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Optimization-Based Calibration of a Building Thermal Performance Simulation Model

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ABSTRACT

Building performance simulation is being increasingly deployed beyond the building design phase and into the building operation phase. Specifically, the predictive feature of the simulation-assisted building systems control strategy provides distinct advantages in view of building systems with high latency and inertia. Needless to say, such advantages could be exploited only if model predictions could be relied upon. Hence, it is essentially important to calibrate simulation models based on monitored data. As such, whole-building simulation applications require extensive input data to accurately model the thermal performance. It would be thus beneficial to conduct the model calibration in an efficient manner. In the optimization-aided calibration approach, some input parameters of the model are adjusted through an optimization process so that the difference between the model outputs and the monitored data is minimized.

This master thesis reports on the use of optimization-aided model calibration in the context of an existing university building. Thereby, the main objective was to deploy data obtained via the monitoring system to both populate the initial simulation model and to maintain its fidelity through an ongoing optimization-based calibration process. The initial simulation model uses, asides from basic physical building information (geometry, layout, materials, etc.), monitoring data to define assumptions pertaining occupancy, state of devices such as luminaires and windows, and energy output of heating terminals. By doing so, one of the main sources of inaccuracy in building model can be addressed. The calibration and validation process will be performed in different summer and winter conditions in order to analyze the building model accuracy in different environmental conditions. To judge the quality of the implemented calibration, the model predictions were examined using long-term monitored data. The results suggest that the calibration can significantly and sustainably improve the predictive performance of the thermal simulation model.

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Dedicated to my loving husband, Mehrad

NOMENCLATURE

EP	EnergyPlus
EMS	Energy Management System
Erl	EnergyPlus Runtime Language
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
HVAC	Heating, Ventilation and Air Conditioning
CV(RMSD)	Coefficient of Variation of the Root Mean Squared Deviation
R^2	Coefficient of Determination
f	Cost function
m	Measured value
$\overline{m}$	Mean of the measured values
s	Simulated value
n	Number of time steps in a run period

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1 INTRODUCTION

1.1 Overview

Getting insight into the buildings' energy requirements, energy-efficient designs, energy consumption predictions and cost saving, presenting labels as well as building energy ratings and several other demands in the context of energy and building performance is supported by the application of energy simulation modeling. Energy simulation is a computerized modeling, focusing on the performance of the building. In fact, building performance simulation tools provide the essential information to evaluate the thermal performance of buildings (Hensen & Lamberts 2011). Thereby, designers are benefiting from applying energy simulations on their designs to evaluate the crucial properties of the designs such as the energy efficiency, sustainability, and environmental impacts. However, declaring an energy simulation as a successful procedure mainly depends on the accuracy of the analyses and predictions (Polly et al. 2011).

In the area of building thermal performance, this master project will focus on evaluation of the simulations and calibration of the thermal performance models. The current applied method is called "optimization-based calibration of a building thermal performance simulation model". The benchmark to judge the fidelity of the simulated model is the data provided by an applied monitoring system. For this purpose, an existing office building, located in the center of Vienna, Austria, was selected as the case study. Three offices in this building are equipped with a monitoring infrastructure in the course of a previous research project. Validation of the simulation results are based on comparing the simulated and measured values (e.g. simulated and monitored indoor temperature).

By distinguishing the differences between actual and simulated results, this master thesis argues that there are certain parameters involved in the simulations, which contribute to deviations. Therefore, optimization will help improving the results by modifying the mentioned design parameters. In the current applied method, to evaluate the simulations and conformity of the results appropriate error indicators are required. Basically, optimization process is based on minimizing a cost function defined as the sum of weighted error indicators (Mahdavi & Tahmasebi 2013). By this it means that, firstly limited number of input parameters, as the most effective input variables on the output results are selected. Afterwards, the formulated optimization process aids tuning these variables with the aim of minimizing the cost function. With the modified variables, the calibrated model is generated which is expected to have predictions similar to the measured values. In order to evaluate the reliability of the proposed method, this process needs to be validated in different run periods. In fact, on a regular and systematic manner calibration-validation processes are required to be conducted. In addition, in the cases where validation outcomes are not satisfactory, recalibrations are essential. Analyzing the results suggest that the optimization-based calibration method has a promising potential toward increasing the accuracy of the predicted building performance.

1.2 Motivation

Simulation tools for predicting the performance of the buildings are conventionally used (Hensen & Lamberts 2011). But still one of the big concerns is the difficulties associated with the large variety of data, complex factors and inaccuracies occurring through the modeling. Synchronous by increasing the amount of input parameters to develop a more detailed model, the complexities in the performance modeling grow up. This leads to numerous sources of mistakes and errors in the simulation process. Despite the fact that use of simulation engines has been raised and many researchers have been performed in this area, developing a procedure to reach reliable results is still a big issue (Westphal & Lamberts 2005). Reviewing the relevant literatures, states that modifying some particular input parameters will provide large changes in the outputs toward more reliable predictions (for example see Mahdavi & Tahmasebi 2012). Therefore, this master project contributes with a methodology for optimization-based calibration of a building simulation model. Obtaining the maximum accordance between the actual data, observed by monitoring system, and the predicted values by the simulation engine, is the approach of the implemented method.

Interested in the context of facilitating energy simulations by building monitoring systems, this work is motivated by the observations presenting how practical are the monitoring infrastructures for validation of the building performance simulations. In the proposed method, building monitoring would help in two ways. First of all, the observed data can be used to create a more accurate initial model. Secondly, comparison between the initial simulated results and monitored values specifies the needs of calibrations. In addition, as we will discuss extensively later, an automatic calibration process will be applicable by means of the monitored parameters. The current work was also motivated to examine the quality of this approach in different conditions which was doable by a long-term monitored model. As a matter of fact, due to the dynamic nature of the building's characteristic during its operation life, the calibration needs to be redone during different periods. By this way, it would be also possible to evaluate the consistency of the proposed method.

1.3 Background

In the followings, this part will focus on the relevant literature reviews, in four main areas as below:

- Building thermal performance simulation
- Monitoring assisted thermal simulations
- Calibration of thermal simulation models
- Optimization-based calibration

1.3.1 Building thermal performance simulation

For several decades computers have been playing crucial role in building performance simulations. Fast improvements of simulations in predicting thermal performance of the buildings and energy requirements, occurred in the early 1970s (Kusuda 1999, Ayers & Stamper 1995). These programs were used in vast areas, such as estimating the saving potential or verifying the savings from retrofits. Therefore, many different methods and procedures were developed for the performance analysis, while none of them could be judged as the best (Eisenhower et al. 2011). In fact, selection between different methods and tools for thermal simulations depends on the available data and required outputs (Rabl 1988).

Performance simulations have been implemented in different phases of building designs and operations. To be more precise, as building performance simulations are conventionally deployed in the building design phase, they also have been used in the building operation time (Mahdavi 2001). This is caused by the crucial role of the existing buildings in energy consumptions and environmental impacts. There are several reasons which prove the necessity of evaluating the building performance during its operation life. For example, it should be assessed if it deviates from the desirable performance or does not reach the optimal performance, which was designed for. Moreover, the efficiency of the building systems might decrease over the time or due to the lack of enough maintenance.

Also mistakes in designs or installations of the building elements might prevent them from the expected performance (Heo et al. 2012).

To start a thermal simulation, several types of parameters are required. The following general categories can be considered as examples in this regard:

- Weather file and outdoor environment due to their impacts on indoor conditions,
- Thermal properties of the constructions' components,
- Specification of the ventilation and infiltration rates,
- Heating and cooling systems,
- Internal loads such as occupants, lightings, etc. (Heo et al. 2012)

At the early stage of building designs the main principal of simulations is predicting the building performance in the future. Therefore, uncertainties are involved due to the assumptions, simplifications, lack of knowledge and mistakes. For example, in some cases building constructions are not exactly the same as descriptions and plans. Moreover, further changes in the design after starting the construction, affects the accuracy of the predictions. In addition, assumptions and simplifications in modeling complex properties and geometries also cause errors and incorrectness (De Wit 2004). Basically these parameters can be categorized in two main groups; controllable and uncontrollable sources of errors. In order to have a better look to these categories more examples are provided. In case of under control causes, we can mention to different simplifications exerted throughout modeling. For example, due to the lack of precise information, the exact properties of elements might not be considered. As another example, sometimes even though the simulation software has the ability of advance modeling such as modeling the 3-dimentional heat transfer, the user may not use these options (e.g. to apply abstractions) (Macdonald et al. 2012). Besides, incomplete database of simulation engine, that user has no control on, is an inevitable obstacle leading undesired model. These examples as well as many other cases demonstrate how errors can be produced during a simulation which leads to incorrect results. These factors can be summarized in either imperfect modeling, incomplete knowledge regarding the building model, careless investigations or restrictions because of the selected simulation tool or method. Therefore, to derive accurate outcomes, user should have a complete insight into the software in addition to comprehensive detailed information about the building being investigated (Westphal & Lamberts 2005).

The parameters causing inaccuracies in building performance investigations are crucial since we expect from simulation engines reliable predictions. These predictions are regarding the building performance in the future or during the service life of the building.

One of the other parameters essential to be considered in performance simulations is the "dynamic nature of the building operation" (Mahdavi & Tahmasebi 2012). More precisely, during the building operation life, even considering one year, we observe changes in the factors effective on the building performance. Some of the examples in this context are changes in the environmental conditions during the seasons or occupant’s behavior. Therefore, these constant changes should be considered in running the simulations. In order to evaluate the reliability of simulation predictions, we need to verify them in different time periods and under different conditions.

1.3.2 Monitoring assisted thermal simulations

Optimization-based calibration method, used in this work, is assisted by a monitoring system. Therefore, for a better understanding of building automation and control systems, literature reviewing in this area has been done. Generally talking about automation systems, networks of hardware and software are used with different objectives. Monitoring and controlling of the environmental conditions, managing different building systems, examining the operational performance in addition to surveying the comfort of the building inhabitants are examples in this context (KMC Controls 2011). Measuring temperature, humidity, air flow, illuminance and occupant processes are some of the required physical parameters for the aforementioned objectives.

In the building performance criteria, simulation tools are often used to predict variables like thermal comfort and energy use. But in the meanwhile, other goals have been also demanded in the research field of building performance. One example is providing the actual data regarding the user behavior to inform occupants about their impacts on energy consumptions in buildings. In addition, in the context of maintenance supports, prevention regimes in energy systems and devices, detections and treatments, monitoring systems have been used for observing the system operation by the real time data (KMC Controls 2011). Another example related to the topic of the current work is utilizing the control and monitoring systems to improve the building performance simulations. Having access to a real time updated building energy performance and operation database will assist the building scientists or engineers' studies on optimum systems. Improving the designs or retrofit processes are some related examples in this regard. Moreover, access to the real-time data, enables calibration of the simulated model with the actual model while a big concern in building simulations is assessment of the simulated models (Zach et al. 2012). A proper method in this regard proposed in different researches is validation of the model by comparing the simulated and measured values (Mahdavi et al. 2009, Zach et al. 2012, Tahmasebi et al. 2012, Taheri et al. 2013). Therefore, for evaluating the simulation results, one option is equipping the model with monitoring systems and collecting the real time data. In this regard, Zach et al., adopted a strategy for implementation of monitoring infrastructures. This system includes different levels from gathering the monitored data up to managing the data for further processing. Commonly the monitoring infrastructure setup in "a building communication network" consists of a four-layer model; namely management level, automation level, field bus level and physical level. Below is a summarized description of each layer:

– Physical layer: This layer refers to the devices and technologies required for data collection. For example, to study the energy consumptions in a building, electricity, gas, water and oil meters are some of the required sensor technologies.

– Fieldbus level: Fieldbus level transfers the measured data to the automation level. Different strategies can be performed to send the measured data from the sensors to the automation level. In each case depends on the data stream, a specific strategy will be used.

– Automation level: The responsibility of the automation level is passing on the monitored data to the control station. Automation level handles higher data rates than the previous level.

– Management level: This layer deals with the data storage. Presentations, visualizations and additional processing are taking place at this level.

This monitoring infrastructure assists the simulation controls. The monitored data would be used in different prescribed scenarios in simulation-improvement process. The initial building model will be populated with the dynamic monitored data such as internal loads, occupancy and device states. Afterwards, by comparing the simulated and monitored values (e.g. zones' indoor temperature), the simulated model can be evaluated. Therefore, the monitored data will be used either as a simulation input or as the benchmark for evaluations (Zach et al. 2012).

In addition, regarding the monitoring assisted thermal simulations, another aspect of using monitored data is creating the local weather data. Dynamic simulations in order to determine the indoor thermal conditions and energy use, require hourly weather data. Qingyuan et al. (2002) proposed that for computer simulations the least required information for generating the weather data are hourly records of temperature, humidity, wind speed and direct and total solar radiations. Therefore by monitoring the mentioned parameters, instead of using a predefined typical year weather file, the local weather file can be produced.

1.3.3 Calibration of thermal simulation models

By developing computer simulation models, validation of the predicted results in order to assure their accuracy and consistency is required. As discussed before, the evaluations can be based on the actual monitored building performance. In fact, the simulation outcomes will be improved by applying these additional procedures and developing the calibrated models (Tahmasebi & Mahdavi 2012). The accuracy level of simulations can be judged by comparing the simulated and measured values. For example comparing the measured and simulated indoor temperature or measured and simulated energy use informs the user about the simulations precision (Zach et al. 2012). For this kind of statistical analysis there are different statistical parameters existing. It was proposed by literatures that the "Coefficient of the Variation of the Root Mean Squared Deviation *CV(RMSD)* " and "Coefficient of Determination R^2 " are reliable and practical indicators for error and fitness analysis, respectively (Mahdavi & Tahmasebi 2012). The two indicators are explained as below:

– Coefficient of the Variation of the Root Mean Squared Deviation *CV(RMSD)*

RMSD is used to measure the rate of accordance between the simulated and monitored values at the same time step. *CV(RMSD)* is a single dimensionless number which indicates the errors or the deviation of the predictions from the actual values (Mahdavi & Tahmasebi 2012).

In the following relations "$m= [x_1, x_2, x_3, ..., x_n]$ " and "$s= [y_1, y_2, y_3, ..., y_n]$ " stand for the monitored and simulated values (e.g. indoor air temperature) during a specified period among the building operation time, respectively. Then we have:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}\left(m_i - s_i\right)^2}{n}} \tag{1-1}$$

$$CV(RMSD) = \frac{RMSD}{\overline{m}}.100 \tag{1-2}$$

While "n" is the number of time steps during the time period and "$\overline{m}$" is the mean of the measured values.

As a function of the calibration procedure, getting the smallest value of *RMSD* is the most desirable condition while zero is the ideal value (Polly et al. 2011, Tahmasebi et al. 2012).

– Coefficient of Determination R^2

In this context, R^2 is another indicator representing the similarity between the future outcomes and the simulated values. This indicator has been referred mostly in the literatures as the representative for "goodness of fit" of the model which determines the likeness between the actual data points and the regression line. R^2 has the range from 0 to 1 where the maximum amount is the desired value (Mahdavi & Tahmasebi 2012). R^2 equal to zero expresses that there is no linear relationship between the actual and simulated values and R^2 equal to one indicates a perfect relationship.

With the same parameters of "m" and "s" as above, R^2 will be calculated as:

$$R^2 = \left(\frac{n\sum m_i s_i - \sum m_i \sum s_i}{\sqrt{\left(n\sum m_i^2 - \left(\sum m_i\right)^2\right).\left(n\sum s_i^2 - \left(\sum s_i\right)^2\right)}} \right) \tag{1-3}$$

The higher amount of R^2 represents smaller degree of error variance whereas Santhi et al. (2001) and Van Liew et al. (2003) concluded that the values more than 0.5 are counted as the acceptable results.

By recognizing variation of the simulation predictions from the real performance of the model, the next step would be studying the causes. As it has been stated before, there are large amount of variables involved in creating a simulated model such as geometry, materials, constructions, internal loads. Therefore, while building performance simulations, the inaccuracies abound (Macdonald & Strachan 2001). Hence the consequential step in thermal simulations is modifying the model so that the predictions fit the real observed values to the greatest possible extent (De Wit & Augenbroe 2002). This process in the thermal building performance studies is called calibration. In calibration of a building simulation model, recognizing the input parameters having the most influence on outputs is an important phase. Slight changes in the mentioned parameters will cause big amount of variations in the results. In building simulations several strategies has been used to recognize the errors in the outputs, caused by input uncertainties (for example, cf. De Wilde & Tian 2009, Reddy et al. 2007, Macdonald & Strachan 2001). By reviewing the studies carried out in this field, there are two common manners for identification of the inaccuracy sources in building performance modeling. First method is incorporating the mathematical techniques and statistical analysis within the thermal simulations, such as applying sensitivity analysis (for example cf. Macdonald & Strachan 2001, Westphal & Lamberts 2005, Eisenhower et al. 2011). On the other hand, a second method proposed in some studies is selection of a group of parameters which are probably the most influential, by an expert (Mahdavi & Tahmasebi 2012, Taheri et al. 2013). In any of the different proposed methods, the whole point is that spending more time and using more detailed information, together with the help of statistical analyses leads to better predictions.

Next point regarding the model calibration is that calibration is not a single time process. In some cases, the calibration process needs to be repeated in order to obtain an acceptable match between the simulated and measured data (Tahmasebi et al. 2012, Taheri et al. 2013). It can be anticipated from this kind of procedures to be time consuming. Therefore, the optimal and desirable calibration method requires less time and effort, performs automatically and provides an accurate model. In the next sections a selected calibration method, applied on a simulation model within a systematic process, will be explained in detail.

1.3.4 Optimization-based calibration

Reliability and fidelity of the simulations' outcomes are the key points required to assure the users to make further decisions in case of preliminary designs, retrofit projects, etc. based on the simulation results. Hence, the approach is finding an automated method for calibration of the simulation models through an optimization based process in order to minimize the differences between the actual and predicted performance of the building (Mahdavi & Tahmasebi 2012).

In general, optimization is the process of finding optimal values for a set of independent parameters which leads to minimizing an objective function. In a building simulation model, as examples for the independent variables are the thicknesses of materials, control set points, size of the openings (Peeters et al. 2010). The objective function in an optimization problem is the function has been defined to be optimized and dependent on a specific problem different objective functions are possible to be defined. For example minimizing the operation costs, energy consumption, difference between the simulated and actual values in a model or maximizing the thermal comfort are some of the expected demands from an optimization problem (Wetter 2008).

Although, the use of building simulations in parallel with model optimization has been growing, but designing appropriate algorithms for the optimizations might not be considered in all cases (Wetter 2001). As it was proposed by Brain Coffey in his studies regarding "Simulation-Based Supervisory Control", "a standardized platform for design optimization studies" is required to assist further development of the simulation based controls (Coffey 2008). In this regard, there are different means existing for performing an optimization problem. Reviewing the existing literatures indicate that GenOpt as an optimization program has been used in this area and assisted the simulation based controls (Liu & P. Henze 2005, Peeters et al. 2010, Tahmasebi et al. 2012, Taheri et al. 2013).

GenOpt (LBNL 2011) is an optimization program developed by Michael Wetter (Wetter 2001). It is a Java program free for downloading with the main target of assisting the thermal building simulations. GenOpt can be referred as an interface between the text-based building simulation programs, for instance EnergyPlus (EnergyPlus 2012), and optimization algorithms (Coffey 2008). By having multiple parameters and a cost function GenOpt can find the optimal values for these user-selected parameters. The developer, Michael Wetter, tested the idea of using GenOpt to solve optimization problems in thermal performance simulations such as "minimizing source energy consumption of an office building using EnergyPlus" in his studies (Wetter 2001).

In GenOpt "… the user can select an optimization algorithm from an algorithm library, or implement a custom algorithm … however that optimization is not easy: The efficiency and success of an optimization is strongly affected by the properties and the formulation of the cost function, and by the selection of an appropriate optimization algorithm" (Wetter 2008).

In a "data fitting process" for calibration of a building model based on the actual observed data, first step is defining a cost function to be minimized by GenOpt in order to maximize the accuracy of the results. A proposed method by Mahdavi and Tahmasebi, presented a cost function as a weighted function of two indicators: *CV(RMSD)* and R^2 (Mahdavi & Tahmasebi 2012). According to this equation, which is presented below, the optimization process will minimize the cost function, which simultaneously means minimizing the *CV(RMSD)* and maximizing R^2 :

$$f_i = 0.5.CV\left(RMSD\right)_i + 0.5\left(1-R_i^2\right).\frac{CV\left(RMSD\right)_{ini}}{\left(1-R_{ini}^2\right)} \qquad (1\text{-}4)$$

As the equation demonstrates two components, R^2 and *CV(RMSD)*, are involved in calculations with equal weights.

Different optimization problems can be solved with GenOpt's optimization algorithms and based on the problem the suitable algorithms have been recommended (Wetter 2008). In one class of these problems the cost function can be evaluated by a building simulation program. In building simulation programs such as Energyplus the cost function can be computed by the program. In the most general form, as Wetter presented in GenOpt manual Version 2.1.0, "Let X be as a user-specified constraint set, and f a user-defined cost function. The constraint set X includes all possible design options, and the cost function f measures the system performance. GenOpt tries to find a solution to the problem: $\min_{x \in X} f\left(x\right)$. "

In order to run an optimization by GenOpt with a cost function computed in the building simulation programs such as Energyplus, the files described below are required to be specified (Wetter 2008):

1. GenOpt initialization file: This text file illustrates the information such as location of the files including the optimization problem, which simulation program is being used and number of the cost function value in the simulation output file.

2. GenOpt command file: This text file clarifies the optimization design variables, their initial values and the upper and lower boundaries. The optimization algorithm and settings are also required to be specified in this folder.

3. GenOpt configuration file: This file contains the information regarding the used simulation program.

4. Log file: The GenOpt log file contains information about the optimization process and it is named as GenOpt.log.

5. Output file: Two output files i.e. "OutputListingMain.txt" (contains the main iteration steps) and "OutputListingAll.txt" (contains all iteration steps) list the optimization steps.

To sum up, in order to set up an optimization problem in GenOpt, it is required to define a cost function, the optimization variables, their allowable ranges and the files described above (Wetter 2008).

2 METHODOLOGY

2.1 Objective

The main objective in this master thesis is to populate the initial thermal performance model for an existing office building and maintain the precision in the predictions by means of an optimization-based calibration process. An available calibration method was chosen and applied on a real building model. Thereby, the method was evaluated in the sense of accuracy, stability, easiness in application and capability for practical purposes. It should be noted that in the current work, the whole process ab initio i.e. creating the initial model, to the end, generating the calibrated model and evaluating the fidelity of the results, was aided by the observed data provided by a monitoring system. Figure 2-1 schematically demonstrates different steps of this contribution which ultimately leads to an optimization based calibrated model.

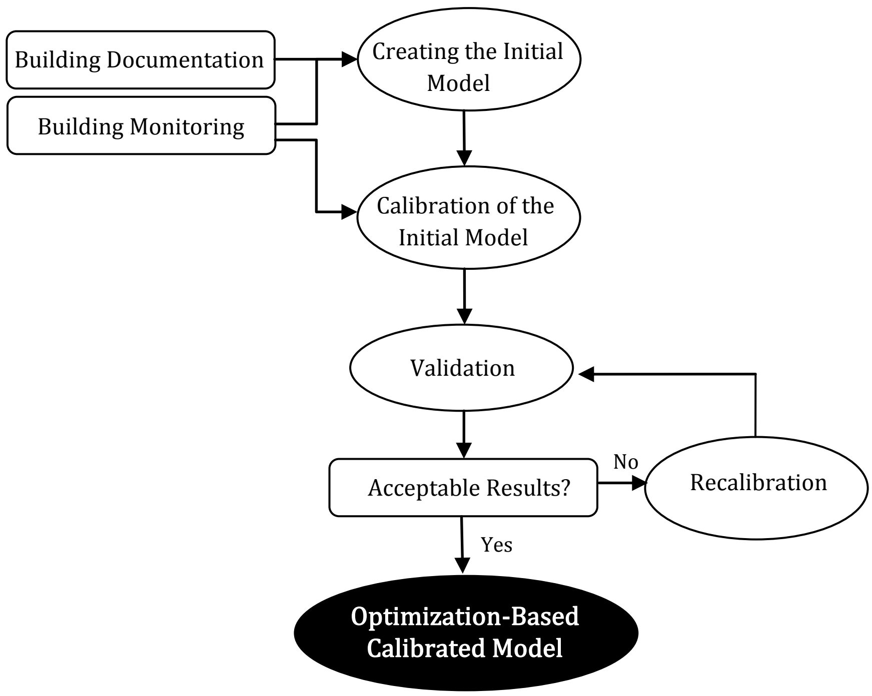


Figure 2-1 Objective mind map

2.2 Applied building simulation programs

The building energy simulation tool, assisting the building performance modeling in this master thesis, is "EnergyPlus (EP) version 7.0" provided by US department of energy (EnergyPlus 2012). There are several benefits and reasons underlying the selection of EP, such as the ability to simulate advanced building features, validity and finally availability for free. Since EP doesn't provide GUI (Graphical User Interface), in order to ease the geometry modeling "Ecotect Analysis 2011", Autodesk, with a higher level of user interface was used (Autodesk Ecotect Analysis 2012). Even though Ecotect is an environmental analysis program and building performance simulation tool, but here it was used only as a 3D modeler, compatible with EP.

2.3 Initial model

A typical building simulation process starts up with definition of the initial building model. Whole building simulation programs, like EP, require extensive input data to accurately model the energy use and performance of the buildings (EnergyPlus 2012). The input data used in the current work can be summarized in two main categories:

– Firstly, the so called physical input data, such as building geometry, building elements' constructions, thermal properties of the materials.

– Secondly, the dynamic input data namely the monitored data, like the data points from occupants' behaviors, output of heating terminals, state of the devices such as luminaires, windows and blinds.

In the subsequent paragraphs description of the required input variables in order to create the initial model (Appendix A) has been presented.

2.3.1 Location and geometry

The case study of this thesis, located in Lehargasse 1040, center of Vienna, Austria, is a new building of Vienna University of Technology called Lehartrakt. This case study consists of two offices and one conference room in which the thermal performance was evaluated. Lehartrakt was completed in 2010 and equipped with various building monitoring infrastructures. The selected part of this building was equipped with the essential monitoring system, required for the method applied in the current work. We will focus in more details on the monitoring system of this model in the subsection 2.3.4 entitled "Monitored data".

By means of the existing plans, measurements and observations at the building site the required information for the geometry modeling was collected. Figure 2-2 illustrates the geometry model of the three monitored rooms in Ecotect.

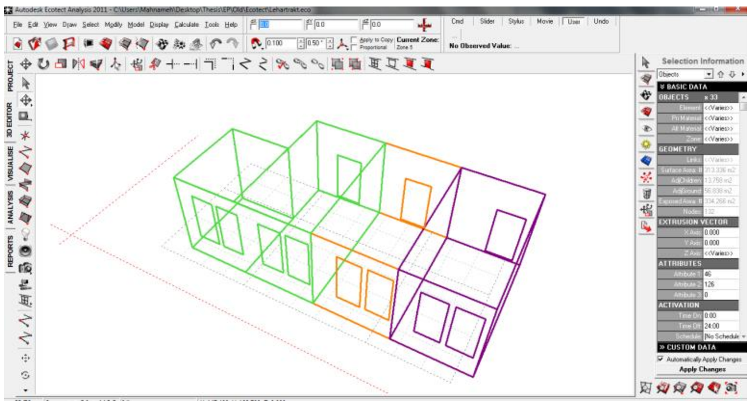


Figure 2-2 3-Dimentional model of the geometry, Ecotect

2.3.2 Thermal properties of the constructions

After the geometry modeling next step would be assigning the respective constructions to each building element. As such in all simulation programs, in order to create the initial model in EP, thermal properties of the constitutive materials of the building components are required. Different types of materials with thermal properties of each will generate opaque or transparent constructions. Identifying the thermal properties of the building constructions enables EP to consider thermal mass of the material, evaluate the conduction phenomenon, or generally produce the thermal model of the building.

As we discussed in the previous parts, generating more exact models from the initial level leads to more accurate predictions and ease the next required calibration processes. In the current work, definition of the properties of the materials and constructions was firstly based on available building plans. Secondly, product labels in cases such as façade, glazing and frames were useful to find the constructions and thermal properties from the catalogs provided by the factories. Although even with the fully detailed descriptions of the model, credibility of the simulation results could be influenced by lack of certainty in input parameters, at each stage we should try to reduce the inaccuracies.

Table 2-1, 2-2 and 2-3 demonstrate the properties of different layers of the building elements and materials, required to create the initial model in EP. They provide listed thermal properties of opaque, glazing and gas layers.

Building Component	Layers (outside to inside)	Thickness [m]	Conductivity [W. m^{-1}. K^{-1}]	Density [kg. m^{-3}]	Specific heat [J. kg^{-1}. K^{-1}]
Exterior wall (West)	Aluminium Sheet	0.002	204	2700	896
	Air	0.20			
	Insulation Mineral Wool	0.10	0.039	70	840
	Concrete	0.21	0.72	1400	840
	Plaster	0.02	0.07	1600	1110
Exterior wall (South)	Glazing- Green 6mm	0.006			
	Insulation Mineral Wool	0.10	0.039	70	840
	Concrete	0.21	0.72	1400	840
	Plaster	0.002	0.07	1600	1110
Interior wall 1	Wood board	0.025	0.09	400	1300
	Air	0.10			
	Wood board	0.025	0.09	400	1300
Interior wall 2	Plaster	0.02	0.07	1600	1110
	Brick	0.11	0.39	1000	880
	Plaster	0.02	0.07	1600	1110
Floor	Plaster	0.02	0.007	1600	1110
	Concrete	0.20	1.00	1800	1110
	Insulation EPS	0.04	0.038	24	1210
	Concrete Screed	0.03	0.785	1600	840
	Ceramic	0.0127	1.20	1920	1260
Ceiling	Concrete tile	0.03	1.10	2100	837
	Cement mortar	0.05	1.40	2000	920
	Insulation XPS	0.34	0.05	30	1210
	Concrete	0.20	1.00	1800	1110
	Plaster	0.02	0.07	1600	1110

Table 2-1 Properties of the enclosure elements

Material: Air gap	Thickness [m]	Thermal resistance [m^2. K. W^{-1}]
Air - Exterior wall	0.20	0.15
Air - Interior wall	0.10	0.15

Table 2-2 Properties of the air-gaps

Window Material		
Glazing	Solar transmittance [-]	Solar reflectance [-]
Clear 6mm	0.78	0.07
Green 6mm	0.48	0.37
Blind	Slat Width [m]	Slat separation [m]
Blind with medium reflectivity slats	0.025	0.01875
Gas	Thickness [m]	
Argon	0.013	

Table 2-3 Properties of the window components

2.3.3 Thermal zoning

Thermal zones are the fundamentals in building energy simulations. A room or group of rooms with similar thermal loads, with the same HVAC (Heating, Ventilation and Air Conditioning) system or the same thermostat set-points can be considered as a zone. In thermal zoning different strategies are existing which two of them can be mentioned as simple or detailed zoning (EnergyPlus 2012). For example in our case study with three monitored rooms, estimating the total loads can be done with a simple one zone model without a considerable difference with a more detailed thermal zoning. But on the other hand, for a more detailed energy or load calculations in each room, a more detailed zoning is required. Therefore, considering the second method in zone definition results a more detailed information concerning the distributions of loads/energy. Since in this project separate study on the simulation results in each monitored room is required, the model is divided in three zones (Table 2-4). Thus more detailed outputs such as the simulated mean air temperature in each zone can be provided. In addition, two non-monitored zones are also involved in parts of this work to define different model calibration scenarios, as will be dealt with later.

Zone	Ceiling height[m]	Volume [m^3]
Zone2	3.6	89.33
Zone3	3.6	58.59
Zone4	3.6	57.26

Table 2-4 Monitored thermal zones

2.3.4 Monitored data

Monitored data aiding thermal simulations in creating local weather files, simulation validations and calibrations has been discussed previously within the subsection 1.3.2 "Monitoring assisted thermal simulation". With this background, in the followings we will concentrate on incorporation of the observed data by monitoring system in the current case study.

2.3.4.1 Local weather file

Generating the local weather file based on the measured values by a local established weather station is beneficial to run more accurate simulations.

Department of Building Physics & Building Ecology of Technical University of Vienna, is equipped with a weather station. Therefore, the available weather file based on the observed data for years 2011 and 2012 were used in the current work. EnergyPlus reads the text-based weather files with the file extension of EPW. Before running the simulations in EP-launch i.e. main directory of EnergyPlus, the relevant weather file for the project needs to be specified.

Table 2-5 demonstrates the observed data points to create the local weather file (Mahdavi & Tahmasebi 2012)

Data point	Unit
Global horizontal radiation	$W.m^{-2}$
Diffuse horizontal radiation	$W.m^{-2}$
Outdoor dry bulb temperature	°C
Outdoor air relative humidity	%
Wind speed	$m.s^{-1}$
Wind direction	degree
Atmospheric pressure	Pa

Table 2-5 Monitored data points for creating the weather file

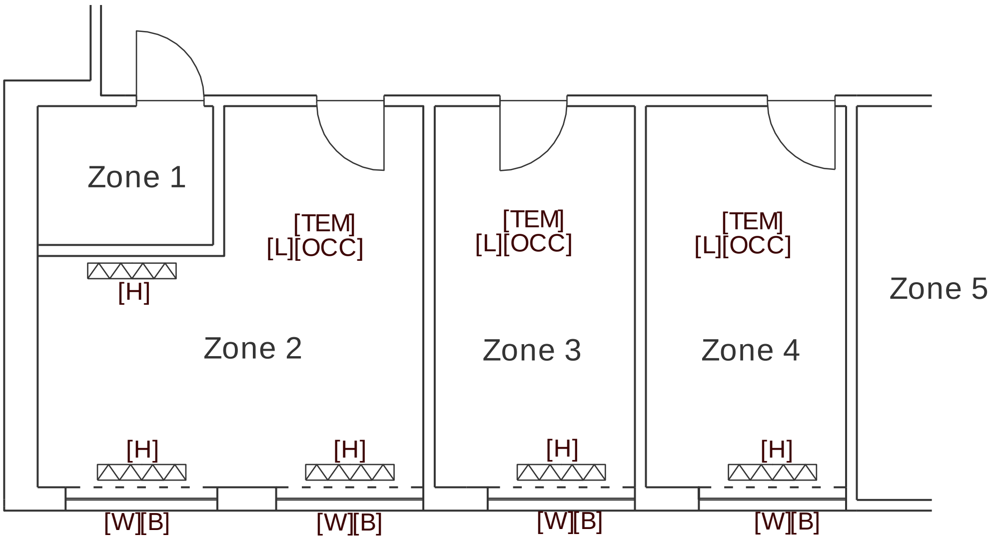
2.3.4.2 Preparing compact schedules

The case study of this work consists of two offices and one conference room has been equipped with a four-layer model of a monitoring system in the course of another research project. The existing sensors in the physical level measure:

– Indoor temperature
– Relative humidity
– Carbon dioxide
– Volatile organic
– Heat power
– Electrical power
– Window contacts
– Door contacts
– State of blinds
– Light
– Occupancy

To assist simulation, calibration and validation processes measured data streams were used in two ways. First of all in creating the initial model the observed data was incorporated as the scheduled variables such as state of windows (open/closed), blinds (open/closed), occupancy (absence/presence), light (on/off) and heat emission of the radiators. Secondly, in the further steps for calibration and validation of the simulated model, monitored data were aiding the evaluations (by comparing the measured and simulated indoor temperature). The implementation of optimization-based calibration will be fully discussed later in the relevant section; however, in the rest of this part we will focus on preparation of the scheduled variables. Figure 2-3 and 2-4 illustrates the installed sensors in the rooms. As Figure 2-4 shows two unmonitored zones are also involved in part of the predefined scenarios in this work, which we will deal with later. Table 2-6 demonstrates number and IDs of the applied sensors in each zone.

Figure 2-3 Installed sensors, Lehartrakt



Window contact	[W]
Temperature	[TEM]
Heat power	[H]
Occupancy	[OCC]
Blind	[B]
Light	[L]

Figure 2-4 Building floor plan, thermal zones and installed sensors

Zone	Available Sensor	No.	ID
	State of window openings [W]	4	Con28,Con29,Con30,Con31
	Occupancy [OCC]	1	Occ12
Zone 2	Heat power [H]	3	Hea-pow2, Hea-pow3, Hea-pow4
	State of the lights [L]	1	Light1-sw
	Indoor temperature [TEM]	1	Tem1
	State of the blinds [B]	2	blind1-position
	State of window openings [W]	2	Con32, Con33
	Occupancy [OCC]	1	Occ14
Zone 3	Heat power [H]	1	Hea-pow5
	State of the lights [L]	1	Light2-sw
	Indoor temperature [TEM]	1	Tem2
	State of the blinds [B]	1	Blind2-position
	State of window openings [W]	2	Con34, Con35
	Occupancy [OCC]	1	Occ15
Zone 4	Heat power [H]	1	Hea-pow6
	State of the lights [L]	1	Light3-sw
	Indoor temperature [TEM]	1	Tem3
	State of the blinds [B]	1	blind3-position

Table 2-6 Available sensors

Incorporating the values of the time-varying input parameters in the model was accomplished with the aid of the scripts written in MATLAB 7.11.0 (MATLAB 2012). This program reads the monitored data from building management system database and converts it to an event based compact schedule using the compatible syntax of EP input file. These schedules are later assigned to the corresponding input parameter in the model. This will prevent the simulations from some of the inadequate considerations and assumptions.

2.3.4.3 Run periods

Simulations were applied to four monitoring periods, about five month including summer and winter seasons. In the different run periods both passive and active operation situations are included. In fact, both summer period as the passive operation mode and winter period with the active heating system are incorporated in the simulations.

Long-term monitoring besides the usability in evaluation of the initial model in different run periods will help the model calibrations. The resulting calibrated model in one run period can be evaluated in other run periods, namely validation periods. Subsequently, it would be possible to analyze and re-calibrate the calibrated model under different conditions, for example in the sense of environmental conditions. The criterion for evaluation of simulation validity in this work is comparing the simulated values (i.e. simulated zone air temperature) with the monitored data (measured zone air temperature) in the initial and calibrated models. These explanations reveal the influential help of a long term monitoring in implementation of calibration and testing process in different run periods. It should be stated here that this research has been done before summer 2012. Therefore, as monitored data for summer 2012 was not available at the time of analysis, two different summer periods in the same year (2011) were chosen. Table 2-7 summarizes different run periods with their beginning and end date.

Period	Start date	End date
1st summer period	10.06.2011	23.07.2011
2nd summer period	24.07.2011	26.08.2011
1st winter period	15.02.2011	24.03.2011
2nd winter period	15.02.2012	24.03.2012

Table 2-7 Run periods

2.4 Calibration of the initial model

By calibration of the initial model, the objective was maintaining fidelity in the simulation model through a systematic process. "Calibration" is an expression which has been used here to express the process of finding optimal values for a set of uncertain-input parameters to obtain the maximum accuracy in a simulation model. As a matter of fact for any optimization process some starting values are needed, since there is no exact data about the starting values thus a set of trial values in the initial model was assigned to these parameters for initializing the optimization. The optimization process hopefully leads to finding an optimal set of design parameters while there is no guaranty to converge to the global optimal condition. By the method applied in the current work, calibration is an iterative process starting with the base case model, over the successive steps, to obtain a model which faithfully represents the thermal performance of the building. In the following parts, the applied optimization-based calibration method and its requirements have been described in detail.

2.4.1 Calibration variables

Generally thermal simulation tools are used to assess thermal performance of building models in design levels or refurbishment projects. We can assume the sources of inaccuracies in the simulation results in three categories provided below (based on the background e.g. Macdonald et al. 2012):

– First of all, while transferring a model to a computer, simplifications are done which reduce the accuracy level of the modeling.

– Secondly, there might be differences between the provided information by database or the collected information by the users and the actual properties of the model. One of the sources of this mismatch is the assumptions made in modeling.

– Thirdly, apart from the assumptions and simplifications, the required level of detailed information by simulation tools for modeling is also affecting the accuracy of models.

Commonly, the main sources of user-dependent errors placed in the first two categories (Macdonald et al. 2012). In addition, subjecting all the input parameters of a thermal performance model to an optimization based calibration is computationally expensive (Tahmasebi et al. 2012). Given this background, in the current work the focus will be on the second category. Uncertainty in our knowledge regarding the exact values of some input parameters, which is one of the justifications for deviation of the simulated values from the measured values, highlights the importance of calibrations. This part contributes with the definition of these important input parameters that would receive special attention in our analyses. These variables address the heat transfer (convection, conduction and solar radiation) in the model (Taheri et al. 2013). The background from previous studies in this area (which was discussed in section 1.3.3 "Calibration of thermal simulation model") provided reasonable guidance for selection of the parameters with higher impacts on the outputs.

These key selected parameters namely the calibration variables are:

- Infiltration rate
- Ventilation rate
- Solar transmittance of the glazing
- Thermal conductivity of insulations
- Density of concrete
- Mean air temperature of the adjacent non-monitored zones during summer and winter

A remarkable point here to be considered is that in some cases modification of a property is associated with changes in some other properties. Hence, the correlation between the parameters should be also considered. Equation 2-1 and 2-2 demonstrate the relation between the thermal conductivity and density in concrete which is derived from the litreture Gösele & Schüle (1983):

$$\lambda_C = 0.0008 * \rho_C - 0.4617 \tag{2-1}$$

$$\lambda_W = 0.0007 * \rho_W - 0.2533 \tag{2-2}$$

Here λ_C and ρ_C denote thermal conductivity [W.m^{-1}.K] and density [kg.m^{-3}] of the ceiling concrete, respectively. Similarly, λ_W and ρ_W are the thermal conductivity [W.m^{-1}.K] and density [kg.m^{-3}] of the wall concrete. To prevent the optimization from going through unrealistic combinations of these two properties, the relation between them was considered. Therefore, thermal conductivity of the concrete (wall/ceiling) is not directly involved in the optimization process and its optimized value is dependent on the optimized density.

After specifying the calibration variables, the next step is defining their variation ranges. In fact, the pertinent parameters are allowed to be tuned during the optimization process in the defined ranges, to deduce which combination will lead to the minimum error. Allowable ranges for variables representing solar transmittance, thermal conductivity and density is 30%, while for ventilation and infiltration rate wider ranges has been defined.

Concerning the mean air temperature in the adjacent non-monitored zones (zone 1 and 5) a logical assumption of their initial values is also required. Therefore, for zone one, the average temperature of its adjacent zone, zone two, in the first summer period was assigned as the initial value of the summer indoor temperature. With the same method, for the first winter period average temperature of zone two (in the first winter period) has been used. The same in zone five, the average temperature in zone four, in the first summer and first winter periods were assigned as the initial values. Then the upper and lower bounds for these two parameters were specified based on the ASHRAE standard 55-2004 (ASHRAE 2004). These bounds allow indoor temperature of zones one and five to vary within the whole range of operative temperature in the comfort area given by ASHRAE, till finding the combination which minimizes the cost function. Table 2-8 illustrates the initial values, upper and lower limits for the independent parameters subjected to calibration.

Variables		Unit	Lower Limit	Initial Value	Upper Limit
Infiltration rate		h^{-1}	0.10	0.20	0.40
Ventilation rate		h^{-1}	0.50	1.00	3.00
Solar transmitance					
	Green 6mm	-	0.34	0.48	0.62
	Clear 6mm	-	0.54	0.78	1.00
Thermal conductivity					
	Mineral wool	$W.m^{-1}.k^{-1}$	0.03	0.04	0.05
	XPS	$W.m^{-1}.k^{-1}$	0.03	0.05	0.07
Density					
	Ceiling Concrete	$kg.m^{-3}$	1260	1800	2340
	Wall Concrete	$kg.m^{-3}$	980	1400	1820
Mean air temperature					
Zone 1	summer	^oC	23.6	26.7	28.3
	winter	^oC	19.6	24.2	26.3
Zone 5	summer	^oC	23.6	26.6	28.3
	winter	^oC	19.6	23.9	26.3

Table 2-8 Initial values together with lower and upper limits of the variables subjected to calibrations

2.4.2 Optimization

Calibration of the thermal simulation model of this case study is an optimization-based process. In this method without the intervention of users, simulation and optimization work automatically in parallel. The optimization problem has been defined to minimize a user-supplied cost function by adjusting a user-specified set of variables in defined ranges. The cost function in this work, is an equally weighted function of two error indicators, *CV(RMSD)* (Eq. 1-2) and R^2 (Eq. 1-3).

In thermal simulation programs like EnergyPlus, the cost function can be computed by the program. Thus, to define the cost function *f* (Eq. 1-4), a custom programming in EP, Energy Management System (EMS), is required. "EMS is one of the high-level control methods available in EnergyPlus. An EMS is able to get access to a wide variety of "sensor" data and use this data to direct various types of control actions" (EnergyPlus 2012). The programming language in EMS is EnergyPlus Runtime Language (Erl). To explain concisely, first of all two virtual sensors representing the simulated and monitored indoor temperature were added in EMS. The measured temperature will be imported to EP as an scheduled variable. By running the simulation, one of these sensors will read the simulated temperature (Y) and the other one the measured temperature (X). Therefore, by inserting the pertinent equations in "EnergyManagementSystem:Program" for *CV(RMSD) and* R^2, the cost function *f* will be calculated. Through the equations, after each run the difference between actual temperature and simulated temperature demonstrates the error quantity in the run period. Subsequently, the statistics of each EMS variable, such as *CV(RMSD),* R^2 and *f* are available by invoking EP for providing reports through "EnergyManagementSystem:OutputVariable" and ''Output: Variable''.

What was tried to explain above is a summarized explanation to gain a brief insight regarding the programming in EP. In fact, a full description of the procedure is beyond the scope of this thesis and it is freely available online as documents called

"Application Guide for EMS" and "EergyPlus InputOutputReference"(EnergyPlus 2012).

Next step of optimization is coupling GenOpt with EP to get the optimized values for the chosen variables and minimizing the cost function. GenOpt can work as an interface between text-based building simulation programs such as EnergyPlus and optimization algorithms (Coffey 2008). In case of multiple involved parameters and an objective function, in order to minimize the objective function we will get the optimal values for the defined parameters from GenOpt. The search algorithm is based on iterations, consecutively making numbers of evaluations and improvements within the search area in order to reach the optimized result. As elucidated in the previous subsections, the selected variables for optimization in this work are infiltration and ventilation rates, G-values of glazing, thermal conductivity of mineral wool and XPS, density in wall/ceiling concrete as well as the average indoor temperature of the adjacent non-monitored zones during summer and winter. Therefore, to set up the optimization problem the required files explained in the section 1.3.4 "Optimization-based calibration" must be specified (refer to Appendix B). As we described above, the cost function *f* will be computed by EnergyPlus. Therefore, at each optimization step GenOpt should write the selected values for the optimization variables in the simulation input file to enable the simulation engine calculate the cost function. Hence, in the "simulation input template file" (defined in the GenOpt initialization file) we replace the values of the selected variables to %VariableName%. This string refers to variables' name which has been specified in the GenOpt command file. Finally, list of the optimization steps, the optimized variables and the minimum cost function as the optimization results are available in the GenOpt output files. By means of the optimized values the calibrated model will be generated.

2.4.3 Validations and recalibrations

The optimized values derived from the optimization process, which was applied in the calibration period, are required to be validated in other run periods. In fact, validations are necessary to ensure how accurate the calibrated model represents the actual model under different conditions. Therefore, in this work, the results from each calibration have been examined in the validation periods.

As explained before, due to the dynamic nature of building, calibration cannot be an ad hoc or one-time activity. Hence in order to achieve the calibrated model of the offices under study, through two predefined scenarios successive optimization-aided calibrations were performed. In the next section, the results from implementation of the described methodology will be discussed in detail.

3 RESULTS

After a comprehensive description of the methodology applied in the current thesis, I would like to present the results, with diagrams and tables along with the discussions. It should be noted that the available "monitored" case study is the focal point for this thesis, since it enables examining different scenarios which provided interesting results.

3.1 First scenario

In order to reduce the errors in simulation results, one beneficial option is accumulating enough, accurate and comprehensive information to create the initial model. In the current case study, we evaluate the thermal performance of three monitored zones. In the first scenario a single zone model of the middle office (zone3) was deployed. This enables us to use the monitored temperature in the adjacent offices (zone 2 and 4) as the boundary conditions of zone 3. It should be stated here that definitions of boundary condition of zones had an important effect in determination of different scenarios in the current work.

As the first step, to reduce the volume of assumptions in simulations, the calibration started from one-zone model with more actual observed data regarding its adjacent zones.

3.1.1 First step: One zone

3.1.1.1 Initial one-zone model

The initial model was generated by the collected input information described in section 2 "Methodology". At the beginning of the first scenario, the thermal performance in zone three will be evaluated. Therefore, the schedules generated based on the measured indoor temperature in zones two and four as predefined thermostats in these zones can be added to the initial model. In this way, the actual temperature in these two zones will be used as the boundary conditions of the central zone.

For this purpose the "HVAC Template Objects" in EP has been used. From the category of HVAC Template Objects in EP, two objects called "HVACTemplate:Thermostat" and "HVACTemplate:Zone:IdealLoadsAirSystem" were added to the model. "HVACTemplate:Thermostat" is an EP object which can be used either to specify constant temperature set-points for a zone, or set-points by a defined schedule for the run period. Afterwards, each thermostat will be applied to the specific zone (in this case zone 2 and 4) through "HVACTemplate:Zone:IdealLoadsAirSystem". The measured indoor temperatures of the zones two and four have been converted to compact schedules with the aid of a script written in MATLAB. Subsequently, the related schedules were assigned to the zones as the heating and cooling set points.

By generating the initial model and running it in four run periods, the initial results will be achieved. On top of that, as explained before, *CV(RMSD)*, R^2 and f will be calculated by EP based on differences between the measured and simulated zone temperature.

3.1.1.2 First calibrated one-zone model

After obtaining the initial simulation results, next step is the first calibration of the initial model. At this stage, an optimization-based calibration will be applied on the initial model. The first calibration will be performed in the first summer period and the accuracy of the resulted calibrated model will be examined in the summer and winter validation periods. Figure 3-1 represents the process of creating the initial model, calibration and validations.

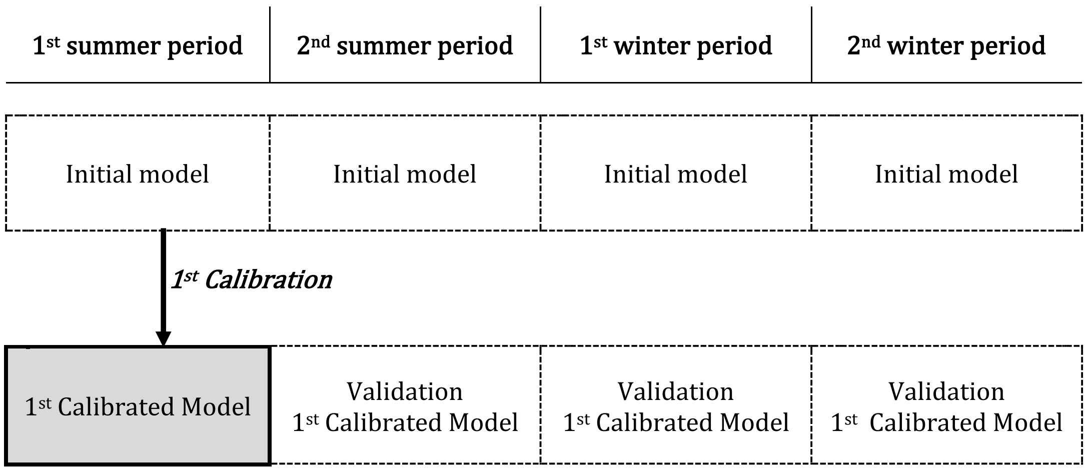


Figure 3-1 The process of creating the initial model, calibration and validations in one-zone model [1]

In the first calibration eight design variables were subjected to the optimization-based calibration. Table 3-1 demonstrates these parameters with their initial and optimized values. Figure 3-2 presents the graphs formed based on the parameters behavior in different optimization steps, in order to get a better insight into the optimization process. The graphs illustrate how different values have been assigned to the variables until reaching the combination with the minimum possible resulted cost function.

[1] The calibration period is highlighted.

Variables		Unit	Initial Value	1st Optimized Value
Infiltration rate		h^{-1}	0.20	0.40
Ventilation rate		h^{-1}	1.00	0.50
Solar transmitance				
	Green 6mm	-	0.48	0.38
	Clear 6mm	-	0.78	0.62
Thermal conductivity				
	Mineral wool	$w.m^{-1}.k^{-1}$	0.039	0.047
	XPS	$w.m^{-1}.k^{-1}$	0.05	0.07
Density				
	Ceiling Concrete	$Kg.m^{-3}$	1800	1260
	Wall Concrete	$Kg.m^{-3}$	1400	980

Table 3-1 The values of optimization parameters in initial and calibrated one-zone model

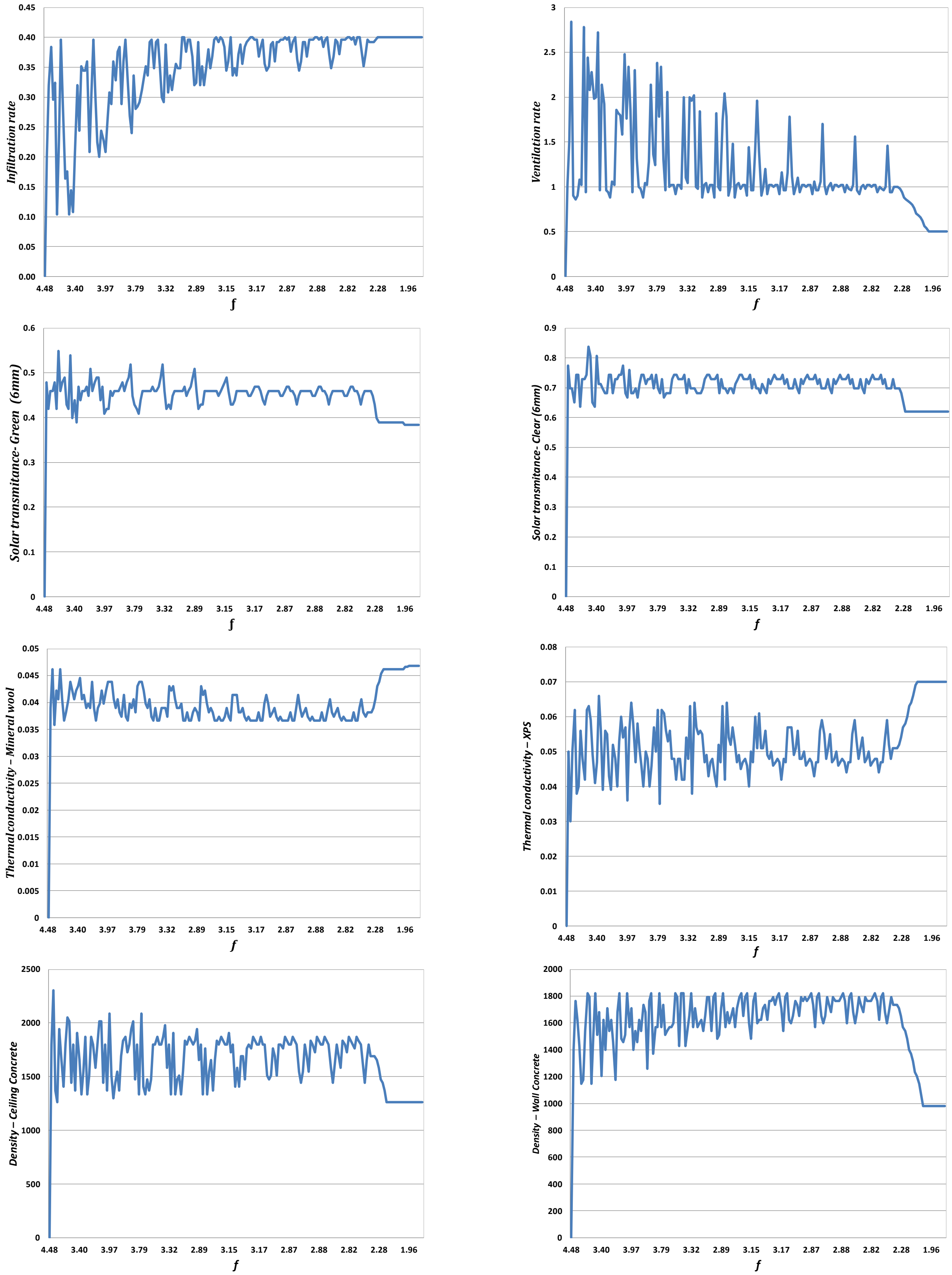


Figure3-2 Graphical demonstration; Behaviour of the eight parameters involved in the 1st optimization to minimize the cost function f

With the obtained optimized values the first calibrated model can be created. The only difference between this model and the initial model is the assigned values to the eight optimization parameters and the two other dependent parameters (Eq. 2-1 and 2-2). Running the first calibrated model in four run periods will give us new results regarding the error indicators. Table 3-2 demonstrates *CV(RMSD)* and R^2 resulted from the initial models and the first calibrated models in all run periods.

	1st summer period		**2nd summer period**		**1st winter period**		**2nd winter period**	
	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2
Initial model	4.51 %	0.77	4.89 %	0.94	15.14 %	0.26	16.31 %	0.69
1st Calibrated Model	1.48 %	0.88	2.22 %	0.96	4.40 %	0.35	5.53 %	0.81

Table 3-2 CV(RMSD) and R^2 in initial and 1st calibrated one-zone model

As illustrated in Table 3-2, comparing *CV(RMSD)* and R^2 shows that in the initial models, the conformity between the monitored and simulated indoor temperature in the summer periods is higher than the winter periods. This difference can be justified through more complexity of the input parameters related to the winter simulations than summer, such as the heating systems which may cause more inaccuracies. On the other hand, comparing the results from the initial and first calibrated models demonstrates significant improvements after the first calibration. Thus, we can argue that the errors in all four periods are so low that recalibrations are not required at this level (*CV(RMSD)* $< 6\%$ and $R^2 > 0.5$) , except the R^2 in the first winter period that is not desirable and we will discuss about it in the next sections and further recalibrations.

Inasmuch the simulated indoor temperature are provided as hourly reports by EP, line charts can give us a better impression concerning how calibrations can improve the simulated model. Therefore, Figure 3-3 depicts monitored temperature together with the simulated temperature in initial and first calibrated model. Comparing the charts demonstrates considerable improvements in the predicted indoor temperature after the first calibration, especially in the two winter periods. More similar trends between the line charts from simulated and measured indoor temperature in the first calibrated model highlights the positive impacts of optimization-based calibration on the simulation predictions.

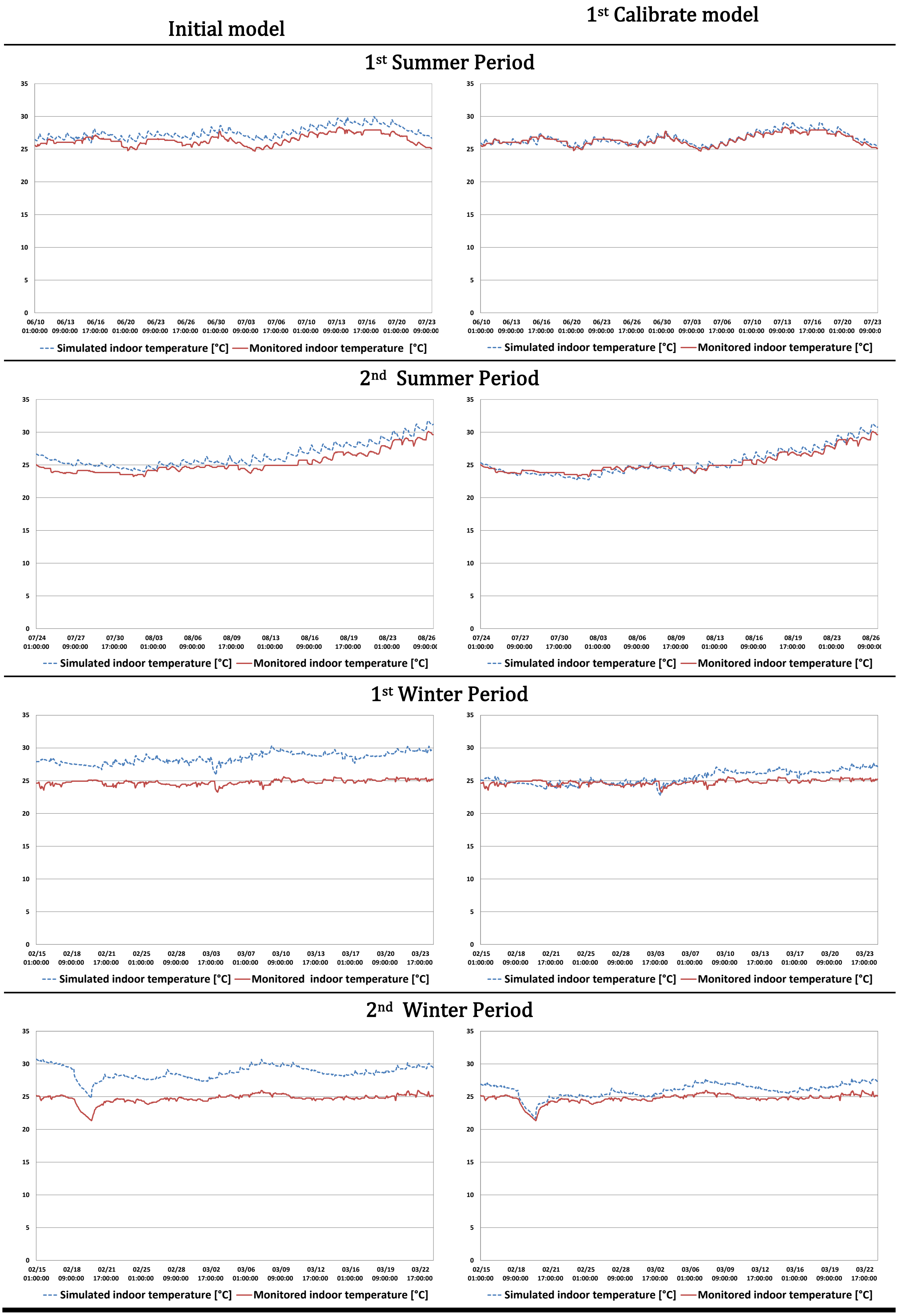


Figure 3-3 Monitored and simulated indoor temperature in different run periods, initial (left) and 1st Calibrated (right) one-zone model

3.1.2 Second step: Three zones

In the first calibration of one-zone model, eight input parameters of the model have been optimized to better fit the model to the measurements. In the followings, simulations and recalibrations of the three-zone model, based on the results from the first calibration are provided.

3.1.2.1 First calibrated three-zone model

The initial model of three zones will be populated based on the results from the first calibration in one zone as the initial values of the eight parameters. Since evaluation of the thermal performance in three zones is demanded at this stage, the "HVAC Template Objects" which helped to define thermostats in zones two and four should be removed. Moreover, in the optimizations applied to three zones, cost function will be the weighted sum of averaged *CV(RMSD)* and also averaged R^2 in three zones. Thus we derive the averaged relations based on Equations 1-2 to 1-4:

$$CV\left(RMSD\right)_{ave} = \frac{CV\left(RMSD\right)_{zone2} + CV\left(RMSD\right)_{zone3} + CV\left(RMSD\right)_{zone4}}{3} \tag{3-1}$$

$$R^2_{ave} = \frac{R^2_{zone2} + R^2_{zone3} + R^2_{zone4}}{3} \tag{3-2}$$

$$f_{ave} = 0.5.CV\left(RMSD\right)_{ave} + 0.5.\left(1 - R^2_{ave}\right).\frac{CV\left(RMSD\right)_{ave_{ini}}}{\left(1 - R^2_{ave_{ini}}\right)} \tag{3-3}$$

By running the simulations we obtain the results from the first calibrated three-zone model, which will be subjected to the second and third calibrations.

3.1.2.2 Second and third calibrated three-zone model

In the later calibrations, in the three zone-model, six of the optimized parameters from the 1st calibration which are related to physical properties of the building (i.e. G-value of the glazing, thermal conductivity of the insulations and concrete plus density of concrete) have been used without being subjected to recalibration anymore. However, the infiltration and ventilation rates, as time-varying input parameters, have been calibrated in the three-zone model. Therefore the second and third calibrations were applied to the first summer and first winter periods, respectively. Thereafter by running the simulations based on the second and third optimized values of the infiltration and ventilation rates, the calibrated models will be generated. Afterwards, the resulting calibrated models were evaluated in other summer and winter periods as the validation periods (Fig. 3-4). Table 3-3 illustrates the initial, first, second and third optimized values of the optimization variables. As presented in this table, six parameters have been constant after the first calibration, while infiltration and ventilation rates were calibrated in the later calibrations.

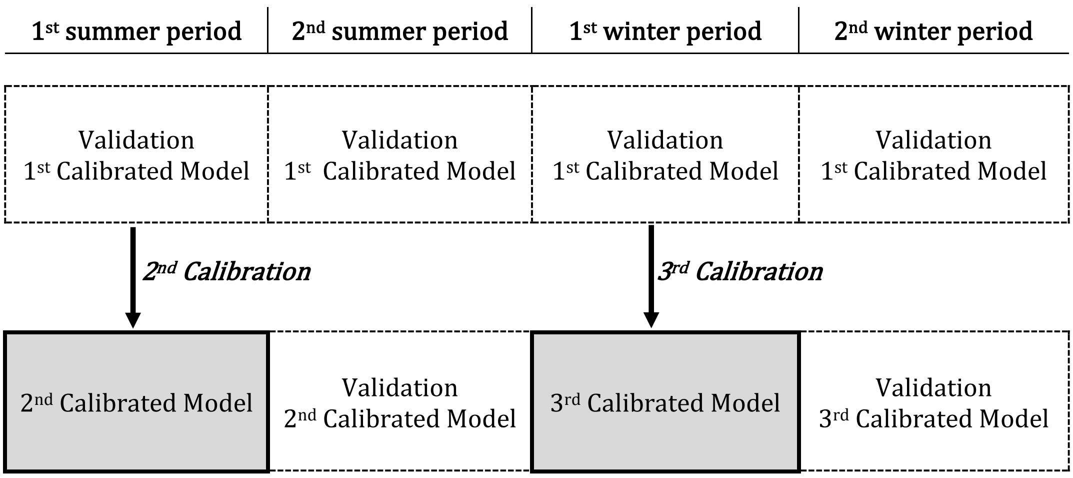


Figure 3-4 Calibration and validation process, three-zone model [2]

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[2] The calibration periods are highlighted.

Variables	Initial Value	1st Optimized Value	2nd Optimized Value	3rd Optimized Value
Infiltration rate	0.2	**0.4**	**0.12**	**0.28**
Ventilation rate	1.0	**0.5**	**0.59**	**0.50**
Solar transmitance				
Green 6mm	0.48	**0.38**	0.38	0.38
Clear 6mm	0.78	**0.62**	0.62	0.62
Thermal conductivity				
Mineral wool	0.039	**0.047**	0.047	0.047
XPS	0.05	**0.07**	0.07	0.07
Density				
Ceiling Concrete	1800	**1260**	1260	1260
Wall Concrete	1400	**980**	980	980

Table 3-3 The values of optimization parameters in initial and calibrated three-zone models [3]

It was noted that the indicators, *CV(RMSD)* and R^2, have been computed based on the differences between simulated and monitored temperature. Apart from their contribution in the optimization process, they were also utilized in this work to judge the accuracy of the simulated model. Therefore, Table 3-4 will ease assessing the contradiction between the simulated model and the actual model by presenting *CV(RMSD)* and R^2 in first, second and third calibrated three-zone models in all run

[3] The optimized parameters in each optimization process are illustrated by bold fonts.

periods . It demonstrates that, the first calibrated three-zone model, the same as in the single-zone model, has higher accuracy in summer run periods than in the winter. With the same justification, this difference can be explained by engagement of more uncertain input parameters in the winter simulations, such as state of the heating systems. The results from the summer periods state that second calibration improves the *CV(RMSD),* while decreases the R^2. In order to describe this problem it must be reminded that these indicators are counted with equal weights in the cost function calculations. As the related cost function equation represents, optimization is supposed to minimize f by reducing *CV(RMSD)* and increasing R^2. But sometimes a general improvement like minimizing f by minimizing *CV(RMSD)* in a great amount without maximizing R^2 will be resulted from the optimization. In the current case as Table 3-4 demonstrates, the reduction in R^2 in comparison to the improvements in *CV(RMSD)* is negligible. In the cases that improving an indicator causes remarkable deterioration in the other one, further researches in order to define a different equation to calculate the cost function are required. Evaluation of the results in winter periods also states that similar situation occurred in the winter calibration, where reducing the amount of *CV(RMSD)* caused a slight reduction in R^2. The outcomes in the winter period, especially in the first winter period demonstrate that despite the improvement in *CV(RMSD)* the results are not satisfactory enough.

In order to inspect more precisely in the results, Figure 3-5 to 3-8 illustrate the line charts based on the hourly reports of the simulated and monitored temperature in all run periods for the first, second and third calibrated models. Whereas *CV(RMSD)* and R^2 are indicating the average errors in the three zones, these charts would enable us to have a more detailed insight into the accuracy of the outcomes in each zone. Comparing the charts reveals that the simulation results in the summer periods are more accurate than the winter periods. By more precise investigations in the winter results, it can be concluded that the difference between the monitored and predicted indoor temperature in zone four is more than the other two zones. In order to explain this inaccuracy, in the followings further studies on three zones are provided.

	1st summer period		2nd summer period		1st winter period		2nd winter period	
	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2
1st Calibrated Model	7.67 %	0.69	7.32 %	0.89	19.35 %	0.50	13.16 %	0.61
2nd Calibrated Model	5.06 %	0.65	4.41 %	0.86	-	-	-	-
3rd Calibrated Model	-	-	-	-	11.95 %	0.48	7.32 %	0.60

Table 3-4 CV(RMSD) and R^2 in initial and calibrated three-zone models

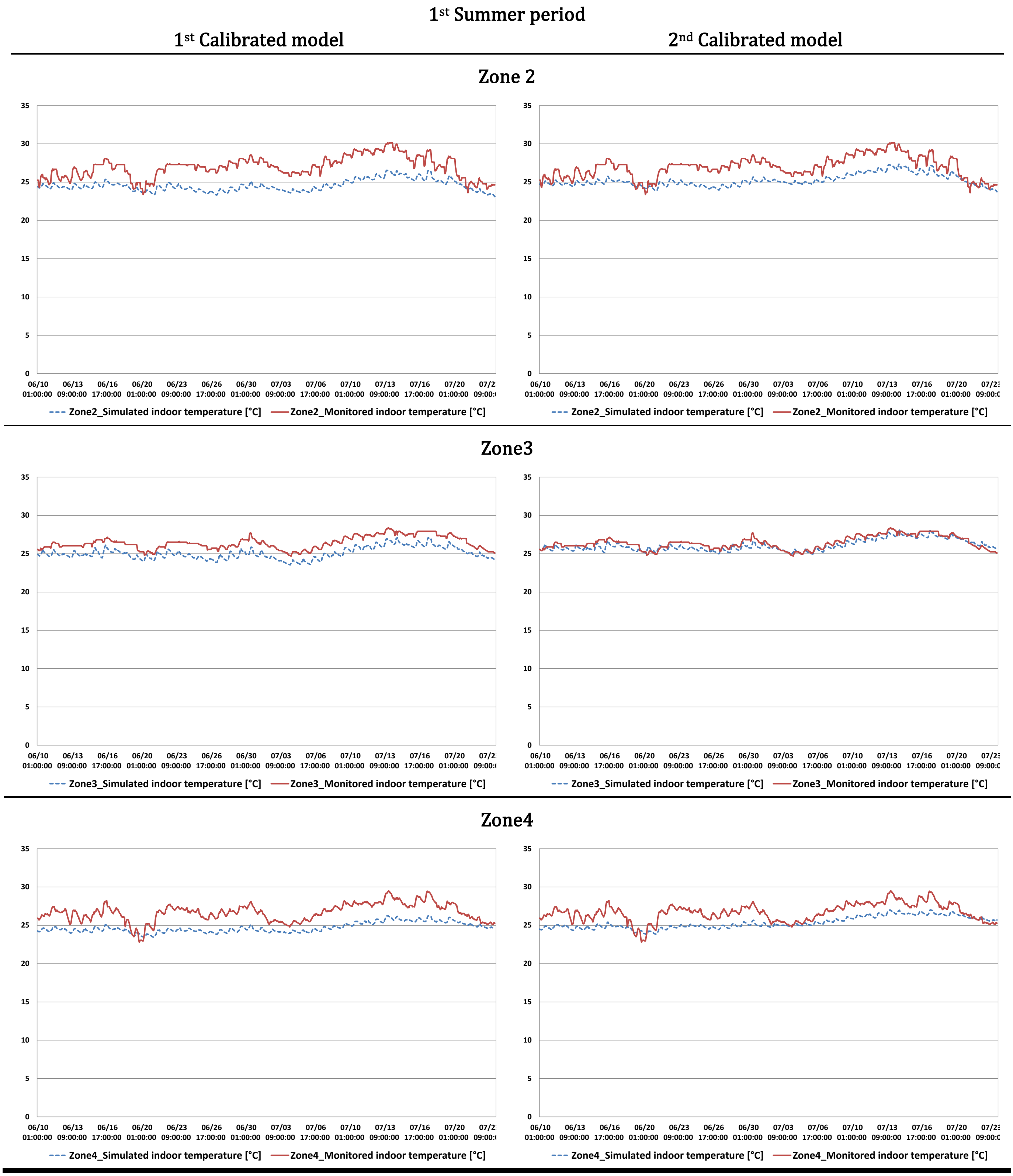


Figure 3-5 Monitored and simulated indoor temperature in 1st summer period,
1st Calibrated (left) and 2nd Calibrated (right) three-zone model

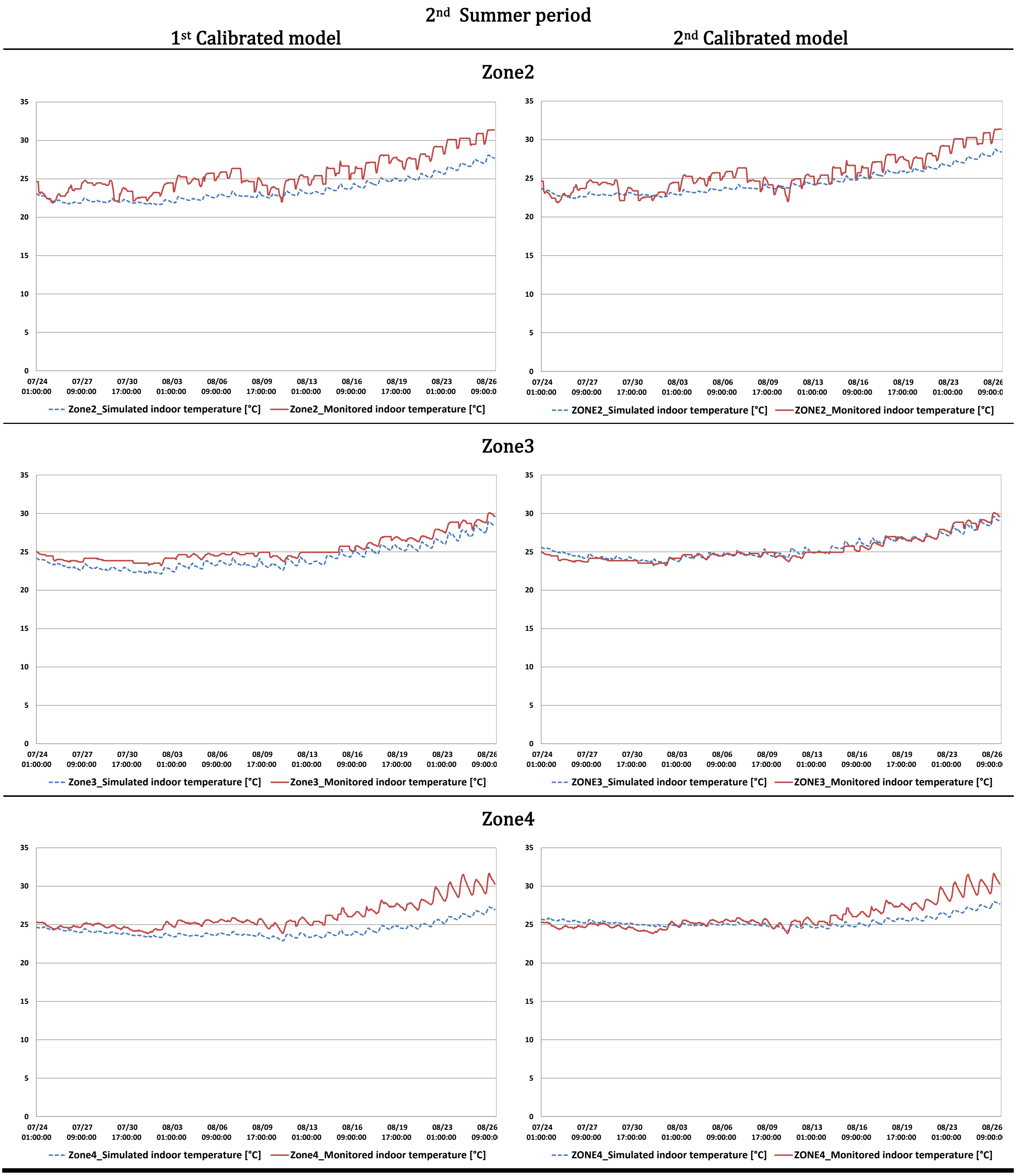


Figure 3-6 Monitored and simulated indoor temperature in 2nd summer period, 1st Calibrated (left) and 2nd Calibrated (right) three-zone model

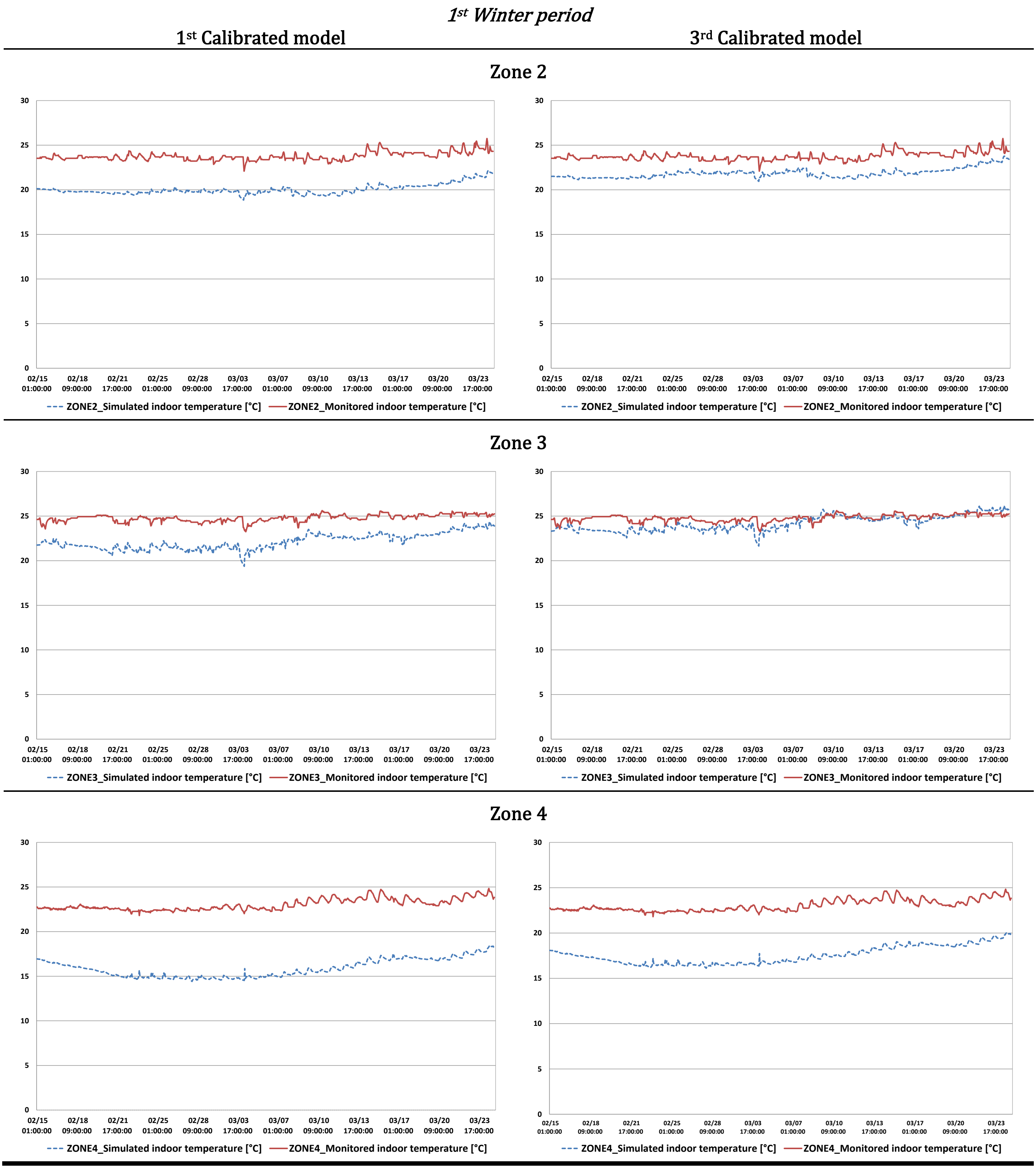


Figure 3-7 Monitored and simulated indoor temperature in 1st winter period, 1st Calibrated (left) and 3rd Calibrated (right) three-zone model

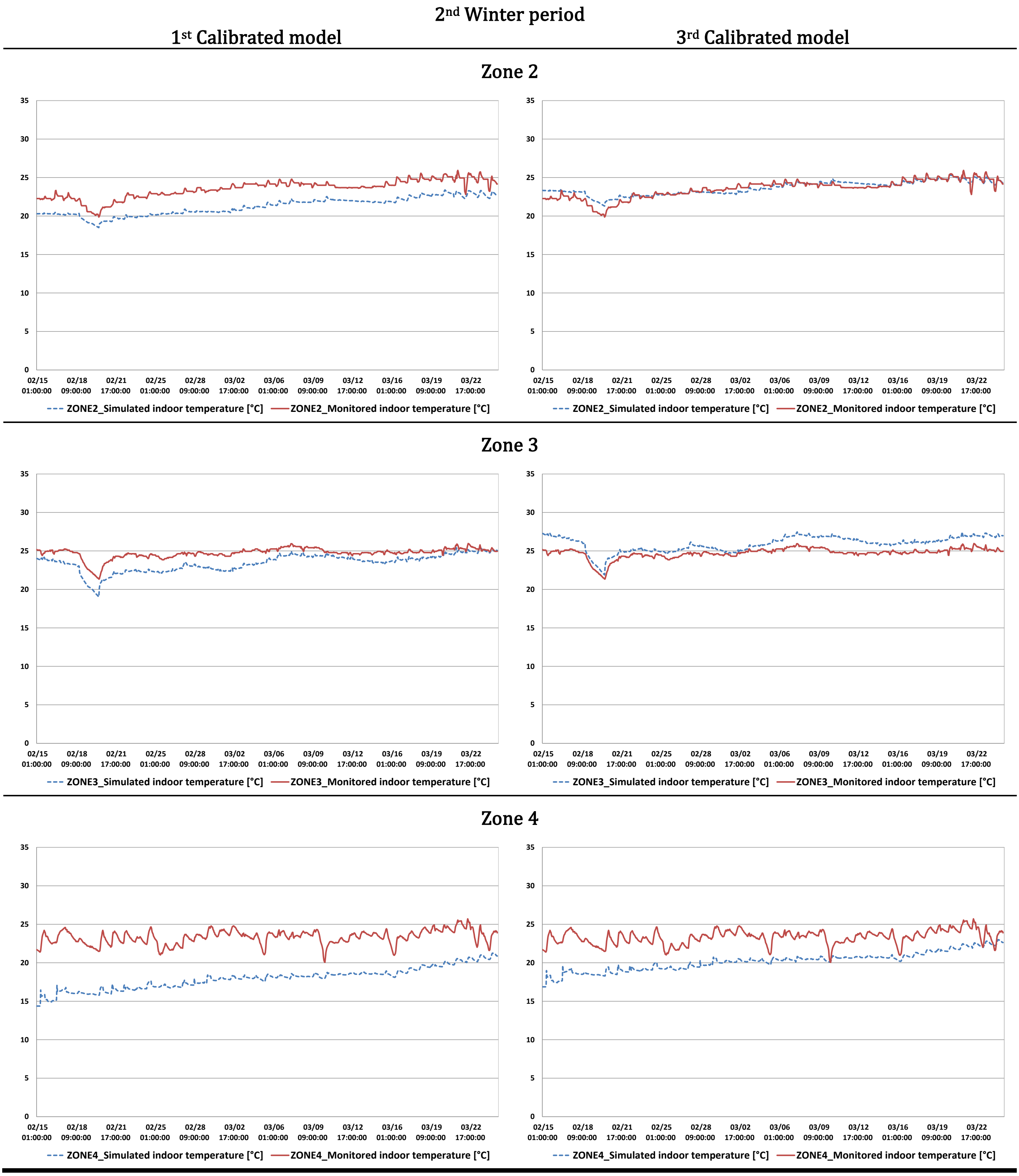


Figure 3-8 Monitored and simulated indoor temperature in 2nd winter period, 1st Calibrated model (left) and 3rd Calibrated (right) three-zone model

Several reasons concerning the error amount observed in the calibrated model of zone four compared to the other zones could be mentioned. First of all, we will start with comparing the dissimilar input parameters in the three zones:

– Regarding the boundary definitions in three zones, they are in contact with outside through ceilings and with the lower floor by an adiabatic element. All zones are connected to a non-monitored corridor toward north, while zone two and four are in turn connected to other two non-monitored zones (zone 1 and 3, see: Fig. 2-4).

– On the other hand, since the most inaccurate results were achieved in winter run periods, it is noteworthy to compare the heat distribution by the radiators in three zones. For this purpose the monitored heat power of the radiators were useful and by dividing the monitored heat power [W] to the zone area the heat power per floor area [$W.m^{-2}$] in each zone was resulted.

Figure 3-9 by line charts illustrates the heat distributions in different zones in the first winter run period. Firstly, in zone two by three installed radiators (one operating) the calculated average heat power per floor area is equal to 18.26 [$W.m^{-2}$]. Secondly, zone three had one operant radiator with the average heat power per floor area equal to 26.62 [$W.m^{-2}$]. Finally, in zone four one radiator had been rarely working with the calculated average heat power per floor area of 1.89 [$W.m^{-2}$].

Therefore, by these observations, the heating of zone four during the winter period is source of a doubt. In the next step of this scenario and also in the next predefined scenario, we will try again to improve the accuracy of the simulation predictions by calibrating the initial model along with modifying the causative factors of errors. The significant influence of the boundary condition definitions in thermal simulations is a remarkable issue which should be considered in order to populate more accurate models.

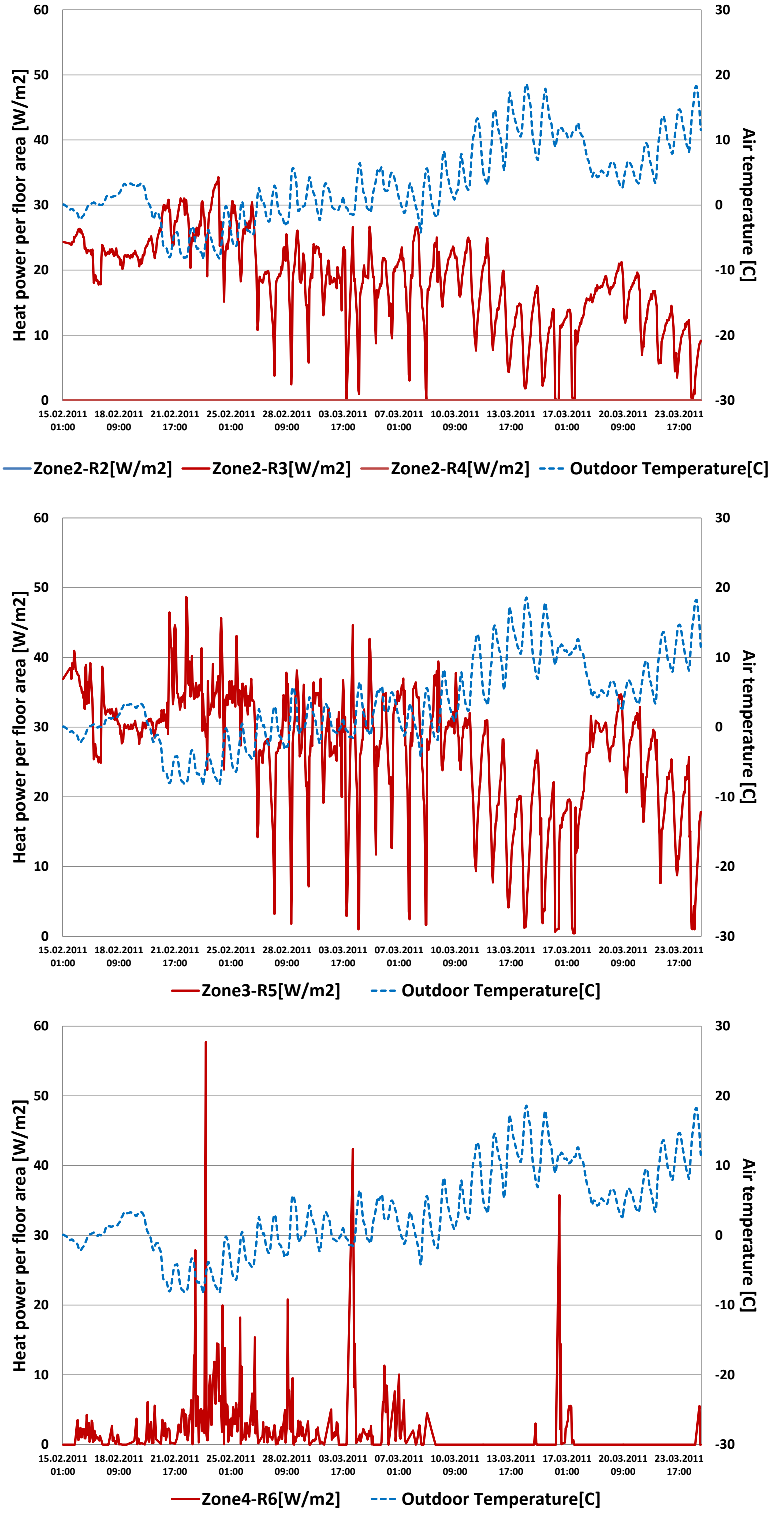


Figure 3-9 Heat power per floor area [W.m^{-2}] and outdoor temperature [°C] during the 1st winter period

3.1.3 Third step: Two zones

Following the results and discussions in the previous step regarding the impacts of boundary conditions on thermal behavior of zones, we will examine a two-zone model of the offices. In this step, simulation and optimization based calibration will be applied on zone two and three and the evaluations are based on the differences between the simulated and monitored indoor temperature in these two zones. Furthermore, the monitored air temperature of zone four as the boundary condition of zone three will be used and thus reduce the uncertainty in calibration results.

3.1.3.1 First calibrated two-zone model

First of all, a two-zone model will be populated initially with the values of eight input parameters resulted from the first calibration. Secondly, in order to control the temperature in zone four with the measured temperature "HVAC Template Object" will be added to the EP model. To do so, from the subsets of "HVAC Template Object", objects "HVACTemplate:Thermostat" and "HVACTemplate:Zone:IdealLoadsAirSystem" are required. Therefore, the monitored temperature will be incorporated into the model by scheduled values with a thermostat object defined in "HVACTemplate:Thermostat". Afterwards, in "HVACTemplate:Zone:IdealLoadsAirSystem" this thermostat will be assigned to the relevant zone (zone 4). Hence during the simulation, the indoor temperature of zone four would be the actual temperature in the real model which enables us to have more accurate boundary conditions in the simulation and reduce the uncertainties.

Accuracy of the predicted indoor temperature in zone two and three will be evaluated while the measured temperature of zone four is also used in the simulation as an input. Since the initial model here is created by the same values from the first optimization, the initial models in four selected run periods have been called first calibrated models.

3.1.3.2 Second and third calibrated two-zone model

Second and third calibrations in the two-zone model will be implemented the same as in the three-zone model. To do so, six input parameters from the eight initial optimization parameters are unchanged, keeping their first calibrated values in the later calibrations. However, the infiltration and ventilation rates will be subjected to recalibrations. The second calibration is applied to the first summer period and the second calibrated model will be validated in the second summer period. Moreover, the third calibration is performed in the first winter period and subsequently accuracy of the results will be evaluated in the second winter period.

Figure 3-10 presents the validation and recalibration process in two zones. As it illustrates two calibrations are taken into account in first summer and first winter periods. In addition to that the derived optimized parameters will be validated and evaluated in the second summer and second winter periods.

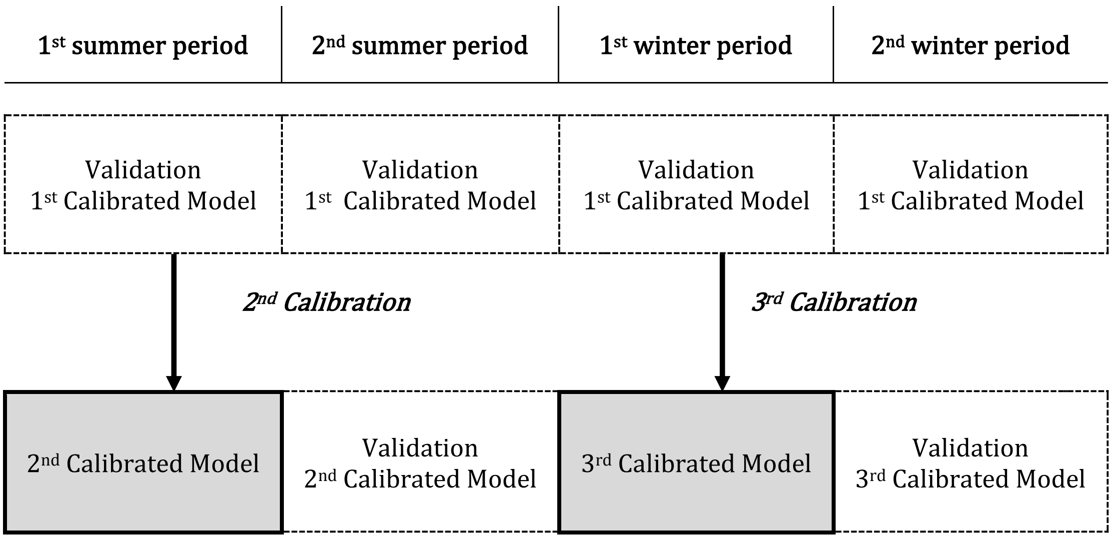


Figure 3-10 Calibration and validation process, two- zone model [4]

It should be noticed here that, to address the errors in the cost function the averaged *CV(RMSD)* and R^2 in two zones are considered. Therefore, the relevant equations for calculating *CV(RMSD)*, R^2 and f has been modified as below:

$$CV\left(RMSD\right)_{ave} = \frac{CV\left(RMSD\right)_{zone2} + CV\left(RMSD\right)_{zone3}}{2} \tag{3-4}$$

$$R^2_{ave} = \frac{R^2_{zone2} + R^2_{zone3}}{2} \tag{3-5}$$

$$f_{ave} = 0.5.CV\left(RMSD\right)_{ave} + 0.5.\left(1 - R^2_{ave}\right).\frac{CV\left(RMSD\right)_{ave_{ini}}}{\left(1 - R^2_{ave_{ini}}\right)} \tag{3-6}$$

[4] The highlighted cells belong to the calibration periods.

Table 3-5 gives the optimization variables with their initial, first, second and third optimized values. As illustrated in this table with bold numbers, in the first calibration (one-zone model) all eight parameters have been optimized, while re-calibrations (two-zone model) was applied only on infiltration and ventilation rates.

Variables	Initial Value	1st Optimized Value	2nd Optimized Value	3rd Optimized Value
Infiltration rate	0.20	**0.40**	**0.18**	**0.39**
Ventilation rate	1.00	**0.50**	**0.54**	**0.50**
Solar transmitance				
Green 6mm	0.48	**0.38**	0.38	0.38
Clear 6mm	0.78	**0.62**	0.62	0.62
Thermal conductivity				
Mineral wool	0.039	**0.047**	0.047	0.047
XPS	0.05	**0.07**	0.07	0.07
Density				
Ceiling Concrete	1800	**1260**	1260	1260
Wall Concrete	1400	**980**	980	980

Table 3-5 The values of optimization parameters in initial and calibrated two-zone models

In order to evaluate the accuracy of the calibrated two-zone model, Table 3-6 demonstrates the *CV(RMSD)* and R^2 in all run periods. By reviewing the values provided in this table we can conclude overall improvements in the accuracy of the second and third calibrated models. According to Table 3-6 *CV(RMSD)* reduced in all run periods but the improvements are more considerable in summer periods than winter. On the other side, R^2 had acceptable values in three run periods in the first calibrated model, but after the second and third calibrations it was not improved at all. To visualize the performance of the simulated models, Figure 3-11 to 3-14 illustrate the line charts generated based on the simulated and monitored indoor temperature in each zone. In the line charts also the slight improvements are recognizable.

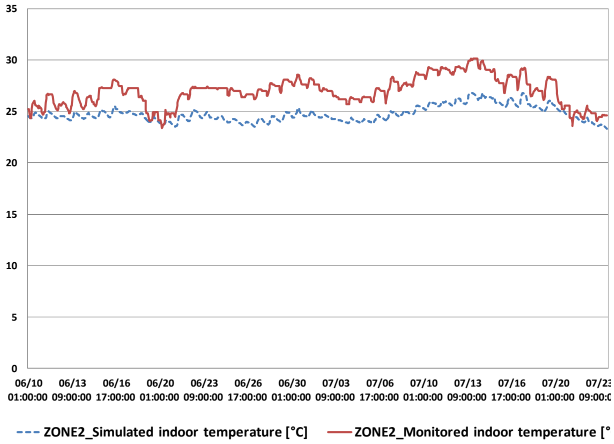
	1st summer period		**2nd summer period**		**1st winter period**		**2nd winter period**	
	CV(RMSD)	**R^2**	**CV(RMSD)**	**R^2**	**CV(RMSD)**	**R^2**	**CV(RMSD)**	**R^2**
1st Calibrated Model	5.77 %	0.74	5.41 %	0.92	6.24 %	0.32	5.02 %	0.82
2nd Calibrated Model	4.13 %	0.74	3.90 %	0.91	-	-	-	-
3rd Calibrated Model	-	-	-	-	5.99 %	0.32	4.94 %	0.82

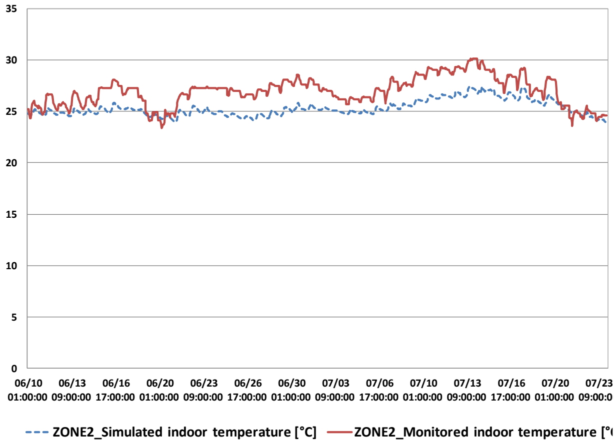
Table 3-6 CV(RMSD) and R^2 in initial and calibrated two-zone model

1^{st} Summer period

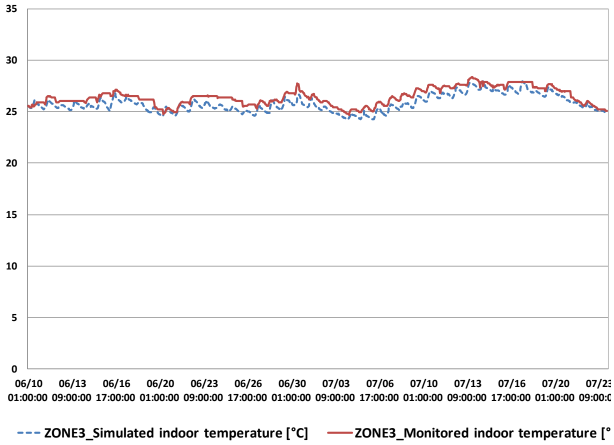
1st Calibrated model	2nd Calibrated model

Zone 2





Zone 3



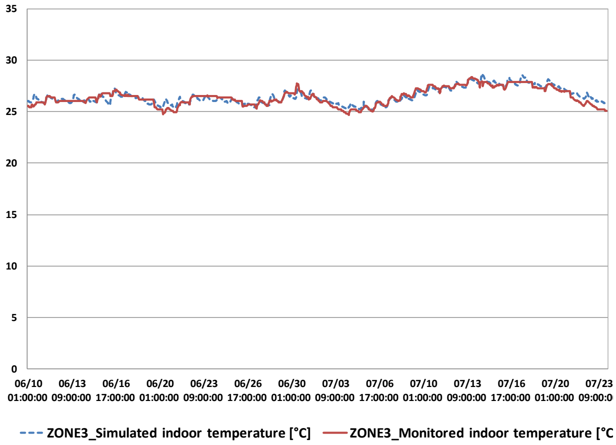
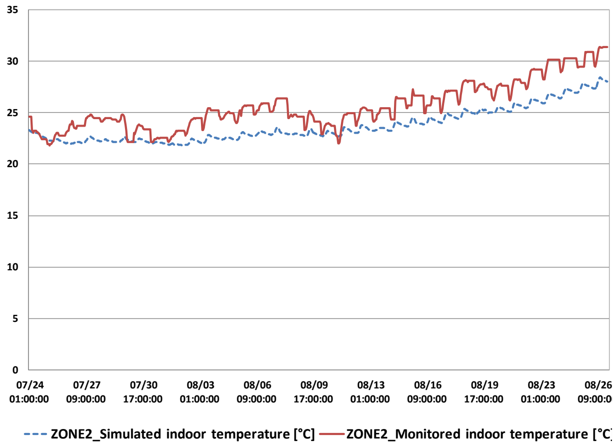


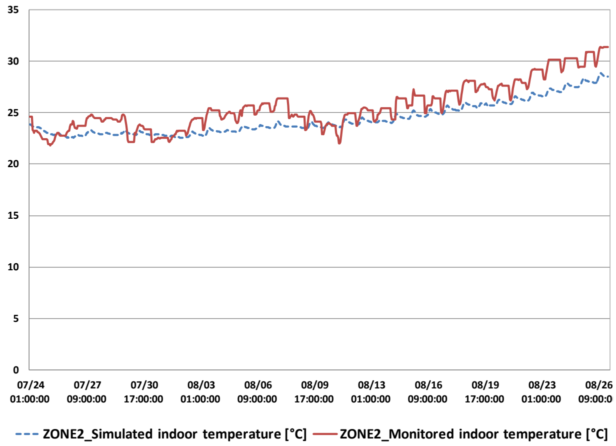
Figure 3-11 Monitored and simulated indoor temperature in 1st summer period, 1st Calibrated (left) and 2nd Calibrated (right) two-zone model

2^{nd} Summer period

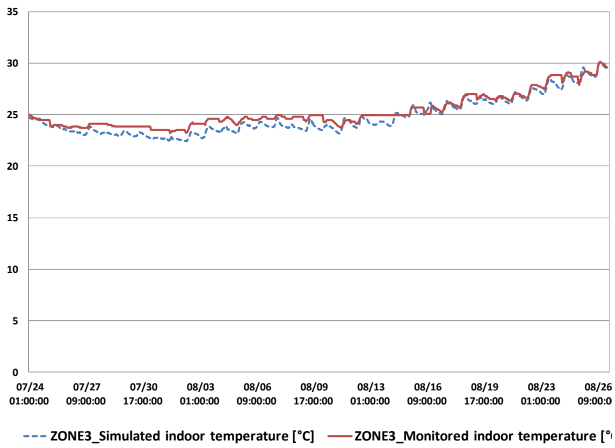
1st Calibrated model	2nd Calibrated model

Zone 2





Zone 3



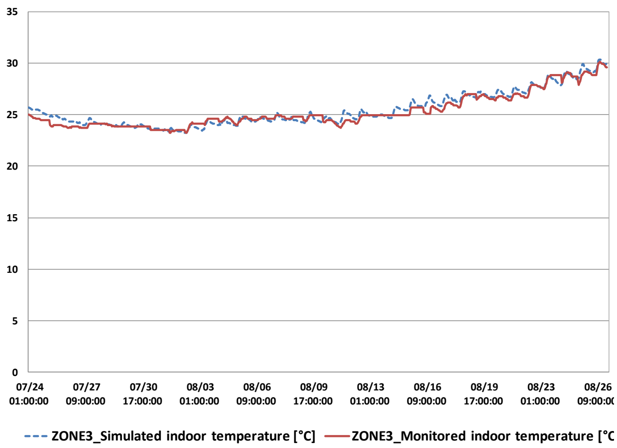
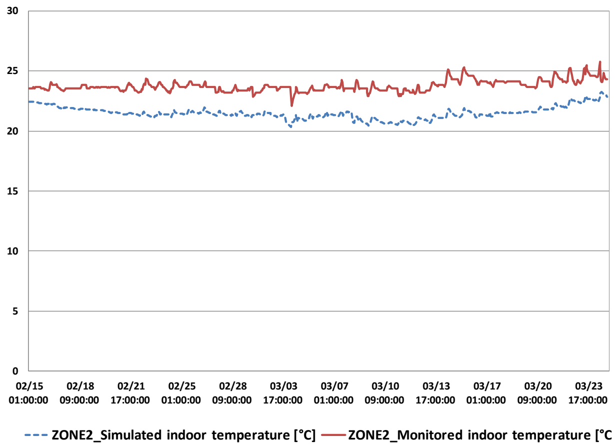


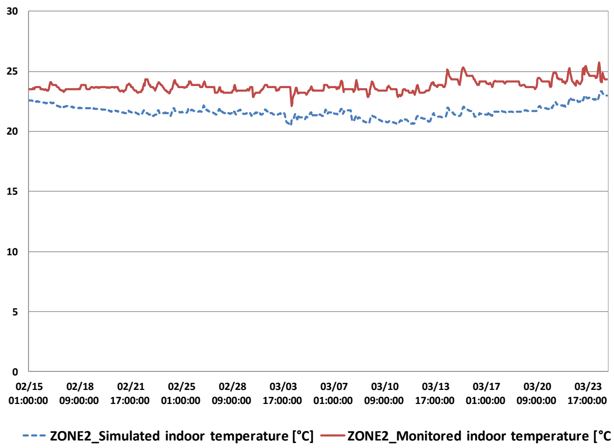
Figure 3-12 Monitored and simulated indoor temperature in 2^{nd} summer period, 1^{st} Calibrated (left) and 2^{nd} Calibrated (right) two-zone model

1st Winter period

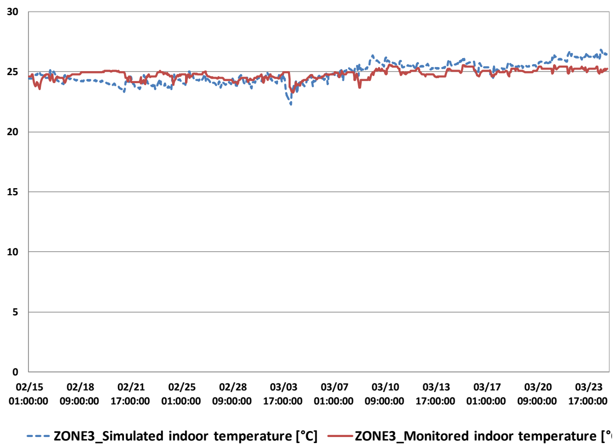
1st Calibrated model	3rd Calibrated model

Zone 2





Zone 3



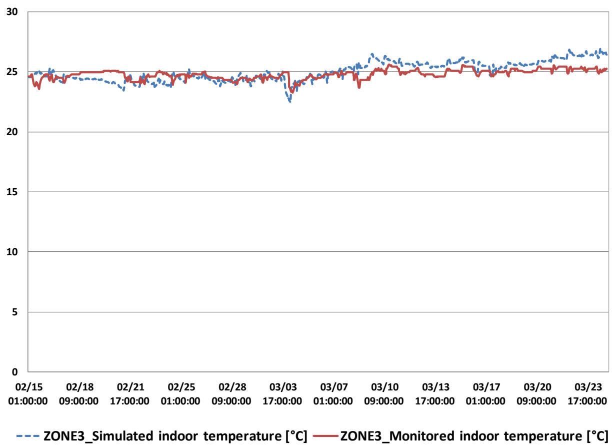
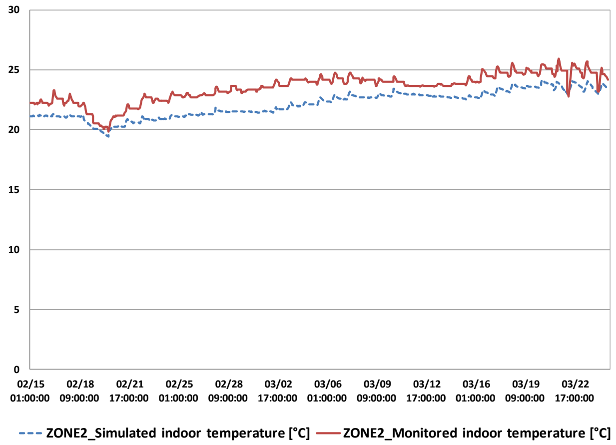


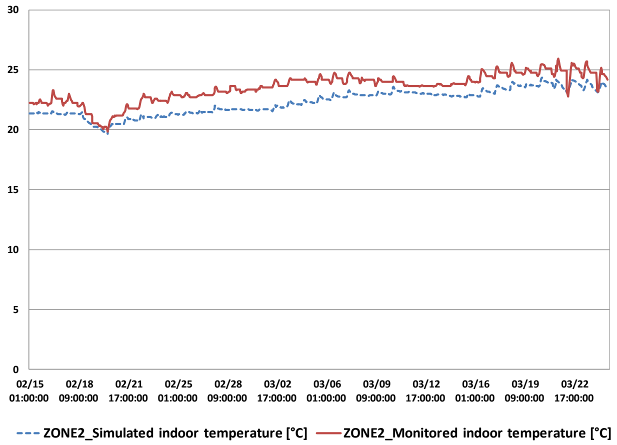
Figure 3-13 Monitored and simulated indoor temperature in 1st winter period, 1st Calibrated (left) and 3rd Calibrated (right) two-zone model

2nd Winter period

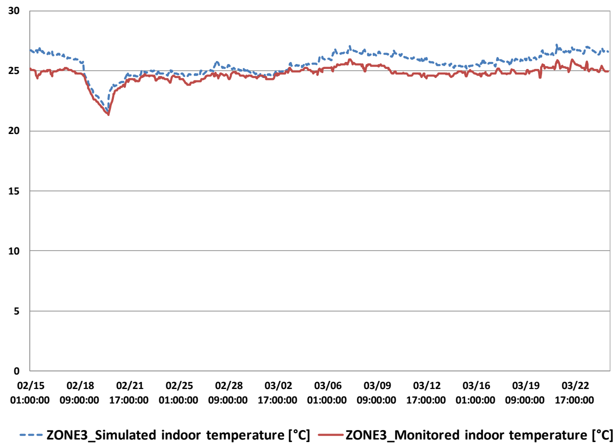
1st Calibrated model | **3rd Calibrated model**

Zone 2





Zone 3



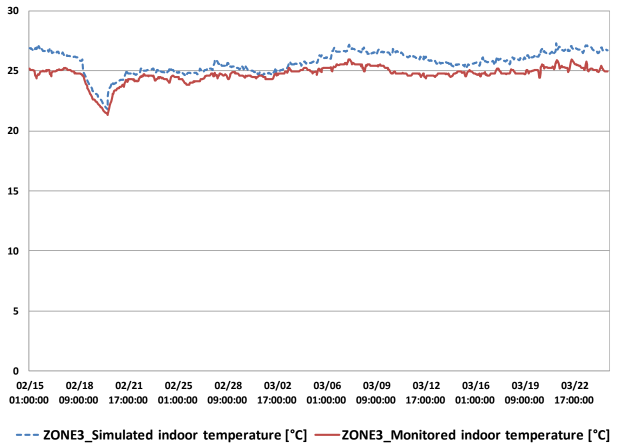


Figure 3-14 Monitored and simulated indoor temperature in 2nd winter period, 1st Calibrated (left) and 3rd Calibrated (right) two-zone model

3.2 Second scenario

At last but not least, the second scenario will deal with the concept of boundary conditions' definition in thermal simulations and reducing the negative impact due to the lack of accurate information about the adjacent zones, by optimization-based calibration method. The final goal of running thermal simulations is to achieve appropriate predictions as reliable answers to the concerns regarding the building performance for further decision makings at design level, retrofit analysis, etc. At this stage, it was tried to modify the assumption related to the adjacent non-monitored zones in order to minimize the error and maximize the goodness of fit through an optimization process. In this scenario, thermal performance of the three monitored zones will be evaluated and improved by calibrations. The two new optimization parameters in the second scenario are the mean air temperature of the adjacent zones (zone 1 and 5).

3.2.1 Five-zone model

In this scenario a five-zone model, consists of three monitored zones and two non-monitored zones was used (Fig. 2-4).

From the error amount in the results provided in section 3.1.2, we can argue that the reason might be the uncertainty regarding the boundary zone assumptions. Internal walls separating zones 1 and 2 as well as zones 4 and 5 were assumed to be adiabatic. By this definition we assumed that two zones in both side of the joint wall have the same thermal conditions without any heat transfer. But at this stage we will change these "adiabatic" walls to the boundary object of "surface" which permit heat exchange and assign indoor temperature in the adjacent zones (zone 1 and 5). By specifying a wall as "surface" in EP the heat balance between two adjacent zones will be taken into account in simulations. Commonly in cases with significant temperature difference, walls would be defined as surfaces otherwise the adiabatic definition will be used. Figure 3-15 demonstrates two different geometry definitions used in this work within two different scenarios.

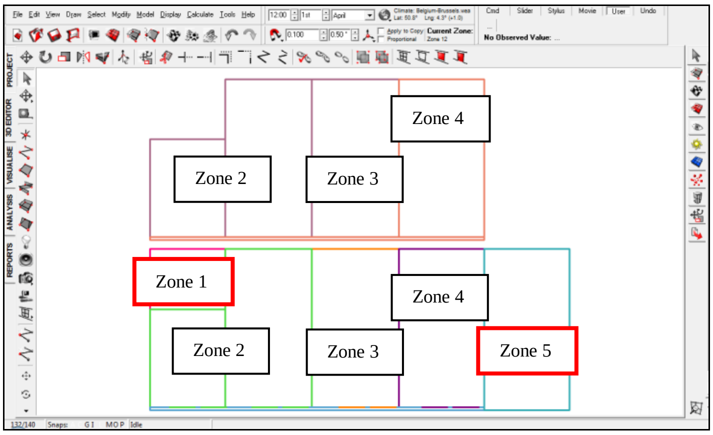


Figure 3-15 Ecotect model, 1st scenario (up), 2nd scenario (down)

In fact, the current scenario has been defined to evaluate: first of all, how assumptions regarding adjacency can affect the simulation predictions, and secondly, possibility of improvements by an optimization-based calibration method.

In the new EP model the assumed indoor temperatures will be assigned to the adjacent zones (zone 1 and 5). Hence, the average temperature during the first summer period in zone two was the initial value for the summer indoor temperature of zone one. With the same method, the average temperature of zone two in the first winter period has been used as the winter indoor temperature of zone one. in zone five, the average temperature of zone four, in the first summer and first winter periods were specified as the initial values. Since "HVAC Template Object" enables us to set the indoor temperature in the zones, so by two "HVACTemplate:Thermostat" objects, thermostats with constant temperature were added to the model and through "HVACTemplate:Zone:IdealLoadsAirSystem" the thermostats will be assigned to the relevant zones.

The other point to ponder regarding the five-zone model is that this model was populated initially with the values from the second and third three-zone calibrations for summer and winter periods, respectively.

3.2.1.1 Fourth and fifth calibrated models

In the first scenario, first calibration started with optimizing eight input parameters to better fit the model to the measurements. Afterwards, in the second and third calibrations six of them remained constant with the first calibrated values, while infiltration and ventilation rates as the time-varying input parameters were subjected to calibrations. Afterwards at this level, in fourth and fifth calibrations the first eight optimization parameters are constant and mean air temperature of the adjacent zones will be calibrated. Therefore, the optimization process will be defined so that adjusts indoor temperature of two currently added zones and minimizing the inaccuracies of the results due to the assumptions regarding the adjacency definitions. By means of the optimization results, the fourth and fifth calibrated models in summer and winter periods will be created. Subsequently, the accuracy of the calibrations will be examined in summer and winter validation periods. To elucidate the process, Figure 3-16 illustrates the consecutive steps in the second scenario. Accordingly, Table 3-7 demonstrates the resulted fourth and fifth optimized values for the indoor temperature in zone one and five.

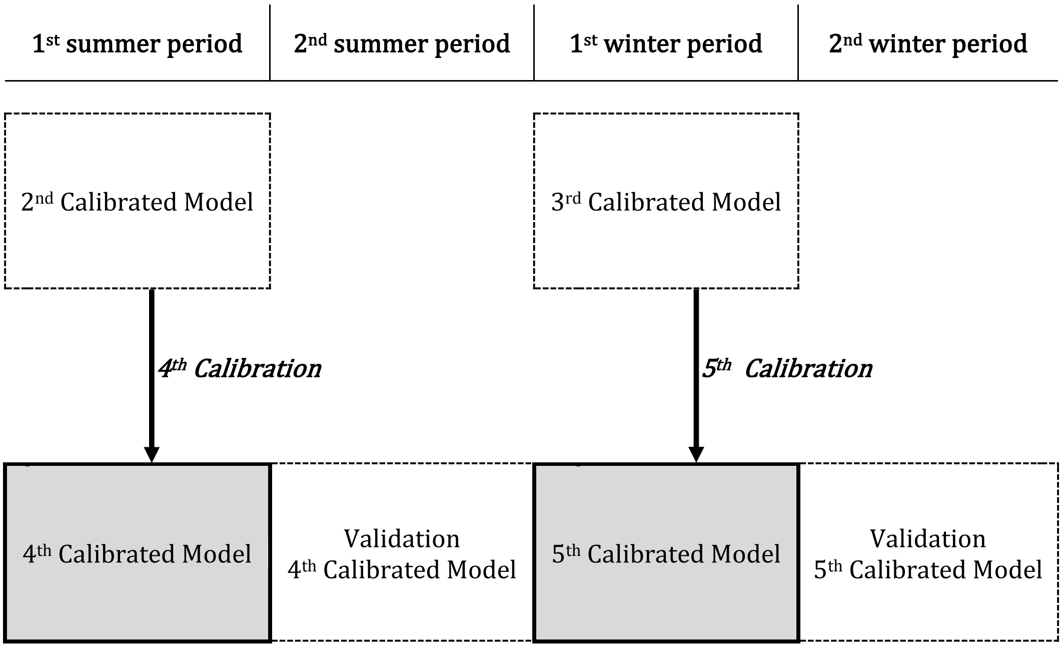


Figure 3-16 Schema of calibration and validation process in the second scenario [5]

[5] The highlighted cells belong to the calibration periods.

Variables		Initial Value	4th Optimized Value	5th Optimized Value
Infiltration rate		0.2	Constant with the values from the 2nd calibration	Constant with the values from the 3rd calibration
Ventilation rate		1.0		
Solar transmitance				
	Green 6mm	0.48		
	Clear 6mm	0.78		
Thermal conductivity				
	Mineral wool	0.039		
	XPS	0.05		
Density				
	Ceiling Concrete	1800		
	Wall Concrete	1400		
Temperature in adjacent zone 5				
	Summer	26.7	28	-
	Winter	24.2	-	25.4
Temperature in adjacent zone 6				
	Summer	26.6	26.9	-
	Winter	23.9	-	26

Table 3-7 The values of optimization parameters in initial, 4th and 5th calibrated models

The proposed scenario was aimed the same as previous scenario to minimize the defined cost function. Via two aforementioned indicators, *CV(RMSD)* and R^2, the error and goodness of fit has been defined to be automatically calculated after each run (as averaged values for three monitored zones) as well as the cost function f (see: Eq. 3-1 to 3-3). Table 3-8 displays derived *CV(RMSD)* and R^2 from the current calibration-validation process. According to this table, all the calibrated models have less than 7% error in the simulated zone mean air temperature. The results also represent that except the first winter period, in other run periods R^2 was higher than 0.6. As discussed formerly, for R^2 which ranges from 0 to 1, typically the results more than 0.5 are acceptable. Thereby, by the results it can be deduced that except the first winter period, the linear relation between the monitored and simulated values is acceptable.

Table 3-9 provides a comparison between the results from the second and third calibrations in the first scenario (3-zone model) and the performed calibrations in the second scenario. This comparison implies that by implementing the second scenario the model was improved in all run periods. Evidently *CV(RMSD)* reduced in all run periods and R^2 improved except in the first winter period, in which it remained constant. As it has been observed in the previous results R^2 in the first winter period is not as satisfying as in the other run periods. For further illustrations of the simulation results in the calibrated models compared to the actual model, Figure 3-17 and 3-18 depict both simulated and monitored indoor temperature of the three zones in all run periods.

	1st summer period		2nd summer period		1st winter period		2nd winter period	
	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2	CV(RMSD)	R^2
4th Calibrated Model	3.80 %	0.68	3.82 %	0.89	-	-	-	-
5th Calibrated Model	-	-	-	-	6.55 %	0.48	6.08 %	0.63

Table 3-8 CV(RMSD) and R^2 in 4th and 5th calibrated models

Run periods	**1st Scenario (3 zone model) → 2nd scenario**	
1st summer period	**CV(RMSD)**	5.06 % → 3.80 %
	R^2	0.65 → 0.68
2nd summer period	**CV(RMSD)**	4.41 % → 3.82 %
	R^2	0.86 → 0.89
1st winter period	**CV(RMSD)**	11.95 % → 6.55 %
	R^2	0.48 → 0.48
2nd winter period	**CV(RMSD)**	7.32 % → 6.08 %
	R^2	0.60 → 0.63

Table 3-9 Comparison between the results of the three-zone models in the 1st and 2nd scenarios

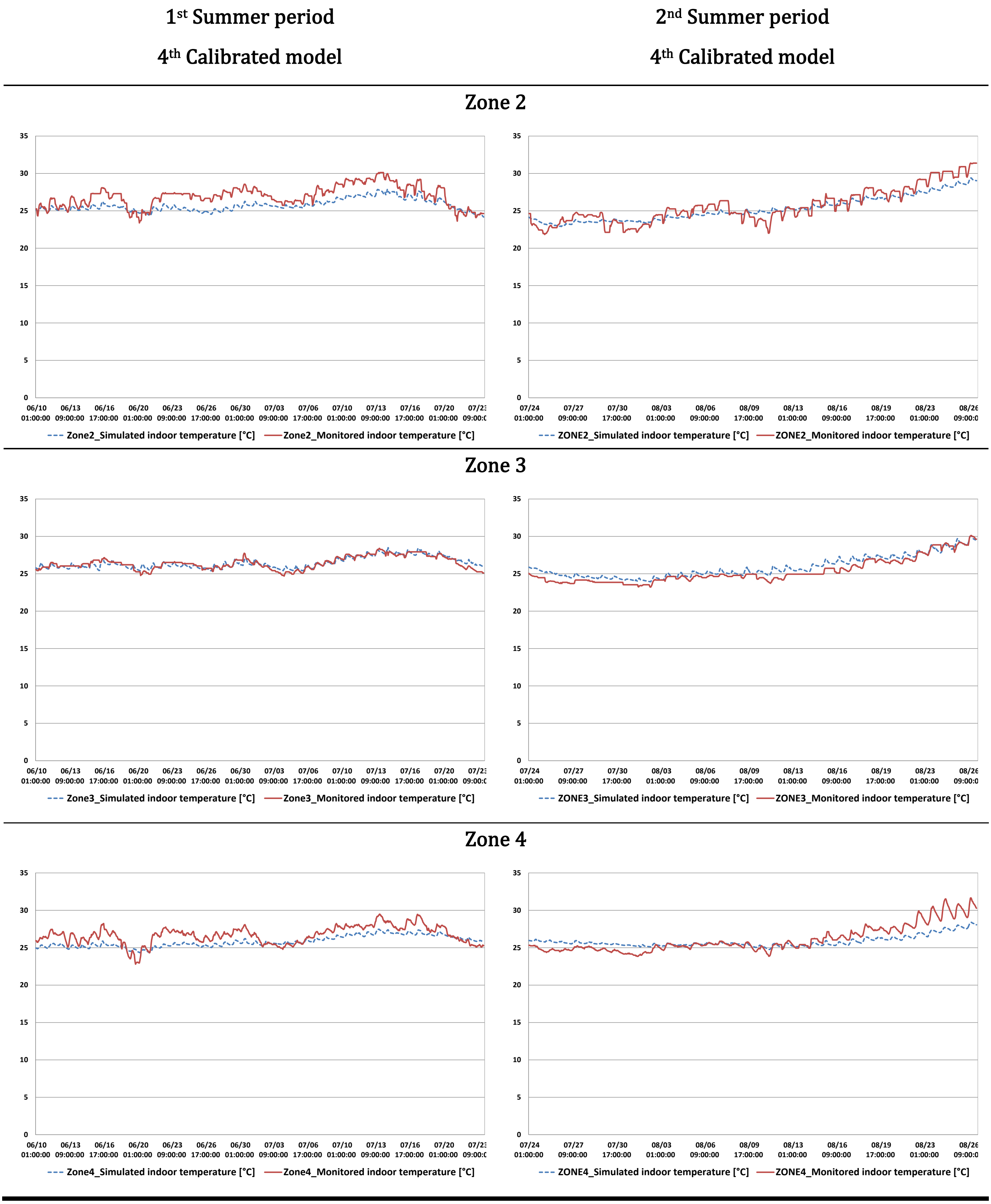


Figure 3-17 Monitored and simulated indoor temperature in the 4th Calibrated model, 1st summer period (left), 2nd summer period (right)

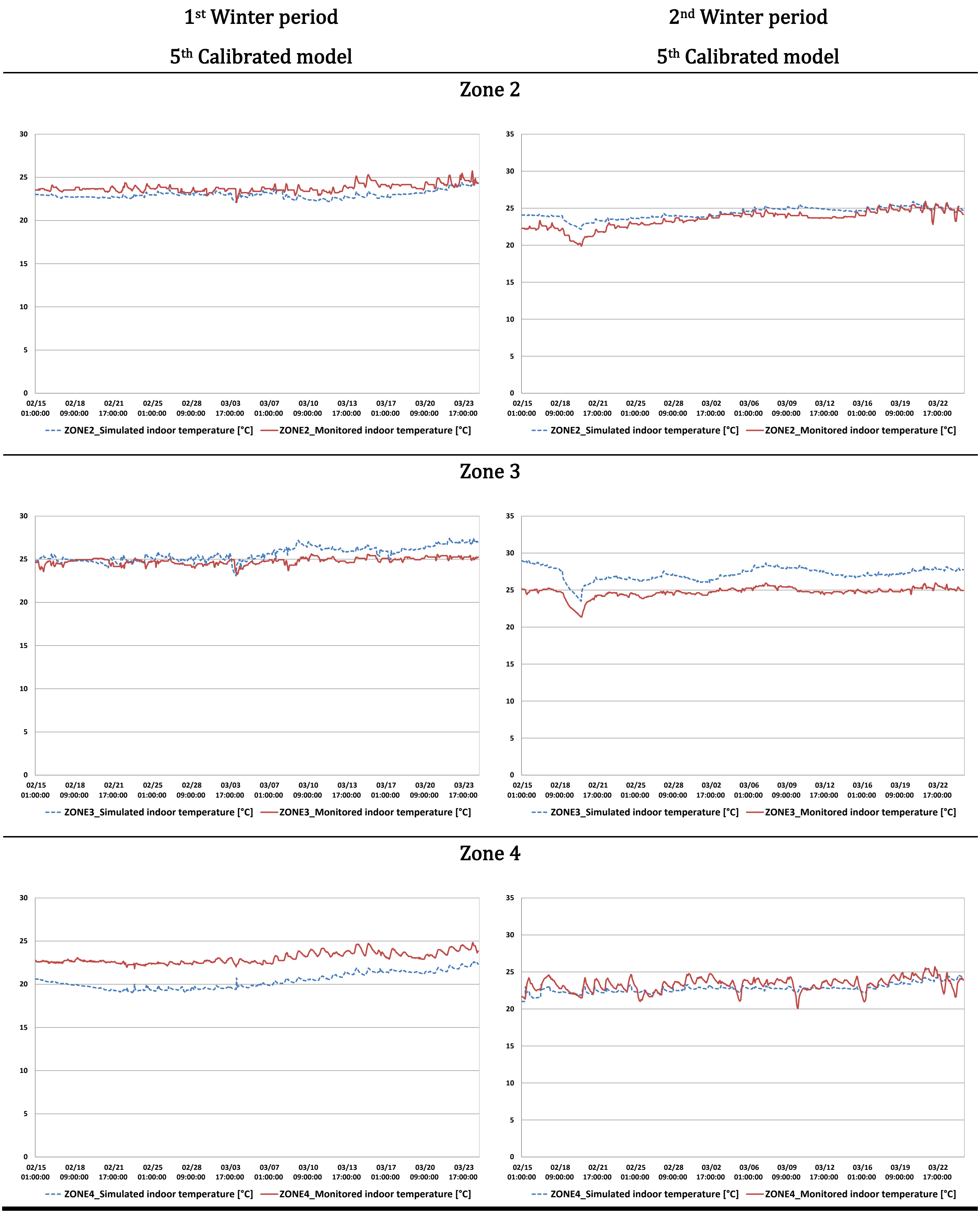


Figure 3-18 Monitored and simulated indoor temperature in the 5th Calibrated model, 1st winter period (left), 2nd winter period (right)

4 DISCUSSION

The summarized results in Figure 4-1 and 4-2 display the outcomes from application of the optimization-based calibration method. In Figure 4-1 the results are briefly compiled in two charts which are presenting *CV(RMSD)* in different scenarios, for the two and three-zone model. The charts demonstrate an overall improvements by limiting the errors up to 7% in all cases. Fortunately as expected from the outcomes of the second scenario, in the three-zone model by modifying the assumed boundary conditions through the calibration process, considerable progress particularly in winter was obtained.

Inspecting the results of two-zone model shows that initially there was low level of errors and remarkable progress was not observed in the final results. In the two-zone model at the initial level, using the measured temperature of the controlled zone i.e. zone four and defining more accurate boundary conditions for the model resulted acceptable outcomes. Hereby it can be concluded that optimizing the selected parameters obviously could not cause great improvements in this case.

Figure 4-2 illustrates the summarized results of R^2 which demonstrates that except the first winter period, in other run periods R^2 was bigger than 0.6 in the three-zone model and higher than 0.7 in the two-zone model. As discussed formerly, in case of R^2 which ranges from 0 to 1, typically the results more than 0.5 are acceptable. According to these results, we can deduce that except the first winter period, the linear relation between the monitored and simulated values is acceptable.

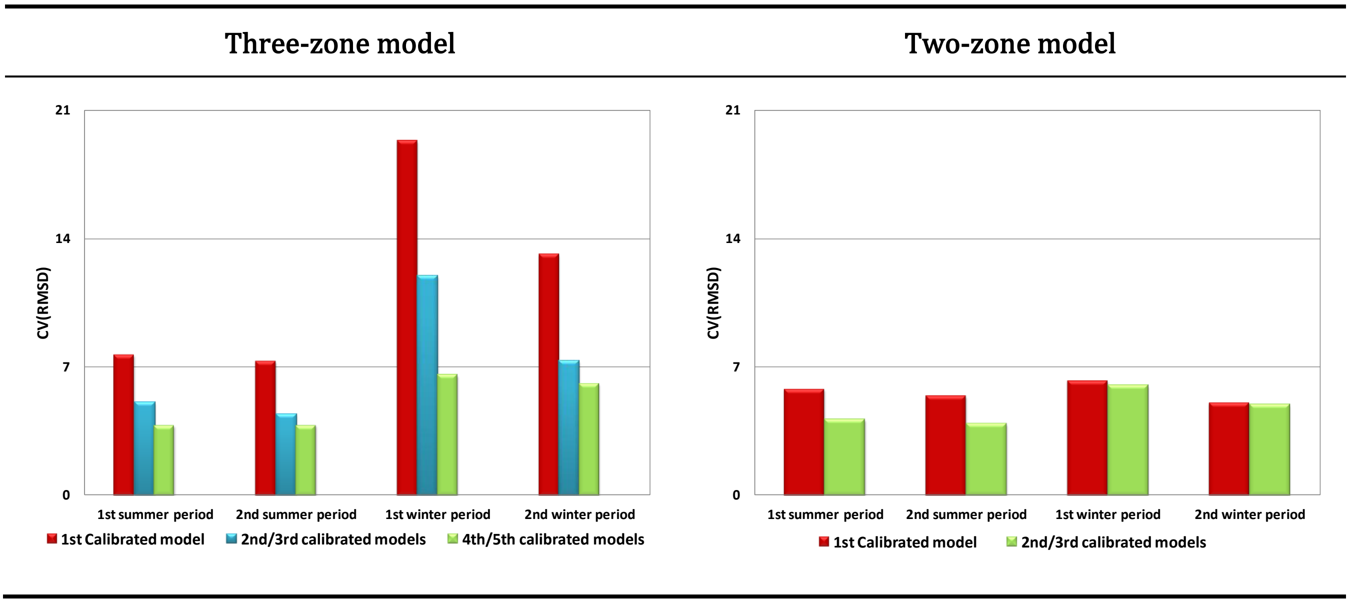


Figure 4-1 Summarized results of CV(RMSD)

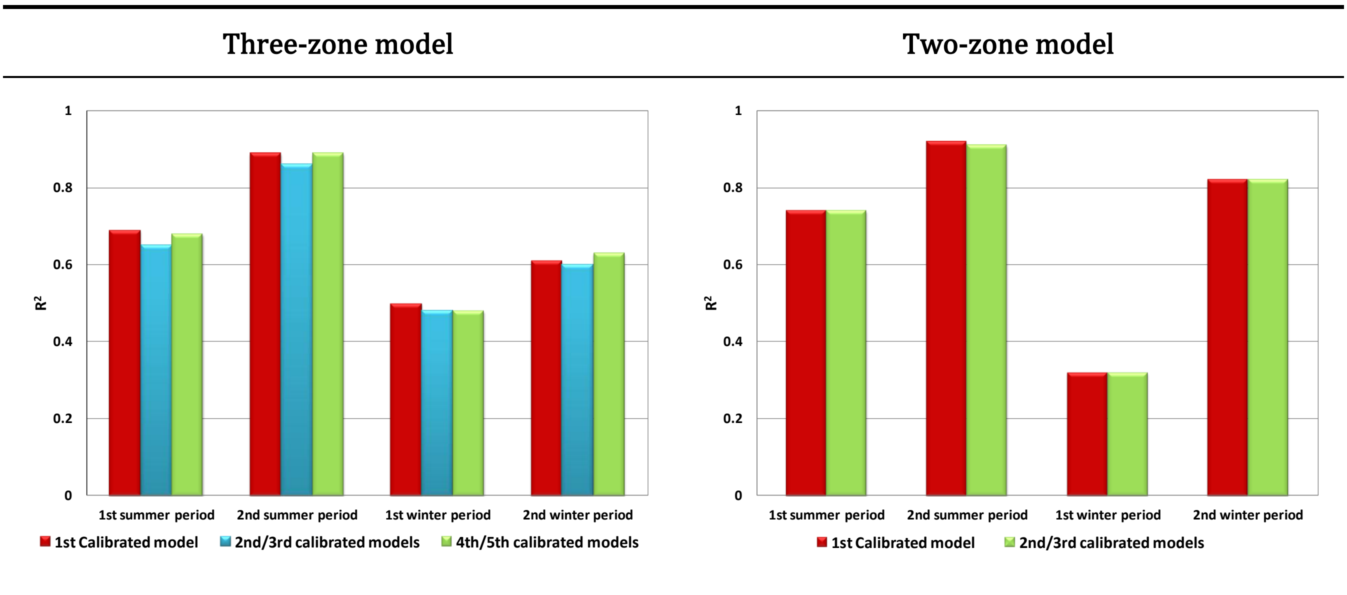


Figure 4-2 Summarized results of R^2

5 CONCLUSION

Based upon the research conducted in this master thesis, despite the widespread use of energy performance simulation tools for the future performance predictions or improving the energy efficiency of the existing buildings, the current conventional methods are not adequate to ensure the quality of the model predictions. This work tried to point out that in the performance analysis there is always a concern if the simulation input values are the same as the actual model. Due to the propagation of errors from input to the performance simulations, the outcomes are also going to be affected. In this master thesis from the outset it was tried to emphasize the important first step of energy analysis which is preparation of the required realistic and free from errors input data. Despite of increasing the complexity, applying detailed building simulations is required in order to taking into account all the influential parameters on the performance. Simultaneously the employed simulation program should be sophisticated and capable of modeling the chosen building type as well as building's features and systems. But it should be admitted that in spite of all these provisions, there will be always uncertainties in some input parameters. Therefore, the current master project implemented an optimization-based calibration method for a thermal performance model of an office building which was assisted by the monitoring systems. The provided data via monitoring infrastructures were used to generate the initial model for the simulation and also in calibration process in order to reach the desirable accurate predictions. The acceptable accuracy in this method will be fulfilled under two conditions, maintaining the goodness of fit of the model and minimizing the errors between the monitored and simulated values, at the same time. As a result the optimization-based calibration process was dependent on a cost function defined by sum of two weighted indicators. By minimizing the cost function the optimization was entailed to minimize the difference between the actual and simulated model by minimizing the error and maximizing the goodness of fit. This method was not only implemented in different summer and winter time periods but also the results were validated in other distinct time periods, benefiting from long-term monitored data. Eventually by results obtained from implemented scenarios, it can be concluded that the calibrated model has a noticeable improvement in displaying the predictive thermal performance.

6 FURTHER RESEARCHES

Optimization-based calibration remains an interesting field of research for the author. It is hoped that this case study could imply the noticeable improvement achieved by calibration of simulated model with the capability of providing predictions that are more accurate. For the sake of improvements in the applied methodology, the following issues need to be resolve:

– More case studies are required and necessary to inspect the improvements resulted by this method in different cases with distinctive building functions, designs, systems, etc.

– It should be declared that the current method was relying on the experts' assessments, especially in the case of choosing the calibration parameters. Identification of the involved uncertain input data will remove one of the important obstacles on the way of improving the simulation results by calibrations. Therefore, extra work regarding this issue is required in order to calibrate the thermal performance model through an ultimately automated process.

– In terms of the observed R^2 results, the desired improvements in the outcomes in some cases were not obtained. Therefore it is a suggested area of the further researches to improve the results by investigating the possible modifications regarding the cost function definitions.

– Importance of the accurate and detailed energy simulation tools for thermal performance modeling demonstrates the significance of cooperation between energy analysts and software developers. Although it should be stated here that advanced energy performance tools such as EnergyPlus by providing more opportunities for the building scientists, enabled them to obtain more exact models and results.

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8 APPENDIX

8.1 Appendix A: The initial EnergyPlus model

```
!-Generator IDFEditor 1.43
!-Option SortedOrder UseSpecialFormat

!-NOTE: All comments with '!-' are ignored by the IDFEditor and are generated
automatically.
!-      Use '!' comments if they need to be retained when using the IDFEditor.


!-   ===========  ALL OBJECTS IN CLASS: VERSION ===========

Version,7.0;

!-   ===========  ALL OBJECTS IN CLASS: SIMULATIONCONTROL ===========


SimulationControl,
    No,                      !- Do Zone Sizing Calculation
    No,                      !- Do System Sizing Calculation
    No,                      !- Do Plant Sizing Calculation
    No,                      !- Run Simulation for Sizing Periods
    Yes;                     !- Run Simulation for Weather File Run Periods


!-   ===========  ALL OBJECTS IN CLASS: BUILDING ===========

Building,
    Lehartrakt,              !- Name
    0.00000,                 !- North Axis {deg}
    City,                    !- Terrain
    0.05000,                 !- Loads Convergence Tolerance Value
    0.50000,                 !- Temperature Convergence Tolerance Value {deltaC}
    FullInteriorAndExteriorWithReflections,  !- Solar Distribution
    25,                      !- Maximum Number of Warmup Days
    6;                       !- Minimum Number of Warmup Days


!-   ===========  ALL OBJECTS IN CLASS: TIMESTEP ===========

Timestep,6;

!-   ===========  ALL OBJECTS IN CLASS: SITE:LOCATION ===========


Site:Location,
    VIENNA_ SCHWECHAT_AUT Design_Conditions,  !- Name
    48.12,                   !- Latitude {deg}
    16.57,                   !- Longitude {deg}
    1.00,                    !- Time Zone {hr}
    190.00;                  !- Elevation {m}


!-   ===========  ALL OBJECTS IN CLASS: RUNPERIOD ===========

RunPeriod,
    ,                        !- Name
    6,                       !- Begin Month
    6,                       !- Begin Day of Month
```

```
    7,                       !- End Month
    23,                      !- End Day of Month
    UseWeatherFile,          !- Day of Week for Start Day
    Yes,                     !- Use Weather File Holidays and Special Days
    Yes,                     !- Use Weather File Daylight Saving Period
    Yes,                     !- Apply Weekend Holiday Rule
    Yes,                     !- Use Weather File Rain Indicators
    Yes;                     !- Use Weather File Snow Indicators

!-   ===========  ALL OBJECTS IN CLASS: SITE:GROUNDTEMPERATURE:BUILDINGSURFACE
===========

Site:GroundTemperature:BuildingSurface,5.09000,5.59000,7.60000,9.75000,11.68000,13
.66000,15.09000,14.75000,12.76000,10.61000,8.69000,6.58000;

!-   ===========  ALL OBJECTS IN CLASS: SCHEDULETYPELIMITS ===========


ScheduleTypeLimits,
    On/Off,                  !- Name
    0,                       !- Lower Limit Value
    1,                       !- Upper Limit Value
    Discrete,                !- Numeric Type
    Dimensionless;           !- Unit Type

ScheduleTypeLimits,
    Fraction,                !- Name
    0.0,                     !- Lower Limit Value
    1.0,                     !- Upper Limit Value
    Continuous;              !- Numeric Type

ScheduleTypeLimits,
    Any Number,              !- Name
    ,                        !- Lower Limit Value
    ,                        !- Upper Limit Value
    ,                        !- Numeric Type
    Dimensionless;           !- Unit Type


!-   ===========  ALL OBJECTS IN CLASS: SCHEDULE:COMPACT ===========

Schedule:Compact,
    REPORTSCHEDULE,          !- Name
    On/Off,                  !- Schedule Type Limits Name
    Through: 6/09,           !- Field 1
    for: alldays,            !- Field 2
    until: 24:00, 0,         !- Field 4
    Through: 12/31,          !- Field 5
    for: alldays,            !- Field 6
    until: 24:00, 1;         !- Field 8

Schedule:Compact,
    Ventilation,             !- Name
    On/Off,                  !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    for: alldays,            !- Field 2
    until: 24:00, 1;         !- Field 4

Schedule:Compact,
    Infiltration,            !- Name
    On/Off,                  !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    for: alldays,            !- Field 2
    until: 24:00, 1;         !- Field 4

Schedule:Compact,
    People Activity,         !- Name
```

```
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    for: alldays,            !- Field 2
    until: 24:00, 117;       !- Field 4

Schedule:Compact,
    NRMSD_reporting,         !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 7/22,           !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00, 0,         !- Field 4
    Through: 7/23,           !- Field 5
    For: AllDays,            !- Field 6
    Until: 23:50, 0,         !- Field 8
    Until: 24:00, 1,         !- Field 10
    Through: 12/31,          !- Field 11
    For: AllDays,            !- Field 12
    Until: 24:00, 0;         !- Field 14


!-   ===========  ALL OBJECTS IN CLASS: MATERIAL ===========

Material,
    Insulation_EPS,          !- Name
    MediumSmooth,            !- Roughness
    0.04,                    !- Thickness {m}
    0.038,                   !- Conductivity {W/m-K}
    24,                      !- Density {kg/m3}
    1210;                    !- Specific Heat {J/kg-K}

Material,
    Concrete_Floor,          !- Name
    MediumRough,             !- Roughness
    0.2,                     !- Thickness {m}
    1,                       !- Conductivity {W/m-K}
    1800,                    !- Density {kg/m3}
    1110;                    !- Specific Heat {J/kg-K}

Material,
    Insulation_Glass Wool,   !- Name
    MediumRough,             !- Roughness
    0.1,                     !- Thickness {m}
    0.04,                    !- Conductivity {W/m-K}
    200,                     !- Density {kg/m3}
    670;                     !- Specific Heat {J/kg-K}

Material,
    Concrete_Tile_roof,      !- Name
    MediumRough,             !- Roughness
    0.03,                    !- Thickness {m}
    1.1,                     !- Conductivity {W/m-K}
    2100,                    !- Density {kg/m3}
    837;                     !- Specific Heat {J/kg-K}

Material,
    Cement_Mortar,           !- Name
    Rough,                   !- Roughness
    0.05,                    !- Thickness {m}
    1.4,                     !- Conductivity {W/m-K}
    2000,                    !- Density {kg/m3}
    920,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    0.6,                     !- Solar Absorptance
    0.6;                     !- Visible Absorptance

Material,
    SolidCore_PineTimber_L0, !- Name
    Rough,                   !- Roughness
```

```
    0.04000,                 !- Thickness {m}
    0.34309,                 !- Conductivity {W/m-K}
    550.00000,               !- Density {kg/m3}
    2301.00000,              !- Specific Heat {J/kg-K}
    0.90000,                 !- Thermal Absorptance
    0.40400,                 !- Solar Absorptance
    0.33725;                 !- Visible Absorptance

Material,
    Concrete_Wall,           !- Name
    MediumRough,             !- Roughness
    0.21,                    !- Thickness {m}
    0.72,                    !- Conductivity {W/m-K}
    1400,                    !- Density {kg/m3}
    840;                     !- Specific Heat {J/kg-K}

Material,
    Brick,                   !- Name
    Rough,                   !- Roughness
    0.11,                    !- Thickness {m}
    0.39,                    !- Conductivity {W/m-K}
    1000,                    !- Density {kg/m3}
    880;                     !- Specific Heat {J/kg-K}

Material,
    Plaster,                 !- Name
    Rough,                   !- Roughness
    0.02,                    !- Thickness {m}
    0.07,                    !- Conductivity {W/m-K}
    1600,                    !- Density {kg/m3}
    1110;                    !- Specific Heat {J/kg-K}

Material,
    Insulation_Mineral Wool, !- Name
    MediumRough,             !- Roughness
    0.1,                     !- Thickness {m}
    0.04,                    !- Conductivity {W/m-K}
    70,                      !- Density {kg/m3}
    840;                     !- Specific Heat {J/kg-K}

Material,
    Wood_Board,              !- Name
    MediumSmooth,            !- Roughness
    0.025,                   !- Thickness {m}
    0.09,                    !- Conductivity {W/m-K}
    400,                     !- Density {kg/m3}
    1300;                    !- Specific Heat {J/kg-K}

Material,
    Concrete screed,         !- Name
    MediumRough,             !- Roughness
    0.03,                    !- Thickness {m}
    0.785,                   !- Conductivity {W/m-K}
    1600,                    !- Density {kg/m3}
    840;                     !- Specific Heat {J/kg-K}

Material,
    Insulation_XPS,          !- Name
    MediumSmooth,            !- Roughness
    0.34,                    !- Thickness {m}
    0.05,                    !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    1210;                    !- Specific Heat {J/kg-K}

Material,
    Ceramic,                 !- Name
    VeryRough,               !- Roughness
    0.0127,                  !- Thickness {m}
```

```
    1.2,                     !- Conductivity {W/m-K}
    1920,                    !- Density {kg/m3}
    1260;                    !- Specific Heat {J/kg-K}

Material,
    Aluminum Sheet,          !- Name
    MediumRough,             !- Roughness
    0.002,                   !- Thickness {m}
    204,                     !- Conductivity {W/m-K}
    2700,                    !- Density {kg/m3}
    896;                     !- Specific Heat {J/kg-K}

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:AIRGAP ===========

Material:AirGap,
    Wall_air_10cm,           !- Name
    0.15;                    !- Thermal Resistance {m2-K/W}

Material:AirGap,
    Ceiling_air,             !- Name
    0.18;                    !- Thermal Resistance {m2-K/W}

Material:AirGap,
    Wall_air_20cm,           !- Name
    0.15;                    !- Thermal Resistance {m2-K/W}

!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:GLAZING ===========

WindowMaterial:Glazing,
    GREEN 6MM,               !- Name
    SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    0.006,                   !- Thickness {m}
    0.479,                   !- Solar Transmittance at Normal Incidence
    0.373,                   !- Front Side Solar Reflectance at Normal Incidence
    0.373,                   !- Back Side Solar Reflectance at Normal Incidence
    0.316,                   !- Visible Transmittance at Normal Incidence
    0.535,                   !- Front Side Visible Reflectance at Normal Incidence
    0.453,                   !- Back Side Visible Reflectance at Normal Incidence
    0.0,                     !- Infrared Transmittance at Normal Incidence
    0.837,                   !- Front Side Infrared Hemispherical Emissivity
    0.837,                   !- Back Side Infrared Hemispherical Emissivity
    1;                       !- Conductivity {W/m-K}

WindowMaterial:Glazing,
    CLEAR 6MM,               !- Name
    SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    0.006,                   !- Thickness {m}
    0.775,                   !- Solar Transmittance at Normal Incidence
    0.071,                   !- Front Side Solar Reflectance at Normal Incidence
    0.071,                   !- Back Side Solar Reflectance at Normal Incidence
    0.881,                   !- Visible Transmittance at Normal Incidence
    0.080,                   !- Front Side Visible Reflectance at Normal Incidence
    0.080,                   !- Back Side Visible Reflectance at Normal Incidence
    0.0,                     !- Infrared Transmittance at Normal Incidence
    0.84,                    !- Front Side Infrared Hemispherical Emissivity
    0.84,                    !- Back Side Infrared Hemispherical Emissivity
    0.9;                     !- Conductivity {W/m-K}

!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:GAS ===========

WindowMaterial:Gas,
    ARGON 13MM,              !- Name
    Argon,                   !- Gas Type
```

```
    0.0127;                  !- Thickness {m}


!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:BLIND ===========

WindowMaterial:Blind,
    BLIND WITH MEDIUM REFLECTIVITY SLATS,  !- Name
    Horizontal,              !- Slat Orientation
    0.025,                   !- Slat Width {m}
    0.01875,                 !- Slat Separation {m}
    0.001,                   !- Slat Thickness {m}
    3,                       !- Slat Angle {deg}
    0.9,                     !- Slat Conductivity {W/m-K}
    0.0,                     !- Slat Beam Solar Transmittance
    0.5,                     !- Front Side Slat Beam Solar Reflectance
    0.5,                     !- Back Side Slat Beam Solar Reflectance
    0.0,                     !- Slat Diffuse Solar Transmittance
    0.5,                     !- Front Side Slat Diffuse Solar Reflectance
    0.5,                     !- Back Side Slat Diffuse Solar Reflectance
    0.0,                     !- Slat Beam Visible Transmittance
    0.5,                     !- Front Side Slat Beam Visible Reflectance
    0.5,                     !- Back Side Slat Beam Visible Reflectance
    0.0,                     !- Slat Diffuse Visible Transmittance
    0.5,                     !- Front Side Slat Diffuse Visible Reflectance
    0.5,                     !- Back Side Slat Diffuse Visible Reflectance
    0.0,                     !- Slat Infrared Hemispherical Transmittance
    0.9,                     !- Front Side Slat Infrared Hemispherical Emissivity
    0.9,                     !- Back Side Slat Infrared Hemispherical Emissivity
    0.050,                   !- Blind to Glass Distance {m}
    0.5,                     !- Blind Top Opening Multiplier
    0.5,                     !- Blind Bottom Opening Multiplier
    0.5,                     !- Blind Left Side Opening Multiplier
    0.5,                     !- Blind Right Side Opening Multiplier
    ,                        !- Minimum Slat Angle {deg}
    ;                        !- Maximum Slat Angle {deg}


!-   ===========  ALL OBJECTS IN CLASS: CONSTRUCTION ===========

Construction,
    Shaded_Window SG_Z2,     !- Name
    GREEN 6MM,               !- Outside Layer
    BLIND WITH MEDIUM REFLECTIVITY SLATS;  !- Layer 2

Construction,
    Out_Wall_West,           !- Name
    Aluminum Sheet,          !- Outside Layer
    Wall_air_20cm,           !- Layer 2
    Insulation_Mineral Wool, !- Layer 3
    Concrete_Wall,           !- Layer 4
    Plaster;                 !- Layer 5

Construction,
    Floor,                   !- Name
    Plaster,                 !- Outside Layer
    Concrete_Floor,          !- Layer 2
    Insulation_EPS,          !- Layer 3
    Concrete screed,         !- Layer 4
    Ceramic;                 !- Layer 5

Construction,
    Ceiling,                 !- Name
    Concrete_Tile_roof,      !- Outside Layer
    Cement_Mortar,           !- Layer 2
    Insulation_XPS,          !- Layer 3
    Concrete_Floor,          !- Layer 4
    Plaster;                 !- Layer 5
```

```
Construction,
    Inside-Wall-Corridor,    !- Name
    Plaster,                 !- Outside Layer
    Brick,                   !- Layer 2
    Plaster;                 !- Layer 3

Construction,
    Window DG,               !- Name
    CLEAR 6MM,               !- Outside Layer
    ARGON 13MM,              !- Layer 2
    CLEAR 6MM;               !- Layer 3

Construction,
    Window SG,               !- Name
    GREEN 6MM;               !- Outside Layer

Construction,
    Facade1,                 !- Name
    Insulation_Mineral Wool, !- Outside Layer
    Concrete_Wall,           !- Layer 2
    Plaster;                 !- Layer 3

Construction,
    Facade2,                 !- Name
    Insulation_Mineral Wool, !- Outside Layer
    Concrete_Wall,           !- Layer 2
    Plaster;                 !- Layer 3

Construction,
    Shaded_Window SG_Z3,     !- Name
    GREEN 6MM,               !- Outside Layer
    BLIND WITH MEDIUM REFLECTIVITY SLATS;  !- Layer 2

Construction,
    Shaded_Window SG_Z4,     !- Name
    GREEN 6MM,               !- Outside Layer
    BLIND WITH MEDIUM REFLECTIVITY SLATS;  !- Layer 2

Construction,
    Inside_Wall_Wood,        !- Name
    Wood_Board,              !- Outside Layer
    Wall_air_10cm,           !- Layer 2
    Wood_Board;              !- Layer 3


!-   ===========  ALL OBJECTS IN CLASS: GLOBALGEOMETRYRULES ===========

GlobalGeometryRules,
    UpperLeftCorner,         !- Starting Vertex Position
    CounterClockWise,        !- Vertex Entry Direction
    World,                   !- Coordinate System
    World;                   !- Daylighting Reference Point Coordinate System


!-   ===========  ALL OBJECTS IN CLASS: ZONE ===========

Zone,
    Zone_2,                  !- Name
    0.00000,                 !- Direction of Relative North {deg}
    0.0, 0.0, 0.0,                      !- X,Y,Z  {m}
    1,                       !- Type
    1.0,                     !- Multiplier
    3.60000,                 !- Ceiling Height {m}
    89.32684;                !- Volume {m3}

Zone,
    Zone_3,                  !- Name
    0.00000,                 !- Direction of Relative North {deg}
```

```
    0.0, 0.0, 0.0,                      !- X,Y,Z  {m}
    1,                       !- Type
    1.0,                     !- Multiplier
    3.60000,                 !- Ceiling Height {m}
    58.59459;                !- Volume {m3}

Zone,
    Zone_4,                  !- Name
    0.00000,                 !- Direction of Relative North {deg}
    0.0, 0.0, 0.0,                      !- X,Y,Z  {m}
    1,                       !- Type
    1.0,                     !- Multiplier
    3.60000,                 !- Ceiling Height {m}
    57.25858;                !- Volume {m3}

Zone,
    Zone_5,                  !- Name
    0.00000,                 !- Direction of Relative North {deg}
    0.0, 0.0, 0.0,                      !- X,Y,Z  {m}
    1,                       !- Type
    1.0,                     !- Multiplier
    3.60000,                 !- Ceiling Height {m}
    19.16445;                !- Volume {m3}

Zone,
    Zone_6,                  !- Name
    0.00000,                 !- Direction of Relative North {deg}
    0.0, 0.0, 0.0,                      !- X,Y,Z  {m}
    1,                       !- Type
    1.0,                     !- Multiplier
    3.60000,                 !- Ceiling Height {m}
    4.24342;                 !- Volume {m3}


!-   ===========  ALL OBJECTS IN CLASS: BUILDINGSURFACE:DETAILED ===========

BuildingSurface:Detailed,
    Obj:0030,                !- Name
    WALL,                    !- Surface Type
    Out_Wall_West,           !- Construction Name
    Zone_2,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16830, 134.89405, 3.60000,      !- X,Y,Z  1 {m}
    151.16830, 134.89405, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 131.53758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0031,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_2,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0042,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    151.16977, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 131.53758, 3.60000;      !- X,Y,Z  4 {m}
```

```
BuildingSurface:Detailed,
    Obj:0032,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_2,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0012,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0033,                !- Name
    WALL,                    !- Surface Type
    Inside-Wall-Corridor,    !- Construction Name
    Zone_2,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    156.71114, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    153.74492, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    153.74492, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0034,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_2,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0023,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    153.74492, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  3 {m}
    153.74492, 134.89405, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0035,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_2,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0022,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 134.89405, 3.60000,      !- X,Y,Z  1 {m}
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  2 {m}
    151.16830, 134.89405, 0.00000,      !- X,Y,Z  3 {m}
    151.16830, 134.89405, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0036,                !- Name
    FLOOR,                   !- Surface Type
    Floor,                   !- Construction Name
```

```
    Zone_2,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    1.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 136.96013, 0.00000,      !- X,Y,Z  1 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    153.74514, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    153.74492, 136.96013, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0037,                !- Name
    FLOOR,                   !- Surface Type
    Floor,                   !- Construction Name
    Zone_2,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    1.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  1 {m}
    153.74514, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    151.16830, 134.89405, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0038,                !- Name
    CEILING,                 !- Surface Type
    Ceiling,                 !- Construction Name
    Zone_2,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    153.74514, 131.53758, 3.60000,      !- X,Y,Z  2 {m}
    156.71114, 131.53758, 3.60000,      !- X,Y,Z  3 {m}
    156.71114, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0039,                !- Name
    CEILING,                 !- Surface Type
    Ceiling,                 !- Construction Name
    Zone_2,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16830, 134.89405, 3.60000,      !- X,Y,Z  1 {m}
    151.16977, 131.53758, 3.60000,      !- X,Y,Z  2 {m}
    153.74514, 131.53758, 3.60000,      !- X,Y,Z  3 {m}
    153.74492, 134.89405, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0008,                !- Name
    FLOOR,                   !- Surface Type
    Floor,                   !- Construction Name
    Zone_3,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
```

```
    NoWind,                  !- Wind Exposure
    1.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 136.96013, 0.00000,      !- X,Y,Z  1 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 136.96013, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0009,                !- Name
    WALL,                    !- Surface Type
    Inside-Wall-Corridor,    !- Construction Name
    Zone_3,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0010,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_3,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0018,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 131.53839, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0011,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_3,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0041,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 131.53839, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0012,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_3,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0032,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
```

```
    156.71114, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 131.53758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0013,                 !- Name
    CEILING,                  !- Surface Type
    Ceiling,                  !- Construction Name
    Zone_3,                   !- Zone Name
    Outdoors,                 !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    SunExposed,               !- Sun Exposure
    WindExposed,              !- Wind Exposure
    0.00000,                  !- View Factor to Ground
    4,                        !- Number of Vertices
    156.71114, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    156.71114, 131.53758, 3.60000,      !- X,Y,Z  2 {m}
    159.70611, 131.53839, 3.60000,      !- X,Y,Z  3 {m}
    159.70611, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0014,                 !- Name
    FLOOR,                    !- Surface Type
    Floor,                    !- Construction Name
    Zone_4,                   !- Zone Name
    Adiabatic,                !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    NoSun,                    !- Sun Exposure
    NoWind,                   !- Wind Exposure
    1.00000,                  !- View Factor to Ground
    4,                        !- Number of Vertices
    162.63275, 136.96013, 0.00000,      !- X,Y,Z  1 {m}
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 136.96013, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0015,                 !- Name
    WALL,                     !- Surface Type
    Inside-Wall-Corridor,     !- Construction Name
    Zone_4,                   !- Zone Name
    Adiabatic,                !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    NoSun,                    !- Sun Exposure
    NoWind,                   !- Wind Exposure
    0.50000,                  !- View Factor to Ground
    4,                        !- Number of Vertices
    162.63275, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    162.63275, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0016,                 !- Name
    WALL,                     !- Surface Type
    Inside_Wall_Wood,         !- Construction Name
    Zone_4,                   !- Zone Name
    Surface,                  !- Outside Boundary Condition
    ,                         !- Outside Boundary Condition Object
    NoSun,                    !- Sun Exposure
    NoWind,                   !- Wind Exposure
    0.50000,                  !- View Factor to Ground
    4,                        !- Number of Vertices
    162.63275, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    162.63275, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    162.63275, 136.96013, 3.60000;      !- X,Y,Z  4 {m}
```

```
BuildingSurface:Detailed,
    Obj:0017,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_4,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0040,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 131.53839, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  2 {m}
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    162.63275, 131.53758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0018,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_4,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0010,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 131.53839, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0019,                !- Name
    CEILING,                 !- Surface Type
    Ceiling,                 !- Construction Name
    Zone_4,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 131.53839, 3.60000,      !- X,Y,Z  2 {m}
    162.63275, 131.53758, 3.60000,      !- X,Y,Z  3 {m}
    162.63275, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0020,                !- Name
    FLOOR,                   !- Surface Type
    Floor,                   !- Construction Name
    Zone_5,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    1.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 136.96013, 0.00000,      !- X,Y,Z  1 {m}
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  2 {m}
    151.16830, 134.89405, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 136.96013, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0021,                !- Name
    WALL,                    !- Surface Type
    Out_Wall_West,           !- Construction Name
```

```
    Zone_5,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    151.16977, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    151.16830, 134.89405, 0.00000,      !- X,Y,Z  3 {m}
    151.16830, 134.89405, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0022,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_5,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0035,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16830, 134.89405, 3.60000,      !- X,Y,Z  1 {m}
    151.16830, 134.89405, 0.00000,      !- X,Y,Z  2 {m}
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  3 {m}
    153.74492, 134.89405, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0023,                !- Name
    WALL,                    !- Surface Type
    Inside_Wall_Wood,        !- Construction Name
    Zone_5,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0034,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 134.89405, 3.60000,      !- X,Y,Z  1 {m}
    153.74492, 134.89405, 0.00000,      !- X,Y,Z  2 {m}
    153.74492, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    153.74492, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0024,                !- Name
    CEILING,                 !- Surface Type
    Ceiling,                 !- Construction Name
    Zone_5,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    151.16830, 134.89405, 3.60000,      !- X,Y,Z  2 {m}
    153.74492, 134.89405, 3.60000,      !- X,Y,Z  3 {m}
    153.74492, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0043,                !- Name
    WALL,                    !- Surface Type
    Out_Wall_West,           !- Construction Name
    Zone_5,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
```

```
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    152.16977, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    152.16977, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0044,                !- Name
    WALL,                    !- Surface Type
    Inside-Wall-Corridor,    !- Construction Name
    Zone_5,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    153.74492, 136.96013, 3.60000,      !- X,Y,Z  1 {m}
    153.74492, 136.96013, 0.00000,      !- X,Y,Z  2 {m}
    152.16977, 136.96013, 0.00000,      !- X,Y,Z  3 {m}
    152.16977, 136.96013, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0025,                !- Name
    FLOOR,                   !- Surface Type
    Floor,                   !- Construction Name
    Zone_6,                  !- Zone Name
    Adiabatic,               !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    1.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  1 {m}
    162.63275, 131.43758, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 131.43758, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 131.53758, 0.00000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0026,                !- Name
    WALL,                    !- Surface Type
    Out_Wall_West,           !- Construction Name
    Zone_6,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    151.16977, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 131.43758, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 131.43758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0027,                !- Name
    WALL,                    !- Surface Type
    Facade2,                 !- Construction Name
    Zone_6,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 131.43758, 3.60000,      !- X,Y,Z  1 {m}
```

```
    151.16977, 131.43758, 0.00000,      !- X,Y,Z  2 {m}
    162.63275, 131.43758, 0.00000,      !- X,Y,Z  3 {m}
    162.63275, 131.43758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0028,                !- Name
    WALL,                    !- Surface Type
    Out_Wall_West,           !- Construction Name
    Zone_6,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    162.63275, 131.43758, 3.60000,      !- X,Y,Z  1 {m}
    162.63275, 131.43758, 0.00000,      !- X,Y,Z  2 {m}
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    162.63275, 131.53758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0029,                !- Name
    CEILING,                 !- Surface Type
    Ceiling,                 !- Construction Name
    Zone_6,                  !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
    WindExposed,             !- Wind Exposure
    0.00000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    151.16977, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    151.16977, 131.43758, 3.60000,      !- X,Y,Z  2 {m}
    162.63275, 131.43758, 3.60000,      !- X,Y,Z  3 {m}
    162.63275, 131.53758, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0040,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_6,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0017,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    162.63275, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    162.63275, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  3 {m}
    159.70611, 131.53839, 3.60000;      !- X,Y,Z  4 {m}

BuildingSurface:Detailed,
    Obj:0041,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_6,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0011,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    159.70611, 131.53839, 3.60000,      !- X,Y,Z  1 {m}
    159.70611, 131.53839, 0.00000,      !- X,Y,Z  2 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    156.71114, 131.53758, 3.60000;      !- X,Y,Z  4 {m}
```

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BuildingSurface:Detailed,
    Obj:0042,                !- Name
    WALL,                    !- Surface Type
    Facade1,                 !- Construction Name
    Zone_6,                  !- Zone Name
    Surface,                 !- Outside Boundary Condition
    Obj:0031,                !- Outside Boundary Condition Object
    NoSun,                   !- Sun Exposure
    NoWind,                  !- Wind Exposure
    0.50000,                 !- View Factor to Ground
    4,                       !- Number of Vertices
    156.71114, 131.53758, 3.60000,      !- X,Y,Z  1 {m}
    156.71114, 131.53758, 0.00000,      !- X,Y,Z  2 {m}
    151.16977, 131.53758, 0.00000,      !- X,Y,Z  3 {m}
    151.16977, 131.53758, 3.60000;      !- X,Y,Z  4 {m}


!-   ===========  ALL OBJECTS IN CLASS: FENESTRATIONSURFACE:DETAILED ===========

FenestrationSurface:Detailed,
    SubObj:0069,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0031,                !- Building Surface Name
    SubObj:0057,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    155.72500, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    155.72500, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    156.60000, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    156.60000, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0070,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0031,                !- Building Surface Name
    SubObj:0058,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    154.65000, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    154.65000, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    155.52500, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    155.52500, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0071,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0031,                !- Building Surface Name
    SubObj:0060,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    152.90500, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    152.90500, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    153.78000, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    153.78000, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
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    SubObj:0072,              !- Name
    WINDOW,                   !- Surface Type
    Window DG,                !- Construction Name
    Obj:0031,                 !- Building Surface Name
    SubObj:0064,              !- Outside Boundary Condition Object
    0.50000,                  !- View Factor to Ground
    ,                         !- Shading Control Name
    Wins_in,                  !- Frame and Divider Name
    1.00000,                  !- Multiplier
    4,                        !- Number of Vertices
    151.83000, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    151.83000, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    152.70500, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    152.70500, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0075,              !- Name
    WINDOW,                   !- Surface Type
    Window DG,                !- Construction Name
    Obj:0011,                 !- Building Surface Name
    SubObj:0054,              !- Outside Boundary Condition Object
    0.50000,                  !- View Factor to Ground
    ,                         !- Shading Control Name
    Wins_in,                  !- Frame and Divider Name
    1.00000,                  !- Multiplier
    4,                        !- Number of Vertices
    158.72500, 131.53817, 3.00000,      !- X,Y,Z  1 {m}
    158.72500, 131.53817, 1.00000,      !- X,Y,Z  2 {m}
    159.60000, 131.53839, 1.00000,      !- X,Y,Z  3 {m}
    159.60000, 131.53839, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0076,              !- Name
    WINDOW,                   !- Surface Type
    Window DG,                !- Construction Name
    Obj:0011,                 !- Building Surface Name
    SubObj:0055,              !- Outside Boundary Condition Object
    0.50000,                  !- View Factor to Ground
    ,                         !- Shading Control Name
    Wins_in,                  !- Frame and Divider Name
    1.00000,                  !- Multiplier
    4,                        !- Number of Vertices
    157.65000, 131.53791, 3.00000,      !- X,Y,Z  1 {m}
    157.65000, 131.53791, 1.00000,      !- X,Y,Z  2 {m}
    158.52500, 131.53813, 1.00000,      !- X,Y,Z  3 {m}
    158.52500, 131.53813, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0073,              !- Name
    WINDOW,                   !- Surface Type
    Window DG,                !- Construction Name
    Obj:0017,                 !- Building Surface Name
    SubObj:0051,              !- Outside Boundary Condition Object
    0.50000,                  !- View Factor to Ground
    ,                         !- Shading Control Name
    Wins_in,                  !- Frame and Divider Name
    1.00000,                  !- Multiplier
    4,                        !- Number of Vertices
    161.55775, 131.53786, 3.00000,      !- X,Y,Z  1 {m}
    161.55775, 131.53786, 1.00000,      !- X,Y,Z  2 {m}
    162.43275, 131.53761, 1.00000,      !- X,Y,Z  3 {m}
    162.43275, 131.53761, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0074,              !- Name
    WINDOW,                   !- Surface Type
    Window DG,                !- Construction Name
    Obj:0017,                 !- Building Surface Name
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    SubObj:0052,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    160.48275, 131.53809, 3.00000,      !- X,Y,Z  1 {m}
    160.48275, 131.53809, 1.00000,      !- X,Y,Z  2 {m}
    161.35775, 131.53784, 1.00000,      !- X,Y,Z  3 {m}
    161.35775, 131.53784, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0049,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    151.18950, 131.43800, 0.98000,      !- X,Y,Z  1 {m}
    151.18950, 131.43800, 0.02000,      !- X,Y,Z  2 {m}
    162.61250, 131.43800, 0.02000,      !- X,Y,Z  3 {m}
    162.61250, 131.43800, 0.98000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0050,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    151.18975, 131.43758, 3.58000,      !- X,Y,Z  1 {m}
    151.18975, 131.43758, 3.02000,      !- X,Y,Z  2 {m}
    162.61275, 131.43758, 3.02000,      !- X,Y,Z  3 {m}
    162.61275, 131.43758, 3.58000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0051,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0040,                !- Building Surface Name
    SubObj:0073,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    162.43275, 131.53761, 3.00000,      !- X,Y,Z  1 {m}
    162.43275, 131.53761, 1.00000,      !- X,Y,Z  2 {m}
    161.55775, 131.53786, 1.00000,      !- X,Y,Z  3 {m}
    161.55775, 131.53786, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0052,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0040,                !- Building Surface Name
    SubObj:0074,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
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    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    161.35775, 131.53784, 3.00000,      !- X,Y,Z  1 {m}
    161.35775, 131.53784, 1.00000,      !- X,Y,Z  2 {m}
    160.48275, 131.53809, 1.00000,      !- X,Y,Z  3 {m}
    160.48275, 131.53809, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0053,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    Shade Control4 - On,     !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    160.48275, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    160.48275, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    162.43275, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    162.43275, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0054,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0041,                !- Building Surface Name
    SubObj:0075,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    159.60000, 131.53839, 3.00000,      !- X,Y,Z  1 {m}
    159.60000, 131.53839, 1.00000,      !- X,Y,Z  2 {m}
    158.72500, 131.53817, 1.00000,      !- X,Y,Z  3 {m}
    158.72500, 131.53817, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0055,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0041,                !- Building Surface Name
    SubObj:0076,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    158.52500, 131.53813, 3.00000,      !- X,Y,Z  1 {m}
    158.52500, 131.53813, 1.00000,      !- X,Y,Z  2 {m}
    157.65000, 131.53791, 1.00000,      !- X,Y,Z  3 {m}
    157.65000, 131.53791, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0056,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    Shade Control3 - On,     !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    157.65000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    157.65000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
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```
    159.60000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    159.60000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0057,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0042,                !- Building Surface Name
    SubObj:0069,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    156.60000, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    156.60000, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    155.72500, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    155.72500, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0058,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0042,                !- Building Surface Name
    SubObj:0070,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    155.52500, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    155.52500, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    154.65000, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    154.65000, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0059,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    Shade Control2 - On,     !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    154.65000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    154.65000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    156.60000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    156.60000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0060,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0042,                !- Building Surface Name
    SubObj:0071,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    153.78000, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    153.78000, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    152.90500, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    152.90500, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
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    SubObj:0062,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    Shade Control2 - On,     !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    151.83000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    151.83000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    153.78000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    153.78000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0063,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    151.19000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    151.19000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    151.81000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    151.81000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0064,             !- Name
    WINDOW,                  !- Surface Type
    Window DG,               !- Construction Name
    Obj:0042,                !- Building Surface Name
    SubObj:0072,             !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_in,                 !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    152.70500, 131.53758, 3.00000,      !- X,Y,Z  1 {m}
    152.70500, 131.53758, 1.00000,      !- X,Y,Z  2 {m}
    151.83000, 131.53758, 1.00000,      !- X,Y,Z  3 {m}
    151.83000, 131.53758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0065,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    153.80000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    153.80000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    154.63000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    154.63000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0066,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
```

```
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    156.62000, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    156.62000, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    157.63000, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    157.63000, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0067,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    159.61975, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    159.61975, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    160.46275, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    160.46275, 131.43758, 3.00000;      !- X,Y,Z  4 {m}

FenestrationSurface:Detailed,
    SubObj:0068,             !- Name
    WINDOW,                  !- Surface Type
    Window SG,               !- Construction Name
    Obj:0027,                !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    0.50000,                 !- View Factor to Ground
    ,                        !- Shading Control Name
    Wins_out,                !- Frame and Divider Name
    1.00000,                 !- Multiplier
    4,                       !- Number of Vertices
    162.45275, 131.43758, 3.00000,      !- X,Y,Z  1 {m}
    162.45275, 131.43758, 1.00000,      !- X,Y,Z  2 {m}
    162.61275, 131.43758, 1.00000,      !- X,Y,Z  3 {m}
    162.61275, 131.43758, 3.00000;      !- X,Y,Z  4 {m}


!-   ===========  ALL OBJECTS IN CLASS: WINDOWPROPERTY:SHADINGCONTROL ===========

WindowProperty:ShadingControl,
    Shade Control2 - On,     !- Name
    InteriorBlind,           !- Shading Type
    Shaded_Window SG_Z2,     !- Construction with Shading Name
    OnIfScheduleAllows,      !- Shading Control Type
    blind1-position,         !- Schedule Name
    ,                        !- Setpoint {W/m2, W or deg C}
    Yes,                     !- Shading Control Is Scheduled
    No,                      !- Glare Control Is Active
    ,                        !- Shading Device Material Name
    FixedSlatAngle,          !- Type of Slat Angle Control for Blinds
    ;                        !- Slat Angle Schedule Name

WindowProperty:ShadingControl,
    Shade Control3 - On,     !- Name
    InteriorBlind,           !- Shading Type
    Shaded_Window SG_Z3,     !- Construction with Shading Name
    OnIfScheduleAllows,      !- Shading Control Type
    blind2-position,         !- Schedule Name
    ,                        !- Setpoint {W/m2, W or deg C}
    Yes,                     !- Shading Control Is Scheduled
    No,                      !- Glare Control Is Active
```

```
    ,                         !- Shading Device Material Name
    FixedSlatAngle,           !- Type of Slat Angle Control for Blinds
    ;                         !- Slat Angle Schedule Name

WindowProperty:ShadingControl,
    Shade Control4 - On,      !- Name
    InteriorBlind,            !- Shading Type
    Shaded_Window SG_Z4,      !- Construction with Shading Name
    OnIfScheduleAllows,       !- Shading Control Type
    blind3-position,          !- Schedule Name
    ,                         !- Setpoint {W/m2, W or deg C}
    Yes,                      !- Shading Control Is Scheduled
    No,                       !- Glare Control Is Active
    ,                         !- Shading Device Material Name
    FixedSlatAngle,           !- Type of Slat Angle Control for Blinds
    ;                         !- Slat Angle Schedule Name


!-   ===========  ALL OBJECTS IN CLASS: WINDOWPROPERTY:FRAMEANDDIVIDER ===========

WindowProperty:FrameAndDivider,
    Wins_in,                  !- Name
    0.1,                      !- Frame Width {m}
    0.015,                    !- Frame Outside Projection {m}
    0.015,                    !- Frame Inside Projection {m}
    2.326112,                 !- Frame Conductance {W/m2-K}
    1.511321,                 !- Ratio of Frame-Edge Glass Conductance to Center-
Of-Glass Conductance
    0.9,                      !- Frame Solar Absorptance
    0.9,                      !- Frame Visible Absorptance
    0.9,                      !- Frame Thermal Hemispherical Emissivity
    DividedLite,              !- Divider Type
    ,                         !- Divider Width {m}
    ,                         !- Number of Horizontal Dividers
    ,                         !- Number of Vertical Dividers
    ,                         !- Divider Outside Projection {m}
    ,                         !- Divider Inside Projection {m}
    ,                         !- Divider Conductance {W/m2-K}
    1,                        !- Ratio of Divider-Edge Glass Conductance to Center-
Of-Glass Conductance
    ,                         !- Divider Solar Absorptance
    ,                         !- Divider Visible Absorptance
    0.9;                      !- Divider Thermal Hemispherical Emissivity

WindowProperty:FrameAndDivider,
    Wins_out,                 !- Name
    0.01,                     !- Frame Width {m}
    0.015,                    !- Frame Outside Projection {m}
    0.015,                    !- Frame Inside Projection {m}
    2.326112,                 !- Frame Conductance {W/m2-K}
    1.511321,                 !- Ratio of Frame-Edge Glass Conductance to Center-
Of-Glass Conductance
    0.9,                      !- Frame Solar Absorptance
    0.9,                      !- Frame Visible Absorptance
    0.9,                      !- Frame Thermal Hemispherical Emissivity
    DividedLite,              !- Divider Type
    ,                         !- Divider Width {m}
    ,                         !- Number of Horizontal Dividers
    ,                         !- Number of Vertical Dividers
    ,                         !- Divider Outside Projection {m}
    ,                         !- Divider Inside Projection {m}
    ,                         !- Divider Conductance {W/m2-K}
    1,                        !- Ratio of Divider-Edge Glass Conductance to Center-
Of-Glass Conductance
    ,                         !- Divider Solar Absorptance
    ,                         !- Divider Visible Absorptance
    0.9;                      !- Divider Thermal Hemispherical Emissivity
```

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!-   ===========  ALL OBJECTS IN CLASS: PEOPLE ===========

People,
    A8,                      !- Name
    Zone_4,                  !- Zone or ZoneList Name
    occ15,                   !- Number of People Schedule Name
    People,                  !- Number of People Calculation Method
    1,                       !- Number of People
    ,                        !- People per Zone Floor Area {person/m2}
    ,                        !- Zone Floor Area per Person {m2/person}
    0.5,                     !- Fraction Radiant
    autocalculate,           !- Sensible Heat Fraction
    People Activity,         !- Activity Level Schedule Name
    3.82E-08,                !- Carbon Dioxide Generation Rate {m3/s-W}
    No,                      !- Enable ASHRAE 55 Comfort Warnings
    ZoneAveraged;            !- Mean Radiant Temperature Calculation Type

People,
    A4,                      !- Name
    Zone_2,                  !- Zone or ZoneList Name
    occ12,                   !- Number of People Schedule Name
    People,                  !- Number of People Calculation Method
    1,                       !- Number of People
    ,                        !- People per Zone Floor Area {person/m2}
    ,                        !- Zone Floor Area per Person {m2/person}
    0.5,                     !- Fraction Radiant
    autocalculate,           !- Sensible Heat Fraction
    People Activity,         !- Activity Level Schedule Name
    3.82E-08,                !- Carbon Dioxide Generation Rate {m3/s-W}
    No,                      !- Enable ASHRAE 55 Comfort Warnings
    ZoneAveraged;            !- Mean Radiant Temperature Calculation Type

People,
    A6,                      !- Name
    Zone_3,                  !- Zone or ZoneList Name
    occ14,                   !- Number of People Schedule Name
    People,                  !- Number of People Calculation Method
    1,                       !- Number of People
    ,                        !- People per Zone Floor Area {person/m2}
    ,                        !- Zone Floor Area per Person {m2/person}
    0.5,                     !- Fraction Radiant
    autocalculate,           !- Sensible Heat Fraction
    People Activity,         !- Activity Level Schedule Name
    3.82E-08,                !- Carbon Dioxide Generation Rate {m3/s-W}
    No,                      !- Enable ASHRAE 55 Comfort Warnings
    ZoneAveraged;            !- Mean Radiant Temperature Calculation Type


!-   ===========  ALL OBJECTS IN CLASS: LIGHTS ===========

Lights,
    A4,                      !- Name
    Zone_2,                  !- Zone or ZoneList Name
    light1-sw,               !- Schedule Name
    LightingLevel,           !- Design Level Calculation Method
    60,                      !- Lighting Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Return Air Fraction
    0.42,                    !- Fraction Radiant
    0.18,                    !- Fraction Visible
    1,                       !- Fraction Replaceable
    General,                 !- End-Use Subcategory
    No;                      !- Return Air Fraction Calculated from Plenum
Temperature

Lights,
```

```
    A6,                         !- Name
    Zone_3,                     !- Zone or ZoneList Name
    light2-sw,                  !- Schedule Name
    LightingLevel,              !- Design Level Calculation Method
    60,                         !- Lighting Level {W}
    ,                           !- Watts per Zone Floor Area {W/m2}
    ,                           !- Watts per Person {W/person}
    0,                          !- Return Air Fraction
    0.42,                       !- Fraction Radiant
    0.18,                       !- Fraction Visible
    1,                          !- Fraction Replaceable
    General,                    !- End-Use Subcategory
    No;                         !- Return Air Fraction Calculated from Plenum
Temperature

Lights,
    A8,                         !- Name
    Zone_4,                     !- Zone or ZoneList Name
    light3-sw,                  !- Schedule Name
    LightingLevel,              !- Design Level Calculation Method
    60,                         !- Lighting Level {W}
    ,                           !- Watts per Zone Floor Area {W/m2}
    ,                           !- Watts per Person {W/person}
    0,                          !- Return Air Fraction
    0.42,                       !- Fraction Radiant
    0.18,                       !- Fraction Visible
    1,                          !- Fraction Replaceable
    General,                    !- End-Use Subcategory
    No;                         !- Return Air Fraction Calculated from Plenum
Temperature


!-   ===========  ALL OBJECTS IN CLASS: OTHEREQUIPMENT ===========

OtherEquipment,
    Z2_rad2,                    !- Name
    Zone_2,                     !- Zone Name
    hea-pow2,                   !- Schedule Name
    EquipmentLevel,             !- Design Level Calculation Method
    1,                          !- Design Level {W}
    ,                           !- Watts per Zone Floor Area {W/m2}
    ,                           !- Watts per Person {W/Person}
    0,                          !- Fraction Latent
    0.5;                        !- Fraction Radiant

OtherEquipment,
    Z2_rad3,                    !- Name

    Zone_2,                     !- Zone Name

    hea-pow4,                   !- Schedule Name
    EquipmentLevel,             !- Design Level Calculation Method
    1,                          !- Design Level {W}
    ,                           !- Watts per Zone Floor Area {W/m2}
    ,                           !- Watts per Person {W/Person}
    0,                          !- Fraction Latent
    0.5;                        !- Fraction Radiant

OtherEquipment,
    Z2_rad4,                    !- Name
    Zone_2,                     !- Zone Name

    hea-pow3,                   !- Schedule Name
    EquipmentLevel,             !- Design Level Calculation Method
    1,                          !- Design Level {W}
    ,                           !- Watts per Zone Floor Area {W/m2}
    ,                           !- Watts per Person {W/Person}
    0,                          !- Fraction Latent
```

```
    0.5;                    !- Fraction Radiant

OtherEquipment,
    Z3_rad5,                !- Name
    Zone_3,                 !- Zone Name
    hea-pow5,               !- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    1,                      !- Design Level {W}
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/Person}
    0,                      !- Fraction Latent
    0.5;                    !- Fraction Radiant

OtherEquipment,
    Z4_rad6,                !- Name
    Zone_4,                 !- Zone Name
    hea-pow6,               !- Schedule Name
    EquipmentLevel,         !- Design Level Calculation Method
    1,                      !- Design Level {W}
    ,                       !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/Person}
    0,                      !- Fraction Latent
    0.5;                    !- Fraction Radiant


!-   ===========  ALL OBJECTS IN CLASS: ZONEINFILTRATION:DESIGNFLOWRATE
===========

ZoneInfiltration:DesignFlowRate,
    Zone2_Infiltration,     !- Name
    Zone_2,                 !- Zone or ZoneList Name
    Infiltration,           !- Schedule Name
    AirChanges/Hour,        !- Design Flow Rate Calculation Method
    ,                       !- Design Flow Rate {m3/s}
    ,                       !- Flow per Zone Floor Area {m3/s-m2}
    ,                       !- Flow per Exterior Surface Area {m3/s-m2}
    0.2,                    !- Air Changes per Hour {1/hr}
    1,                      !- Constant Term Coefficient
    ,                       !- Temperature Term Coefficient
    ,                       !- Velocity Term Coefficient
    ;                       !- Velocity Squared Term Coefficient

ZoneInfiltration:DesignFlowRate,

    Zone3_Infiltration,     !- Name
    Zone_3,                 !- Zone or ZoneList Name
    Infiltration,           !- Schedule Name
    AirChanges/Hour,        !- Design Flow Rate Calculation Method
    ,                       !- Design Flow Rate {m3/s}
    ,                       !- Flow per Zone Floor Area {m3/s-m2}
    ,                       !- Flow per Exterior Surface Area {m3/s-m2}
    0.2,                    !- Air Changes per Hour {1/hr}
    1,                      !- Constant Term Coefficient
    ,                       !- Temperature Term Coefficient
    ,                       !- Velocity Term Coefficient
    ;                       !- Velocity Squared Term Coefficient

ZoneInfiltration:DesignFlowRate,
    Zone4_Infiltration,     !- Name
    Zone_4,                 !- Zone or ZoneList Name
    Infiltration,           !- Schedule Name
    AirChanges/Hour,        !- Design Flow Rate Calculation Method
    ,                       !- Design Flow Rate {m3/s}
    ,                       !- Flow per Zone Floor Area {m3/s-m2}
    ,                       !- Flow per Exterior Surface Area {m3/s-m2}
    0.2,                    !- Air Changes per Hour {1/hr}
    1,                      !- Constant Term Coefficient
    ,                       !- Temperature Term Coefficient
```

```
    ,                         !- Velocity Term Coefficient
    ;                         !- Velocity Squared Term Coefficient


!-   ===========  ALL OBJECTS IN CLASS: ZONEVENTILATION:DESIGNFLOWRATE ===========

ZoneVentilation:DesignFlowRate,
    Zone2/1_Ventilation,      !- Name
    Zone_2,                   !- Zone or ZoneList Name
    con28,                    !- Schedule Name
    AirChanges/Hour,          !- Design Flow Rate Calculation Method
    ,                         !- Design Flow Rate {m3/s}
    ,                         !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                         !- Flow Rate per Person {m3/s-person}
    1,                        !- Air Changes per Hour {1/hr}
    Natural,                  !- Ventilation Type
    ,                         !- Fan Pressure Rise {Pa}
    1,                        !- Fan Total Efficiency
    1,                        !- Constant Term Coefficient
    ,                         !- Temperature Term Coefficient
    ,                         !- Velocity Term Coefficient
    ,                         !- Velocity Squared Term Coefficient
    -100,                     !- Minimum Indoor Temperature {C}
    ,                         !- Minimum Indoor Temperature Schedule Name
    100,                      !- Maximum Indoor Temperature {C}
    ,                         !- Maximum Indoor Temperature Schedule Name
    -100,                     !- Delta Temperature {deltaC}
    ,                         !- Delta Temperature Schedule Name
    -100,                     !- Minimum Outdoor Temperature {C}
    ,                         !- Minimum Outdoor Temperature Schedule Name
    100,                      !- Maximum Outdoor Temperature {C}
    ,                         !- Maximum Outdoor Temperature Schedule Name
    40;                       !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    Zone2/2_Ventilation,      !- Name

    Zone_2,                   !- Zone or ZoneList Name

    con29,                    !- Schedule Name
    AirChanges/Hour,          !- Design Flow Rate Calculation Method
    ,                         !- Design Flow Rate {m3/s}
    ,                         !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                         !- Flow Rate per Person {m3/s-person}
    1,                        !- Air Changes per Hour {1/hr}
    Natural,                  !- Ventilation Type
    ,                         !- Fan Pressure Rise {Pa}
    1,                        !- Fan Total Efficiency
    1,                        !- Constant Term Coefficient
    ,                         !- Temperature Term Coefficient
    ,                         !- Velocity Term Coefficient
    ,                         !- Velocity Squared Term Coefficient
    -100,                     !- Minimum Indoor Temperature {C}
    ,                         !- Minimum Indoor Temperature Schedule Name
    100,                      !- Maximum Indoor Temperature {C}
    ,                         !- Maximum Indoor Temperature Schedule Name
    -100,                     !- Delta Temperature {deltaC}
    ,                         !- Delta Temperature Schedule Name
    -100,                     !- Minimum Outdoor Temperature {C}
    ,                         !- Minimum Outdoor Temperature Schedule Name
    100,                      !- Maximum Outdoor Temperature {C}
    ,                         !- Maximum Outdoor Temperature Schedule Name
    40;                       !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    Zone2/3_Ventilation,      !- Name
    Zone_2,                   !- Zone or ZoneList Name
```

```
    con30,                   !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Flow Rate per Person {m3/s-person}
    1,                       !- Air Changes per Hour {1/hr}
    Natural,                 !- Ventilation Type
    ,                        !- Fan Pressure Rise {Pa}
    1,                       !- Fan Total Efficiency
    1,                       !- Constant Term Coefficient
    ,                        !- Temperature Term Coefficient
    ,                        !- Velocity Term Coefficient
    ,                        !- Velocity Squared Term Coefficient
    -100,                    !- Minimum Indoor Temperature {C}
    ,                        !- Minimum Indoor Temperature Schedule Name
    100,                     !- Maximum Indoor Temperature {C}
    ,                        !- Maximum Indoor Temperature Schedule Name
    -100,                    !- Delta Temperature {deltaC}
    ,                        !- Delta Temperature Schedule Name
    -100,                    !- Minimum Outdoor Temperature {C}
    ,                        !- Minimum Outdoor Temperature Schedule Name
    100,                     !- Maximum Outdoor Temperature {C}
    ,                        !- Maximum Outdoor Temperature Schedule Name
    40;                      !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,

    Zone2/4_Ventilation,     !- Name

    Zone_2,                  !- Zone or ZoneList Name

    con31,                   !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Flow Rate per Person {m3/s-person}
    1,                       !- Air Changes per Hour {1/hr}
    Natural,                 !- Ventilation Type
    ,                        !- Fan Pressure Rise {Pa}
    1,                       !- Fan Total Efficiency
    1,                       !- Constant Term Coefficient
    ,                        !- Temperature Term Coefficient
    ,                        !- Velocity Term Coefficient
    ,                        !- Velocity Squared Term Coefficient
    -100,                    !- Minimum Indoor Temperature {C}
    ,                        !- Minimum Indoor Temperature Schedule Name
    100,                     !- Maximum Indoor Temperature {C}
    ,                        !- Maximum Indoor Temperature Schedule Name
    -100,                    !- Delta Temperature {deltaC}
    ,                        !- Delta Temperature Schedule Name
    -100,                    !- Minimum Outdoor Temperature {C}
    ,                        !- Minimum Outdoor Temperature Schedule Name
    100,                     !- Maximum Outdoor Temperature {C}
    ,                        !- Maximum Outdoor Temperature Schedule Name
    40;                      !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,

    Zone3/5_Ventilation,     !- Name

    Zone_3,                  !- Zone or ZoneList Name

    con32,                   !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Flow Rate per Person {m3/s-person}
    1,                       !- Air Changes per Hour {1/hr}
```

```
    Natural,                 !- Ventilation Type
    ,                        !- Fan Pressure Rise {Pa}
    1,                       !- Fan Total Efficiency
    1,                       !- Constant Term Coefficient
    ,                        !- Temperature Term Coefficient
    ,                        !- Velocity Term Coefficient
    ,                        !- Velocity Squared Term Coefficient
    -100,                    !- Minimum Indoor Temperature {C}
    ,                        !- Minimum Indoor Temperature Schedule Name
    100,                     !- Maximum Indoor Temperature {C}
    ,                        !- Maximum Indoor Temperature Schedule Name
    -100,                    !- Delta Temperature {deltaC}
    ,                        !- Delta Temperature Schedule Name
    -100,                    !- Minimum Outdoor Temperature {C}
    ,                        !- Minimum Outdoor Temperature Schedule Name
    100,                     !- Maximum Outdoor Temperature {C}
    ,                        !- Maximum Outdoor Temperature Schedule Name
    40;                      !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    Zone3/6_Ventilation,     !- Name

    Zone_3,                  !- Zone or ZoneList Name

    con33,                   !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Flow Rate per Person {m3/s-person}
    1,                       !- Air Changes per Hour {1/hr}
    Natural,                 !- Ventilation Type
    ,                        !- Fan Pressure Rise {Pa}
    1,                       !- Fan Total Efficiency
    1,                       !- Constant Term Coefficient
    ,                        !- Temperature Term Coefficient
    ,                        !- Velocity Term Coefficient
    ,                        !- Velocity Squared Term Coefficient
    -100,                    !- Minimum Indoor Temperature {C}
    ,                        !- Minimum Indoor Temperature Schedule Name
    100,                     !- Maximum Indoor Temperature {C}
    ,                        !- Maximum Indoor Temperature Schedule Name
    -100,                    !- Delta Temperature {deltaC}
    ,                        !- Delta Temperature Schedule Name
    -100,                    !- Minimum Outdoor Temperature {C}
    ,                        !- Minimum Outdoor Temperature Schedule Name
    100,                     !- Maximum Outdoor Temperature {C}
    ,                        !- Maximum Outdoor Temperature Schedule Name
    40;                      !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    Zone4/7_Ventilation,     !- Name
    Zone_4,                  !- Zone or ZoneList Name

    con34,                   !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Flow Rate per Person {m3/s-person}
    1,                       !- Air Changes per Hour {1/hr}
    Natural,                 !- Ventilation Type
    ,                        !- Fan Pressure Rise {Pa}
    1,                       !- Fan Total Efficiency
    1,                       !- Constant Term Coefficient
    ,                        !- Temperature Term Coefficient
    ,                        !- Velocity Term Coefficient
    ,                        !- Velocity Squared Term Coefficient
    -100,                    !- Minimum Indoor Temperature {C}
    ,                        !- Minimum Indoor Temperature Schedule Name
```

```
    100,                      !- Maximum Indoor Temperature {C}
    ,                         !- Maximum Indoor Temperature Schedule Name
    -100,                     !- Delta Temperature {deltaC}
    ,                         !- Delta Temperature Schedule Name
    -100,                     !- Minimum Outdoor Temperature {C}
    ,                         !- Minimum Outdoor Temperature Schedule Name
    100,                      !- Maximum Outdoor Temperature {C}
    ,                         !- Maximum Outdoor Temperature Schedule Name
    40;                       !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    Zone4/8_Ventilation,      !- Name
    Zone_4,                   !- Zone or ZoneList Name
    con35,                    !- Schedule Name
    AirChanges/Hour,          !- Design Flow Rate Calculation Method
    ,                         !- Design Flow Rate {m3/s}
    ,                         !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                         !- Flow Rate per Person {m3/s-person}
    1,                        !- Air Changes per Hour {1/hr}
    Natural,                  !- Ventilation Type
    ,                         !- Fan Pressure Rise {Pa}
    1,                        !- Fan Total Efficiency
    1,                        !- Constant Term Coefficient
    ,                         !- Temperature Term Coefficient
    ,                         !- Velocity Term Coefficient
    ,                         !- Velocity Squared Term Coefficient
    -100,                     !- Minimum Indoor Temperature {C}
    ,                         !- Minimum Indoor Temperature Schedule Name
    100,                      !- Maximum Indoor Temperature {C}
    ,                         !- Maximum Indoor Temperature Schedule Name
    -100,                     !- Delta Temperature {deltaC}
    ,                         !- Delta Temperature Schedule Name
    -100,                     !- Minimum Outdoor Temperature {C}
    ,                         !- Minimum Outdoor Temperature Schedule Name
    100,                      !- Maximum Outdoor Temperature {C}
    ,                         !- Maximum Outdoor Temperature Schedule Name
    40;                       !- Maximum Wind Speed {m/s}


!-   ===========  ALL OBJECTS IN CLASS: HVACTEMPLATE:ZONE:IDEALLOADSAIRSYSTEM
===========

HVACTemplate:Zone:IdealLoadsAirSystem,
    Zone_2,                   !- Zone Name
    Zone_2;                   !- Template Thermostat Name

HVACTemplate:Zone:IdealLoadsAirSystem,
    Zone_4,                   !- Zone Name
    Zone_4;                   !- Template Thermostat Name
```

8.2 Appendix B: File specifications for GenOpt

8.2.1 Initialization file

```
/* GenOpt example initialization file for EnergyPlus
   Operating system: Windows 7
   MWetter@lbl.gov, 2011-11-30
*/
Simulation {
  Files {
    Template {
      File1 = Ini_Sum_Leh_Eco11_01_1Z_template.idf;
    }
    Input {

      File1 = Ini_Sum_Leh_Eco11_01_1Z.idf;
    }
    Log {
     File1 = Ini_Sum_Leh_Eco11_01_1Z.err;
    }
    Output {
     File1 = Ini_Sum_Leh_Eco11_01_1Z.eso;
    }
    Configuration {
      File1 = "\\cfg\\EnergyPlus-7-0-0-Win7.cfg";
    }
  }
  CallParameter { // optional section
    // The weather file without extension
    Suffix = BPI_0102_1010_2011;
  }
  ObjectiveFunctionLocation
  {
      Name1             = F;
      Delimiter1        = "371,";
      FirstCharacterAt1 = 1;


      Name2            = NRMSD;
      Delimiter2        = "369,";
      FirstCharacterAt2 = 1;

      Name3             = R2;
      Delimiter3        = "370,";
      FirstCharacterAt3 = 1;
  }
```

```
} // end of section Simulation
Optimization {
  Files {
    Command {
      File1 = command.txt;
    }
  }
} // end of configuration file
```

8.2.2 Configuration file

```
/* GenOpt configuration file for
   EnergyPlus on Windows XP
   MWetter@lbl.gov, 11/30/11
*/

// Error messages of the simulation program.
SimulationError
{
    ErrorMessage = "** Fatal  **";
    ErrorMessage = "** EnergyPlus Terminated--Error(s)
Detected";
}

// Number format for writing the simulation input files.
IO
{
    NumberFormat = Double;
}

/*  Specifying how to start the simulation program.
    In "Command", only those words in %xx% are
    replaced (possibly with empty Strings).
*/
SimulationStart
{
    // The command line below calls RunEPlus.bat.
    Command = "cmd /C \"\"C:\\EnergyPlusV7-0-
0\\RunEPlus.bat\" \"%Simulation.Files.Input.File1%\"
\"%Simulation.CallParameter.Suffix%\"\"";
    WriteInputFileExtension = false;
}
```

8.2.3 Command file

```
/* GenOpt example command file
   MWetter@lbl.gov, 06/18/2003
*/
Vary{
  Parameter{   // infiltration
    Name    = infil;
    Min     =   0.1;
    Ini     =   0.2;
    Max     =   0.4;
    Step    =   0.004;
  }

  Parameter{   // Ventilation
    Name    =  venti;
    Min     =   0.5;
    Ini     =   1;
    Max     =   3;
    Step    =   0.02;
  }

  Parameter{   // solar transmittance
    Name    = GValue1;
    Min     =   0.383;
    Ini     =   0.479;
    Max     =   0.62;
    Step    =   0.01;
  }

  Parameter{   // solar transmittance
    Name    = GValue2;
    Min     =   0.540;
    Ini     =   0.775;
    Max     =   0.840;
    Step    =   0.0155;
  }

Parameter{   // landa_Mineral Wool
    Name    = MW_landa;
    Min     =   0.0312;
    Ini     =   0.039;
    Max     =   0.0468;
    Step    =   0.0008;
  }
Parameter{   // landa_XPS
```

```
    Name    = XPS_landa;
    Min     =   0.03;
    Ini     =   0.05;
    Max     =   0.07;
    Step    =   0.001;
  }

  Parameter{   // Ceiling Concrete_Density
    Name    = Density_CC;
    Min     =   1260;
    Ini     =   1800;
    Max     =   2340;
    Step    =   36;
}

Function{
    Name    = aP;
    Function= "multiply (%Density_CC%, 0.0008)" ;
}

Function{
    Name    = Landa_CC;
    Function= "subtract (%aP%, 0.4617)" ;
}


  Parameter{   // External Wall Concrete_Density
    Name    = Density_CW;
    Min     =   980;
    Ini     =   1400;
    Max     =   1820;
    Step    =   28;
}

Function{
    Name    = aA;
    Function= "multiply (%Density_CW%, 0.0007)" ;
}

Function{
    Name    = Landa_CW;
    Function= "subtract (%aA%, 0.2533)" ;
}
  }

OptimizationSettings{
  MaxIte = 2000;
  MaxEqualResults =  100;
```

```
  WriteStepNumber =  false;
  UnitsOfExecution = 0;
}
Algorithm{
  Main = GPSPSOCCHJ;
  NeighborhoodTopology = vonNeumann;
  NeighborhoodSize = 5;
  NumberOfParticle = 10;
  NumberOfGeneration = 10;
  Seed = 1;
  CognitiveAcceleration = 2.8;
  SocialAcceleration = 1.3;
  MaxVelocityGainContinuous = 0.5;
  MaxVelocityDiscrete = 4;
  ConstrictionGain = 0.5;
  MeshSizeDivider = 2;
  InitialMeshSizeExponent = 0;
  MeshSizeExponentIncrement = 1;
  NumberOfStepReduction = 4;
}
```

8.2.4 Log file

```
GenOpt(R) Optimization Version 3.1.0, December 8, 2011

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http://simulationresearch.lbl.gov
Michael Wetter, MWetter@lbl.gov

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___________________________________________________________
____

Configuration file :
C:\Users\Mahnameh\Desktop\Optimization\Eco11\optWin7.ini
Command file       :
C:\Users\Mahnameh\Desktop\Optimization\Eco11\command.txt
```

```
Optimization started  at : Wed Aug 22 18:34:34 CEST 2012
Optimization finished at : Wed Aug 22 19:26:16 CEST 2012
Execution time           :            00:51:42
____________________________________________________________
____

Optimization completed successfully.
```