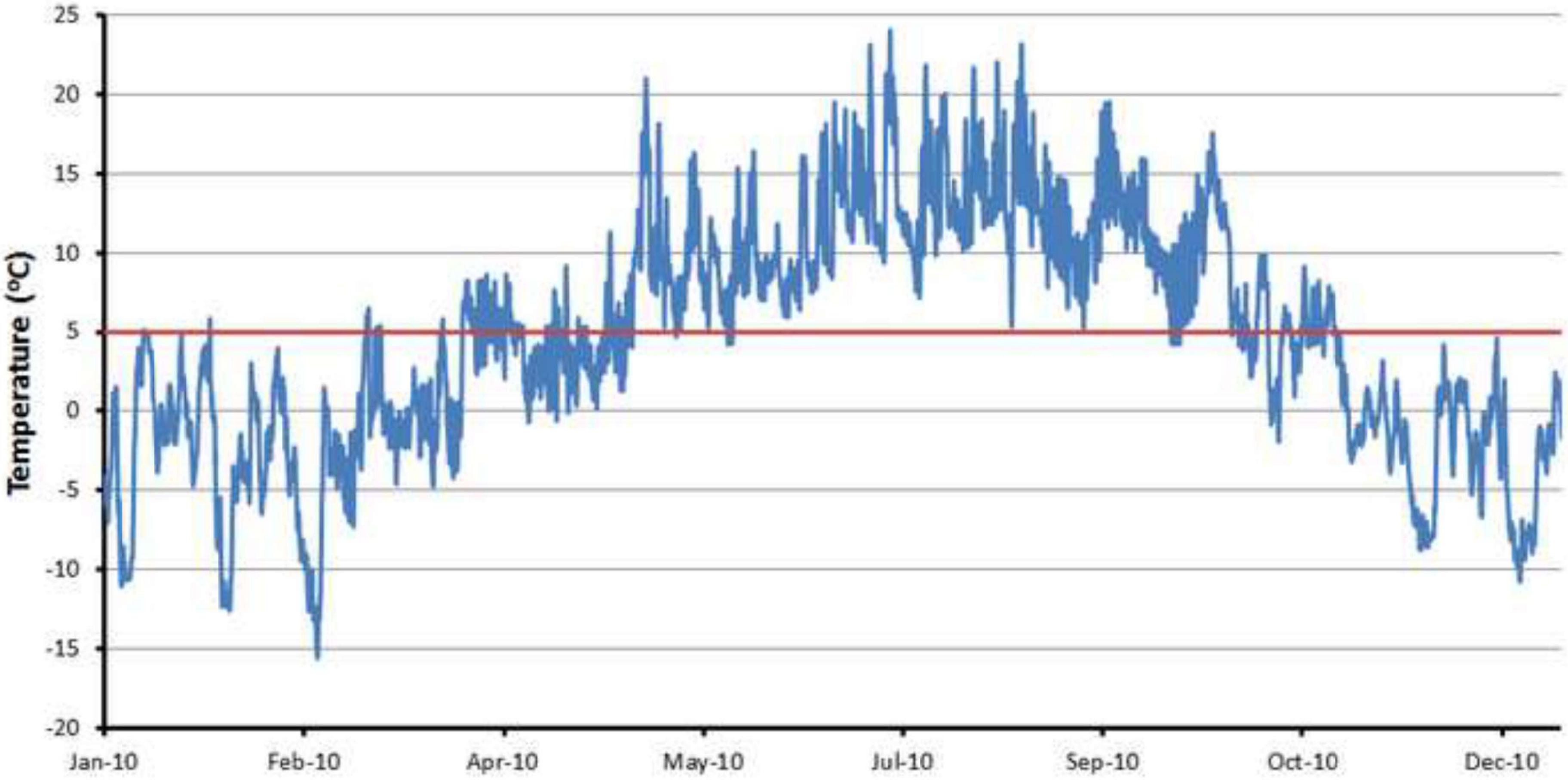

Figure 7

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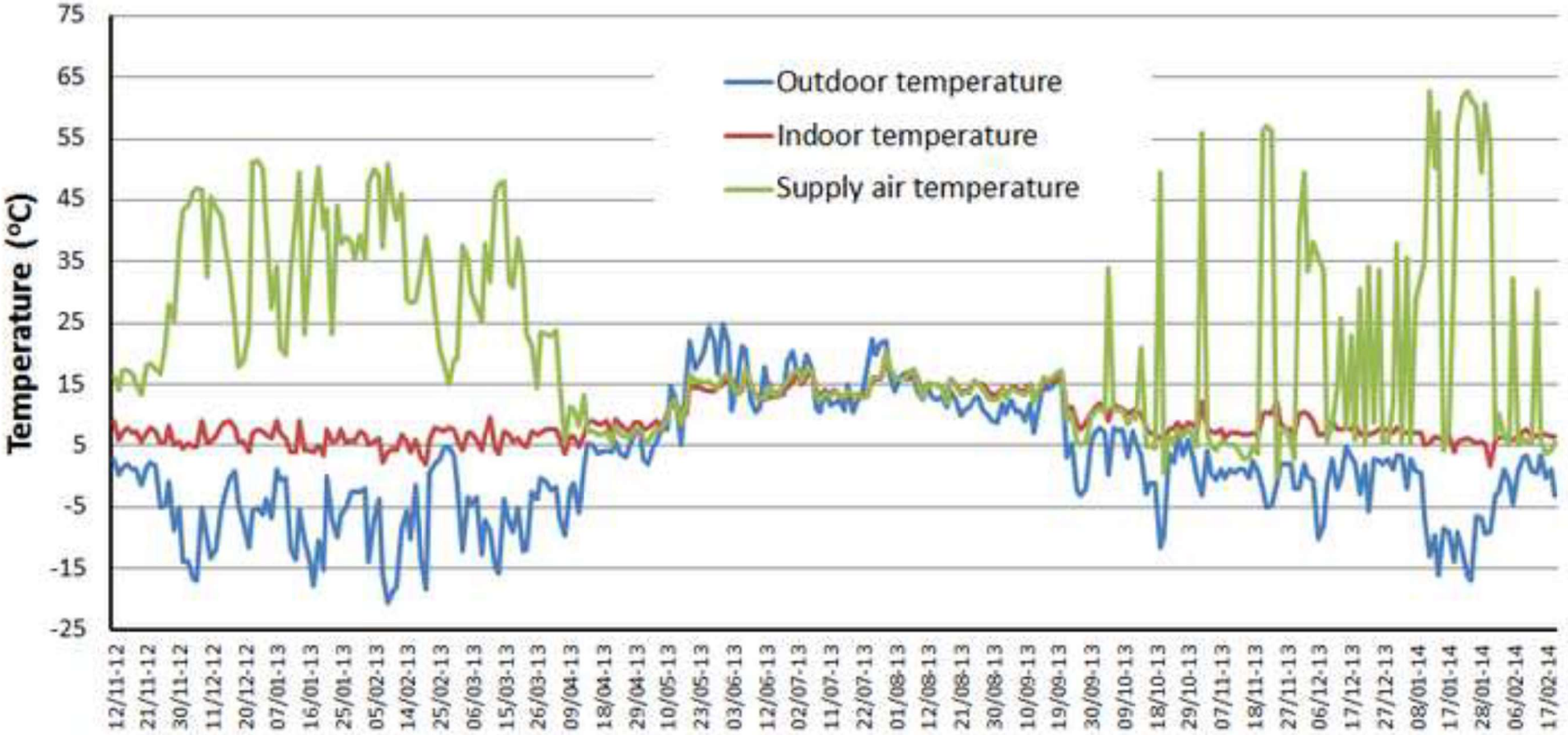

Figure 8
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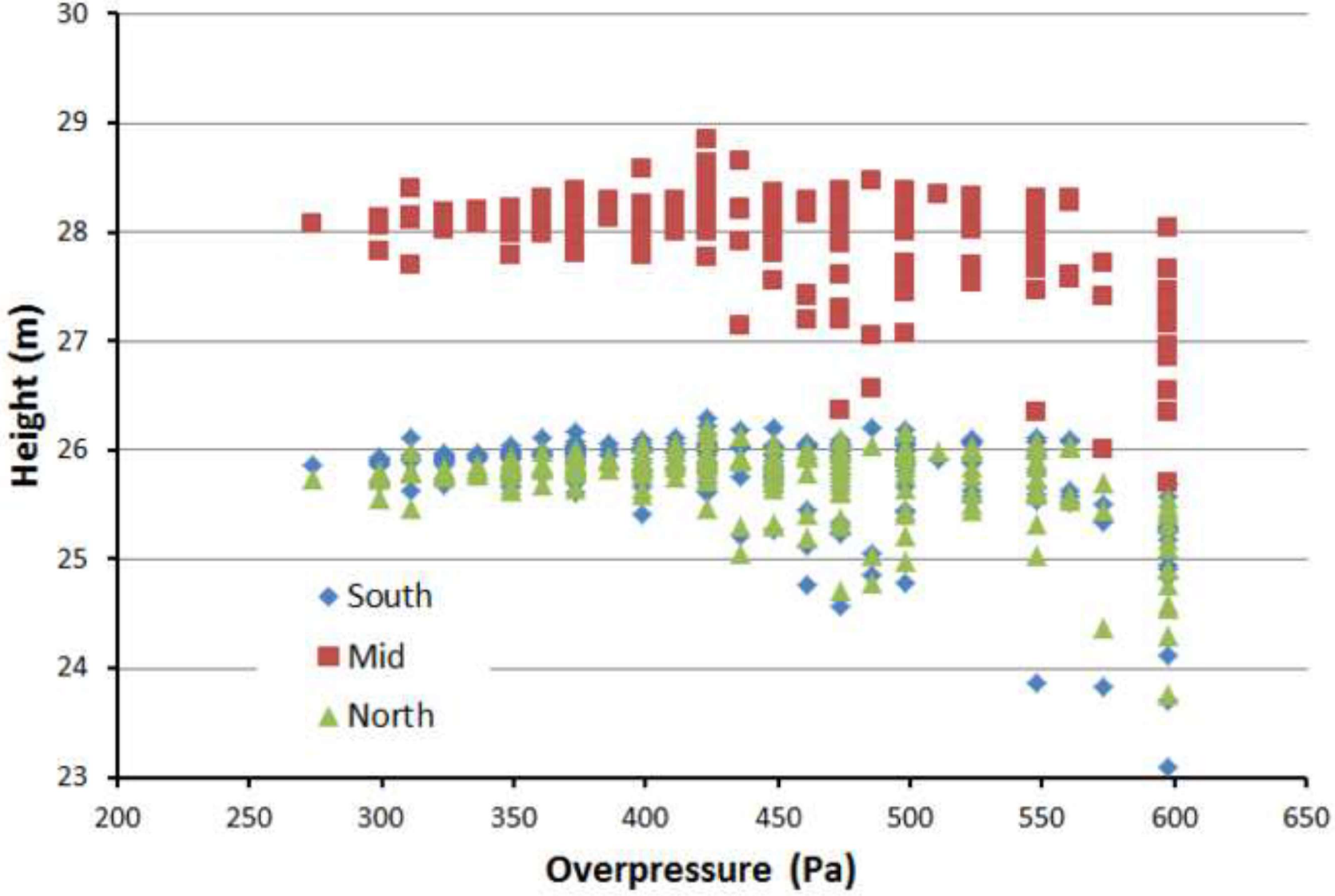


Figure 9

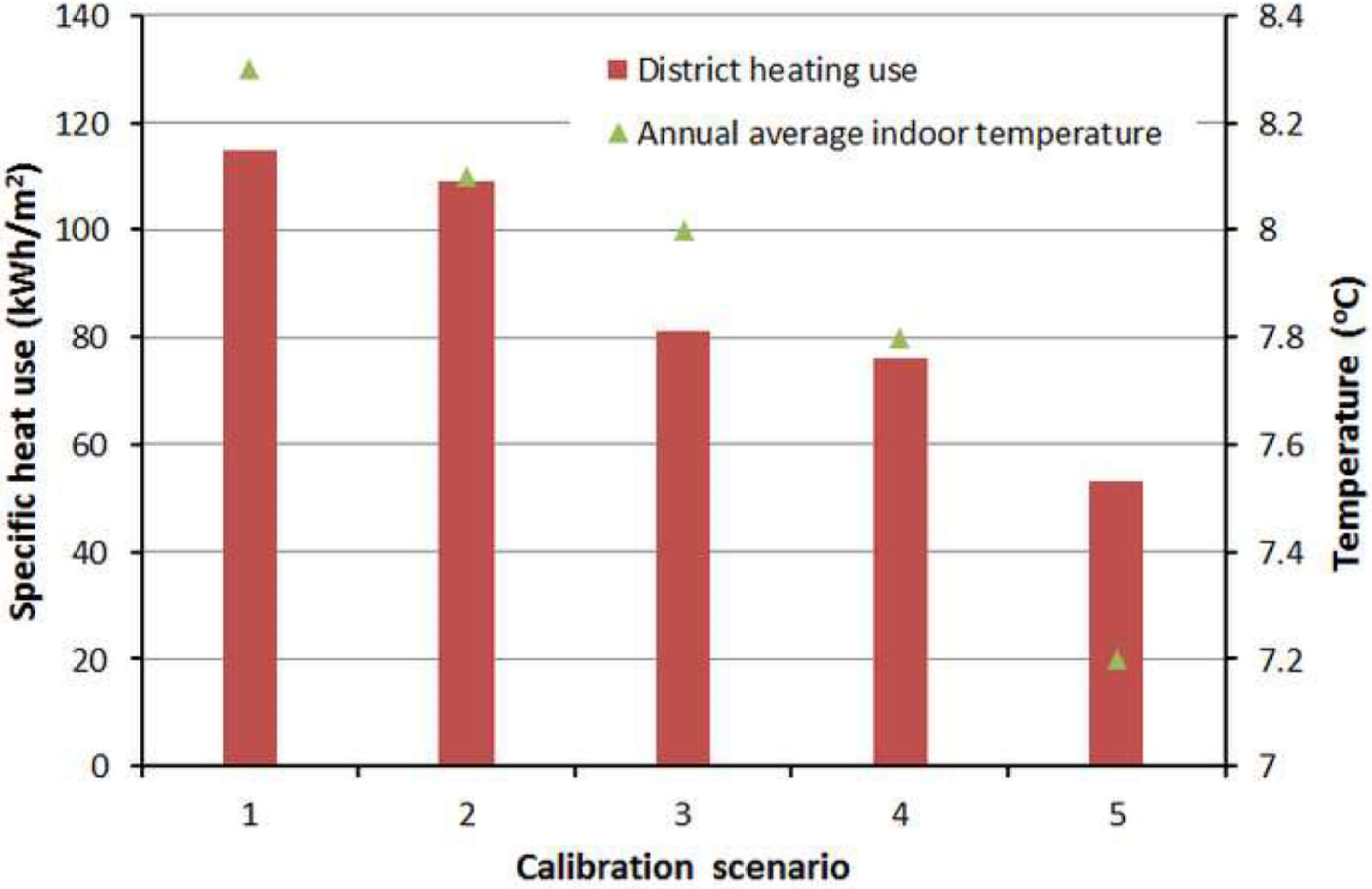
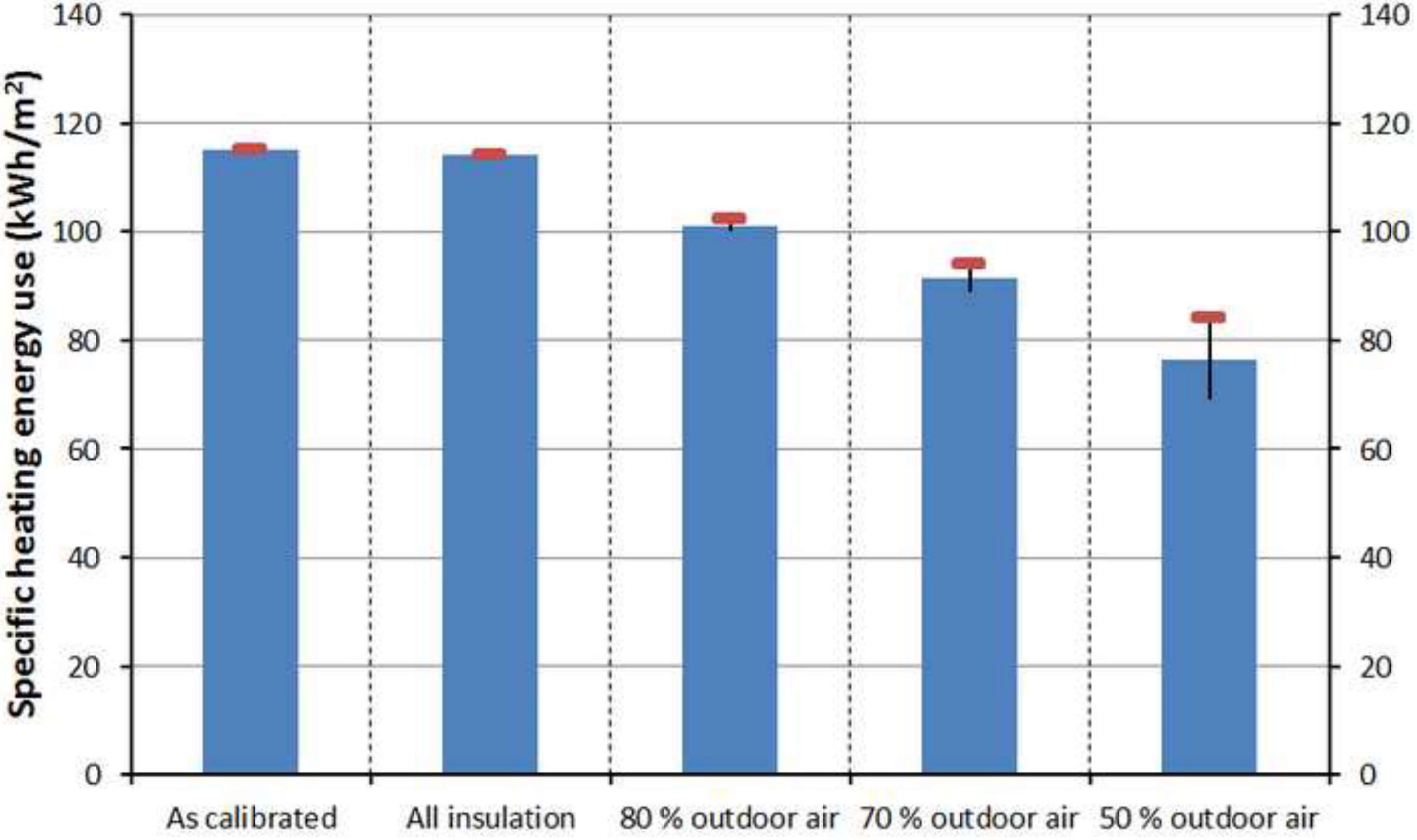

District heating use
Annual average indoor temperature
Specific heat use (kWh/m²)
140
120
100
80
60
40
20
0
Temperature (ºC)
8.4
8.2
8
7.8
7.6
7.4
7.2
7
1
2
3
4
5
Calibration scenario

Figure 10



Specific heating energy use (kWh/m²)
0
20
40
60
80
100
120
140
As calibrated
All insulation
80 % outdoor air
70 % outdoor air
50 % outdoor air

Figure 11

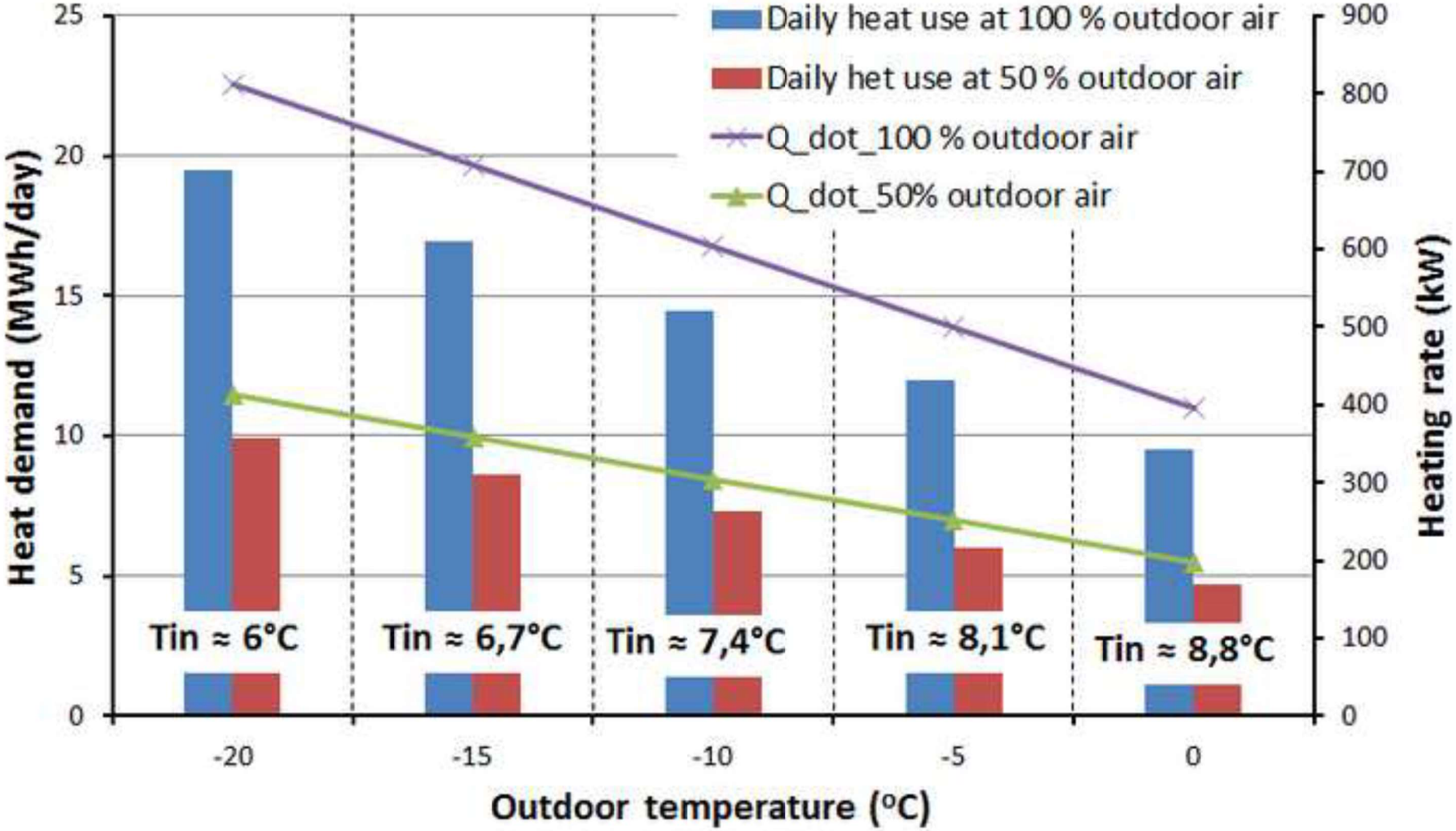

Daily heat use at 100 % outdoor air
Daily het use at 50 % outdoor air
Q_dot_100 % outdoor air
Q_dot_50% outdoor air
Heat demand (MWh/day)
25
20
15
10
5
0
Heating rate (kW)
900
800
700
600
500
400
300
200
100
0
Tin ≈ 6°C
Tin ≈ 6,7°C
Tin ≈ 7,4°C
Tin ≈ 8,1°C
Tin ≈ 8,8°C
-20
-15
-10
-5
0
Outdoor temperature (°C)

Figure 12

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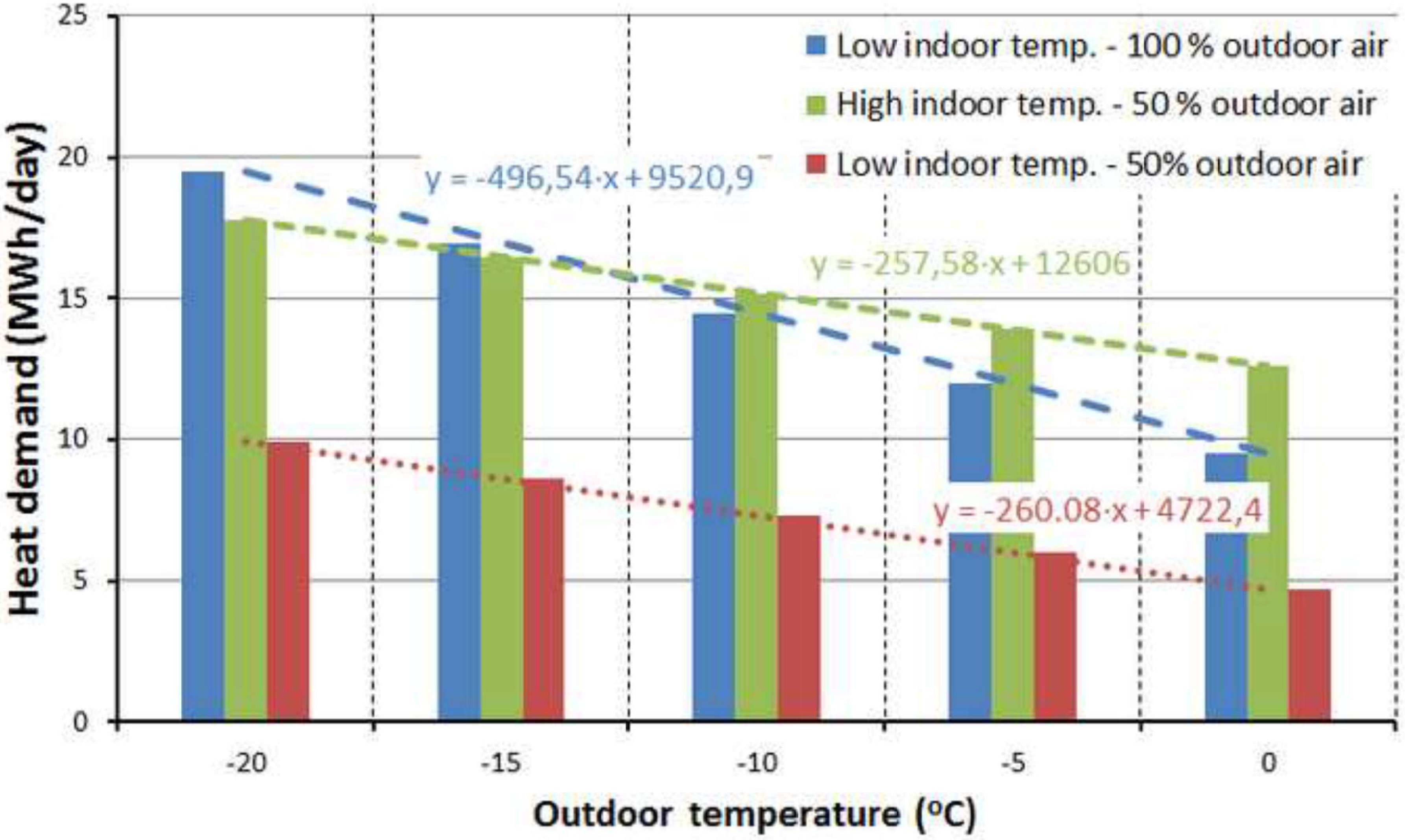

Figure 13

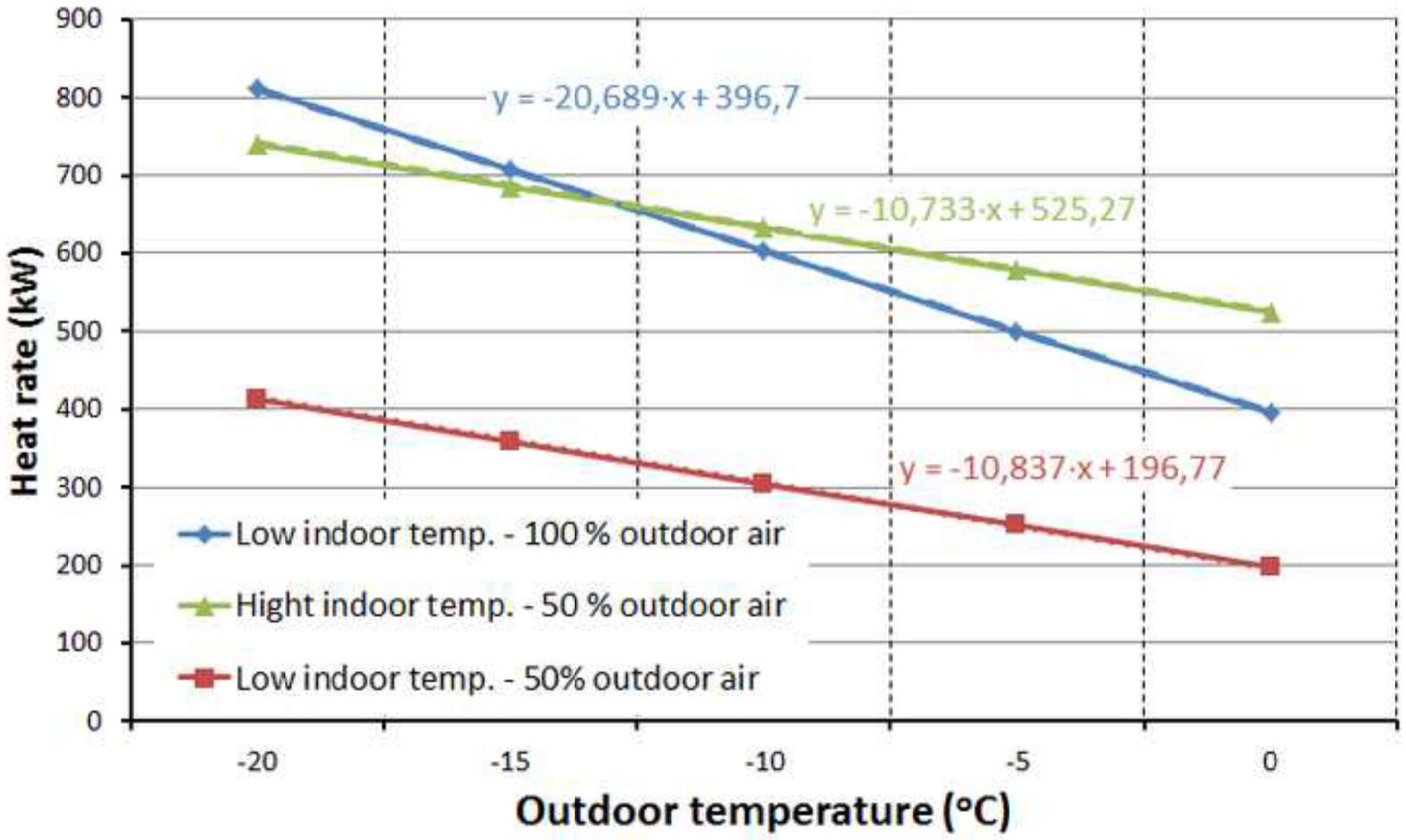
Heat rate (kW)
900
800
700
600
500
400
300
200
100
0
-20
-15
-10
-5
0
Outdoor temperature (°C)
y = -20,689·x + 396,7
y = -10,733·x + 525,27
y = -10,837·x + 196,77
Low indoor temp. - 100 % outdoor air
Hight indoor temp. - 50 % outdoor air
Low indoor temp. - 50% outdoor air

Figure 14

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