Model-Based Coupling of Air and Hydronic System Operation in a High Performance Academic Building

Seyed Arman Mottaghi

A Thesis

in the

Building Science Graduate Program

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Applied Science in Building Engineering/Building Science

at the

British Columbia Institute of Technology

Burnaby, British Columbia, Canada

October 2017

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

Building Science Graduate Program

This is to certify that the thesis prepared

By: Seyed Arman Mottaghi

Entitled: Model-Based Coupling of Air and Hydronic System Operation in a High Performance Academic Building

And submitted in partial fulfillment of the requirement for the degree of:

Master of Applied Science in Building Engineering/Building Science

Complies with the regulations of the Institute and meets the accepted standards with respect to originality and quality.

Signed by the final Examining Committee:

____

Bo Li, Chair and Examiner

____

José Candanedo Ibarra, Examiner, external to program

____

Miroslava Kavgic, Research Advisor

____

Rodrigo Mora, Supervisor

Approved by:

____

Graduate Program Director

Abstract

This research is motivated from preliminary teamwork on analyzing the "Performance Gap" of three high-performance buildings, which are currently under operation. All three buildings are facing operational challenges that are not unusual considering the complexity of their systems. However, evidence from design documents, an existing energy model, and operational data suggests that their performance is not entirely reflecting the design intent. This research follows the premise that there is a need to design buildings as systems-of-systems to be able to understand, interpret, quantify, design, and fine-tune the dynamic couplings between systems. This research was dedicated to a high-performance academic building (HPAB) – one of the above three buildings – as a case-study to gain understanding on the complexities of systems coupling, and learn and apply dynamic simulation-based systems coupling tools and methods. The main focus of the study is the classrooms because of the existing evidence on the significant impact of indoor environmental comfort on student performance in academic facilities.

The HPAB case-study building incorporates, at the source side, ground-coupled water-to-water heat pumps (WWHP) and solar-thermal as primary means of heating, with boiler used as a backup source. Cooling is provided by the cold side of the WWHP system. On the demand side, heating and cooling are delivered via thermally active radiant floors; while air handling systems take care of the ventilation and de/humidification needs, and provide supplementary heating and cooling. The building was initially designed to rely on natural ventilation for summer cooling; however, designers realized that natural ventilation alone was not able to meet the building cooling demands in the summer. Nevertheless, the building has operable windows and a central atrium that seems to be collecting the air from the individual spaces and exhausting it after some heat recovery.

The thermally active building is not adequately meeting the demands from some critical zones. Furthermore, the operation is not consistent with the reduced hours of summer operation of an academic building. These and other observations on the building indicate that the air and radiant systems are not operating in synergy. Existing industry practices in building controls systems, and the research literature show limited evidence of efforts to attempt to harmonize these two complementary systems.

Simulation was used to re-create the HPAB building's mechanical system response in two levels: a classroom-level model, and a Whole Building Energy Model (WBEM). The implementation was in EnergyPlus modeling software. Design documents, and historic operational data from the building automation system (BAS) were used for calibration. In this work, various features of Energy Management System (EMS) module of EnergyPlus has been utilized to create a responsive mechanical system control within the simulation. In the end, the typical

responses of the building spaces could be accurately recreated in the simulation for both models.

In the next step, testing different controls approaches – labelled as Strategies – and comparing them with defined comfort and stability metrics showed that harmonizing the air and radiant systems, in addition to increasing the consistency of the radiant system operation, results in improvement to the system operation without sacrificing the comfort.

This research explores the challenges of employing a WBEM to assist building design decisions by accounting for the building dynamics and enabling the coupling and tuning of systems parameters and control strategies through simulation. The research demonstrates the benefits of improved operational control sequences that are more in tune with the building's design intent.

To mom and dad

Acknowledgements

The following study would not have been possible without the guidance I received through this journey. First, I would like to thank Ron Kato for establishing the foundation of this research, and Dr. Rodrigo Mora, my kind and supportive research supervisor, for his persistence and dedication which encouraged me to work harder and not lose focus.

This work owes a lot to Dr. Miroslava Kavgic, my research advisor. I am profoundly indebted to Dr. Kavgic for steering my energy modeling efforts in the right direction, for her patience, and for sparing many hours of her time to answer my questions.

I would like to thank José Candanedo Ibarra, the member of the examining committee for reviewing my thesis and providing constructive comments on improving it.

I also like to express my gratitude to the staff of the Vancouver Island University specially Daryl Amos and Paul Fruehwirth for their openness and kindness. The data and information shared by the Vancouver Island University was crucial for this research. I am grateful to the experts who helped me better understand this data: Tariq Amlani for his insights on the mechanical systems, and Bo Li (the examining committee chair) for sharing his knowledge and energy modeling experience. I would also like to thank the other staff and the faculty of the Building Science/Building Engineering program in BCIT, as well as all the contributors to my research that I may have missed.

My last thanks go to my parents. Their unconditional support through the years of my study have been more than I could ever ask for. Thank you.

Contents

1 Introduction 1
1.1 Motivation 1
1.1.1 Why Focusing on the HVAC operation? 4
1.1.2 Why the Model-Based Approach? 6
1.2 Background on HVAC Systems and Controls 6
1.2.1 HVAC in Educational Facilities 6
1.2.2 HVAC as System of Systems (SoS) 10
1.2.3 The role of HVAC Control 13
1.2.4 Inner Workings of a Building Automation System (BAS) 15
1.3 The Case-Study 18
1.4 Research Goal 19
1.5 Thesis Organization 20
2 Literature Review 21
2.1 Feature Comparison of Air and Radiant Systems 21
2.2 Simulation Paradigms in Existing Research 23
2.2.1 Black box or White Box modeling 23
2.2.2 Model Predictive Control 24
2.2.3 Co-Simulation 25
2.2.4 Optimization Algorithms 26
2.3 HVAC Control in the Studied Research 27
2.3.1 Distinguishing the control Level 28
2.3.2 Using the Metered Data 28
2.3.3 Defining the Control Variables 29
3 Problem Statement 32
4 Research Objectives 33

4.1 Primary Objectives 33
4.2 Secondary Objectives 33
4.3 Scope and Limitations 34
5 Methodology 35
5.1 Profile the building operation 35
5.2 Evaluate the Available Energy Model 35
5.3 Develop the Classroom-level Model 36
5.4 Develop the Whole building model 36
5.5 Calibrate the Energy Models 39
5.6 Devise Control Improvement Strategies 40
5.7 Measure the Performance 41
6 The Case-Study Building 43
6.1 Building Spaces 44
6.2 HVAC System and Control 45
6.2.1 Air Handling Units (AHUs) 46
6.2.2 Return and Exhaust Fans 50
6.2.3 Valve Boxes 50
6.2.4 Terminal Systems 50
6.2.5 Frequently Used Functions in the Automation Programs 54
6.2.6 Schedules 56
6.3 Observations 57
6.3.1 Design of Demand-Side HVAC Equipment 57
6.3.2 Manual Overrides 57
6.3.3 Disconnected Controls 59
6.3.4 Unmet Air System Set-points 61
6.3.5 Operation inconsistency 62

6.3.6 Slab Insulation 63
6.3.7 Responsiveness to Climate and Occupancy 65
6.4 Existing Case-Study Building Model Review 65
6.4.1 Choice of software 67
6.4.2 General Construction 68
6.4.3 Envelope 70
6.5 Section Conclusion 72
7 Simulation Mechanical Control Implementation 73
7.1.1 Example 1: Air System Room Temperature Reset 74
7.1.2 Example 2: Radiant System Outdoor and Room Temperature Reset 78
7.1.3 Example 3: AHU Control 82
7.1.4 Scaling the controls 82
8 Classroom Level Simulation 85
8.1 Results 86
8.2 Construction and loads 88
8.3 Calibration 91
8.4 Operation Strategies 97
8.4.1 Strategy A: Existing condition of the case-study building 98
8.4.2 Strategy B: Modified room temperature reset 100
8.4.3 Strategy C: Constant Slab Temperature 104
8.4.4 Strategy D: Constant Slab Temperature with Comfort Thermostat 105
8.4.5 Strategy E: Outdoor Air Averaging 105
8.5 Peak-shaving 109
8.6 Section Conclusion 110
9 Whole Building Energy Model (WBEM) 111
9.1 Building Shell 111

9.2 Loads 116
9.3 Mechanical System 118
9.4 EnergyPlus Modifications 121
9.5 Calibration 127
9.6 Modified Controls 130
9.7 Section Conclusion 138
10 Summary and Conclusion 139
10.1 Further Work 140
References 142

Figures

Figure 1 - The case-study building 2
Figure 2 – Energy consumption balance with indoor air quality in a HPAB 7
Figure 3 - Types of HVAC System in profiled educational facilities. 9
Figure 4 - Example of BAS operation 15
Figure 5 - Example of Sensors and Output Devices AHU1, case-study building 16
Figure 6 - Example of Automation Program of AHU1 17
Figure 7 - Distribution of spaces in the case-study building 18
Figure 8 - Infosys Building, Hyderabad, India 22
Figure 9 - Git Graphical User Interface 38
Figure 10 - history of "commits" to the simulation file using Git 38
Figure 11 - the Case-Study Building 43
Figure 12 - Examples of Available Data 44
Figure 13 - Classrooms in the case-study building 44
Figure 14 - In-room thermostats 45
Figure 15 - Mechanical source-side and demand-side connection 46
Figure 16 - AHU operation during typical summer week 48
Figure 17 - AHU operation during typical winter week 49

Figure 18 - Location of the observed classrooms 51
Figure 19 - Typical winter temperatures week of the South-facing classroom 52
Figure 20 - Typical winter week temperatures of the north-facing classroom 52
Figure 21 - Typical summer week temperatures of the north-facing classroom 53
Figure 22 - Typical summer week temperatures of the south-facing classroom....54
Figure 23 – GCL+ Scale Function 56
Figure 24 - Manual overriding of the slab temperature set point 58
Figure 25 -Effect of manual override of slab temperature on the air system 59
Figure 26 – HVAC Cross Connections,....60
Figure 27 - Snapshot of systems connected to room 125 61
Figure 28 - SAT set-point of a VAV, Case-study building....62
Figure 29 - The setpoint and slab temperature corresponding to Valve Box 102 63
Figure 30 - Interior concrete slabs in As-Built drawings....64
Figure 31 - Energy targets compared to consumption 66
Figure 32 – Construction details in the eQUEST model 69
Figure 33 - Effect of Z-transfer function on roof loads....71
Figure 34 - Example air system control 74
Figure 35 – Actuators of the EMS air control, Example 1 75
Figure 36 – Sensors of the EMS air control, Example 1 75
Figure 37 – Program of EMS air control, Example 1 76
Figure 38 - Mechanical system control parameters, Example 1....77
Figure 39 – GlobalVariables of EMS air control, Example 1 78
Figure 40 –ProgramCallingManager of EMS air control, Eample 1....78
Figure 41 – Method of slab temperature control in EnergyPlus....79
Figure 42 –Supervisory Sensors of EMS radiant control, Example 2....80
Figure 43 –Supervisory Actuators of EMS radiant control, Example 2 80
Figure 44 – Program of EMS radiant control, Example 2....81
Figure 45 - AHU temperature setpoint program....82
Figure 46 - The ERL structure in case-study building simulation file 84
Figure 47 - Example of zone program....84
Figure 48 - Load distribution between the air and radiant systems 88
Figure 49 – The classroom level simulation construction....88
Figure 50 – Simulation temperatures of typical summer week....93

Figure 51 – Simulation temperatures of typical winter week 93
Figure 52 - Side-by-side comparison of winter room conditions 94
Figure 53 – Side-by-side comparison of summer room conditions 95
Figure 54 - Heat distribution within the slab in cafeteria....96
Figure 55 - Replicating the PI controller with conditional statements 98
Figure 56 - Strategy A Radiant Control 99
Figure 57 - Strategy A Air Control....99
Figure 58 – Strategy A slab heating and cooling energy.... 100
Figure 59 - Strategy B initial slab control.... 100
Figure 60 - Strategy B initial air control.... 101
Figure 61 - Room temperature comparison of Strategy A and B.... 101
Figure 62 – Strategy B initial air flow rate under different loads.... 102
Figure 63 - Strategy B improved radiant control 103
Figure 64 - Strategy B improved air control.... 103
Figure 65 - Strategy C room temperature compared to the baseline.... 104
Figure 66 - Strategy D room temperature compared to the baseline.... 105
Figure 67 – Strategy E Outdoor air averaging 106
Figure 68 - Erl code for outdoor air averaging.... 107
Figure 69 - Different settings of Strategy E air control 108
Figure 70 - Strategy E room temperature compared to the baseline 108
Figure 71 - Precooling EMS snippet.... 109
Figure 72 - Peakshaving effect on room temperature.... 110
Figure 73 - Effect of early peakshaving on room temperature 110
Figure 74 - Modeled Zones 111
Figure 75 - Building Model in DesignBuilder.... 112
Figure 76 - Comparison of U-Values of WBEMs 113
Figure 77 - Effect of microclimate and weather condition of the simulation year 117
Figure 78 - Load difference between eQUEST and DesignBuilder models 118
Figure 79 - Case-study building mechanical system supply side 119
Figure 80 - DesignBuilder mechanical scheme.... 119
Figure 81 - Connection of the ground loop to heating and cooling loops.... 124
Figure 82 - EnergyPlus CentralHeatPump object.... 125
Figure 83 - Heat Pump Model Alternatives.... 125

Figure 84 - CentralHeatPump connections 126
Figure 85 - Three days of logged consumption data (15-minute interval)...................... 127
Figure 86 - hourly aggregated electricity consumption vs its smoothed profile 128
Figure 87 - Simulated electricity consumption compared to the data 128
Figure 88 - Simulated mechanical system response compared to the actual data....... 129
Figure 89 - Improved radiant system classroom setpoint compared to the baseline ... 131
Figure 90 - Improved air system classroom setpoint compared to the baseline 131
Figure 91 - Baseline and modified temperature control in typical classroom 132
Figure 92 - Electricity savings as a result of control modification 133
Figure 93 - Energy consumption of modified controls vs baseline 133
Figure 94 - Correlation of fan and pump consumption reduction and overall savings.. 134
Figure 95 - The magnitude of energy saving at different time periods 135
Figure 96 - Correlation of OAT and the energy saved by the modified control............... 136
Figure 97 - Correlation of occupancy and the energy saved by the modified control.... 137

Tables

Table 1 - Comparison between Hydronic Radiant Systems and Air Handling Units 11
Table 2 – Radiant & VAV setpoint reset mechanisms at supervisory control level 85
Table 3 –Strategy transferred energy comparison...87
Table 4 - Initial simulation inputs for the test zone 90
Table 5 – Major assemblies of the case-study building and their modeled properties. 114

Abbreviations

AG = Access Group
AHU = Air Handling Unit
AL = Alarm
AO = analog output
BAS = Building Automation System
BI = Binary Input
BO = Binary Output
BV = Binary Variable
CCV = Cooling Coil Valve
CO = Compare input & set point (PID control)
CWR/S = Cold Water Return/Supply
DMP = Damper
DP = Differential Pressure
EAD = Exhaust Air Damper
EMS = Energy Management System
ERL = EnergyPlus Runtime Language
EV = Event
FB = feedback
FLW = Flow
FZ = Freezestat
GV = Global Variable
HCV = Heating Coil Valve
HPAB = High Performance Academic Building
HWR/S = Hot Water Return/Supply
LS = Load Shed
MAD = Mixed Air Damper
MAT = Mixing Air Temperature
MV = Multi-State Value
NRPE = Non-Renewable Primary Energy
NSB = Night Set Back
OAD = Outdoor Air Damper
OS = Optimum Start
PG = Program
PID = Proportional-Integral-Derivative
PMV = Predicted Mean Vote
PP = Pulse Input
RFS = Return Fan Status
RT = Return Temperature
SAT = Supply Air Temperature
SCH = Schedule
SFC = Supply Fan Control
SFS = Supply Fan Status
SP = Set Point
SPD = Supply Fan Speed Drive
SSP = Supply Pressure
TL = Trend-log
VAV = Variable Air Volume
WBEM = Whole Building Energy Model
WS = Weekly Schedule
ZC = Zone Controller
RBC = Rule-Based Control
MPC = Model Predictive Control
SID = System Identification
VB = Valve Box

1 Introduction

Commercial buildings utilise more than 42 percent of all electricity produced, yet waste up to 50 percent of it. Building operations are often cited as one of the most significant costs to any business [1]. In Canada, energy consumed by the educational facilities alone accounts for more than 20% of energy consumption in commercial buildings. Education sector has the highest energy consumption among all sectors in Canada, far ahead of retail and health care [2].

The figures indicate the importance of making sure the energy used in the educational facilities is spent efficiently especially in handling the HVAC systems which have become essential components of buildings [3].

Reviewing the presented evidence in the remainder of this introduction suggests that the HVAC control system practices has not kept up with the increasing complexity of the HVAC systems.

1.1 Motivation

This research is motivated from preliminary teamwork on analyzing the “Performance Gap” of three high-performance buildings, which are currently under operation. All three buildings are facing operational challenges that are not unusual considering the complexity of their systems. However, evidence from design documents, an existing energy model, and operational data suggests that their performance is not entirely reflecting the design intent. This research follows the premise that there is a need to design buildings as systems-of-systems to be able to understand, interpret, quantify, design, and fine-tune the dynamic couplings between systems. The research uses a high-performance academic building (HPAB), which is one of the three buildings presented above, as a case-study to gain understanding on the complexities of systems coupling, and learn and apply dynamic simulation-based systems coupling tools and methods.

Figure 1 - The case-study building

Within the building industry, there is an increasing concern about a mismatch between the predicted energy performance of buildings and actual measured performance, typically addressed as “the performance gap” which is seen to be larger in state-of-the-art, energy efficient and green buildings; In an extreme case, measurements have shown a five-fold difference between actual and predicted performance [4], [5]. Causes of mismatch may vary, but among them is building’s operation. Nowadays, due to the increased fuel costs and higher expectations in thermal comfort, the HVAC systems are expected to be more responsive to the climate and the occupancy. Therefore, they need to be dynamic, interdependent, and synergistic but designers do not always have the means to adequately simulate or verify the responsiveness of these systems. Furthermore, building controls systems – that are responsible for substantiating the systems responses and interactions – are seldom engineered to meet these requirements even though the systems are characterized as "green," "low energy," or "high performance" [6].

Observations of the case-study building suggest that the complex systems in place show little responsiveness to climate and occupancy, their dynamics are not attuned, interdependencies are not visible, and there are no signs of synergism between them. Even though the building is operational and there are few complaints, the building is far from being a high-performance building that fully meets the climate, energy, and occupancy needs. The configuration of the HVAC system might not use all possible resources to run the mechanical system as efficient as possible even though that is not the intention.

The observed shortcomings are listed below. The overarching problem is that the building HVAC does not seem to be operating in harmony with the occupancy (schedules) and the outdoor daily/seasonal climate cycles.

- Monitoring the HVAC operation shows that the air and radiant systems are not communicating with each other. Instead, the systems serve each space independently.
- The automation system makes decisions at any given time based on the conditions of the previous 30 minutes. Being a thermally activated building, the thermal mass of the building causes a lag between when a decision is made and the change in the environment conditions. Research has shown when the control system considers this effect, the building performs significantly better [7].

  In addition, geothermal heat pump systems are considered sensitive to overuse. In another building studied through the Performance Gap Research Framework –

the Van Dusen Botanical Garden Visitor Center – despite all the measures taken, a constant net loss of energy from the ground is expected. The automation system must be efficient in order to sustain the geo-field.

- Through continuous observation of the building systems, manual changes of building schedule were noticed. Although manual override may provide localized benefits, they may not contribute to the smooth operation of the HVAC system in total.
- Occupancy is not tracked. Many spaces lack the sensors to track the level of occupancy and due to this limitation, some demand-side systems constantly operate at full volume.
- Specific challenges were highlighted by the designers. Design Development documentation shows excessive solar heat gain had been predicted in the building to a level that the instantaneous loads can go beyond the capacity of HVAC system. Building modeling confirms this prediction.

The mentioned problems can consequently increase the operation costs and can possibly compromise the long-term performance of the building. This research project is based on the premise that simulations based on a well-conceived and implemented model-based approach can help increase the understanding of the interactions between building systems, and consequently enable the testing of controls strategies to improve operations through the HVAC control mechanisms.

1.1.1 Why Focusing on the HVAC operation?

Control System Commissioning is a quality assurance process to ensure the building is operating according to defined criteria [8]. The commissioning process for Direct Digital Controls (DDC) as described in [9] involves verification checks and functional tests. Beside checking physical conditions of the systems, testing the proper response of the control system is in the process, but this is done only to make sure the initial design intent is met. In contrast, Hatton et al. [10], emphasize the significance of having the right control:

> *commissioning agents often spend limited project dollars triple checking the obvious component level items, rather than focusing on key energy cost drivers (systems) that directly impact a hospital's future energy expenditures.*

Relaying the lessons learned from commissioning a hospital, [10] demonstrated significant savings by HVAC optimization strategies such as improving set-points and reset schedules.

In the case documented by Horsley [11], shortly after the construction of a university building, the stakeholders realized the innovative ground-source energy system has failed to live up to the expectations. After investigation, the most serious problem was found to be control related.

Salsbury and Ashish [8] note the control system often treated as less important than the devices it controls. Moreover, it brings up the conversation of testing. Complex control systems have modularized hardware and software. The control strategy of a particular building can be made from pre-tested individual sub-strategies, but for the unique combination of these sub-strategies can create a system that is untested as a whole.

> *There is little testing of the functional performance of the control logic with the custom interactions set up for the required strategy. However, the development and maturity of simulation technology in the buildings area is creating new opportunities for improving the verification of*

custom-built control strategies without having to use the real plant/building. [8]

1.1.2 Why the Model-Based Approach?

A building model is capable of simulating different conditions of the building and testing strategies quickly with different “what if” scenarios [12]. Model-based control strategies have been, and are being, investigated extensively to help develop advanced supervisory controls systems for buildings, such as predictive controls [13]–[16]. These supervisory and predictive controls will be discussed in Literature Review.

A disambiguation is necessary regarding the term “model-based”: in this study, a building model is used instead of the actual building to interact with the control system and evaluate control strategies; however, in many studies the control system itself embodies a building model, thus is called model-based control. For the scope of this study, the control system is not model-based. Instead, the building model is used to analyze the current operation of the case-study building and explore operational controls improvements.

1.2 Background on HVAC Systems and Controls

What follows is an overview of the HVAC systems in educational facilities and the needs they must satisfy. Due to limited documentation for university system design, some of the resources used for this section belongs to K-12 educational facilities.

1.2.1 HVAC in Educational Facilities

There have been many studies demonstrating the effect of indoor conditions on academic performance of students [17], [18]; but [19] is of particular importance because, as the authors suggest, it is the first study in this context that considers the socioeconomic background of students. Nevertheless, the study concludes ventilation rate and class temperature have a statistically significant association with student scores, particularly in math:

> *Students' mean mathematics scores (average 2286 points) were increased by up to eleven points (0.5%) per each liter per second per person increase in ventilation rate within the range of 0.9 -7.1 l/s per person (estimated effect size 74 points). There was an additional increase of 12 -13 points per each 1°C decrease in temperature within the observed range of 20 -25°C (estimated effect size 67 points).*

In the meantime, within the scope of Hoyt et al. [20], increasing the set-point temperature by 1°C in the warm seasons saved 7% to 15% energy. Therefore, successful HVAC design in educational facilities requires striking the right balance between energy efficiency and comfortable learning environment. Yet, energy efficiency could overshadow the air quality considerations in HPABs when setting the ventilation to minimum allowed is considered a low-hanging fruit for designers and commissioners, as in [10].

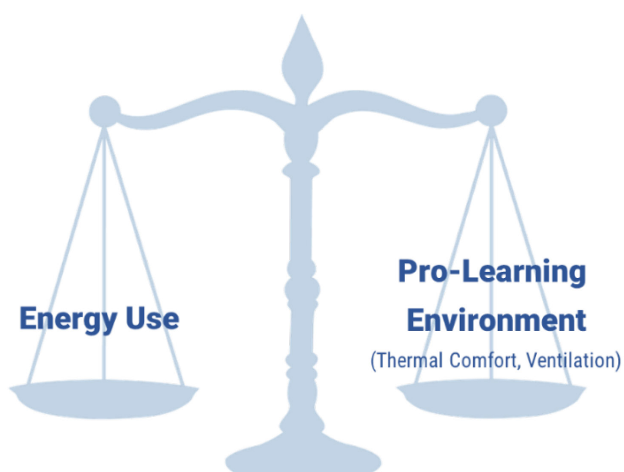


Figure 2 – Energy consumption balance with indoor air quality in a HPAB

Within the process of aiming for higher energy efficiency in HPABs, pushing the design to its limit must not compromise indoor conditions. In the case-study building, the initial design intent was using natural ventilation to reduce mechanical operation, but Urlaub et al. [17] state, in the studied classrooms, natural ventilation caused significantly lower achievement indicator compared with mechanical solutions. Notably, the same study finds mechanical exhaust systems correlate with higher achievement indicators than balanced mechanical ventilations.

Mendell et al. [21] reveal the possible association of ventilation rates and absence due to illness. Urlaub et al. [17] associate absence with CO_2 concentration but it seems the concentration is also due to low ventilation. To explain this association, one hypothesis that comes to mind is the reduction of airborne pathogens due to more air change; however, this hypothesis has not been examined.

Even though the evidence for the importance of ventilation rates in academic performance is overwhelming, as suggested by [19], the classrooms that have the air change level suggested by ASHRAE standard are seldom. The effect of having higher than standard ventilation remained unknown for the study due to the lack of real-life instances.

Beyond the air quality needs, educational facilities have characteristics that may further impact their HVAC design. On one hand, the level of sensitivity to the byproducts of the HVAC system, like noise, is higher; on the other hand, as suggested by ASHRAE 90.1 standard, schools are ideal candidates for scheduling HVAC operations. This indicates, the operators can have in-depth understanding of HVAC needs prior to system design [22], [23]; however, the trending topic of mixed-use operation of the educational facilities [24], not only can complicate the scheduling of the systems, but also can re-define the indoor requirements.

Universities embody classrooms, auditoriums, cafeterias, administrative offices, workshops, laboratories, etc. These spaces with their special needs, further complicate the HVAC control and design. Moreover, the presence of electrical rooms and server rooms inside these facilities must be noted. Such rooms require constant cooling; thus the HVAC system has to be capable of operating specifically for those spaces. Among the reasons for choosing the type of the system, are access to outside air and having a building-wide hydronic loop. When possible, economization is a significant advantage for reducing the energy consumption and costs [25].

The charts below show the common HVAC choices of the educational buildings available in Building Performance Database [26].

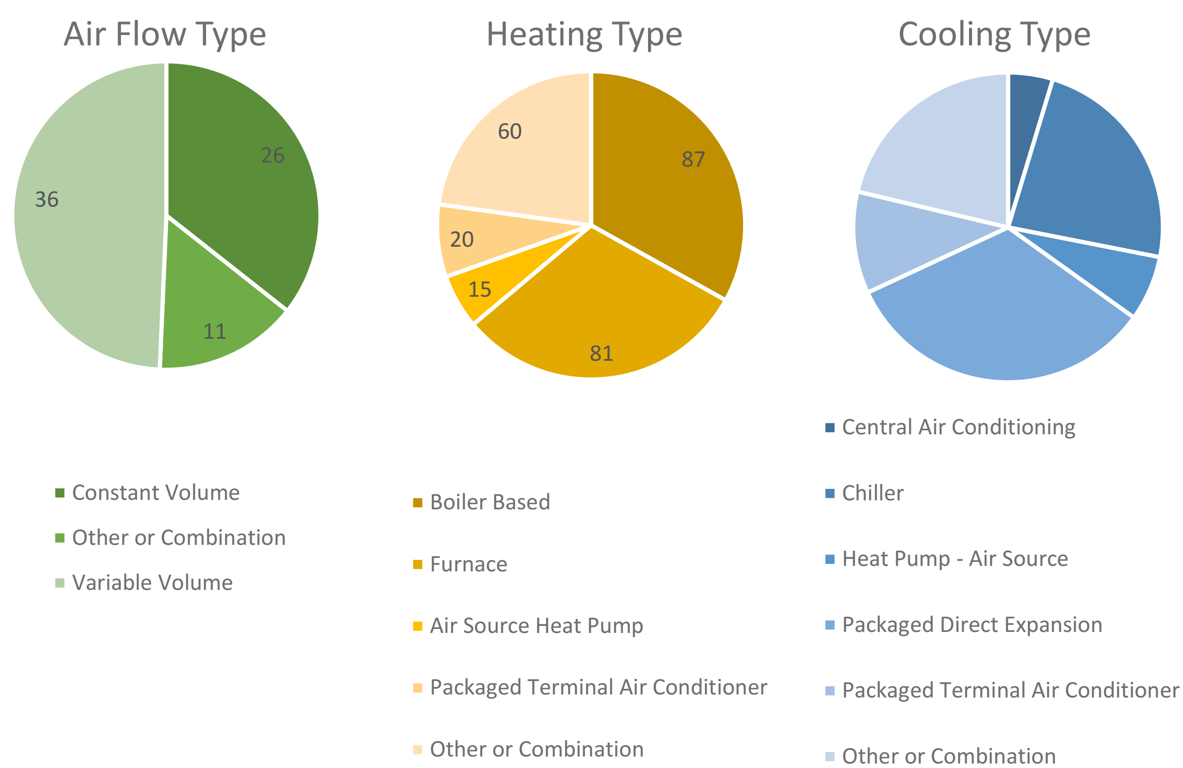


Figure 3 - Types of HVAC System in profiled educational facilities.

Source: [27]

On the supply side, diverse types of central systems are frequent choices in these facilities. On the demand side, the higher number of Variable Volume systems compared to the Constant Volume systems shows most systems are relatively advanced; however, psychrometric analysis of some typical multi-zone HVAC systems (including these two types) performed by Korolija et al. [3] showed efficiency of these systems could not be assumed.

1.2.2 HVAC as System of Systems (SoS)

System of Systems (SoS) are integrated, independently operating systems working in a cooperative mode to achieve higher performance [28]. The HVAC system in the case-study building, as discussed in section 1.1 of this proposal, is clearly not operating as a SoS. Approaching the HVAC control from a SoS point of view and validating strategies through a well-conceived and well-implemented model-based approach can potentially lead to higher levels of performance.

The demand side of the HVAC system includes a hydronic radiant system: Radiant floors are low temperature systems that deliver highest comfort with low use of energy due to the low water temperature, which coupled with ground-source heat pump system reduce the thermal lift (ΔT) and increase mechanical efficiencies. Radiant systems do not introduce fresh air to the interiors. An Air system is therefore needed mainly for ventilation and (de)humidification. However, in the case-study building the air system also supplements spaces' thermal needs in parallel with the radiant system.

In the case-study building, the two systems are loosely coupled: Both systems are connected to the same water loop coming from the water-to-water heat pumps to deliver heating/cooling, and ventilation simultaneously. In the meantime, the systems do not communicate with each other. Instead, the two systems separately monitor the room temperature.

Table 1 outlines the features of both mechanisms:

Table 1 - Comparison between Hydronic Radiant Systems and Air Handling Units

Hydronic Radiation	Air Handling Units
More complex control due to the thermal mass (which causes significant lag in the operation of the system). The system cannot handle instantaneous loads; however, if used correctly, the same system is able to lower the costs by peak shaving[1] [29], [30]. The response time is slow (hours)	Air Handling Units are modulated to perform according to specific needs. With cooling and heating coils, the system can change mode quickly [23]. The response time is fast (minutes).
Hydronic pumps have relatively low energy input than fans in general. High thermal capacity of water is more effective to satisfy thermal needs.	Air is less effective thermal energy transfer medium, and therefore needs large ducts [31], higher supply temperatures, and large fans to deliver energy to spaces.
A separate system for delivering fresh air must be dedicated [29]	Can ventilate, cool, heat, and filter the incoming air.

[1] Preparing the indoor environment prior to the peak time to save energy and boost comfort. Also refer to Green Scheduling, [98]

Set-point temperature in cooling is limited by the dew point [32] unless the coupled air system provides required conditions	Is able to dehumidify the air through ventilation or dehumidification.
Combines radiant and convective heating and cooling thermal process [30].	Only contains convective heating and cooling [30]
Large heat-exchange surfaces result in low supply water temperature in heating and high supply water temperature in cooling to offset spaces' thermal loads. Can save energy because of creating acceptable conditions with better set-points than the air systems [32].	Supply temperature and air flow to each room can be controlled accurately [23], but in practice energy transport, air distribution, and temperature tracking can be poor [31].

Many questions come to mind regarding the coupling of these two dissimilar systems, such as:

- How do these two systems, with such different response times, synergistically respond to frequent loads?
- At given conditions, which system performs more efficiently?
- Related to previous question, what are the opportunities for using free-cooling?
- How is the thermal inertia considered in the control system?
- How does the system respond to simultaneous heating and cooling demand within the various zones in the building?

This project focuses on the coupling of the two systems. Each system requires its own dynamic operation to efficiently respond to the climate and occupancy needs. Furthermore, the need to better connect the two systems together has been recognized.

1.2.3 The role of HVAC Control

A proper control system is capable of handling all the building operation's complexities. With increased expectations for energy efficiency and higher fuel costs, the old industry practices have known to be insufficient. That is the reason many studies are pursuing innovative control strategies to replace the older practices [33], [34]

As described, the building mechanical system is consisted of subsystems. Each subsystem follows a specific goal such as providing heating or cooling but it also has an effect on the operation of other systems. That is the reason these systems need to interplay to maximize the comfort while they reduce maintenance costs and energy consumption. [35], [36]

> *Complex systems consist of many interacting components and many hierarchical layers and, in general, it is impossible to reduce the overall behavior of the system to a set of properties characterizing the individual components. The interaction between components is able to produce properties at the collective level that are simply not present at the component considered individually.* [37]

Added to the interplay of the mechanical systems, a thermally activated building itself responds to the changes in environment conditions with its thermal mass. In buildings with high thermal mass, control systems should be designed to benefit from the thermal mass of the building in order to better serve the occupants or lower the consumption costs. Otherwise, the system will significantly lag in responding to occupant needs [38], [39].

Finding the most efficient equipment and design for a given HVAC system is a good start but there is a bigger challenge in offering ideal conditions to occupants of a building while keeping consumption reasonable with proper management of the system. In the last decades, Energy Management Systems[2] have taken this task:

> *Energy Management Systems use computer-based electronic technology to add "intelligence" to the automatic control of energy using equipment. In commercial facilities, EMS applications can range in sophistication from a simple programmable thermostat with start/stop control over only one or two pieces of equipment, to an extensive network of monitoring stations and hundreds of control points, offering comprehensive management of lighting, heating, cooling, humidity, maintenance, emergency and security alarms, etc. EMSs may perform only "supervisory" functions, or can be programmed to carry out complex localized tasks in response to interactive input from end-users* [40].

Improving the HVAC control, within the Building Automation System, has been counted as a major mechanism for closing the performance gap since it has effectively helped building commissioners to do so [8], [10].

[2] EnergyPlus (software used to simulate the HPAB, discussed later) contains a module with the same name. Throughout this work mentions of *EMS* relates to the said module and not this general concept.

1.2.4 Inner Workings of a Building Automation System (BAS)

In General, a Building Automation System has 5 main components [41]. Due to the scope of this research, the first three components will be discussed in more detail (Figure 4):

- Sensors
- Automation Program
- Output Devices
- Communication Protocols
- User Interface

At its core, the workflow of the automation is simple. The data is collected by the sensors, sent to the program, processed by the program, and finally, the output is sent to output devices in form of instructions (Figure 5). These instructions may be defined as set-points for each system. Some facilities have very specific details about set-point of each system, [42].

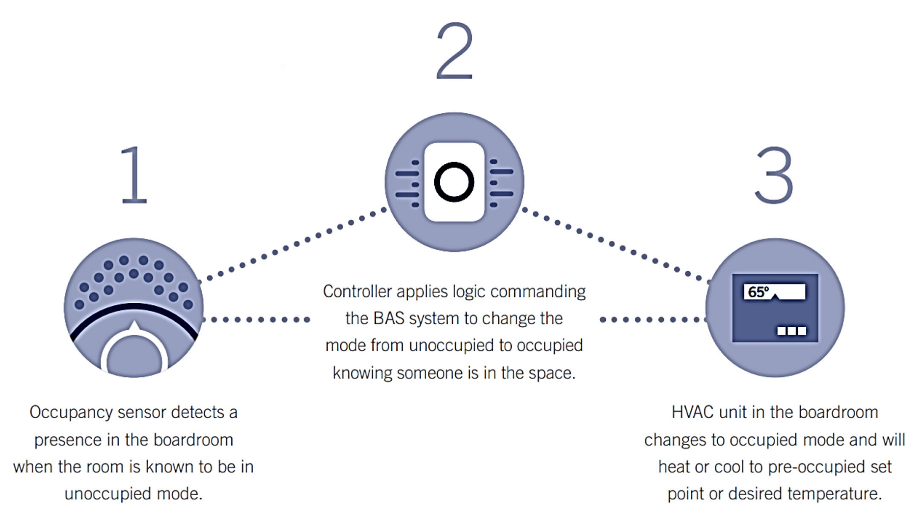


Figure 4 - Example of BAS operation

Source: [41]

An example of how a rule-based automation system establishes the set-points, is the fan speed setting in an Air Handling Unit in the case-study building.

The program for fan speed has been shown in Figure 6. Operation starts with checking the schedule. If the building is in the working hours, the fan is turned on and is gradually sped up. If the building is not in the working hours, the automation system switches to the Night Set-Back (NSB) mode. During that period, the system keeps the return temperature as same as the NSB set-point whenever necessary.

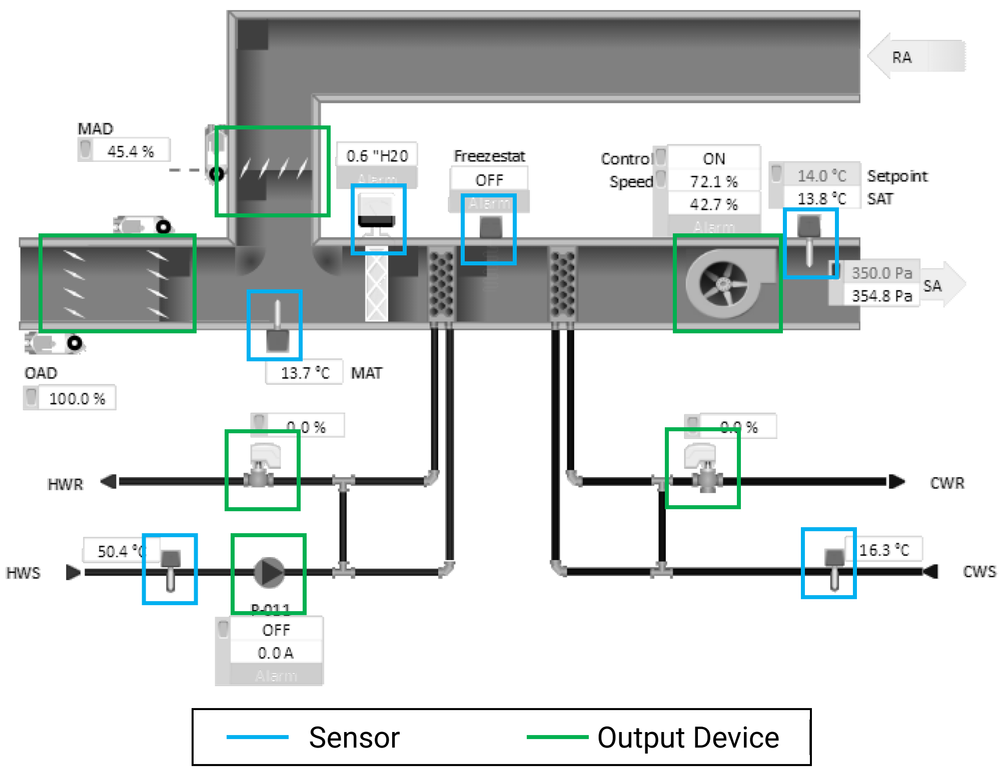


Figure 5 - Example of Sensors and Output Devices

AHU1, case-study building

The programs similar to Figure 6 are made with variables, statements, and functions. Variables can represent Sensors and Output Devices or be control related values. The statements and functions set the different ways the Output Device variables are set. Frequently used functions are further discussed in Section 6.

As it can be seen in Figure 5, the Air Handling Unit is equipped with dampers and coils. These are also controlled in a similar fashion. All programs combined, operate the mechanical systems of the building. In the case of coils, normally, the cooling coil and the heating coil should not be working at the same time. For avoiding such situations, a common practice which can be seen here is defining different building modes [43]. The "heating", "cooling" and "standby" modes have helped organized the operation of single systems but they may not prevent two separate systems (i.e. air and radiant) work in opposite states.

```
AHU1_ENABLE = Max (700000.BLD700_SCH)
If AHU1_ENABLE On Then
 AHU1_SPD_ENABLE = On
 AHU1_NSB_BV = Off
Else
 AHU1_NSB_BV = Switch (AHU1_NSB_BV,AHU1_LOW_RT,AHU1_NSB_SP-1.5,AHU1_NSB_SP)
 AHU1_SPD_ENABLE = AHU1_NSB_BV
End If

If AHU1_SPD_ENABLE On Then
 DoEvery 10S
  AHU1_SPD_RAMP = Limit (AHU1_SPD_RAMP + 2, 0, 100)
 End Do
 AHU1_SPD = Limit (AHU1_SPD_CO, 0, AHU1_SPD_RAMP)
Else
 AHU1_SPD_RAMP = 0
 AHU1_SPD = 0
End If
```

Figure 6 - Example of Automation Program of AHU1
Variables shown in orange, Functions in blue, and statements in pink

Using the mentioned setup can create robust HVAC control; however, as it has been seen in the case study building, the level of complexity of the HVAC system plays an important role in the effectiveness of the control.

1.3 The Case-Study

Completed in June 2011, the Vancouver Island University "Cowichan Campus" building is located in Duncan, BC. The building has three stories: The ground floor is mostly consisted of administrative and common spaces, with classrooms along the north. In addition, at the ground level, the building is extended towards the east to accommodate a theater space, a cafeteria, and an additional classroom. The second floor is dedicated to classrooms and lab spaces while the third floor is mostly consisted of office spaces and the mechanical room access. The gross 4134 m^2 area of the building is allocated as shown in Figure 7. With Energy Usage Intensity (EUI) of 156.7 KWh/m^2 the building is performing better than comparable academic buildings within the same region [44].

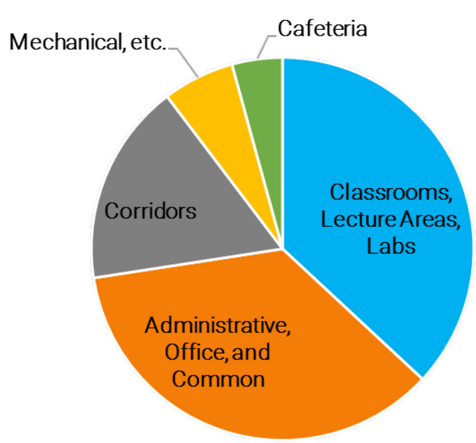


Figure 7 - Distribution of spaces in the case-study building

The HPAB case-study building incorporates, at the source side, ground-coupled water-to-water heat pumps (WWHP) and solar-thermal as primary means of heating, with boiler used as a backup source. Cooling is provided by the cold side of the WWHP system. On the demand side, heating and cooling are delivered via thermally active radiant floors; while air handling systems take care of the ventilation and de/humidification needs, and provide supplementary heating and cooling. The building has operable windows and a central atrium that are added in design for natural ventilation.

This research is based on the documents and data available since building design until recent operation. The documents comprehensively capture the process, the intent and the assumptions in design, while the operation data is mostly obtained from an online interface that collects sensor info and displays the operation logic. A building energy model developed using eQuest was also available.

The collected operation data lacks some ideal representatives of the state in the zones, such as the pollutants and the occupancy, but includes temperatures, the status of the mechanical system equipment, and the schedules. High resolution data could be available since a year before the collection time whereas less frequently logged records are available since when the building became operational.

1.4 Research Goal

The aim of this study is to better understand the operation of air and radiant systems in the classrooms of a high-performance educational building. Demystifying the complex system interactions in the classroom level paves the way towards development of efficient and responsive controls that facilitate learning for students.

This research uses simulation models to support the evaluation of the control, and explore control strategies to synergize the operation of the radiant and air systems in the case-study building. Whole-building simulation models simulate the hourly or sub-hourly energy flows in buildings under dynamic climate, occupancy, and processes. As such, they are powerful tools to develop virtual experiments to understand complex systems' interactions.

1.5 Thesis Organization

The thesis is organized as follows:

In Chapter 2 relevant works regarding using building simulation to support the testing of controls strategies and enhance the performance of complex building systems is discussed, with focus on air and radiant systems.

Chapters 3 to 5 are dedicated to the Problem Statement, the Research Objectives, and the Methodology respectively.

Chapter 6 describes the case-study building and the observations of note in its operation followed by a review of the existing building model to help the modeling process of this research.

Chapter 7 describes how the mechanical controls are simulated in the models that are introduced in the next two Sections.

Chapter 8 describes a classroom-level model which is used for testing and comparing the performance, using different metrics, of various air and radiant system control strategies.

Chapter 9 analyses how the classroom-level control strategies affect the whole building performance using a Whole Building Energy Model.

Chapter 10 concludes and describes the further work derived from this research.

2 Literature Review

The following section reviews the existing work on the characteristics and the control of the systems under study (air and radiant), and explores the existing energy modeling paradigms with regards to the task at hand.

2.1 Feature Comparison of Air and Radiant Systems

Baskin [45] compares the air and radiant systems in both heating and cooling in a case-study building. For the heating, the systems are compared separately and their performance is found to be similar. For cooling however, the report studies coupling by comparing three scenarios: air system stand-alone, air system coupled with radiant system for slab pre-cooling, and air system assisted by night ventilation supplemented with radiant system for slab pre-cooling. It is demonstrated that the second and third scenarios are able to shift the system's peak load.

Some studies have separately compared the two systems in terms of performance. The study by Haddad et al. [46] is of significance for this project because the air and radiant systems are connected to a low-temperature hydronic loop; however, the main energy source in the study are the solar collectors, which play a tangential role in our case-study building.

As discussed, the ventilation rate is an important topic in classrooms; thus, for this study, a takeaway from [46] is the impact of air-change on the performance of the systems. When the air-change rate is 0.55, the air system performs better than the radiant system. The study notes that this is partially due to the low thermal resistance of the envelope that penalizes the radiant system. As the air-change rate raises to 1.5, radiant system has substantially better impact.

Figure 8 - Infosys Building, Hyderabad, India

Source: [47]

Sastry and Rumsey [47] claim they are studying the world's largest side-by-side comparison of HVAC, in a building belonging to Infosys Limited – an Indian company. As Figure 8 shows, on one side an air system, and on the other side a radiant system, are installed. The study (which only reports on cooling) discovers that the radiant system is superior in costs, energy usage, and occupant satisfaction. While the air system requires six AHUs, the radiant system is coupled with only one Dedicated Outdoor Air System (DOAS). As per [46], the building design also might have some advantages for the radiant side: the window to wall ratio is only 30% and the walls have thermal breaks; moreover, daylight is almost eliminated from the building.

Mumma [31] suggests that the humidity control of the radiant system is superior as the DAOS can remove all of the latent load in the outdoor air entering the building. This air then removes the latent load of the space; thus, the radiant system decouples the sensible and latent loads of the indoor space. This could mean that a superior control strategy under high humidity is using the air system for ventilation only, and relying on the radiant system for space conditioning.

2.2 Simulation Paradigms in Existing Research

Within the literature studied for this research, a variety of approaches were employed for simulation. Below, the common approaches are discussed and the applicability of each approach is examined.

2.2.1 Black box or White Box modeling

In advanced modeling, the simulation approach falls between two extremes: on one side there is the physical parameterized modeling or the white box approach, and on the other side, the black box approach [15], [48]. An example for the earlier is using the laws of physics to forecast the changes of indoor conditions, and for the latter is a regression of historical data.

Abstractions vary among the models. As a black box model solely relies on building data, Nassif et al. [49] state that the inclusion of physical models is always necessary. The so-called grey box models (or the hybrids) have been used with the goal of covering the weaknesses of both types [50], [51]. Nevertheless, there are cases in which researchers have worked with purely statistical models [52].

Ahmad et al. [53] have reviewed many of the approaches to modeling and have gone into detail about the specific advantages and disadvantages of each. The conclusion of the study is that none of the solutions is ultimately the best choice for every situation. Thus, the best approach for building modeling, just like many other modeling optimization use-cases, has to be considered case-by-case [54].

There are pros and cons for each of the mentioned extremes but the approach may not be a matter of choice. One particular limitation is amount of historical operation data available. The accuracy of the data-driven models could be an issue when they work outside the training range; thus, a pure black-box model (i.e. total dependence on the experimental data), is not likely to be robust enough [49].

For the mentioned reasons, the feasible building method is going to be physical: based on energy and mass balance integral-differential equations [15]. One of the most widely used methods in building modeling is simulation based on influencing factors. Currently the industry is benefiting from energy modeling engines such as ESP-r, EnergyPlus, and TRNSYS which are capable of multi-domain simulation (thermal, lighting, network airflow, etc.) although it could have high computational requirements [53], [55]. For this research EnergyPlus, as a modern and open energy simulation solution, will be used for modeling the case-study building.

2.2.2 Model Predictive Control

Many studies, like [56], [57], have successfully demonstrated savings by using Model Predictive Control (MPC); however, as Cigler et al. [58] point out, MPC could be too complicated to be currently used in the building industry. In that study, researchers observed that MPC is performing significantly better than a control based on heating curve in one case-study. But in another case-study they found negligible improvement using MPC instead of an existing RBC system even though most of their time is spent on developing the MPC model. It is worth noting, this result was achieved by using specific MPC modeling methods and may not be extendable to all cases.

Clarke et al. [59] have used ESP-r to embed simulations in the control system. This model-based control approach is dismissed by some MPC-related papers such as [60] and [58] for the required computation. Provided that one of the strengths of this study was verifying the control method in a test facility, its “realistic scale” experiment was a relatively simple setting.

In [61] because of dealing with a brand new building, a black-box model could not be created from the real data of the building; therefore, a detailed white-box model of the building was created. Then, BCVTB was used to connect the white-box model to a controller in MATLAB. This environment is used for system identification (SID) which is "a process of developing or improving a mathematical representation of a physical system using data that is collected from a designed operation or experiment, in an active manner" [62].

On the downside, aside from the extra work for setting the environment up, the researchers of [61], [63] have cautioned that the system is relatively slow and its debugging is challenging. The case-study building of that study is about 5 times bigger than the current project's case-study building in terms of total square area. For the purpose of that study, as a representative of all floors, the third floor of the building was modeled, which has a comparable size to the current research's case-study building but the researchers suggest, to the best of their knowledge, is the largest detailed building modeling intended for predictive control.

For the mentioned reasons, MPC was not used for this research.

2.2.3 Co-Simulation

It was frequently seen that when system controls within a simulation environment are the subject of the study, Co-Simulation is used, especially for complex controls. Examples would be [58] and [61] studying a High Performance building that combines air and radiant systems for HVAC. Such studies claim that frequently used computer programs for building modeling lack the flexibility in designing advanced control systems [63]–[65].

A co-Simulation environment such as Building Control Virtual Test Bed (BCVTB) provides an external interface to take advantage of a numerical computing environment (e.g. MATLAB) for the controls.

On one side, the co-simulation environment interacts with the building model to send inputs and extract outputs; on the other side, the control program is linked which receives the model's outputs and generates control commands. This process is continued step-by-step until the end of simulation period [61], [63], [65].

While Co-Simulation provides many advantages for complex controls such as Model Predictive Control, it inserts two more software dependencies at minimum to the simulation. Considering the additional maintenance and configuration involved, for this research, native control capabilities of EnergyPlus provide acceptable results.

2.2.4 Optimization Algorithms

The HVAC architecture in Baumann [66] and the case-study building have many similarities in both supply and demand sides. The study does not specifically target the subject of coupling; instead, it describes the operation of a radiant[3] and an air system in parallel, but uses a generic optimization program (GenOpt) to achieve savings. The systematic optimization of parameters in the HVAC system can potentially improve the overall performance of the systems but the methodology might not provide insights on how the improvements are achieved. The authors also warn about the complexities: for defining zones in the building model, instead of considering the HVAC system, features of different spaces were taken into account which resulted in 13 zones; this raises time and

---

[3] Embedded Hydronic Heating and Cooling System (EEHC) in the terminology of the paper

computation requirements when combined with generic optimization, making the approach unsuitable for the current project.

2.3 HVAC Control in the Studied Research

Control systems in buildings are rule-based. As the name suggests, the control system is operated based on a set of rules. The inputs can be time and conditions from interior and exterior of the building. Inputs are processed based on the basis of “if condition, then action” which adjusts the set-points of HVAC components. [34], [57], [67], [68]

Boardass and Leaman [69] describe the logic behind a rule-based control system implemented in a university building:

> *during occupancy hours, the AHUs endeavoured to maintain a supply air temperature of approx 21C by varying the amount of heat recovery. If slab temperatures in locations towards the room ceiling outlets fell below 20C, the heating was boosted to maximum, with recirculation at night. If the slab temperatures rose above 22C, the heat exchangers were bypassed and outside air cooling was extended overnight.*

This simple, yet well-designed control system was able to halve the gas consumption of the building; showing the benefit of implementing the right set of rules for controlling the HVAC operations. In more advanced cases, using prediction by simple rules or as a part of a model-based approach has shown further improvements.

> *“If properly accounted for, the predicted daily variation of solar radiation availability in the morning can be used to control the heating system in such a way as to avoid the anticipated overheating in the afternoon”.* [70]

For achieving a simple, yet effective control approach, researchers have highlighted the following items.

2.3.1 Distinguishing the control Level

“Typical control implementations in buildings can be divided into two main categories: local control and supervisory control.”, Dong and Lam [33] suggest. Research has manly focused on the supervisory control in the last decade as the supervisory control strategy can impact operation costs. The supervisory control sets the overall system status for the subsystems which can be relayed to local controls as objectives.

Local controls fulfill simpler tasks such as turning a system component on or off, though most local controllers go further than that. Proportional-integral-derivative (PID) are the typical local controller type [33], [71] used for commissioning and can be found in the case-study building as well. Although PID (and its simpler alternative, PI) controllers are never optimum controllers, they are simple and efficient for HVAC systems [72], [73]. These controllers are categorized as classical in [74].

2.3.2 Using the Metered Data

Normally, energy delivered to the buildings are metered for billing; however, it is common in modern buildings to have metering for subsystems and individual components as well. This is in part because of smart metering and in general more available technological infrastructure [4], [75], [76].

Not surprisingly, because of more detailed metering, the amount of produced data has grown significantly. That creates great opportunities for analysis if “big data” limitations and privacy issues are resolved. Researchers suggest the data is rarely used due to complexity and lack of effective data analysis techniques. Meanwhile, the metered data is a good starting point for calibration of the building models [12], [55], [76].

2.3.3 Defining the Control Variables

The control system normally receives status from the building or the climate to perform control functions. According to the International Performance Measurement and Verification Protocol [77], "Characteristics of a facility's use or the environment which govern energy consumption are called independent variables". For system control, independent variables that have an effect on the consumption should be identified. In advanced cases, their significance should be tested through mathematical modeling.

An effective control system would need to monitor at least the most impactful independent variables by deriving them from the inputs. The following inputs were frequently seen in the reviewed studies [51], [60], [70], [78]–[80].

- **Occupancy:** One of the main components that effects the heating and cooling demand of a classroom according to Wang et al. [81]; however, its detection is challenging. For the scope of this research, the applicable occupancy detection methods are motion and CO_2 sensors. Using CO_2 sensors appears to be widespread, but controversial. Studies such as [78] and [79] have used it as a measure for air quality while Xu et al. [80] argue that it is not adequate in many cases. Papers suggest CO_2 Monitoring in buildings does not give any data about other possible pollutants in the air [79], [80].

  Motion sensors are another candidate for occupancy detection as shown by [82] but not stand alone. One way of increasing the reliability of sensor data is creating virtual occupancy sensors [83] which take multiple inputs into account to estimate occupancy, some of which may raise privacy issues.

- **Room Temperature:** Commonly current temperature, but it is possible to use the historical data or make forecasts.
- **Weather:** Typically, the outdoor air dry-bulb temperature (OAD) reported by the building's weather station. Another input could be the solar radiation for heat gain calculations. The use of OAD over the room temperature, has been beneficial for the radiant systems. Baumann [66] dismissed the demand of the building spaces and instead used the weather to develop control for a radiant (must be noted that rooms did not have individual temperature control). The weather was used by averaging the outdoor air temperature. The averaging was from the last three days but the last day was counted twice; that means the last day has more weight in averaging. [66] states that its method of averaging has been the result of testing and analysis through the simulation, but it is unclear how this approach will work in shoulder seasons – when the temperatures vary greatly between consecutive days.

  Gwerder et al. [39] used a smaller averaging horizon (previous 24 hours), and included the room temperature . While the reason for this choice is not specified, the study finds the outside air temperature an ideal input for the control system but finds no apparent improvement with room temperature feedback, which echoes [66].
- **Time of day and year:** Governing specific times that procedures such as pre-cooling must occur. Wang et al. [81] have emphasized the effect of pre-ventilation and night ventilation (during summer) on their studied classroom.
- **Supply and Return temperature of the system loops:** After testing several control strategies for cooling, Sastry and Rumsey [47] found the best strategy to be

controlling valves based on fixed return water temperature. That is could be due to eliminating some of the outdoor elements like daylighting from the space. A limiting factor for the set-point considered in the study is the dew point of air to mitigate condensation. This set-point limitation is for the input water, not the slab surface, because over time moisture can migrate through the slab and reach the tubing. If the temperature of the tube is below the dew point, the condensation will occur there.

3 Problem Statement

As the Building Automation technologies move forward to become more sophisticated, proper control of the systems requires more attention [8], [10], [11]. Nowadays, due to a paradigm-shift in building design towards environment coupled HVAC, the mechanical systems in state-of-the-art buildings create dynamically interactive components and many hierarchical layers [35], [36]. The overall behavior of these systems cannot be controlled by simply considering systems one by one and adding those together [31], [36]. In cases similar to the case-study HPAB, the simulation of the control systems can be a viable tool to help compare different controls strategies for improved performance.

Separate operation of systems leads to cases where the coupled systems do not cooperate, causing unnecessary operation. Excess consumption in green buildings can exceed the capacity of the green energy sources [84], exhaust the geo-field, and make the mechanical system use backup systems to compensate. Thus, increasing the cost of operation.

Building simulation has been a common choice for studying and addressing such complexities; however, simply connecting building systems to each other is not enough [37]. Finding the accurate interactions and the pattern of operation requires embedment of the system controls within the simulation. Proper abstraction of the control programs of existing systems and improving them is the main challenge.

4 Research Objectives

The main objective of this study is gaining insights for controlling coupled HVAC systems through enhancing that of the classrooms in a high-performance academic building. The focus on the classrooms is because they provide excellent cases of air and radiant system interactions within confined spaces. Moreover, classrooms are expected to continuously host high density of occupants for academic activities that are affected by the indoor environment quality. Building on top of the previous studies, the objectives are:

4.1 Primary Objectives

- Assess the available energy model of the building to understand the intents, and identify inaccuracies.
- Create the simulation environment needed for control system testing in two levels: in scale of a classroom, and for the whole building. Calibrate the models to an acceptable degree of accuracy.
- Explore different demand-side control strategies for the classroom air and radiant systems. Compare the strategies with metrics that target comfort in the classrooms for student performance, aside energy and operation metrics.
- Analyze the impact of the top performing classroom-level strategies in whole performance.

4.2 Secondary Objectives

- Exceed the energy performance of the existing control system in the case-study building with one or more of the control strategies.
- Provide new knowledge on the challenges and opportunities of implementing controls systems in building energy simulation models.

4.3 Scope and Limitations

The scope is outlined in such a way that the outcomes of the research are compatible with the existing HVAC equipment of the building. Although the energy model could provide ample data and insights related to the indoor pollutants, such inputs were not included in the control strategies because the case-study building lacks the equipment to monitor those variables.

Another aspect of the compatibility with the building equipment, is working with the existing rule-based control. More specifically, for finding the supervisory setpoints of the equipment, as described in the literature review section.

Finally, the focus of the research is on the demand-side, where the mechanical systems is directly interacting with the classrooms. While the systems serving the classrooms (air and radiant) have different responses, those are both hydronic and connected to the central mechanical system. Therefore, both systems are considered with the same availability and effect on the loops for the energy transferred to condition the spaces. As an example of where this is not applicable, if the air system was equipped with DX coils, additional considerations were necessary since the coil is disconnected from the loops and its operation directly increases the electricity consumption.

Using the building data causes limitations regarding the occupancy, and the occupancy behavior (e.g. use of operable windows). The design documentation and the online data provide general information on occupancy patterns and levels; however, precise occupancy data could not be obtained and standard schedules were used instead. This will not significantly affect the outcome as long as the mechanical system response of the created building model follows the actual data.

5 Methodology

This section describes the methods and tasks that have been planned in this study to address the research objectives stated in Section 4 of this thesis. The methodology was designed with focus on the following items, consistent with the research scope presented in subsection 4.3:

- Demand-side systems (specifically that of the case-study building)
- rule-based controls
- supervisory control level

The below subsections describe the step by step procedure of attaining research objectives.

5.1 Profile the building operation

In the first step, the building spaces, the mechanical system, and the typical seasonal operation patterns is discussed. This leads to the observations made in the operation of the mechanical system on the demand side, specifically when it affects the classrooms.

5.2 Evaluate the Available Energy Model

The next step for modeling is understanding the relevant causes of building's shortcomings, which are discussed in subsection 6.4. One valuable resource of evaluating the initial expectations of the building is the eQUEST model. This model had been used to justify the efficiency of the mechanical system and the building energy consumption.

Learning from the available energy model is important prior to creating a new model. Existing studies on the eQUEST software are reviewed, and the modeling workarounds employed in the model are evaluated.

5.3 Develop the Classroom-level Model

Starting the process of modeling from a small scale removes uncertainties and allows agile testing and verification of assumptions; therefore, at this stage, a simplified model was created that represented a typical classroom in the case-study building.

This step was inspired by [81]. Using this classroom level model, the baseline control, as well as different Strategies with modified controls, were tested to understand the effect of controls on the mechanical system response and the indoor environment. To ensure the accuracy of the model, the building's data was used to compare the simulated and actual indoor conditions.

5.4 Develop the Whole building model

The framework for model development was taken from [85] in which the modeling procedure is started by parsing the documentation and proceeded with iterative documented revisions until it met the acceptable criteria. The article also provides a "source hierarchy" that is the priority of data sources:

1. Data-logged measurements
2. Spot or short-term measurement
3. Direct observation (site surveys)
4. Operator and personnel interviews
5. Operation documents (e.g. Operations & Maintenance (O&M) manuals)
6. Commissioning documents (e.g. As-built drawings)
7. Benchmark studies and best practice guides
8. Standards, specifications and guidelines
9. Design stage information (e.g. the initial model)

The building model was initially created in the DesignBuilder software. DesignBuilder provides a User Interface for the EnergyPlus simulation engine [86] and has been frequently used by researchers (e.g. [87]) to generate EnergyPlus simulations.

DesignBuilder makes defining the building construction easier and provides common modeling tools. On the downside, DesignBuilder is not equipped with all the features of EnergyPlus, some of which are necessary for modeling the case-study building. For this reason, after using the DesignBuilder's options, the model was exported and directly modified as the input of the EnergyPlus (.idf) file.

The IDF file is a plain text file that has to be modified by a text editor or the IDF editor software available in the EnergyPlus package. For compatibility and access to the latest features, the DesignBuilder export was updated to the latest EnergyPlus version published at the time (Version 8.8) using another software available in the EnergyPlus package.

Modifying the simulation file directly poses the risk of damaging the file or making unintended changes. To mitigate these problems and keep the track of changes, a version control software, named Git, was used. [85] had used another version control software to document the calibration process.

Using Git from the start not only helps to keep the track of changes (Figure 9), but also provides a quick way of rolling back the changes made in the past. The software can compare different "commits" and use them as snapshots of the file's state in the past (Figure 10). The versioning makes it possible for a team to continuously use and modify the same model.

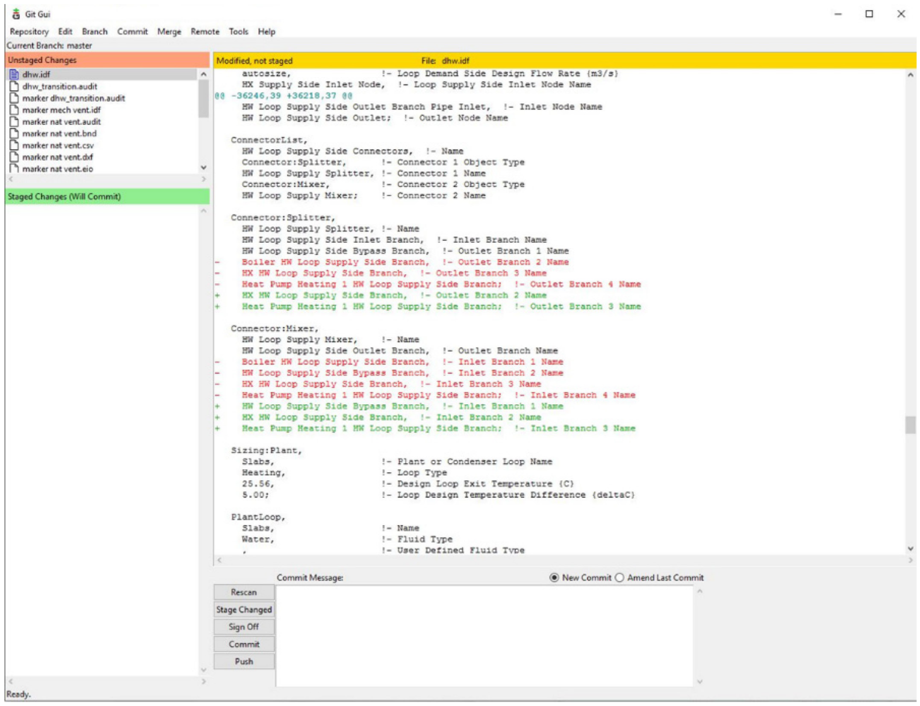


Figure 9 - Git Graphical User Interface

Green lines show additions, red lines show deletions since the previous commit

```
λ git log --oneline
5343866 Sorted IDF file with the IDF editor
5a5aa6b Change thermostats to Dual SP for compatiblity with Nat Vent
2b89b4e Conditions prior to natural ventilation implementation
53184ce Heat Recovery Heat Pump Initial Implementation
7b168f2 Full slab control implementation, lots of troubleshooting ahead!
5a490e3 Corrected the sequencing of Air/Radiant within the zones
e435c11 Initial Radiant control implementation
e6fd50b minor simplification in the radiant heating schedule
0ff2bca Initial DHW implementation
aa40b50 experimenting with radiant setpoints
a1b84ca Added edd output
6d10472 improved the lighting schedule to better reflect reality
8182b7a changed the cooling side chiller to WWHP
e345d44 Multiple fixes to the lighting system as well as the equipments.
bdeca44 changed dual setpoints to HeatorCools
67c0713 added Schedule:File from the real building
0271c5c removed redundant outputs
557ceb3 fixed lumped window warnings
f41b8c0 Fixes to reduce the number of errors:
b900701 Pruned the outputs and added hourly electricity and gas
b9913c2 Fixed three mistakes in slab cooling implementation procedure:
d3f83c2 Step 4 (final) of slab cooling
6a8c548 Step 3 of slab cooling (unsimulatable)
c02cb16 Step 2 of slab cooling (unsimulatable)
9cd2e8b Step 1 of slab cooling (still unsimulatable)
72d8979 upgraded file with slab to EnergyPlus version 8.7
6ff3899 added slab cooling via design builder (file is unsimulatable in this commit)
3fa5e2c upgraded file to V8.7.0
51d5b1a initial
```

Figure 10 - history of "commits" to the simulation file using Git

The changes made directly to the IDF will be discussed in detail.

5.5 Calibrate the Energy Models

Common practices for building model calibration involve using Root Mean Square Error (RMSE) and Mean Bias Error (MBE). These metrics have been commonly used by standards to define whether the building is calibrated [77], [88]. The errors are calculated as follows [89]:

$$\mathrm{MBE} = \frac{\sum_{i=1}^{N_i}(M_i - S_i)}{\sum_{i=1}^{N_i} M_i}$$

$$\mathrm{CV(RMSE)} = \frac{\sqrt{\sum_{i=1}^{N_i}\left[\frac{[(M_i - S_i)]^2}{N_i}\right]}}{\frac{1}{N_i}\sum_{i=1}^{N_i} M_i}$$

Where:

M_i and S_i are measured and simulated consumption data for every unit of time

N_i is total number of values

These errors only take the energy use into account which may not be reliable if detailed sub-metering of the building is not available. Moreover, no specific method is defined for achieving the acceptable error range.

> *When modeling existing plants, if the results don't match actual monitored data, the programmer will typically "adjust" inputs and operating parameters (almost) on a trial-and-error basis until the program output matches the known data. This "fudging" process often results in the manipulation of a large number of variables which may significantly decrease the credibility of the entire simulation.* [90]

Automated optimization methods [66], [89] were not used in calibration process. The process of calibration was simply verifying the data already gathered from different sources. In one example, the lighting schedule taken from the eQUEST model was simplified to better match the building operation.

One major flaw in white box models is the assumptions. Some important conditions could be assumed to be perfect and the values for coefficients might not be accurate. The uncertainties considered in the pilot of [4] were for well over 100 physical parameters like: “convective heat transfer coefficients, infiltration level, temperature gradients, material properties (for instance thickness, density, heat capacity), system coefficients of performance, design levels, flow rates, urban parameters, ground temperature and many others”. Added to that, the researcher found it impossible to account for some important factors such as unintentional changes and the quality of workmanship.

For the goal of this research, the calibrated model not only had to generate an acceptable energy consumption profile, but it also had to re-produce the response of the case-study building’s HVAC system and the indoor temperature.

5.6 Devise Control Improvement Strategies

The primary objective of the research is creating a control system which can surpass the existing operation in both energy consumption and indoor environment condition.

Based on [3], criteria for optimal system configuration have been set. When it comes to system coupling, the goals need to take both systems and their interaction into account simultaneously. Based on the body of work studied for this project, the below targets were chosen for the controls system:

- The system must have the ability to minimize outside air load while maintaining minimum fresh air supply to each zone as required by standards.
- The system should take the full advantage of free cooling when it is available.
- The systems must not work against each other by design
- Thermal Mass to be considered; systems should not change goals constantly.
- The load peaks need to be moderated by the mechanical system as much as possible.

To achieve the above targets, different strategies for air and radiant control were defined and metrics were set to test their effectiveness.

Some considerations should be discussed for defining the scope of strategies which would make them applicable for the existing conditions in the case-study building. For example, the occupant sensors are often nullified by the manual controls and the building does not have CO_2 sensors. The strategies should not use these resources for controls.

Moreover, the maximum and minimum setpoint ranges remain the same as that of the case-study building since these values are set by the operators or designers. For example, for the air system the temperature setpoints will not go below 13 °C.

5.7 Measure the Performance

The metrics for evaluating the performance must revolve around comfort, energy, and operational stability within the scope of the research. Comfort is specifically an area of focus due to its impact on the student performance. For the classroom level simulation, the following four metrics were chosen because of their use in the literature and representing the mentioned areas of concern specifically on the demand-side.

1. **Number of uncomfortable hours as per AHSRAE 55-2004:** Based on the presented research in the methodology section, the indoor air quality in this academic building should not be compromised. ASHRAE standard can indicate when the room is in the comfort zone.
2. **Energy transferred by the air and radiant systems:** High energy transfer could mean that a system is working against itself. Energy transfer rate reflects the operation of the air and radiant systems while it is a demand-side metric [91].
3. **Room temperature difference with the baseline condition:** This metric is necessary for a fair comparison of the strategies. It was seen that slight changes in annual room temperature average has noticeable impact on the HVAC energy transfer (second metric).
4. **Time of HVAC setpoint below condensation threshold:** the concern with condensation was discussed for [47] in the literature review section.

   In the whole building model, the purpose of comparison is discovering how a change in the zonal controls effects the building as a whole. As mentioned in the literature review section, propagation of the impact is only possible when the complex systems are being monitored holistically. Thus, the whole building model metrics would be the total consumption of the primary energy sources.

6 The Case-Study Building

Vancouver Island University's Cowhichan Campus building is a three story post-secondary education facility located in Duncan, BC. The building hosts 500 students and staff and is operational throughout the year.

Figure 11 - the Case-Study Building

courtesy of Vancouver Island University

The following has been made available by University of Vancouver Island (VIU) for this project:

- eQUEST building energy model
- Online building portal with real-time data from the building automation system
- Design documents
- As-Built drawings
- Documentation for certifications and rebates
- Change orders
- Building commissioning reports

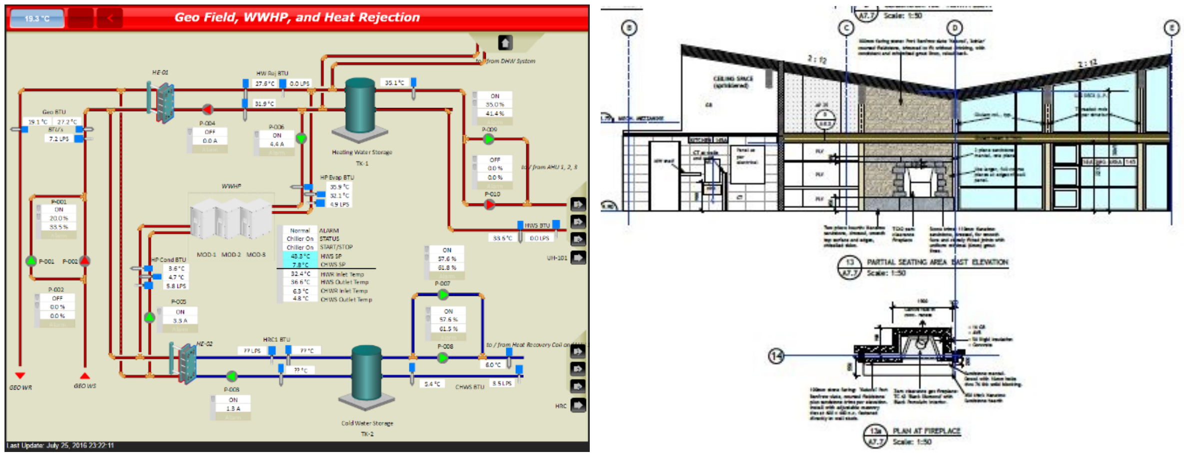


Figure 12 - Examples of Available Data

6.1 Building Spaces

The spaces in the buildings have various roles, but for HVAC, the building is divided in three major zone groups: North, South, and East. The types of activities in Northern, and Southern zones are similar: mostly common spaces, classrooms and lab spaces as well as staff offices. These zones have direct air path to the building's atrium space on the third floor. The eastern zone contains a theatre, a media room and a kitchen-cafeteria space.

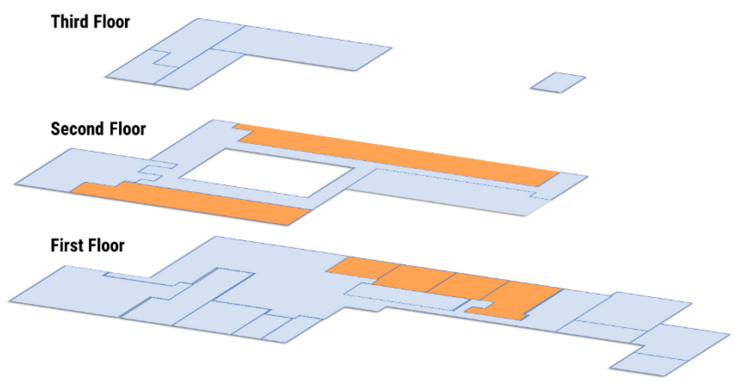


Figure 13 - Classrooms in the case-study building

The classrooms are located on the first and second floor, stretched along the northern and southern walls. Figure 13 shows the classroom locations.

6.2 HVAC System and Control

Most spaces in the building are served by two HVAC systems: a radiant system and an air system. The room setpoint (Figure 14) which determines the air and radiant system operation, is chosen by occupants. The automation system monitors rooms by thermostats and occupancy sensors. Based on monitoring and comparing with the setpoint, the automation system controls valve boxes and Variable Air Volume (VAV) boxes. It should be noted that valve boxes and VAVs are not necessarily dedicated for each room.

Both of the systems are connected to the hydronic loop of the building. The hydronic loop is in charge of providing hot and chilled water for HVAC as well as domestic hot water. The loop is connected to an on-site geo-field through heat exchangers and heat pumps which enables extracting or dumping excess heat to the ground. This process is assisted by gas boilers and solar panels.

Figure 14 - In-room thermostats

The building has a Rule-based automation system. At the core, the system is controlled by a “master” program that sets the “mode” of the HVAC system. The mode can be heating, cooling, or standby based on outdoor air temperature of the previous 30 minutes.

The systems’ and subsystems’ operation is mainly governed by the building schedule and the mode of the system. The next frequently seen variable in building’s programs is the room temperatures and occupancies gathered through thermostats and occupancy sensors.

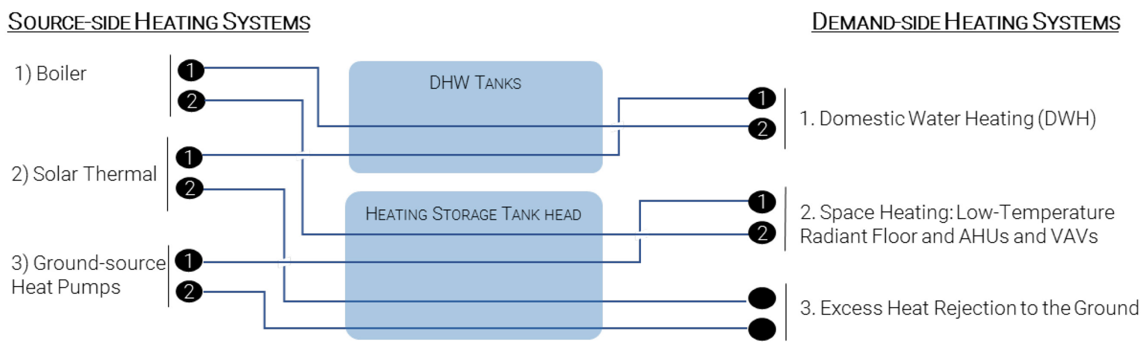


Figure 15 - Mechanical source-side and demand-side connection

Case-study building, white numbers indicate priority

The Supply side HVAC system is consisted of a hydronic loop connected to ground-source heat pumps as well as boilers and solar thermal collectors. Hydronic loops deliver chilled and hot water to a slab cooling/system as well as the air system. Figure 15 illustrates the connection between the two sides.

6.2.1 Air Handling Units (AHUs)

The air system is mainly consisted of 3 Air Handling Units (AHUs). Each AHU serves one of the main zones: North, South, and East. These AHUs are equipped with both heating and cooling coils, Modulating Dampers to control return and fresh air mixing, a freezestat, and a thermostat. These AHUs direct air to VAVs. Each VAV has a damper to control the air flow, and a reheat coil. By design, VAVs have more control over the conditions of each space than the radiant system for small loads.

A server room located on the third floor is independently served by a simpler AHU since it could have Air Conditioning needs through unoccupied hours.

The AHUs fans are configured to maintain a given static pressure in the ducts, and control the supply air temperature and the ratio of fresh air. After checking building's schedule, each AHU monitors Return Temperatures from its connected VAVs. The lowest set-point among all VAVs, plus one degree, becomes the set-point of the AHU. That is because if zones needed heating, their VAVs are equipped with reheat coils connected to same radiant loop as the AHUs, but only AHUs are equipped with cooling coils.

The AHU temperature setpoint is met by modulating the Mixed Air Damper (MAD) and the coil valves. The damper is introducing a minimum of 20% outdoor air at all times. To better understand the dynamics in the AHU, a typical summer week (Figure 16), and a typical winter week (Figure 17) will be described below. The operation pattern in the shoulder seasons does not follow a typical pattern. It must be noted that the hours of building operation vary at different times of the year.

During the typical summer day, the outdoor air temperature is moderately more than the air system's setpoint temperature (14°C) thus, the system is cooling. The cooling coil valve is fully open but even though the temperature does not meet the setpoint, the damper typically remains at the minimum except in the mornings. In the early hours of operation, the damper could briefly open as much as 75%.

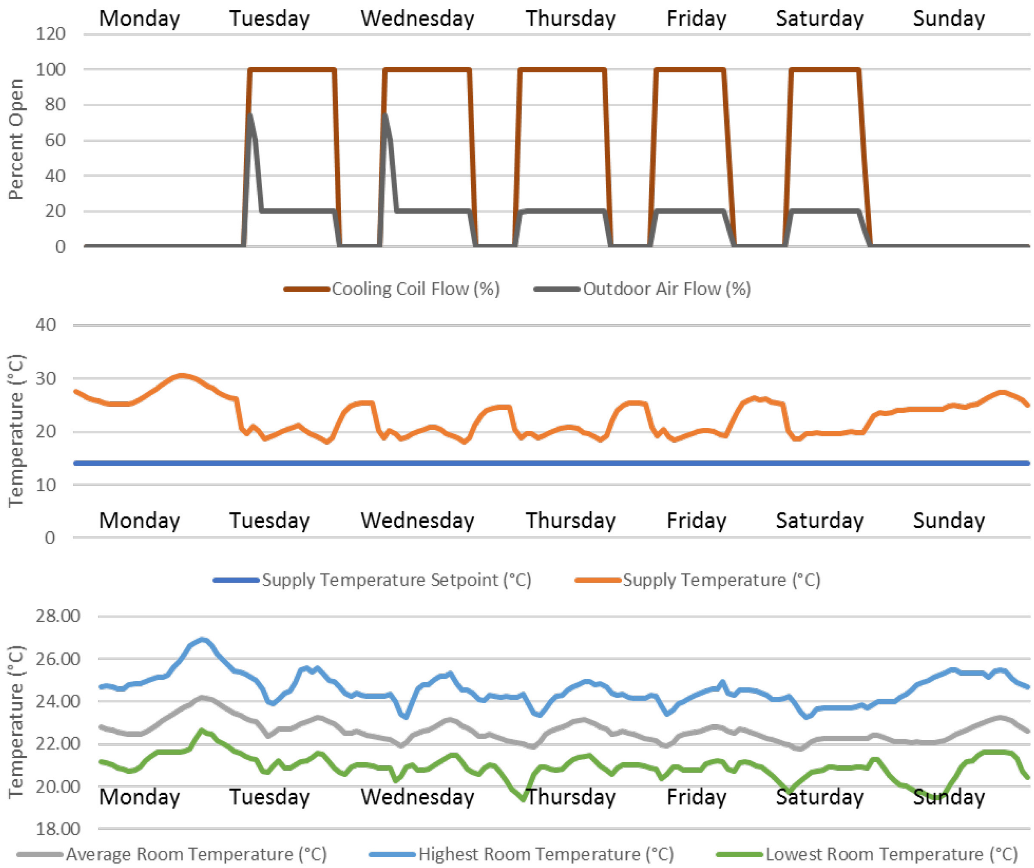


Figure 16 - AHU operation during typical summer week

After the start, the damper logs show that the rate of introduced outdoor air does not go above the minimum allowable (20%) for the main hours of operation. A piece of the AHU program is written to gradually open the damper at the start of building operation. When that program expires, the rest of the program takes over the control and the damper promptly closes.

During the shoulder season, the outdoor air damper does not open more than the minimum as long as the cooling coil can handle the loads, meaning the AHU never uses free cooling. Lack of economization is not necessarily a weakness: the heat collected via the cooling coil is reused in the heat pump or rejected to the ground to re-charge the ground source.

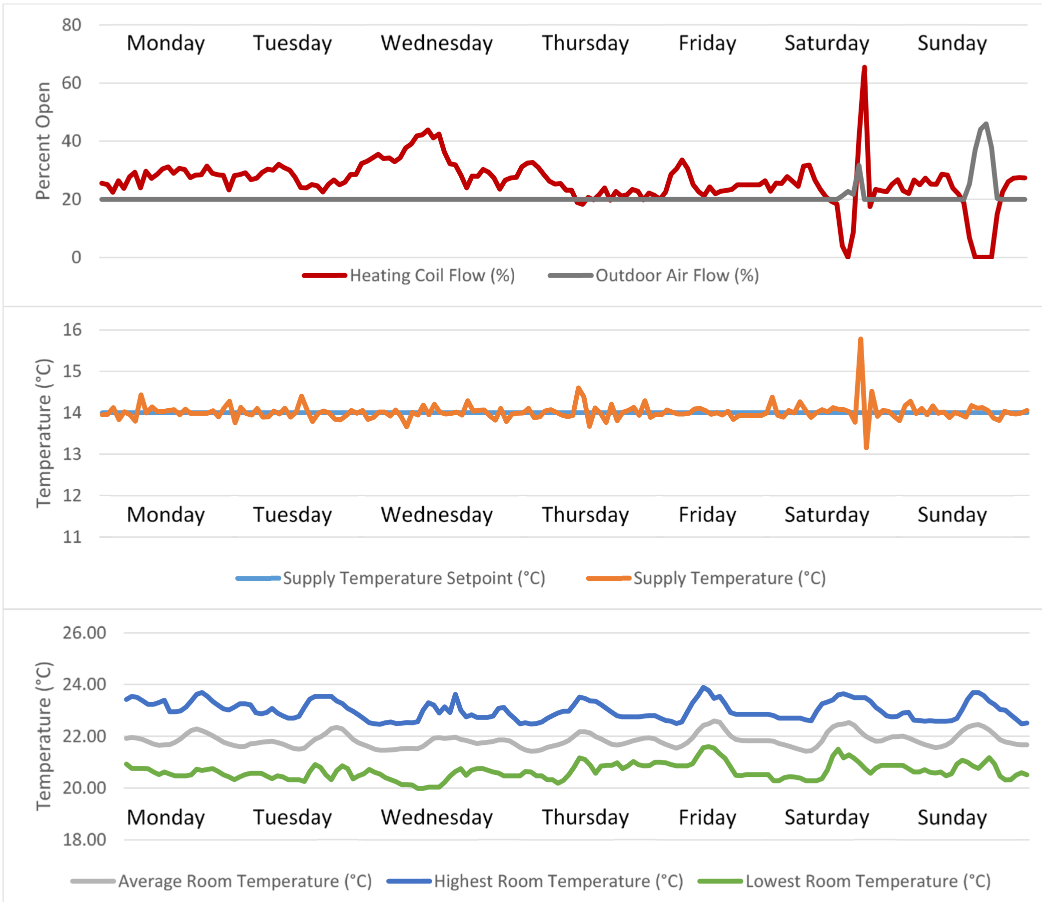


Figure 17 - AHU operation during typical winter week

During the typical winter day, the room temperatures are slightly less on average, the outdoor air damper is at minimum and the setpoint is constantly 14°C. During this period however, the outdoor air must be heated to reach this value and the setpoint is met. Normally about a third of the heating coil valve is enough for heating the air to the setpoint level.

6.2.2 Return and Exhaust Fans

Due to the number of exhaust fans and their different objectives, the logic for the fans vary. For washrooms, the fans are always turned on during the active hours. For more sensitive spaces such as the electrical room, the exhaust fan works based on room temperature.

The atrium space of the building is connected to the mechanical room. Air is directed to the mechanical room or to an exhaust heat recovery system with the help of a return fan. This setup is also equipped with pressure sensors to ensure that the negative pressure of the mechanical room is retained.

6.2.3 Valve Boxes

The hydronic loop has branches for the slab of each floor. Pipes that run through the slab are controlled by valve boxes. There are less number of valve boxes than the VAVs, so in comparison the system has less control over individual spaces in the building.

Valve boxes collect slab temperature as well as the status of all occupancy sensors in zones they serve (example can be seen in item 6.2.5). Based on the mode of the building (heating, cooling, or standby), and the difference of slab temperature and the room setpoint, each Valve Box sets its Set-point and Chilled/Hot water valves.

6.2.4 Terminal Systems

In parallel with the radiant system (slabs), the VAVs serve specific zones. The system sets the air flow damper position and the reheat coil valve based on the difference between the supply and room temperatures from the space(s).

The VAVs have indirect interplay with the radiant system as they both monitor the room temperature and respond to it. This can be explained by exploring the operation in north and south facing classrooms during typical winter and summer times; thus, two classrooms (North and South facing) were observed for the mechanical system behavior (see Figure 19 to Figure 22). It was found that the heating season and the cooling season produce different patterns.

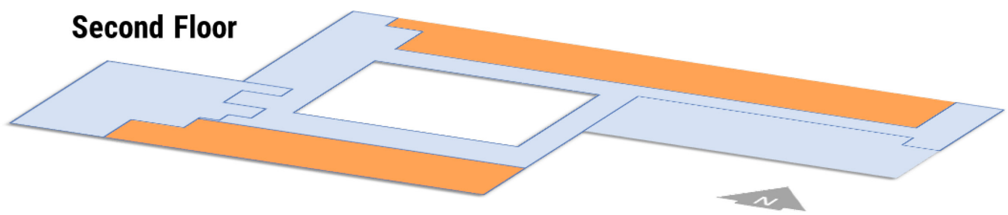


Figure 18 - Location of the observed classrooms

The general operation of the mechanical system has been shown earlier. For both classrooms, the radiant system is at full heating mode during the winter time due to the interior need and the outdoor temperature. The VAV reheat provides additional heating if necessary.

Figure 19 shows the thermal responses to loads on a south-facing classroom, for the air system (top), the room (middle) and the slab (bottom) for a typical winter week.

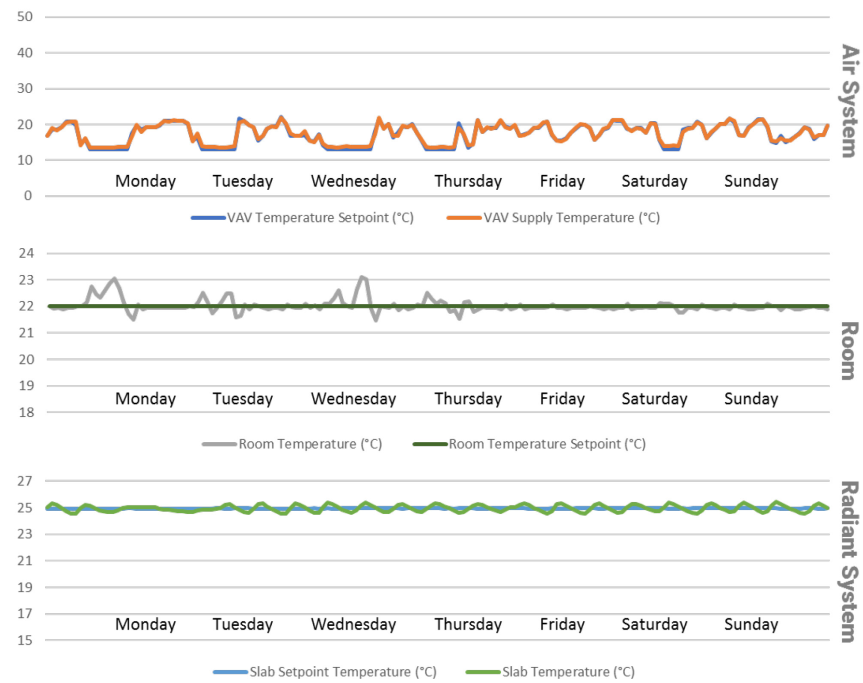


Figure 19 - Typical winter temperatures week of the South-facing classroom

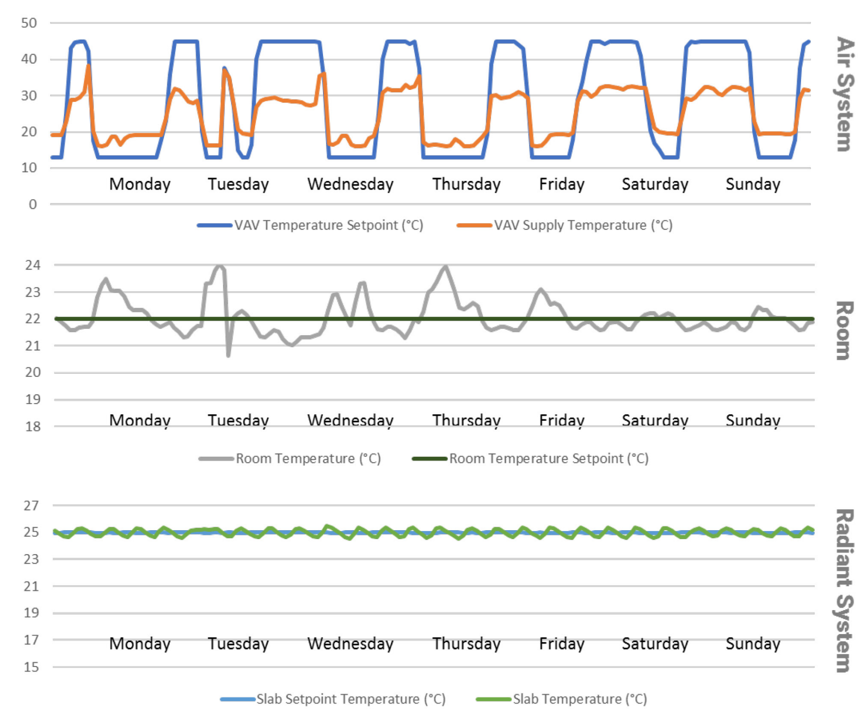


Figure 20 - Typical winter week temperatures of the north-facing classroom

For the North-facing classroom the typical winter week has more reheat time of air system with a more recognizable setpoint pattern. The reheat setpoint rises to 45°C at the start of the typical day and returns to 13 °C in the middle of the day.

In summer (Figure 21 and Figure 22) there is less reheat by the air system; nonetheless, the room temperature control is poor. On air side, as explained for AHUs, the air setpoint often does not reach 14°C in summer so the air system is introducing warm air in the space. On radiant side, the inconsistent pattern of slab operation appears.

The slab heating occurs in the middle of the night until close to the starting hours. This could make early hours of the day uncomfortable for occupants. During the rest of the day, the slab is being cooled. The cooling could be because of the space needs or forced by the outdoor air temperature.

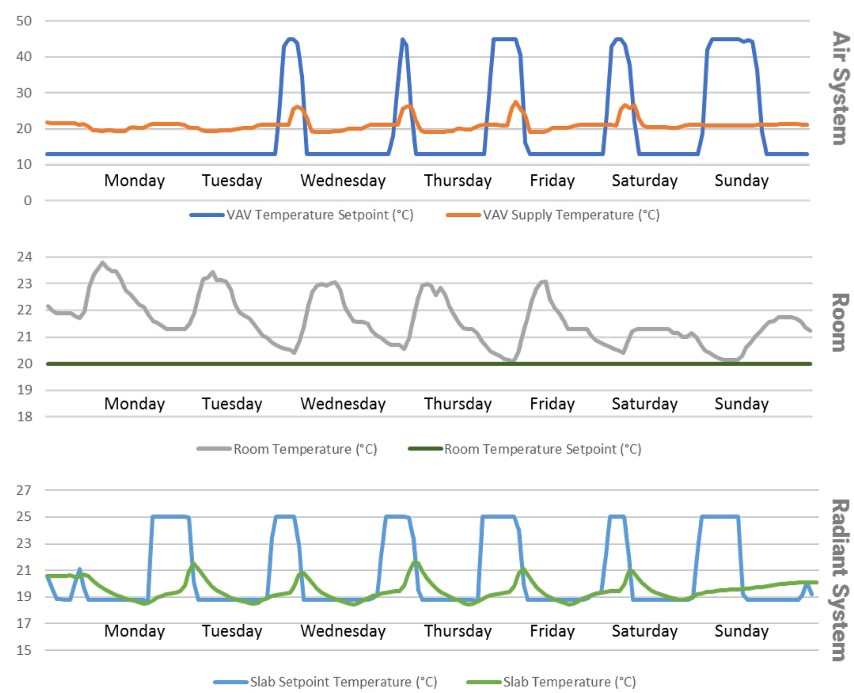


Figure 21 - Typical summer week temperatures of the north-facing classroom

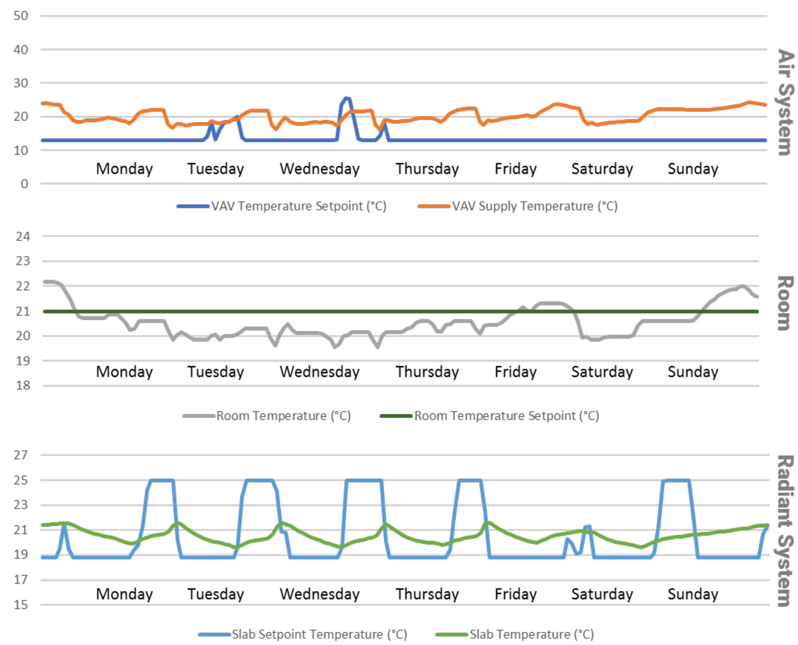


Figure 22 - Typical summer week temperatures of the south-facing classroom

The operation pattern of the north-facing classroom is more frequent among the classrooms. From more than ten observed classrooms and laboratories, only three have an operation pattern comparable to the south-facing classroom. For other spaces, the air system setpoint raises to 45°C but the coils are not capable of producing this temperature. On the other end, low setpoint also does not guarantee the temperature as the AHU could introduce higher temperature which the VAV does not have any means to cool down. Consequently, the reheat temperature setpoint acts in a binary fashion; most of the time it is either at the high setpoint (the flow is minimum and coil is fully functional) or at the low setpoint (the damper is fully open and the coil is off).

6.2.5 Frequently Used Functions in the Automation Programs

Discussing the functions is important because it shows the level of complexity of the controls. In the automation system program (using GCL+), a function, which is always on the right side of the equation, performs a specific task, then "returns" the result to the variable on the left side. The Automation Program uses the following functions frequently:

- **Max and Min:** Returns the highest or lowest value from a set of variables. It is also being used to indicate when "any" or "all" conditions are met. For example, there are a number of inputs each being either 0 (meaning OFF) or 1 (meaning ON). When Max is used with this set, if only one input is 1 and the rest are 0, Max returns 1. In other words, Max is looking for "any" value to be 1. If Min is used, it always returns 0 unless all the inputs are 1; looking for "all" values to be 1.

  This usage can be seen when occupancy is being checked by the radiant system program. VBs can serve multiple zones. If the occupancy sensor of one zone detects movement, it returns the value of 1 which will set the occupancy status to *occupied* for the VB:

```
VB106_OCC = Max (700708.BLD700_VAV108_OCC, 700709.BLD700_VAV109_OCC,
700710.BLD700_VAV110_OCC, 700711.BLD700_VAV111_OCC)
```

- **Average:** With a syntax similar to Max and Min averages all the given inputs.
- **Limit:** Ensures a value is within the maximum and minimum specified value, if not, it makes it equal to them. The syntax is as below:

```
Output = Limit (Input, Minimum, Maximum)
```

- **Switch:** Sets the output to ON if it equals one input, or OFF if it equals another.

```
Output = Switch (Output, Input, ON_Value, OFF_Value)
```

- **Scale:** Is made to simplify programming of reset schedules. This function finds the output from a graph. The function accepts two coordinates (as shown in Figure 23), bias (always set to 0 for this usage), and the input.

```
Output = Scale (Input, Bias, x1, y1, x2, y2)
```

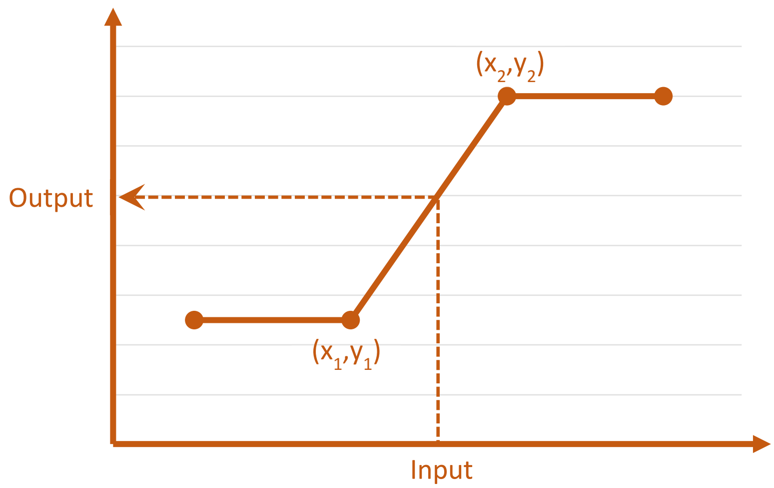


Figure 23 – GCL+ Scale Function

6.2.6 Schedules

There are 4 schedules developed for building operations which are accessible through the building control system's online interface. The "main schedule" is by far the most used schedule by the operation programs. However, it is being manually changed constantly and the online interface does not keep a track of the changes. This schedule was retrieved from the operation logs of the AHUs which operate based on the schedule. The logs show that the mechanical system operates continuously (may shut down for 30 minutes at midnight) during long periods within a year. For other times, the operation is from morning to evening.

Another valuable resource for evaluating the occupancy was the class schedules and events shared on the campus website [92]. The data was not directly usable as it was not available for the whole studied period, and did not appear to reflect all the academic activity including the student activates out of the class times; however, it provided a basis for choosing a standard academic schedule in later stages. This data shows that the classrooms on the first and second floor are frequently used during the morning, afternoon, and occasionally evening periods, with reduced activity during the summer.

6.3 Observations

The following subsection elaborates on our findings regarding some of the existing conditions in the case-study building and some challenges of the building operation.

6.3.1 Design of Demand-Side HVAC Equipment

In multiple zones, HVAC operation is limited because the radiant loops and/or VAV units are shared with adjacent spaces; therefore, change of zone setpoints in favor of one space in one of these zones may cause problems in other spaces of the zone.

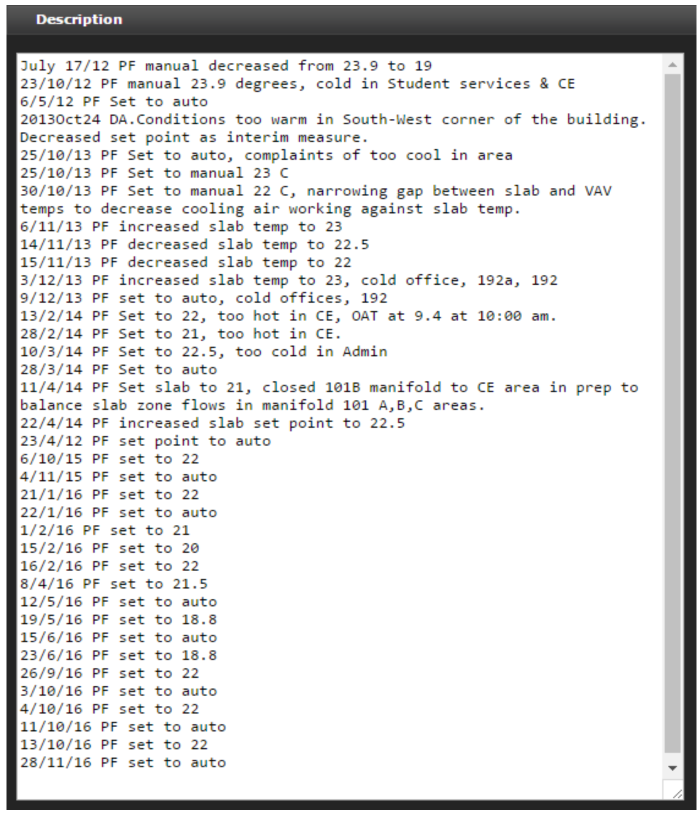
There is also limitation in detecting occupancy. CO2 sensor functions are described in the Sequence of Operation, but are not installed. Also, often only one space in a zone is equipped with the motion sensor, so the occupancy of other spaces is unknown to the system.

6.3.2 Manual Overrides

The automation system gives the option to building operators to take the control of the system in their own hands when it is seen necessary. Naturally, due to the shortcomings of the building automation system, some parts of the HVAC system are being operated manually.

Within the interactive component of the HVAC system, unplanned operation of one system (due to manual settings) can negatively affect the whole system. One example of the interference is overriding the motion sensors, mentioned in the previous item, to always show there is movement. The reason for this change is that the occupancy sensor is shared. If there is no activity in the room with the occupancy sensor, the other rooms in the zone are not conditioned as well. This leaves no option for the operators, other than eliminating the sensor.

Thus, the VAV associated with the space is reporting the rooms are always occupied. This causes change of operation in a much larger scale when the northern AHU, that delivers air to the VAV, keeps working because of the false occupancy reports.



Description

July 17/12 PF manual decreased from 23.9 to 19
23/10/12 PF manual 23.9 degrees, cold in Student services & CE
6/5/12 PF Set to auto
2013Oct24 DA.Conditions too warm in South-West corner of the building.
Decreased set point as interim measure.
25/10/13 PF Set to auto, complaints of too cool in area
25/10/13 PF Set to manual 23 C
30/10/13 PF Set to manual 22 C, narrowing gap between slab and VAV
temps to decrease cooling air working against slab temp.
6/11/13 PF increased slab temp to 23
14/11/13 PF decreased slab temp to 22.5
15/11/13 PF decreased slab temp to 22
3/12/13 PF increased slab temp to 23, cold office, 192a, 192
9/12/13 PF set to auto, cold offices, 192
13/2/14 PF Set to 22, too hot in CE, OAT at 9.4 at 10:00 am.
28/2/14 PF Set to 21, too hot in CE.
10/3/14 PF Set to 22.5, too cold in Admin
28/3/14 PF Set to auto
11/4/14 PF Set slab to 21, closed 101B manifold to CE area in prep to
balance slab zone flows in manifold 101 A,B,C areas.
22/4/14 PF increased slab set point to 22.5
23/4/12 PF set point to auto
6/10/15 PF set to 22
4/11/15 PF set to auto
21/1/16 PF set to 22
22/1/16 PF set to auto
1/2/16 PF set to 21
15/2/16 PF set to 20
16/2/16 PF set to 22
8/4/16 PF set to 21.5
12/5/16 PF set to auto
19/5/16 PF set to 18.8
15/6/16 PF set to auto
23/6/16 PF set to 18.8
26/9/16 PF set to 22
3/10/16 PF set to auto
4/10/16 PF set to 22
11/10/16 PF set to auto
13/10/16 PF set to 22
28/11/16 PF set to auto

Figure 24 - Manual overriding of the slab temperature set point

Another case of overriding can be seen in the notes left in the online portal of the changes starting from early operation of the building and continuing to the present (Figure 24). The operators had to change a slab set-point frequently throughout the year, because of the poor adaptation of the system to seasonal needs.

Apart from the inconvenience the manual maintenance may cause, the complex mechanical system of the building may not react as expected to the override. This can be seen in classroom 125. The slab temperature was fixed manually to 22°C as we pointed out to the operators that the slab temperature is at 25 °C even when the room is hot. The building logs show this have not had the anticipated effect as the reduction of heating delivered to the space since it is immediately compensated by the air system (Figure 25).

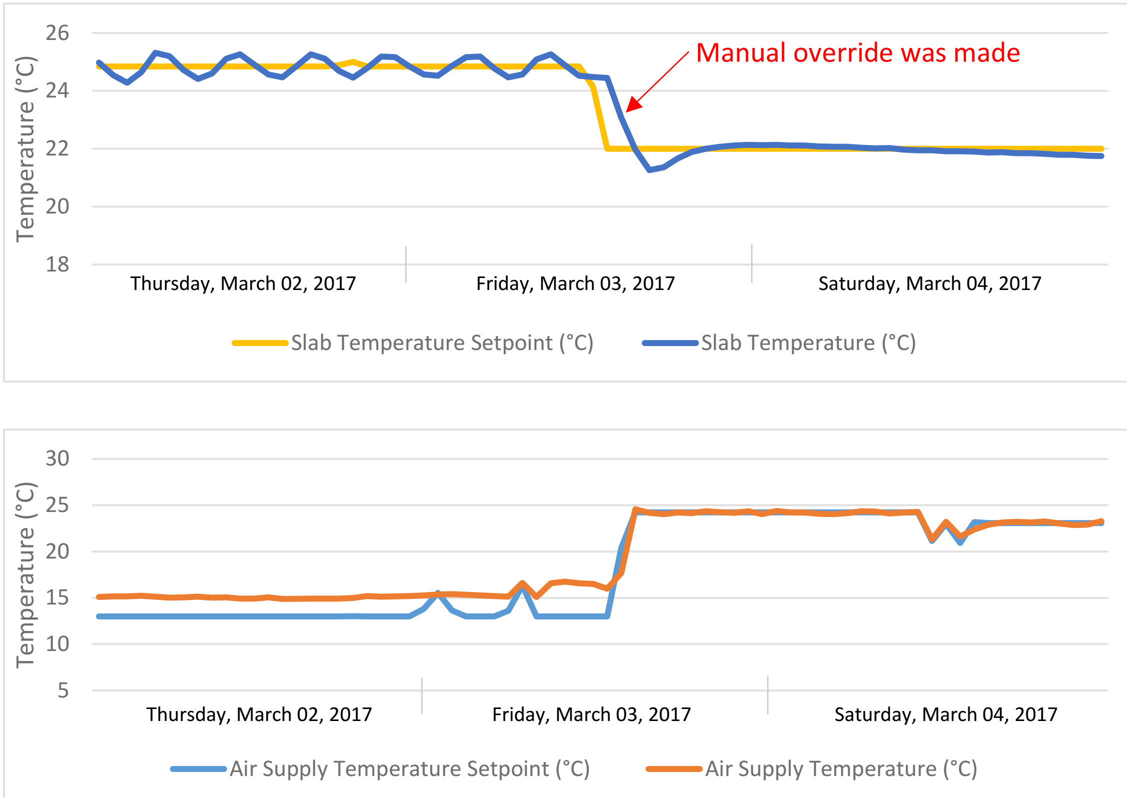


Figure 25 -Effect of manual override of slab temperature on the air system

6.3.3 Disconnected Controls

Figure 27 shows a snapshot of the systems serving room 125 when the building was in the heating mode. The conditions are summarized below:

- Outdoor Air Temperature: **-2.3°C**
- Room Temperature Set-Point: **20°C** (set manually inside the room)
- Room Temperature: **20.6°C**
- Air System Set-Point: **14°C**
- Radiant System Set-Point: **25°C**

As above, the Air System is delivering cold air to the room at the lowest possible set-point while the radiant system is compensating with the highest set-point temperature it can deliver. This condition not only can create discomfort for the occupants, it could be costly.

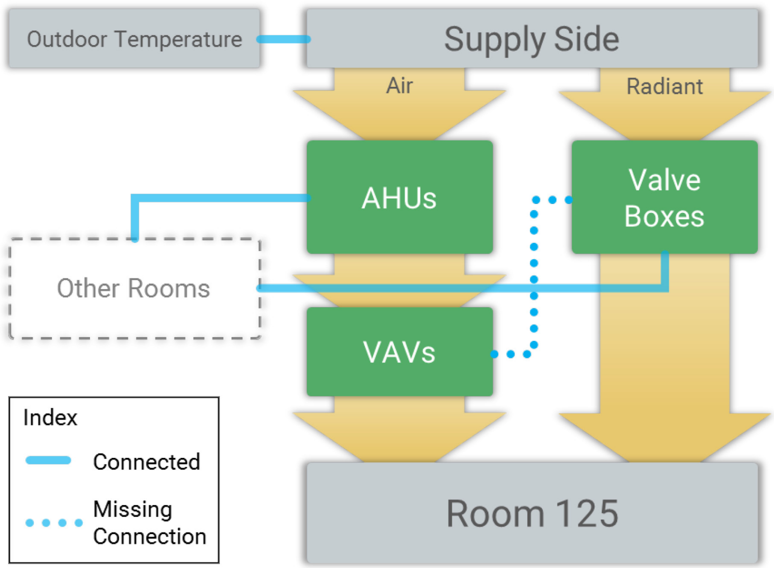


Figure 26 – HVAC Cross Connections, Case-Study Building

The reason air system has a low set-point in this condition is that the room temperature is close to the set-point, so the VAV program does not recognize any need for the re-heat coil. If the room temperature was far from ideal, the air system would have used reheat until the temperature is close to the setpoint, meaning that it would only help whenever the zone heating demand makes the room setpoint unattainable for the radiant system. In the meantime, the radiant setpoint is at maximum.

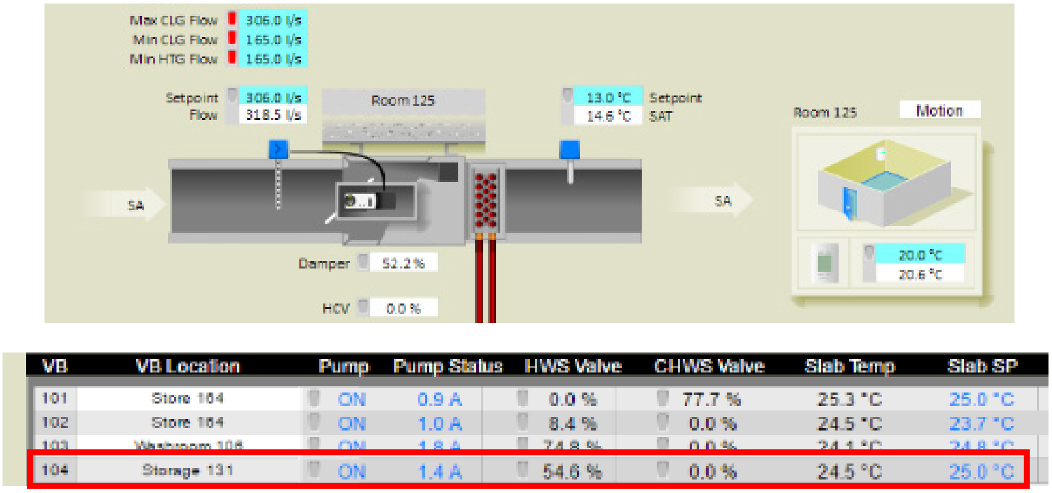


Figure 27 - Snapshot of systems connected to room 125

case-study building, December 16, 2016 at 09:10 am

6.3.4 Unmet Air System Set-points

Figure 28 shows the recorded data for Supply Air Temperature (SAT) set-point of a VAV. The set-point, which has been 13°C for many hours, goes up to 45°C within 1.5 hours.

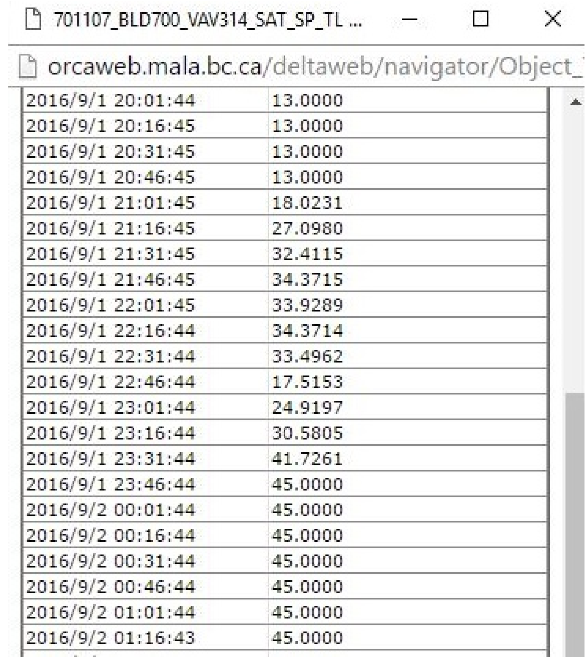
The set-point is set by a PI controller which feeds a Scale function (described earlier) with the low limit of 13°C (when 0%) and high limit of 45°C (when 100%). The PI controller seldom returns values between these two values and often remains in the extremes. The actual air temperature never reaches 45°C.

Added to the above, another problem with the setpoints appears to be from the utilization: in the implementation of the HVAC controls, the temperature setpoint value was not used as the target temperature. Instead, it appears that it was used to shut systems down. In VAV's case, the device is equipped with only a heating coil. Having a setpoint of 13 °C ensures the coil is not operating; it does not mean the output temperature will be 13 °C.

That is because the actual discharged air from VAV never reaches 13 °C as the lowest setpoint for its AHU is 14 °C. That temperature also may not be met during the summer, as it was shown earlier.

6.3.5 Operation inconsistency

Related to the previous item, and the operation snapshots shown earlier, some systems appear to respond too fast to the room conditions; meaning that their setpoints change rapidly. This could occur in both air and radiant systems.


701107_BLD700_VAV314_SAT_SP_TL ...

orcaweb.mala.bc.ca/deltaweb/navigator/Object_

2016/9/1 20:01:44	13.0000
2016/9/1 20:16:45	13.0000
2016/9/1 20:31:45	13.0000
2016/9/1 20:46:45	13.0000
2016/9/1 21:01:45	18.0231
2016/9/1 21:16:45	27.0980
2016/9/1 21:31:45	32.4115
2016/9/1 21:46:45	34.3715
2016/9/1 22:01:45	33.9289
2016/9/1 22:16:44	34.3714
2016/9/1 22:31:44	33.4962
2016/9/1 22:46:44	17.5153
2016/9/1 23:01:44	24.9197
2016/9/1 23:16:44	30.5805
2016/9/1 23:31:44	41.7261
2016/9/1 23:46:44	45.0000
2016/9/2 00:01:44	45.0000
2016/9/2 00:16:44	45.0000
2016/9/2 00:31:44	45.0000
2016/9/2 00:46:44	45.0000
2016/9/2 01:01:44	45.0000
2016/9/2 01:16:43	45.0000

Figure 28 - SAT set-point of a VAV, Case-study building

The valve box 102 is provided as an example of how these changes can cause problem with the thermal mass of the building (Figure 29). At the start of a typical day of operation, the setpoint decreases to the minimum. Before the slab is able to completely adapt the new temperature – at the day's end – the temperature rises again, so the slab is working in the opposite direction.

This pattern can potentially cause unnecessary HVAC operation and energy consumption increase.

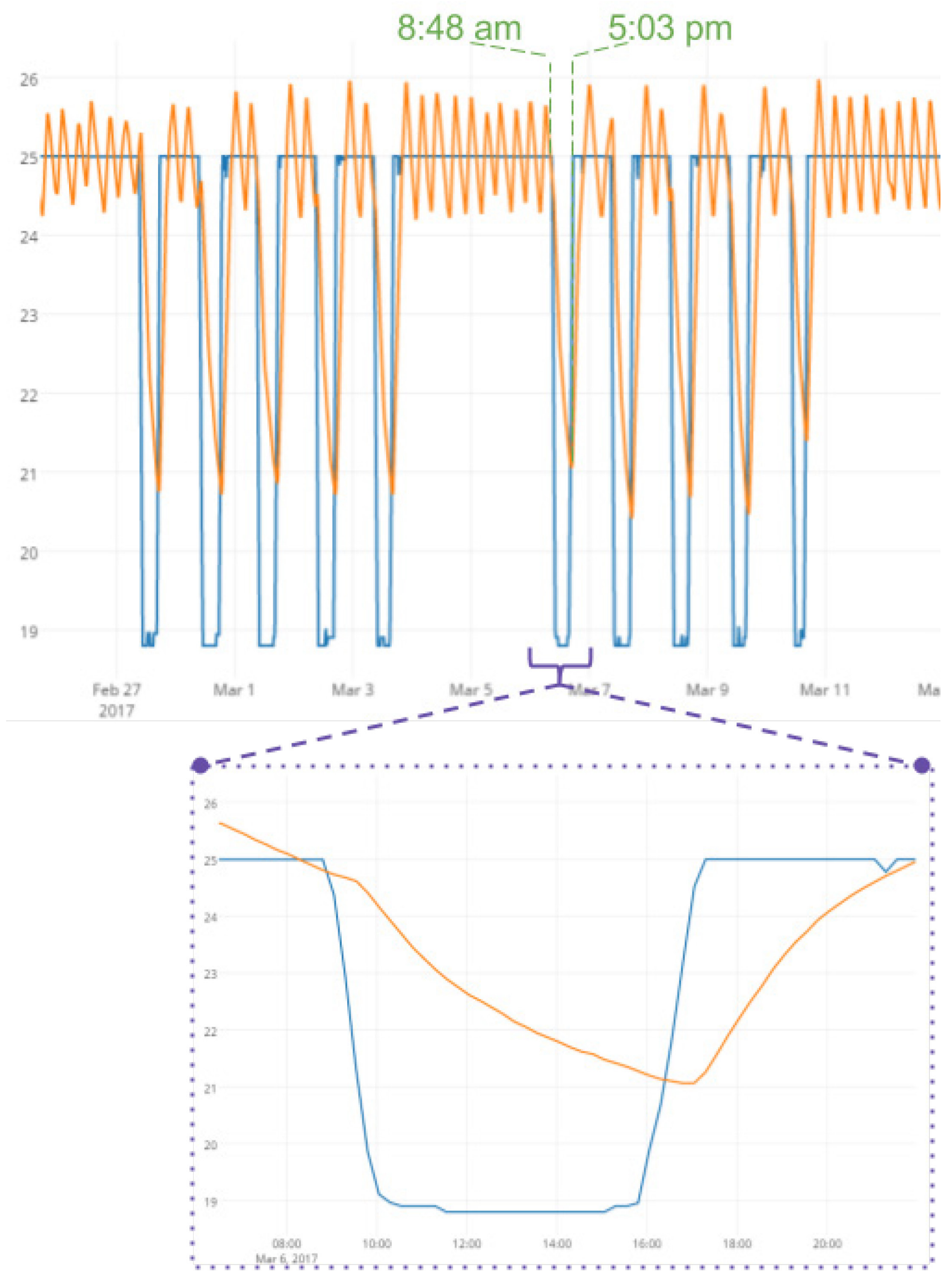


Figure 29 - The setpoint and slab temperature corresponding to Valve Box 102

6.3.6 Slab Insulation

Reviewing the as-built drawings from the case-study building shows no signs of insulation layers beneath the interior slabs (Figure 30). This would mean that the slabs will have radiation to spaces both above and under them while the automation system controls the slabs only with the conditions of the zones above the slab. In such cases, slab temperature might have unintended effect on the zones in which it is the ceiling.

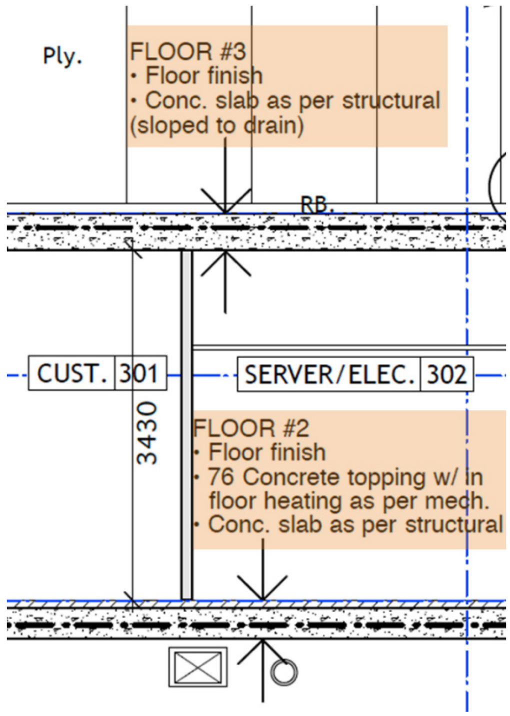


Figure 30 - Interior concrete slabs in As-Built drawings

It must be noted that false ceilings and air systems ducts running beneath the slabs complicate the effect of radiation from the ceiling. Also, using the building mode in the operation of the slabs has eliminated variation between the slab temperatures when the outdoor air temperature is above 18°C. In other cases, lack of insulation or low-emissivity layers would be a design flaw if the radiation of a slab to spaces below it is considerable.

Given the uncertainties, this research will follow the zone division by the designers in which only the zones above the slab are considered, but the subject matter remains an item for further investigation.

6.3.7 Responsiveness to Climate and Occupancy

Energy consumption of the building, while lower in summertime, shows little correlation with the academic schedule or the weather. The consumption is lower during many weekends and changes in consumption pattern appear at different times of the year, but the changes do not follow the expected annual variations in the internal and external loads.

During the summer break, the reduced occupancy can allow more relaxed setpoints and lower overall operation. The mechanical system follows some seasonal rules such as reduced heating loop setpoint during the summer, but such measures are localized.

Moreover, further to the previously shown mechanical system operation patterns, the automation system does not appear to take advantage of the ventilation opportunities at times suitable for economization. The extent that the operable windows of the building are being used in such scenarios is unknown, but the logs from the AHUs show that the outdoor air damper normally remains at 20% during operation while the cooling coil is working at maximum capacity. The potential advantage of this pattern is the rejection of the redundant heat (collected by the cooling coil) to the ground to charge the ground loop. As for the disadvantages, apart from the mentioned energy considerations, the negative impact of low fresh air on the academic performance could be argued.

6.4 Existing Case-Study Building Model Review

Described in the literature review section, the building design stage may be an important contributor to the Performance Gap. In this subsection, the objective is reviewing the building model that justified the design-stage High-Performance Building (HPB) study of the case-study building. The model was the basis for claiming energy-related credits in the building's LEED submission, as well as the validation of Energy Conservation Measures (ECMs) for utility rebates.

The model is available as a part of the documentation provided by the Vancouver Island University. For understanding the design intents, the model was reviewed along with the LEED submissions, High-Performance Building (HPB) study, an ASHRAE Journal article on the building [75], as-builts, etc.

As for the actual performance, the historical gas and electricity consumption logs are available in the building's online interface. The monthly consumption data has been the easiest to acquire this way; however, for most years, the records of one or more months are either not available or are unrealistic to be reported. Therefore, from this data only the years 2013 and 2016 are presented.

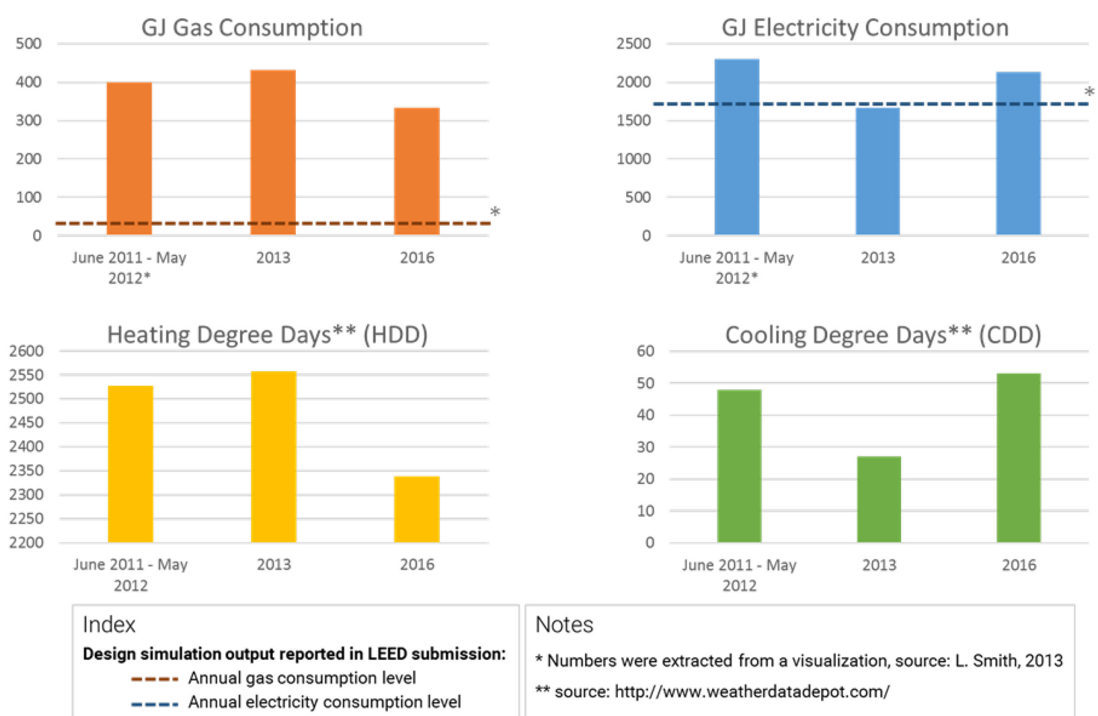


Figure 31 - Energy targets compared to consumption

It is clear in Figure 31, that the building is not meeting the targeted consumption levels (dotted horizontal lines). Moreover, there seems to be a connection between the consumption of gas with Heating Degree Days, and consumption of electricity with Cooling Degree Days. If so, the consumption fluctuation is related to the weather, while the overall status of energy consumption has not changed from what [75] had reported.

The following subsections present what we have identified as some potential causes of the discrepancy stemming from the building model. The mentioned causes, along with lack of control customization options in the available model, make the model unsuitable for this research.

6.4.1 Choice of software

The reason the modelers have decided to use the eQUEST software for the modeling is not specified; however, along with the many features the software provides, the limitations of eQUEST are well-known and studied. Some of these limitations that are directly related to the case-study building are [93], [94]:

- Low-temperature radiant hydronic units are not available
- Does not include a solar thermal collector model
- Does not allow heat pump attached to ground loop with boreholes
- Boilers cannot be connected to ground loops
- Cannot simulate mixed mode operation of natural and mechanical ventilation
- Has limitations in creating optimized shading devices

This has caused a mix of hard-to-follow workarounds which may be acceptable practices alone, but it is not clear whether the same can be said about those combined. The mentioned practices are:

1. Use of dummy zones for natural ventilation
2. Representing Radiant slabs by VAV units with fan power set to 0
3. Using Loop-to-Loop heat pump (classified under chiller)
4. Separating the domestic hot water loop connected to a boiler
5. Connecting the ground loop to a “Lake/Well” source instead of boreholes

For the last item, due to a constraint in eQUEST, it is not possible to connect a ground-source system with borehole structure (as the case-study building) to a condensing loop. Thus, the only available option remains to represent the ground source as a Lake/Well.

As per the software’s help file, the Lake/Well option “allows you to simulate water-wells, lakes, and rivers, where the temperature of these sources is driven by factors other than the loop thermal demands.”[4] This means the program will disregard the thermal capacity of the ground source (G-functions and Earth Energy Designer – EED – borehole heat exchanger design software package) which is one of the significant delicacies of designing such systems.

In conclusion, the mechanical system designed in the software does not appear to correctly represent the mechanical system of the case-study building.

6.4.2 General Construction

The model of the building does not have the same square footage as the reported values. Approximately, the model is 250 square meters larger than the actual gross area. In

[4] eQUEST Content and Index Volume2: Dictionary, HVAC Components, GROUND-LOOP-HX, Keywords

addition, model's sloped roof in the eastern zones does not have the built shape (Figure 32).

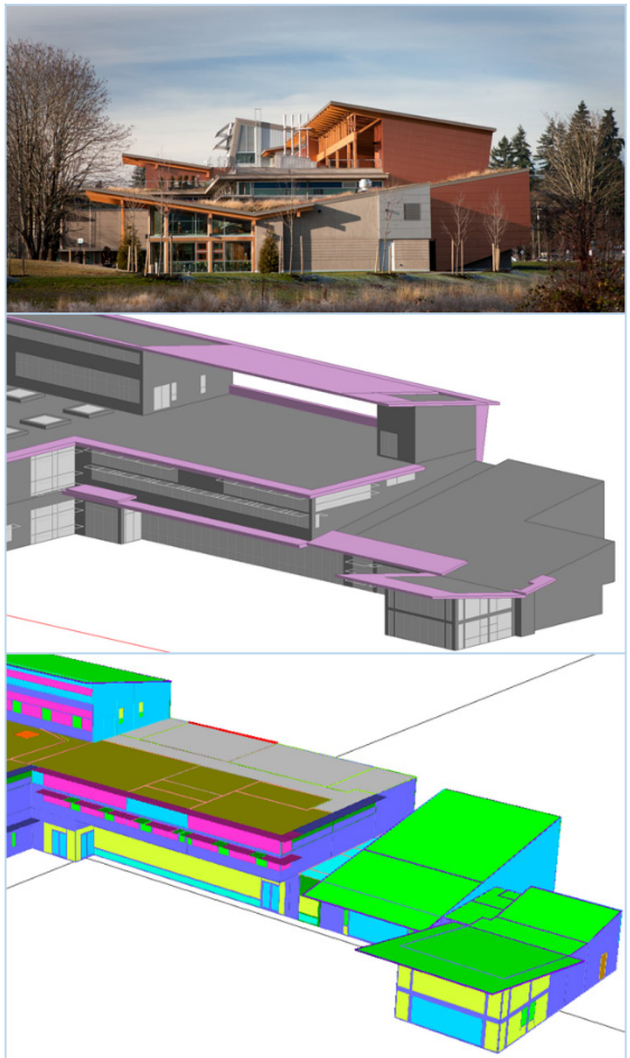


Figure 32 – Construction details in the eQUEST model

Top: Photo of case-study building (courtesy of Vancouver Island University)

Middle: Modeled building in DesignBuilder for this research

Bottom: the eQUEST model

Finally, at the third floor, the sloped shading as well as the enclosed space adjacent to it are not modeled. Observing the solar beam angle in DesignBuilder shows that the constructions cast large shadows on the roof during the warm months. Lack of these shadows, adds to the effect of the mismatch introduced in the next subsection.

6.4.3 Envelope

eQUEST provides two options for defining constructions:

1. Layer-by-Layer definition
2. U-Value input

To account for thermal bridging and complex constructions, the modelers have used U-Value inputs instead of layer-by-layer in some constructions such as the green roof. This approach eliminates the thermal mass of the building.

eQUEST uses weighting factors for room temperature calculation. The calculation requires z-transfer functions, such as:

$$K_{Di}(z) = A_i \sum_{j=0}^{\infty} Z_i(j)\, z^{-j} \quad \text{[95, p. II. 58]}$$

Where *A* is the wall area, and *Z* is Z-response factor of a given wall.

DOE-2 software includes a library of Z-response factors for common materials which could be used once the assembly is defined layer-by-layer.

When the assembly is defined with a U-Value, the software does not have access to a Z-response factor, so the assembly is considered lightweight and any heat flow through the construction "will be considered to be instantaneous"[5]. In this case eQUEST uses:

$$K_{Di}(z) = U_i A_i$$

---

[5] eQUEST Content and Index Volume2: Dictionary, Envelope components, CONSTRUCTION

Where *U* is the U-value of a given wall.

Given that the green roof and the concrete walls of the building have been designed using the U-value input system, the effect of thermal mass is missing from the primary mass constructions in the model.

		Original U-Value Input (U= 0.043 Btu/hr.ft2.F)		**Layer-By-Layer Construction** (U= 0.033 Btu/hr.ft2.F)		**U-Value input** (U= 0.033 Btu/hr.ft2.F)	
(UNITS=MBTU)		WALLS	ROOFS	WALLS	ROOFS	WALLS	ROOFS
JAN	HEATNG	-20.582	-18.465	-20.532	-16.335	-20.524	-16.412
	SEN CL	-3.927	-5.697	-4.002	-5.531	-3.997	-5.230
	LAT CL						
FEB	HEATNG	-16.100	-14.346	-16.027	-12.276	-16.051	-12.740
	SEN CL	-3.823	-5.010	-3.913	-5.185	-3.880	-4.614
	LAT CL						
MAR	HEATNG	-15.440	-13.557	-15.366	-11.210	-15.403	-12.054
	SEN CL	-3.696	-3.497	-3.791	-4.390	-3.742	-3.233
	LAT CL						
APR	HEATNG	-11.445	-10.166	-11.347	-7.324	-11.433	-9.050
	SEN CL	-2.723	0.043	-2.832	-1.790	-2.740	-0.054
	LAT CL						
MAY	HEATNG	-7.945	-7.360	-7.748	-4.258	-7.940	-6.550
	SEN CL	-0.542	6.408	-0.751	3.145	-0.551	5.651
	LAT CL						
JUN	HEATNG	-5.359	-5.191	-5.173	-2.855	-5.3[illegible]5	-4.603
	SEN CL	-0.013	5.151	-0.203	3.078	-0.029	4.548
	LAT CL						
JUL	HEATNG	-4.993	-4.729	-4.851	-2.099	-4.984	-4.203
	SEN CL	2.655	10.520	2.508	7.257	2.645	9.331
	LAT CL						
AUG	HEATNG	-5.295	-5.359	-5.152	-2.591	-5.284	-4.775
	SEN CL	2.238	7.683	2.095	5.120	2.226	6.811
	LAT CL						
SEP	HEATNG	-7.191	-6.397	-7.040	-4.096	-7.176	-5.680
	SEN CL	-0.514	2.159	-0.670	0.231	-0.532	1.845
	LAT CL						
OCT	HEATNG	-11.424	-9.933	-11.306	-7.653	-11.396	-8.811
	SEN CL	-2.820	-2.525	-2.949	-3.594	-2.855	-2.378
	LAT CL						
NOV	HEATNG	-15.674	-13.673	-15.595	-11.795	-15.629	-12.153
	SEN CL	-3.775	-5.358	-3.871	-5.412	-3.828	-4.907
	LAT CL						
DEC	HEATNG	-20.577	-18.913	-20.509	-16.743	-20.546	-16.845
	SEN CL	-3.216	-4.756	-3.304	-4.599	-3.257	-4.369
	LAT CL						

Figure 33 - Effect of Z-transfer function on roof loads

Left: U-Value Input (U=0.043), middle: Layer-by-Layer (U=0.033), right: U-Value Input (U=0.033)

To verify the above, a Layer-by-Layer definition of the green roof was compared with a U-value input version with the same thermal performance. The layer-by-layer construction was already available in the original building model but was not used because it did not include the thermal bridging effect. Figure 33 shows that the difference between the two constructions is more than 1 MBTU for most months.

6.5 Section Conclusion

The observations from the building show no evidence of synergy between the different systems and zone conditions. In many cases, the only solution to discomfort in zones have been manual overrides of setpoints by the staff. Given the complexity of the systems, this approach may have unexpected byproducts.

In the review of the building model, three items were provided as possible sources of inaccuracy in case-study building's predicted performance. It was shown that some modeling decisions have affected the building loads and thermal mass. In the specific example provided – the green roof – the effect of thermal mass was significant when quantified.

Provided the above, the reviewed model and the documentation, along with the data from the building operation, provide valuable information for a new building model that can accurately simulate the building. The next two sections are dedicated to our attempt to model the case-study building. In the next section, a classroom model will be presented which was used for understanding the mechanical system response as well as the building loads in that scale.

7 Simulation Mechanical Control Implementation

Given the importance of mechanical controls in this research, this section provides details on how the controls are implemented in the simulation. The tool for implementation of these controls is “EnergyManagementSystem” objects provided by EnergyPlus.

Although EnergyPlus provides objects such as *FollowSystemNodeTemperature* and *OutdoorAirReset* in its setpoint managers, that come close to the actual controls, significant gaps would have remained if the controls were not customized. For example, the latter can work with the radiant system in the baseline condition for one mode where the temperature is fixed but not for the other where the temperature changes. The object does not have an availability schedule to be mixed with any other type of control as well [91].

Moreover, proper implementation of operation with many of native controllers in EnergyPlus would require fixed schedules made from the weather data as additional inputs. This means, if the weather data was changed, the controls and schedule may need modification. In case of customized controls, the controls react to the weather and other conditions during the simulation. This provided an advantage as for this model there were multiple weather file candidates.

The goal of EnergyManagementSystem is controlling the “Actuators”. These are nodes within the EnergyPlus model, made available to be controlled. “Programs” are where the system logic to modify Actuators is written in form of instructions. The language used in the Programs is EnergyPlus Runtime Language (ERL). The Program may need to import the state of the building to perform its calculations, so the condition of different nodes in the building are inserted in the EnergyManagementSystem using the “Sensors”.

Three examples of how this system was used to simulate controls are presented below. These examples are from actual uses of the system in this research for the baseline modeling or improved controls in the models created for the Sections 8 and 9.

7.1.1 Example 1: Air System Room Temperature Reset

The aim of this control is to use the difference between the room temperature and the room setpoint to calculate the supervisory level setpoints of the VAV coil and damper (Figure 34).

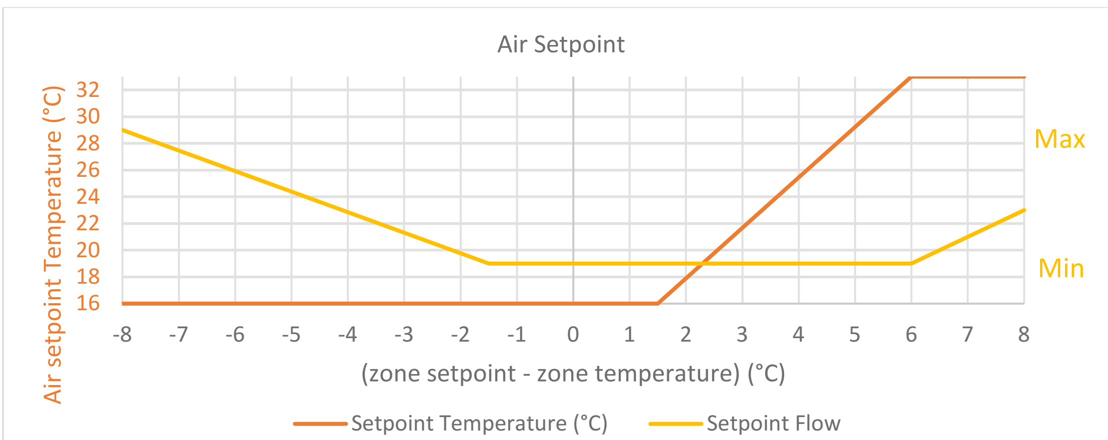


Figure 34 - Example air system control

In the first step, actuators are declared. The actuators created in Figure 35 link to the zone air system setpoint schedules. A program will choose the schedule values at each simulation interval. Schedules are selected because changing the schedule value does not interfere with the control system components; instead, it determines the high-level (supervisory) goal setting.

```
EnergyManagementSystem:Actuator,
  Air_T_SP,
  AHU Temperature Setpoint,
  Schedule:Compact,
  Schedule Value;

EnergyManagementSystem:Actuator,
  Air_Flow_SP,
  AHU SUPPLY FAN AIR OUTLET NODE,
  System Node Setpoint,
  Mass Flow Rate Setpoint;
```

Figure 35 – Actuators of the EMS air control, Example 1

In the next step, the Sensors are defined (Figure 36). For the sensors, the Zone Air Temperature was used to represent the zone thermostats. The zone setpoint temperatures in the case-study building are set with user-controlled thermostat. Those were imported to the EnergyManagementSystem from “ZoneControl:Thermostat” objects.

```
EnergyManagementSystem:Sensor,
Air_T,
Zone1,
Zone Mean Air Temperature;

EnergyManagementSystem:Sensor,
Air_Room_Heat_SP,
Zone1,
Zone Thermostat Heating Setpoint Temperature;
```

Figure 36 – Sensors of the EMS air control, Example 1

The main part of the EnergyManagementSystem is its program. This program performs the necessary operations on the Sensors and Actuators. Figure 37 shows the program of the given air system control.

The below three-step code structure was found to be clear to read and easy to change. At the first stage (1 in Figure 37), some parameters to run the program are set. These parameters appear at different locations within the code; having those set in the beginning makes it possible to evaluate and change values quickly.

```
EnergyManagementSystem:Program,
  zone1_air_program,
  SET zone_min_air_flow = 0.05,
  SET zone_max_air_flow = 0.1,
  SET zone_min_air_temp = 16,
  SET zone_max_air_temp = 33,
  SET flow_ramp_a1 = -4,
  SET flow_ramp_a2 = -1.5,
  SET flow_ramp_b1 = 6,
  SET flow_ramp_b2 = 8,
  SET T_ramp_a1 = 1.5,
  SET T_ramp_a2 = 6,
  SET cooling_flow_ramp = zone_min_air_flow - zone_max_air_flow,
  SET cooling_flow_ramp = cooling_flow_ramp / (flow_ramp_a2 - flow_ramp_a1),
  SET heating_T_ramp = zone_max_air_temp - zone_min_air_temp,
  SET heating_T_ramp = heating_T_ramp / (T_ramp_a2-T_ramp_a1),
  SET zone_diff = Air_Room_Heat_SP - Air_T,
  IF zone_diff < flow_ramp_a2,
    SET zone_diff = zone_diff - flow_ramp_a2,
    SET Air_Flow_SP = (zone_diff * cooling_flow_ramp) + zone_min_air_flow,
    SET Air_T_SP = zone_min_air_temp,
  ELSEIF zone_diff < T_ramp_a1,
    SET Air_T_SP = zone_min_air_temp,
    SET Air_Flow_SP = zone_min_air_flow,
  ELSEIF zone_diff < T_ramp_a2,
    SET zone_diff = zone_diff - T_ramp_a2,
    SET Air_T_SP = (zone_diff * heating_T_ramp) + zone_max_air_temp,
    SET Air_Flow_SP = zone_min_air_flow,
  ELSEIF zone_diff < flow_ramp_b2,
    SET zone_diff = zone_diff - flow_ramp_b1,
    SET Air_T_SP = zone_max_air_temp,
    SET Air_Flow_SP = (-1 * zone_diff * cooling_flow_ramp) + zone_min_air_flow,
  ELSE,
    SET zone_diff = flow_ramp_b2 - flow_ramp_b1,
    SET Air_T_SP = zone_max_air_temp,
    SET Air_Flow_SP = (-1 * zone_diff * cooling_flow_ramp) + zone_min_air_flow,
  ENDIF;
```

Figure 37 – Program of EMS air control, Example 1

The Stage 1 parameters in this code are the temperature and flow limits of the system and the ramps. Figure 38 explains how the ramp values correspond to control limits defined at Stages 2 and 3.

Values of Stage 2 are calculated based on some of the parameters to be later used in the program; in this example, the ramp slopes and the temperature difference. Some instructions need to be distributed into different lines because each line has a character limitation. Stage 3 is the execution stage, consisted of the rules that control the actuators based on Stage 2 and Stage 1.

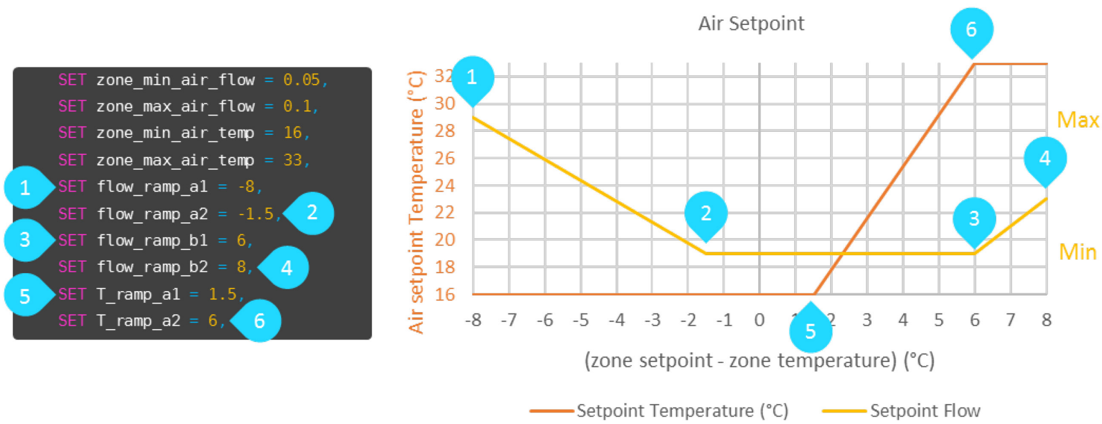


Figure 38 - Mechanical system control parameters, Example 1

The values introduced as parameters within Stage 1 do not come from Actuators and Sensors. So those must be declared, for which GlobalVariable is the most accessible (Figure 39).

Finally, a ProgramCallingManager is necessary to run the Programs (Figure 40). This tells EnergyPlus when a program should run. The calling point used for the above program was "InsideHVACSystemIterationLoop". [96] suggests that this option increases the simulation accuracy. Also, being at the last stage before initialization of *HVAC System Models*, means that the program results replace all necessary parameters in the timestep. The selected option, however, increases the simulation time.

```
EnergyManagementSystem:GlobalVariable,
    zone_intended_SP,
    zone_diff,
    zone_min_air_flow,
    zone_max_air_flow,
    zone_max_flow_heating,
    zone_min_air_temp,
    zone_max_air_temp,
    cooling_flow_ramp,
    heating_flow_ramp,
    heating_T_ramp,
    flow_ramp_a1,
    flow_ramp_a2,
    flow_ramp_b1,
    flow_ramp_b2,
    T_ramp_a1,
    T_ramp_a2,
    air_stable_T;
```

Figure 39 – GlobalVariables of EMS air control, Example 1

```
EnergyManagementSystem:ProgramCallingManager,
    Zone 1 programs,
    InsideHVACSystemIterationLoop,
    zone1_air_program;
```

Figure 40 –ProgramCallingManager of EMS air control, Eample 1

7.1.2 Example 2: Radiant System Outdoor and Room Temperature Reset

The purpose of the following program is to mimic the typical slab control system of the case-study building. The challenge in this example is the slight difference of the control mechanisms in EnergyPlus compared to the case-study building.

At the supervisory level, the resources used for slab control in the building are the air control sensors of the previous example (room temperature and the setpoint) with the addition of the outdoor air temperature. The last one is because the slab follows the building mode which is set by the outdoor temperature. When the building is in standby mode, the slab setpoint becomes the same as the slab temperature, so the slab temperature must also be added as a Sensor.

At the local level of both the simulation and the case-study building, the supervisory-level setpoint (slab temperature setpoint) is reached by modulating the water flow in the slab using hot water and chilled water valves. In the case-study building, the return valves are either at 100% (completely open) or at 0% (completely closed); the supply valves are controlled with a PI controller which is specific to the slabs. This controller compares the slab setpoint and slab temperature.

EnergyPlus however, controls the valves by heating and cooling ramps. Each ramp location is set by a schedule value that indicates the temperature at which the flow is 50% (Figure 41). The ramp steepness is set by a throttling range input with a minimum value of 0.5 °C.

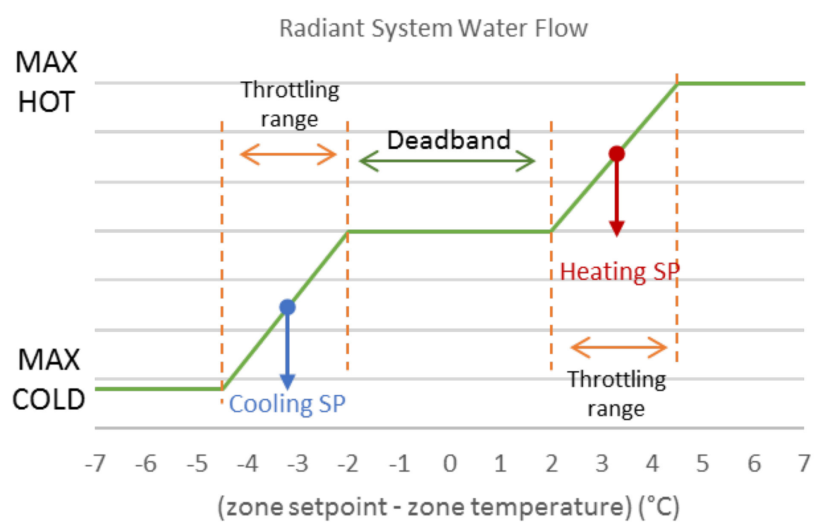


Figure 41 – Method of slab temperature control in EnergyPlus

horizontal axis values are exaggerated for illustration

The incompatibility of the two mechanisms is because EnergyPlus only compares the schedule values to one of the following: zone mean/radiant/operative temperature, or outdoor air dry/wet bulb temperature. The options do not include the slab itself. For this reason, EnergyManagementSystem has to also control the schedule values.

```
EnergyManagementSystem:Sensor,
 OA_Temp,
 *,
 Site Outdoor Air Drybulb Temperature;

EnergyManagementSystem:Sensor,
 Slab_T,
 GroundFloor_0_0_0,
 Surface Inside Face Temperature;
```

Figure 42 –Supervisory Sensors of EMS radiant control, Example 2

```
EnergyManagementSystem:Actuator,
 Radiant_SP_H,
 Radiant Heating Set Point schedule,
 Schedule:Compact,
 Schedule Value;

EnergyManagementSystem:Actuator,
 Radiant_SP_C,
 Radiant Cooling Set Point schedule,
 Schedule:Compact,
 Schedule Value;
```

Figure 43 –Supervisory Actuators of EMS radiant control, Example 2

The program aims to find the correct building mode and represent the PI controllers with conditional statements. The proposition was put to test in model calibration of the upcoming sections.

The zone of the system indicates the “intended” setpoint which could be 25 or 18.8. In the heating mode, *zone_diff* values (found through calibration) find the temperature. The same procedure shown in Figure 44 is repeated for the local level PI controller to control the slab valves.

```
EnergyManagementSystem:Program,
 Scenario2_Radiant_Control,
 SET zone_diff_low = -0.5,
 SET zone_diff_high = 0.5,
 SET slab_local_a = 0.7,
 SET slab_local_b = 0.3,
 SET slab_local_max_flow = 0.1,
 SET zone_diff = Air_Room_Heat_SP - Air_T,
 IF OA_Temp > 18,
   SET slab_intended_SP = 18.8,
 ELSEIF OA_Temp < 17,
    IF zone_diff >  zone_diff_high,
        SET slab_intended_SP = 25.0,
    ELSEIF zone_diff < zone_diff_low,
        SET slab_intended_SP = 18.8,
    ENDIF,
 ELSE,
    SET slab_intended_SP = slab_T,
 ENDIF,
...
```

Figure 44 – Program of EMS radiant control, Example 2

Two clarifications are necessary:

1. In the case-study building the building mode can change after 30 minutes of observing one outdoor air temperature. In the simulation, the mode calculation only can happen once in a timestep, thus the 30-minute lag was excluded.
2. The sudden setpoint change, typical to the radiant system, was previously shown; therefore, in the simulation, the change in the slab setpoint occurs in the span of one timestep.

Needless to say, the variables *zone_diff_low*, *zone_diff_high*, etc. should be declared as GlobalVariables and the Program must be added to a ProgramCallingManager object.

7.1.3 Example 3: AHU Control

The temperature setpoint of the main AHUs is one degree above the minimum of its VAV's setpoints. The supply air static pressure set point at the AHU is 350 Pa. The following program calculates the setpoint temperature of the AHU North. This program uses the @min function available in ERL and is similar to the Dual Duct system EnergyPlus object *SetpointManager:Coldest*.

```
EnergyManagementSystem:Program,
 setAHUNorthSP,
 SET min_AHU_North_T_SP = Air_T_SP_ThirdFloor_Zone1,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthMiscRooms,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthRM130,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthRM125,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthRM115,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthRM110A,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_FirstFloor_NorthAtrium,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_SecondFloor_NorthClassrooms,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_SecondFloor_NorthCenterCorridor,
 SET min_AHU_North_T_SP = @min min_AHU_North_T_SP Air_T_SP_Submechanical_North,
 SET AHU_North_T_SP = min_AHU_North_T_SP + 1;
```

Figure 45 - AHU temperature setpoint program

A GlobalVariable, min_AHUNorth_T_SP is made to store the lowest value. The variable is then compared to setpoint temperature of every zone. The @min function has to be repeated for each zone because it only accepts two arguments. In the end, the minimum VAV setpoint is set for the *AHU_North_T_SP* which is an Actuator representing the AHU North temperature schedule.

7.1.4 Scaling the controls

As it can be seen in the above examples, preparing the necessities for running a program is cumbersome because ERL is consisted of simple blocks of codes. This will become significantly more challenging when the controls are implemented for the whole building as a separate configuration is necessary for each zone. Implementing zone controls separately would cause maintainability issues; it would mean to change a ramp value, it has to be changed for each zone individually.

To overcome this problem, “Subroutines” have been used. Subroutines can store repetitive pieces of ERL code and can be called by the Program objects; therefore, the Program for each zone can contain zone specific information and what is shared among all programs can be put in a Subroutine.

ERL does not have a method of passing parameters of each zone (maximum and minimum flow, room temperature, and temperature setpoint) to the Subroutine, so the GlobalVariables were used as the carriers of data between the Programs and Subroutine. GlobalVariables are reachable everywhere in ERL, hence the name “Global”.

The combination of Subroutines and GlobalVariables were used as follows: First, the Program that intends to call the Subroutine, sets the GlobalVariables it intends to pass to the Subroutine. After that, the Program runs the Subroutine. The Subroutine reads the GlobalVariables and performs the calculations. Finally, the Subroutine writes the answers in other GlobalVariables that are read by the Program and are given to Actuators. This has been shown in Figure 46.

By putting the main control functions in Subroutines, each change in system operation only needs to be done once in the IDF files as all zone controls are simply designed to store temporary values, run subroutines, and modify Actuators.

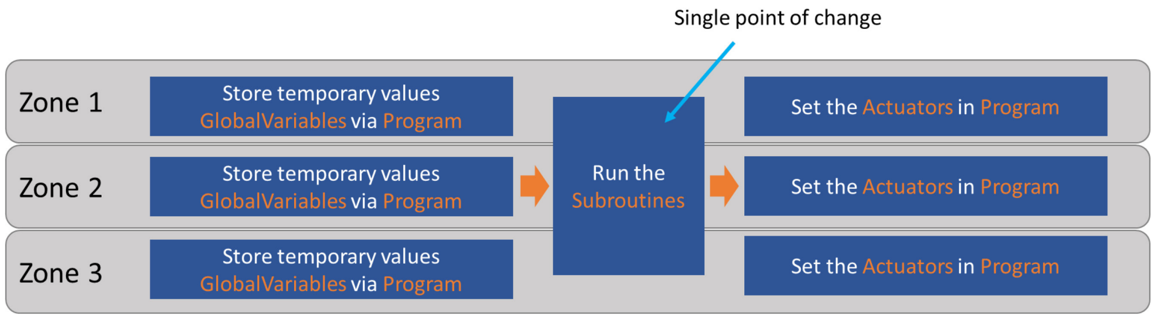


Figure 46 - The ERL structure in case-study building simulation file

The Subroutine contains the main logic of the systems. In the methodology section, this part of the program was labeled “the execution code” (stage 3). The rest of the program remains in the zone programs where the specific zone conditions are defined (Figure 47).

```
EnergyManagementSystem:Program,
  Air_Control_ThirdFloor_Zone1,
  SET zone_air_t = Air_T_ThirdFloorSlope_Zone1,
  SET zone_air_room_sp = Air_Room_SP_ThirdFloorSlope_Zone1,
  SET zone_min_air_flow = 0.00007,
  SET zone_max_air_flow = 0.00025,
  SET zone_min_air_temp = 13.0,
  SET zone_max_air_temp = 45.0,
  RUN findVAVSPs,  !- Running the Subroutine
  SET Air_Flow_SP_ThirdFloorSlope_Zone1 = zone_air_flow_sp,
  SET Air_T_SP_ThirdFloorSlope_Zone1 = zone_air_t_sp;
```

Figure 47 - Example of zone program

In the end, the baseline model of the building required approximately 1700 lines added to the IDF file, as the code had to be propagated for each individual zone; however, this addition did not cause noticeable change in the simulation time.

8 Classroom Level Simulation

To focus on the mechanical system response in the scale of the classrooms in the case-study building, a simplified construction was created to represent one classroom. The simplified model reduces the unnecessary effort caused by uncertainties and redundant entities, while it allows rapid testing of control strategies.

This simplified construction is used to explore different control *Strategies*. These strategies will define how the air and radiant systems are controlled. The first strategy (i.e. Strategy A) is the baseline case designed to replicate the behavior patterns of the actual rooms being modeled.

Local and supervisory controls were introduced and compared in the Literature Review section; as such, the focus of this section is solely on improving the supervisory controls. Refer to Table 2 for the strategies and their proposed supervisory controls.

Table 2 – Radiant & VAV setpoint reset mechanisms at supervisory control level

Strategy	**Radiant Controller**	**Air Controller**
A **(Baseline)**	Building Mode (cooling or heating) and room temperature	Room temperature
B	Room temperature	Room temperature
C	Constant slab temperature	Room temperature
D	Constant slab temperature	Comfort thermostat
E	3-day average outdoor air temperature	Room temperature

To test the effectiveness of a strategy, four metrics were defined:

1. Number of uncomfortable hours as per AHSRAE 55-2004
2. Energy transferred by the air and radiant systems
3. Room temperature difference with the baseline condition
4. Time of HVAC setpoint below condensation threshold

Moreover, for fair comparison of strategies and applicability of the strategies to the case-study building, the limits set for the HVAC equipment were not exceeded. For example, the minimum and maximum VAV air flow rate was kept for all strategies. The VAV setpoint temperature was limited as per ASHRAE Guideline 36P [97] the maximum and minimum values were set to 16°C and 33°C respectively instead of 13°C and 45°C.

For the strategies with Thermal Comfort Thermostat, little can be done to change room temperature. This resulted in low correlation with baseline room temperature, which increased the energy transfer. Using the thermal comfort thermostat in the alternatives was mainly to test the responsiveness of the HVAC system to the internal and external loads.

8.1 Results

Based on the strategy comparison, the Strategy B (tweaked rule-based controls) has acceptable performance and the least energy transfer. In the next section, the controls of this strategy will be used in the case-study building to see the changes in indoor environment as well as the overall energy consumption of the mechanical system.

Table 3 compares the total load transferred in the strategies. In different strategies, the room was positioned once towards north and once towards south as the classrooms of the case-study building are facing these directions.

Table 3 –Strategy transferred energy comparison

Facing	Strategy	Energy transferred for heating [KWh]	Energy transferred for cooling [KWh]	**Total transferred energy [KWh]**	**Percent Change**
North	**A**	33973	4284	**38257**	**Baseline**
	B	18400	1267	**19667**	**49%**
	C	24029	842	**24871**	**35%**
	D	22053	289	**22342**	**41%**
	E	25498	794	**26292**	**31%**
South	**A**	32306	4819	**37125**	**Baseline**
	B	16862	1623	**18485**	**50%**
	C	21934	906	**22840**	**38%**
	D	22052	288	**22340**	**40%**
	E	23438	867	**24305**	**34%**

The improvement achieved compared to the baseline must be put into context with the room temperature control. This is not to the advantage of Strategy C (constant slab temperature); moreover, in the south facing room the controls in this strategy and strategy E have not responded well to the additional load.

For other strategies, the change of facing lowers the heating load and raises the cooling load. Because of the window overhang and the low solar heat gain of window this effect is not significant.

Insights can also be found in the balance between the systems. Figure 48 shows that the strategies with the most air energy transfer have the best operation although a correlation cannot be seen for the opposite.

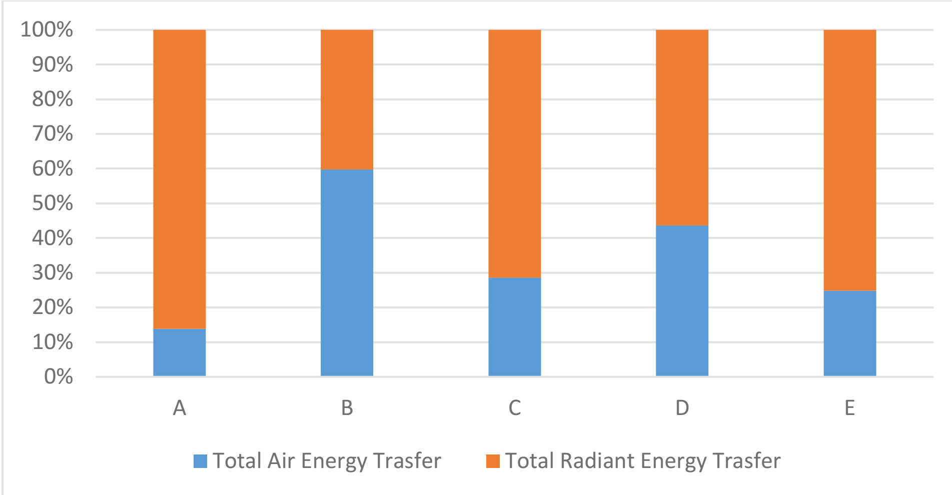


Figure 48 - Load distribution between the air and radiant systems

North-facing strategies

8.2 Construction and loads

This setup is consisted of a test room surrounded by a buffer zone representing the rest of the building (Figure 49). The size and the construction material of the room is similar to the classrooms on the first and second floor of the case-study building. The boundary (buffer) zone has high thermal mass, and no internal cooling and heating load.

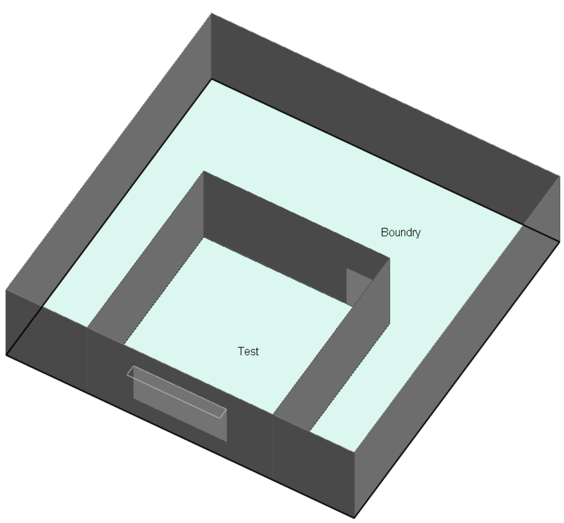


Figure 49 – The classroom level simulation construction

The buffer zone provides the necessary boundary conditions (representing the rest of the building) for tuning and calibrating the classroom operation to match the actual data. It maintains temperatures between 19 to 21 in cold seasons and 20 to 22 in warm seasons. This is achieved by an air system that serves the zone.

The modeled construction of the ground and roof are the same as the ground slab and the green roof in the case-study building. Three walls of the room are shared with the boundary zone. The fourth wall is exterior, with the construction of typical exterior wall in the case-study building, and has an operable window with overhang. The window to wall ratio of the exterior wall is as same as the classrooms on the first floor.

For modeling, DesignBuilder was used to create the initial EnergyPlus file. The EnergyPlus was modified so that the terminal mechanical systems are identical to the real classrooms. In other words, the test room is served by an AHU connected to one VAV box working in parallel with radiant slab. This system is completely separate from the buffer zone mechanical system.

Early simulations showed that the air system is causing high simulation iterations. Since the AHU is connected to only one VAV box, the box could be removed to rectify this problem. Thus, the VAV controls were added to the AHU directly.

Table 4 provides an overview of the initial input values of the test zone. The choice of ASHRAE 90.1 school schedules is of note. For occupancy, the schedule was compatible with the available occupant and operation data mentioned in the case-study building section, especially when late classes are considered.

Table 4 - Initial simulation inputs for the test zone

Property	**Value**
Area	68 m^2, approximate size of the typical classroom in the case-study building
Window/Wall Ratio	50%, approximate value in the typical classroom of the case-study building
People	Base value of 20 multiplied by DesignBuilder's ASHRAE 90.1 schedule value.
Lights, equipment	Base value of 1000 Watts multiplied by DesignBuilder's ASHRAE 90.1 schedule value.
Infiltration	Average of 0.01 m^3/s from original eQUEST simulation
Weather File	Victoria Climate file
Exterior Wall Construction	RSI 3 concrete wall, as-built drawings
Window Specifications	Double pane Low-E Argon-filled, HPB report
Roof Construction	Green Roof of the case-study building, as-built drawings
Slab Construction	Structural concrete with 76mm topping on the internal source, as-built drawings

While the mechanical system schema is identical to the case-study building on the demand-side, sizing values could not be transferred. Instead, the design parameters of the mechanical system were used to auto-size the mechanical system based on Strategy B. The same sizing results were then applied for all strategies.

The reason Strategy A (baseline) could not be used for auto-sizing is that in the strategy, the air system typically has setpoints in the range of 13°C to 45°C which is not met throughout the year, especially on the higher extreme. Using these extreme values would have caused oversizing since the auto-sizing algorithm would try to size the systems in such a way that it meets the setpoints.

An auto-sizing example is the AHU coils. The design flow, design entering/leaving air properties, and entering/leaving water temperature of the AHUs in the case-study building were used to auto-size coils "UA value" and the capacity. Due to the combined AHU and VAV systems in this model, the capacity data of the case-study building should not be used.

The auto-sized values are as follows:

- AHU coil capacity and UA
- Loop volumes
- Simulation convergence tolerances
- Radiant system tubing length and capacity

8.3 Calibration

The purpose of calibration for the test model is abstracting the building's classrooms both in indoor conditions and the demand-side mechanical system response. The calibration aims to recreate realistic internal and external loads in the classroom level.

For simulations of comparable size, one frequently seen approach to evaluate the model calibration/validation, in the reviewed literature, is observing the indoor condition of the room and following the trends [49], [59], [81], along with taking the logged mechanical system responses into account [33].

As the system controls are implemented within the simulation, replication of room mechanical system setpoints and input temperatures as well as the room temperature is only possible if the simulated controls are corresponding to the case-study building; therefore, the model was considered calibrated when the following parameters closely follow the logged data from the case-study building:

- Room temperature
- Slab temperature and temperature setpoint
- Air system diffusing air temperature and setpoint
- Mechanical ventilation flow rate and setpoint

An early change in the calibration process was removing the mixed-mode operation of the mechanical system and natural ventilation. This reduced the uncertainties that arise from the occupant behavior and the effectiveness of the mixed mode operation. To compensate for this effect, the infiltration value was increased. The infiltration increases the heating load in the cold season, but because of the climate, in summertime it usually helps with the cooling.

Calibration involved adjusting values both in the controls and the room. The controls needed to show acceptable resemblance to the PI controller of the case-study building. This was achieved by finding at what “zone difference” (difference of the setpoint and room temperature) the air and radiant system respond by cooling and heating, after observing the logged setpoints. Figure 50 and Figure 51 show the simulated operation during the typical week while Figure 52 and Figure 53 provide a side-by-side comparison of the simulated values and the logged data of the classrooms introduced in the case-study building section, for typical weeks.

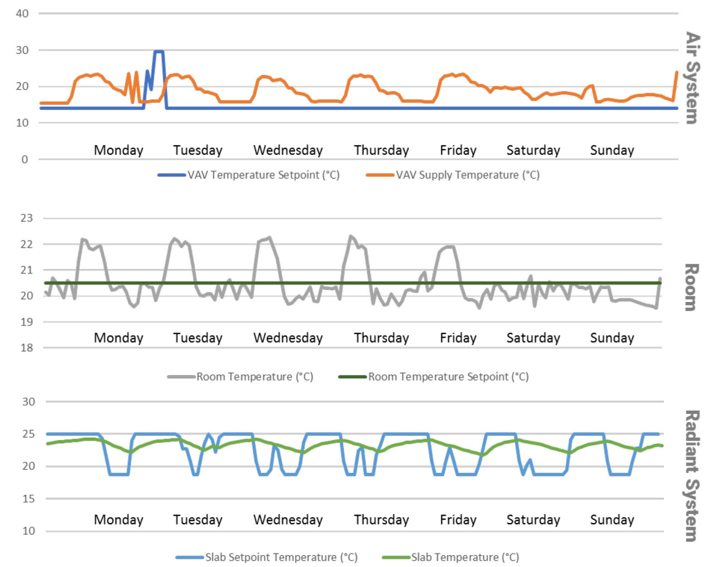


Figure 50 – Simulation temperatures of typical summer week

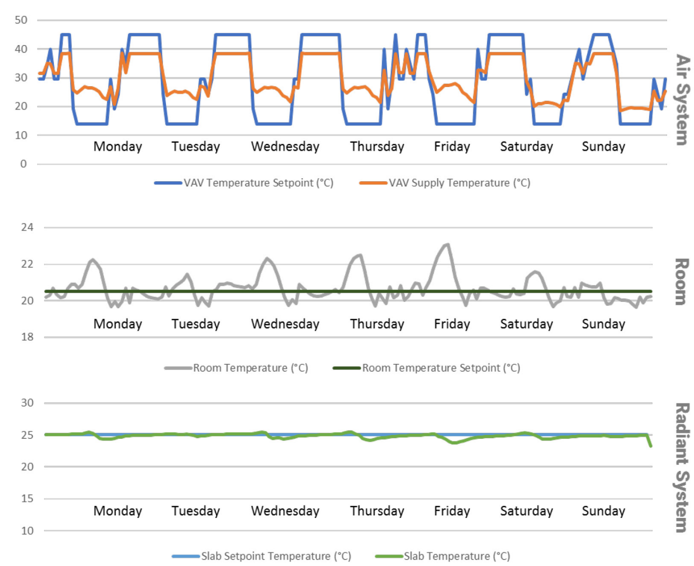


Figure 51 – Simulation temperatures of typical winter week

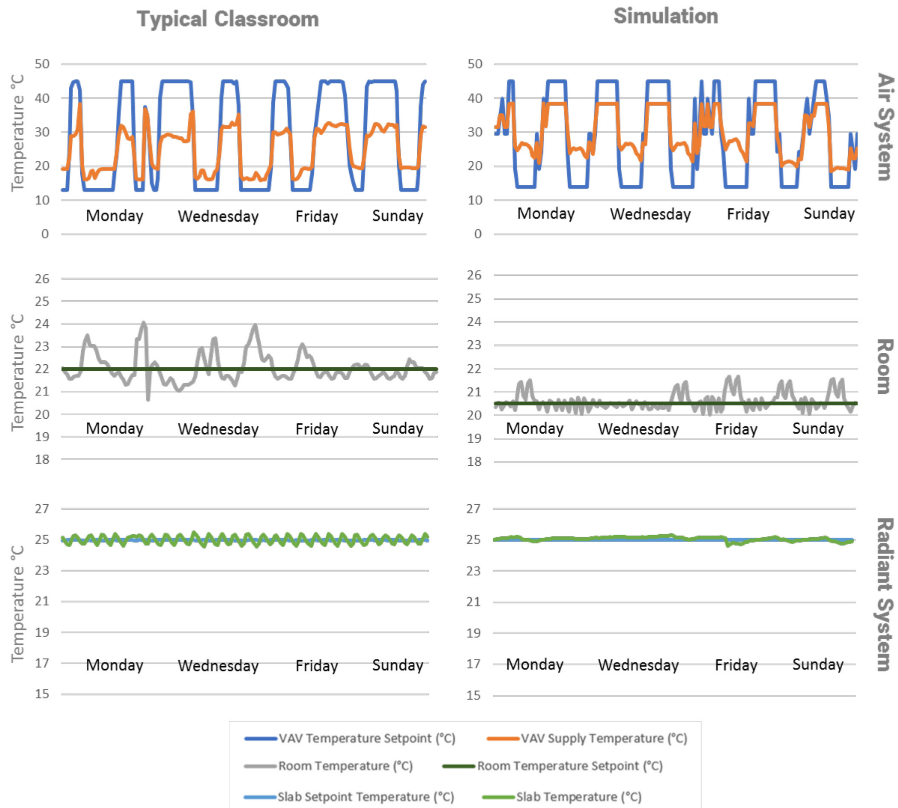


Figure 52 - Side-by-side comparison of winter room conditions typical classroom

Three disparities are apparent in the modeled and actual patterns. First, in the simulation, the air system setpoint fluctuations is due to hourly averaging of the value. The representation of the PI control in the simulation has discrete controls by which the setpoint may drop from 45°C as soon as the temperature reaches the dead-band horizon. Employing a delay in reducing the value has improved the consistency but this will not be further pursued as the actual entering air temperature is at the intended value.

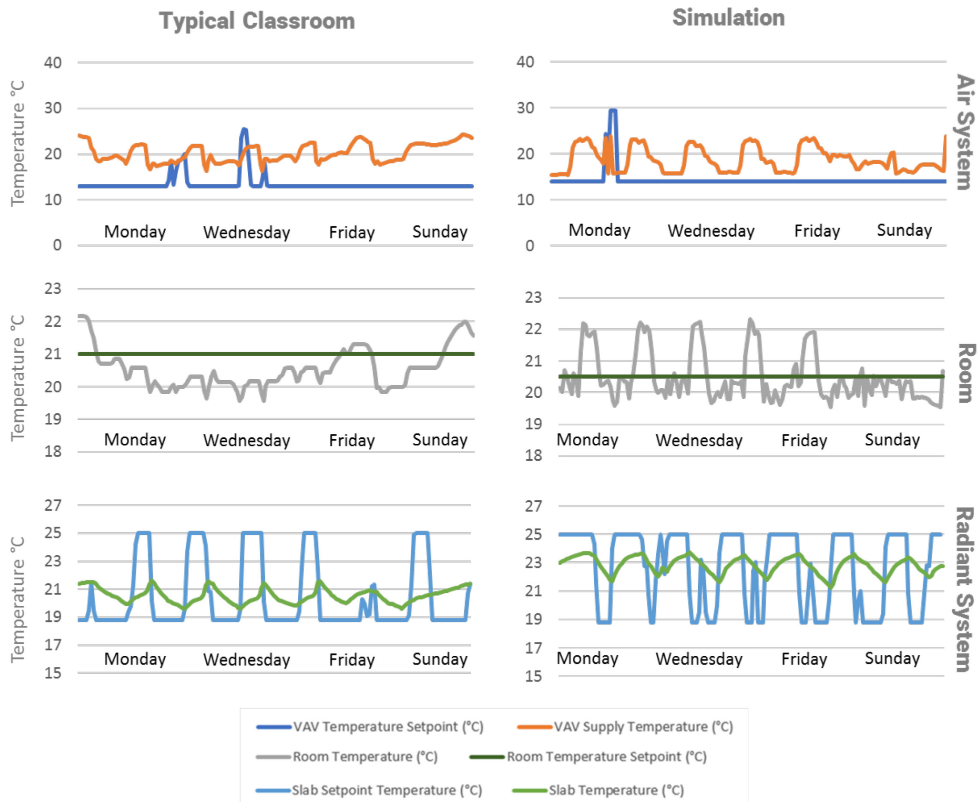


Figure 53 – Side-by-side comparison of summer room conditions typical classroom

Second, the room temperature setpoint varies. The occupants change the classroom temperature setpoint throughout the year and there is no connection between the setpoints of different spaces; therefore, considering the setpoints of all classrooms, the room setpoint in the simulation was set to 20.5 °C.

Finally, the radiant system temperature rises and falls with different curves in simulation versus the actual data in summer. The reported value in building records is a thermostat installed on a wall at the edge of the slab, while in the simulation the value is an average of the whole slab surface. The thermal mass of the slab and the temperature distribution within it due to hydronic pipes (Figure 54) delays the appearance of the temperature change in logs. The decreasing pace of response in the simulation is acceptable and was expected [66].

Figure 54 - Heat distribution within the slab in cafeteria

Infrared photo artifacts may be from reflection or surface angle

The setpoint pattern of the radiant system is affected by the occupancy schedule. Figure 53 shows sharp rises and a subsequent falls in the slab setpoint temperature of the simulation. The reason is that the used ASHRAE occupancy schedule has low occupancy at noon so the room temperature falls.

As mentioned, the focus in this section are the supervisory controls. Nonetheless, proper calibration can only be achieved with local controls simulated realistically. For the air system, comparing the operation logs and simulation variables showed that the supervisory controls cause similar local control responses in both cases.

Consequently, using the slab temperature and setpoint logs from the case-study building, the ramps (cooling/heating throttling range and 50% flow temperature schedule) were set in such a way that heating or cooling starts as soon as the setpoint to slab temperature difference reaches 0.75 °C.

Considering the above, the test zone operation matches the monitored data for the typical days. Under the same setpoints, the logged room temperature could be simulated with 3% RMSE. At this stage, the simulation was considered calibrated for the said purpose.

8.4 Operation Strategies

The initial intent for improvement strategies was providing a consistent temperature by the radiant system and use the air system for dealing with the instantaneous loads and closing the gap with setpoint temperature. It will be shown in this subsection that this did not achieve the ideal indoor conditions, revealing that both air and radiant systems must cooperate in the process.

Ideal indoor conditions could be achieved by using both systems in parallel. The disadvantage of this type of rule-based control is the potential of having the two systems working in opposite modes, if the controls are not carefully designed. Below, the strategies, and their design process will be described. In the end, the strategies will be compared based on the indoor conditions and the total energy they have transferred.

8.4.1 Strategy A: Existing condition of the case-study building

This Strategy has the same control as the case study building. The slab temperature setpoint will remain at 18.8 degrees when the outdoor air temperature is below 17 degrees. It will change between 18.8 and 25 degrees otherwise. The air system provides ventilation and reheat, but the reheat rules are simpler than the previous Strategy.

The major difference of controls in this Strategy and other strategies is the input (X axis of Figure 56 and Figure 57). The input is a percentage generated by the PI controller which is calculated based on difference.

In building introduction section, the instantaneous changes of the system setpoints were observed. Because of this behavior, using the room temperature to setpoint difference directly inside a conditional statement could replace the proportional-integral calculations. In the example of Figure 55, low_PI_treshold and high_PI_treshold are tweaked to correspond to the differences causing high and low PI control values. The full control setup of this strategy is available in the section 4.3.

For more complex replication of a PI controller, the integral calculations can be done by iterative addition/subtraction of the error at every timestep, although that is only possible if the timesteps are reasonably short.

```
SET zone_diff = Air_Room_Heat_SP - Air_T,
IF zone_diff > high_PI_treshold,
  ! PI controller percentage is high
ELSEIF zone_diff < low_PI_treshold,
  ! PI controller percentage is low
ENDIF;
```

Figure 55 - Replicating the PI controller with conditional statements

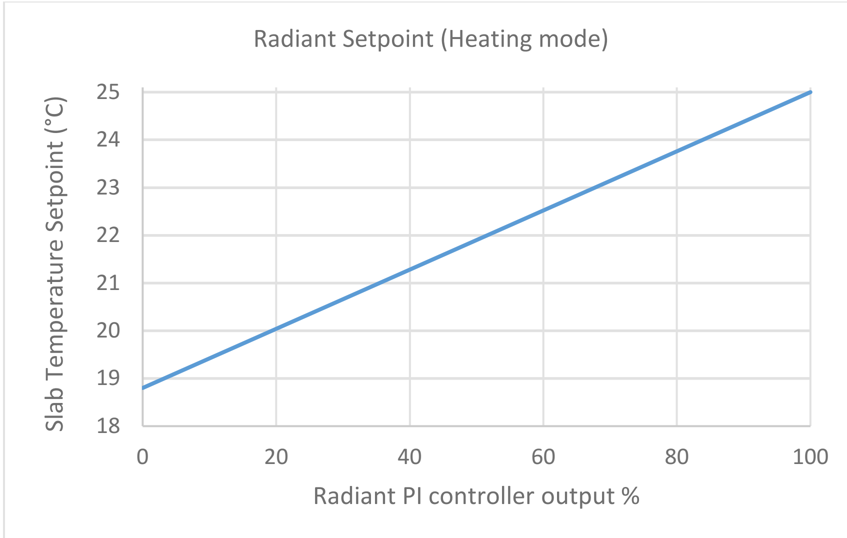


Figure 56 - Strategy A Radiant Control

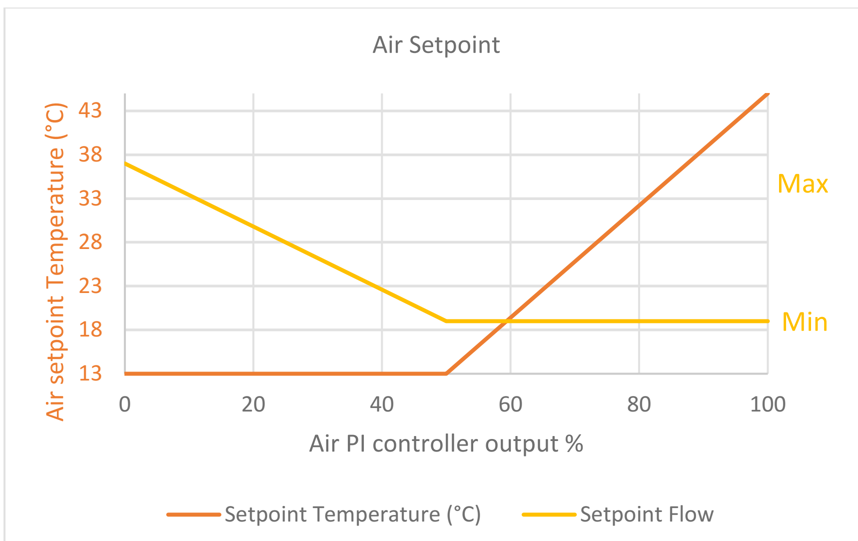


Figure 57 - Strategy A Air Control

In this strategy, the temperature of the room is comfortable for 8523 hours which is more than 96% of the occupied and unoccupied hours; however, the load transfer is high. The reason for this, is constant slab setpoint change. Figure 58 shows the cooling and heating time of the slab during a shoulder season.

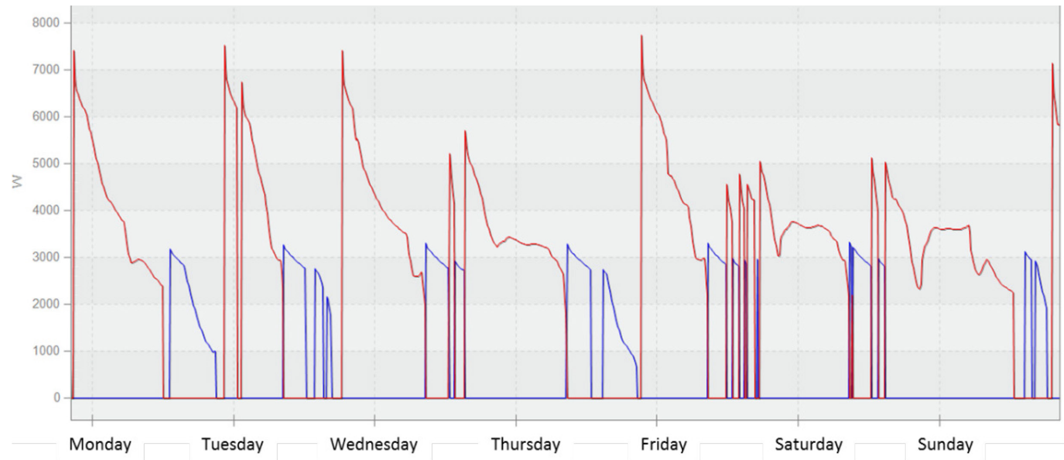


Figure 58 – Strategy A slab heating and cooling energy

typical week in shoulder season; Red: Heating Energy, Blue: Cooling Energy

8.4.2 Strategy B: Modified room temperature reset

In the first try, the radiant system was tasked with maintaining the room temperature in an acceptable range while the air system separately monitored the room temperature and responded. Figure 59 and Figure 60 show the initial controls used for this strategy. These controls could achieve indoor temperature like the baseline case.

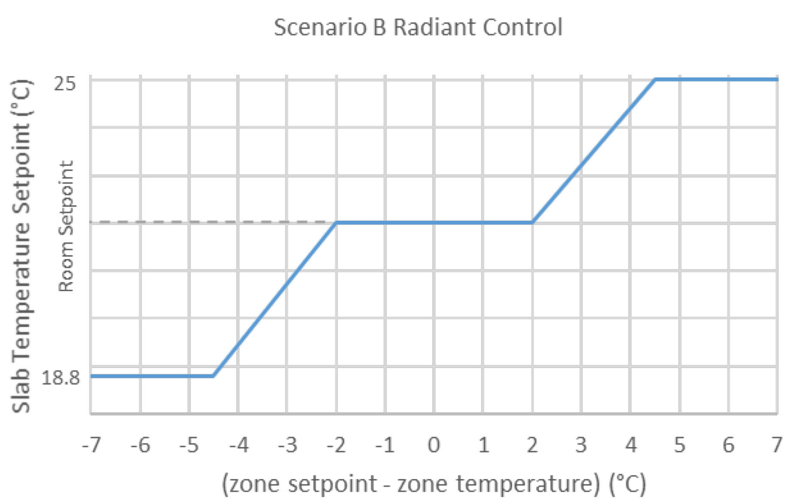


Figure 59 - Strategy B initial slab control

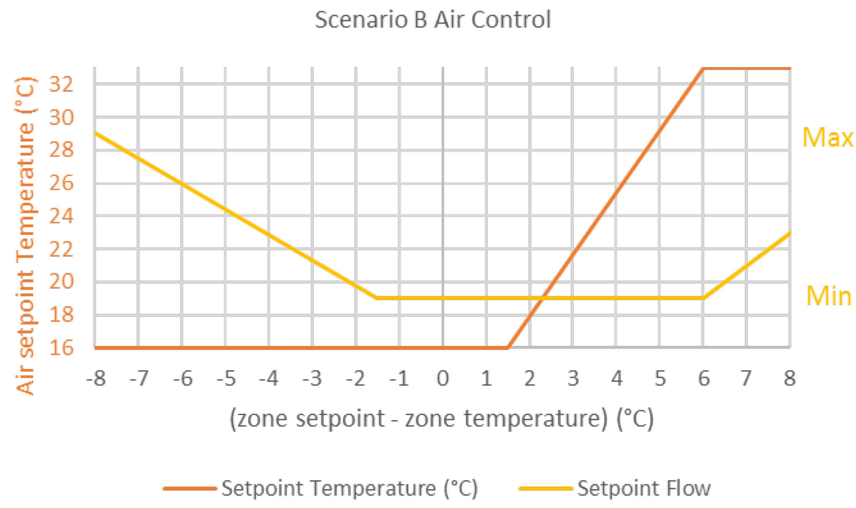


Figure 60 - Strategy B initial air control

The air system ramps were created with a 3 °C dead-band for the temperature difference between the setpoint and the room. This was smaller compared to the radiant system (4 °C) to take advantage of the quicker action of the air system. Radiant system on the contrary had steeper ramps to account for its slow response.

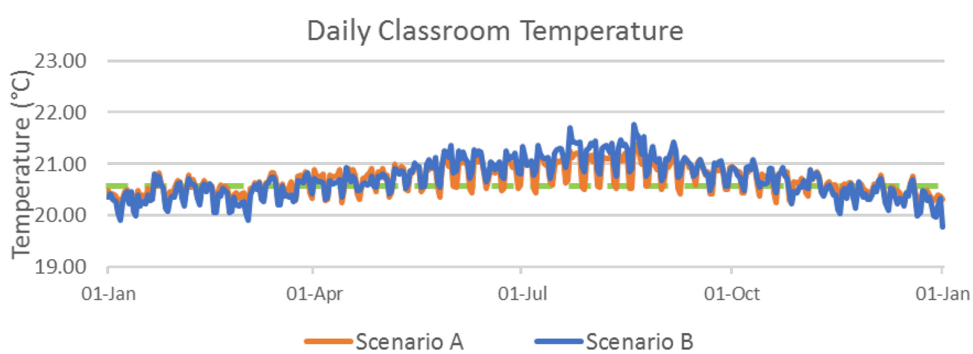


Figure 61 - Room temperature comparison of Strategy A and B

Green line is the room setpoint

The results show close match with the strategy's room temperature and the baseline. A total of 8211 comfortable hours in unoccupied and occupied time as per ASHRAE 55. No setpoint values were below condensation time in the simulation period.

Unlike other strategies, by change of facing, the total energy transfer was increased. This creates the hypothesis that the above controls may not perform well under higher loads. To test this hypothesis the internal load of the room was changed to test the response of the systems (Figure 62).

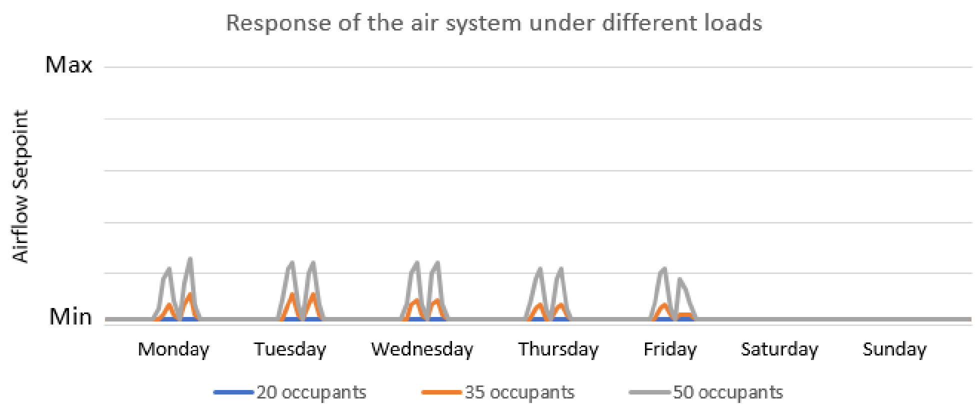


Figure 62 – Strategy B initial air flow rate under different loads

Even though the room temperature was substantially increasing under high load, the air system was not increasing the flow to the maximum, even though this has to be the first reaction. To improve this, the controls were modified.

As previously noted, the values for minimum and maximum air temperature and air flow setpoints would not be changed from the values in the case-study building; therefore, the changeable values are the ramps. The ramp parameters were tweaked so that under high loads the air system uses the maximum ventilation.

Removing the symmetry in the ramps was beneficial in improving the response. For radiant system, the cooling response was made faster. The positive impact seen with faster cooling response could be because the cooling loads of the room are long lasting. For the air system, the ventilation ramp for both heating and cooling was made steeper. The dead-band was also made smaller to enable faster action.

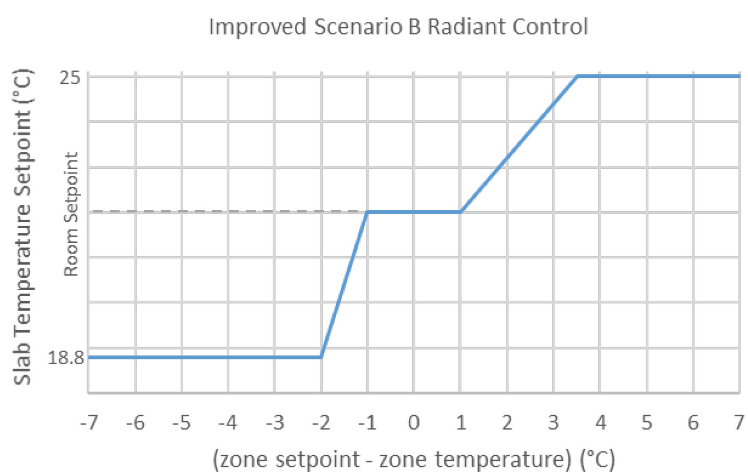


Figure 63 - Strategy B improved radiant control

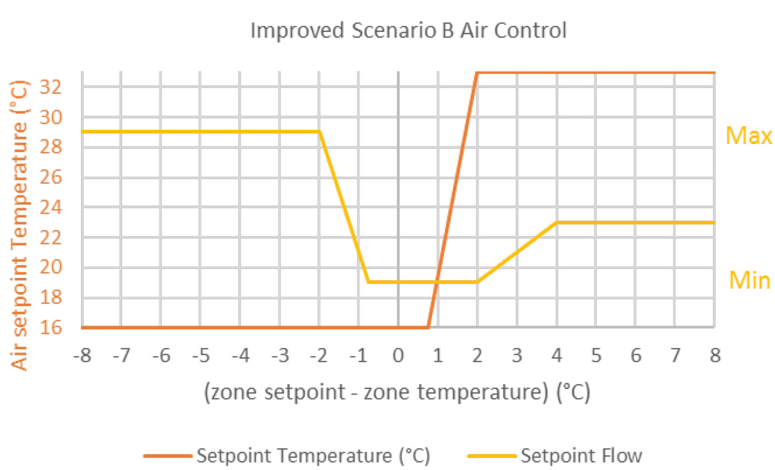


Figure 64 - Strategy B improved air control

The improved controls significantly reduce the energy transfer to 19667. The comfortable hours throughout the year reduce to 6385 hours but the majority of the change is during the unoccupied hours.

8.4.3 Strategy C: Constant Slab Temperature

The air control of this strategy is the same as Strategy B but the slab temperature setpoint is constant. The weakness of this strategy is lack of responsiveness. If the loads in a room change, or at the extremes of outdoor conditions, the slab may overheat/underheat the space. This should be minimized by the air system, but in the span of one year, it may result in excess energy consumption.

The major parameter that has to be determined for this strategy is the slab temperature. In the classroom model, the temperatures below 23 °C do not provide enough heat in the winter and the values above 23 °C cause excessive room temperature rise in summer. With this strategy, energy transfer rate can be lower than any other strategy but with low slab setpoint temperatures. The main weakness of this strategy is that it lacks the flexibility to respond to loads. Even if the best temperature is found for a load pattern, as soon as that load pattern changes (e.g. class times change), the system may not work as expected.

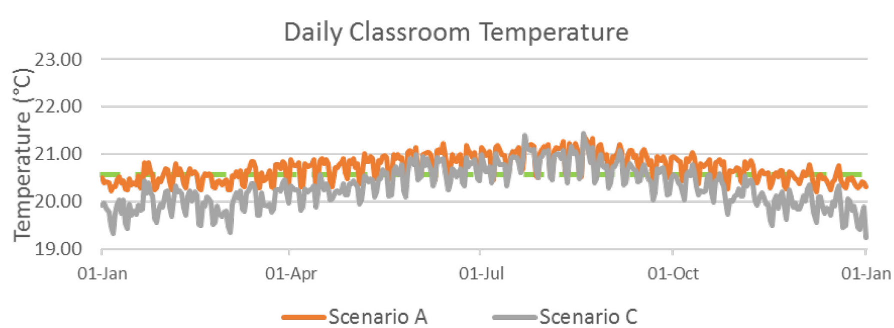


Figure 65 - Strategy C room temperature compared to the baseline

In this strategy, a total of 24871 KWh energy was transferred and 7291 hours were comfortable.

8.4.4 Strategy D: Constant Slab Temperature with Comfort Thermostat

The air system control of the previous strategy is replaced with the ZoneControl:Thermostat:ThermalComfort object of EnergyPlus. The control provides the dry-bulb temperature of the Fanger Comfort Model [86].

This model was tested once with the Predicted Mean Vote (PMV) of 0, and once such that the room temperature is slightly cold in cold months, and slightly warm in warmer months (-1 and +1 PMV). In neither of both cases a smooth temperature profile could be achieved. Different static radiant temperatures also do not improve the consistency. In addition, the temperature setpoints are too high for the air system.

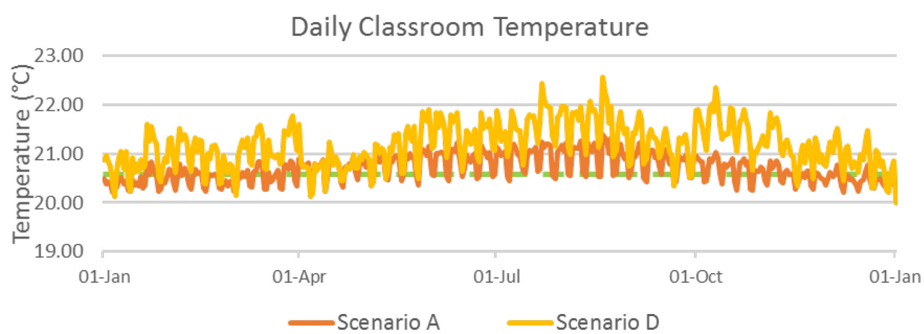
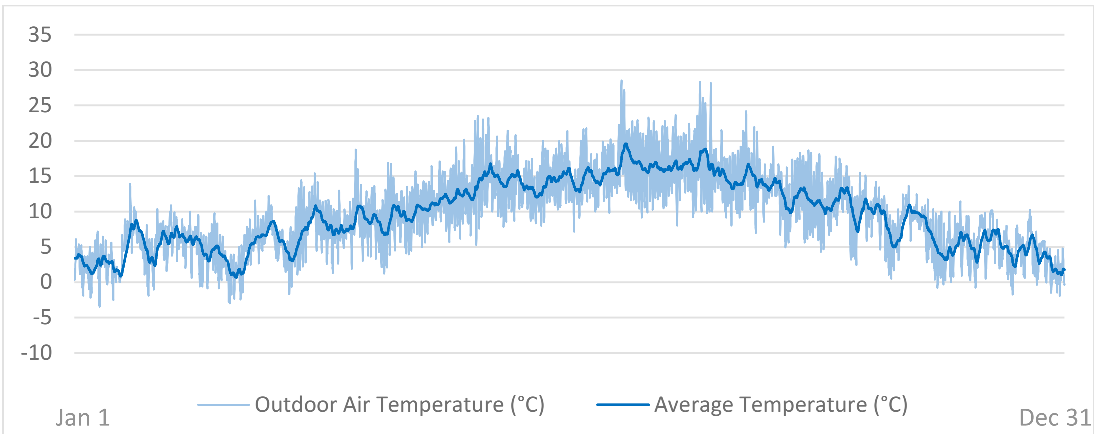


Figure 66 - Strategy D room temperature compared to the baseline

8.4.5 Strategy E: Outdoor Air Averaging

The case-study building's mode is set based on the outdoor air temperature; therefore, it is acceptable to assume that the internal condition of the building is considerably impacted by the exterior loads. The problem with relying on outdoor air for radiant setpoint is the fluctuation of the temperature. Averaging of the temperature stabilizes the setpoint while representing the exterior temperature.

Outdoor air averaging was seen in multiple studies but the specific averaging method for this strategy was taken from [66]. The outdoor air temperature of the previous 72 hours was averaged while the previous 24 hours was given twice the weight. This averaging is done in real-time inside the simulation. Figure 67 provides the result



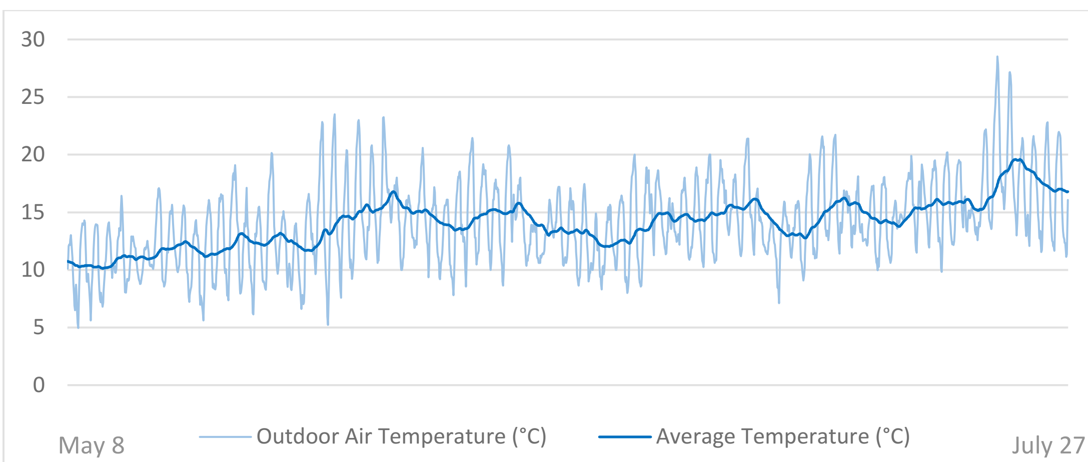


Figure 67 – Strategy E Outdoor air averaging

The averaging was achieved with EnergyManagementSystem:TrendVariable object of EnergyPlus. Figure 68 shows the Program for this TrendVariable. In the figure, *average_OA_T_72hrs* is the TrendVariable, capable of storing 432 values. The numbers 432 and 144 reflect the number of simulation time-steps in 72 and 24 hours respectively.

```
SET averaged_OA = @TrendSum average_OA_T_72hrs 432,
SET averaged_OA = averaged_OA + (@TrendSum average_OA_T_72hrs 144),
SET averaged_OA = averaged_OA / (432 + 144),
```

Figure 68 - Erl code for outdoor air averaging

The remaining challenge is taking advantage of the average value in the slab program. To do so, a linear equation was used.

$$T_{slab} = T_0 - (A_{Outdoor} \times k)$$

Where:

T_{slab} is the slab temperature setpoint,

T_0 is the desired slab temperature when the $A_{outdoor}$ is zero,

$A_{Outdoor}$ is the result of the above Program,

k is a multiplier for the effect of $A_{Outdoor}$ fluctuations,

These values initially were set so that at the lowest and highest average temperatures the slab setpoint is 25 °C and 18.8 °C respectively. The value of T_0 was set to 25 and k was set to 0.25. This resulted in redundant heating in cold months and extra cooling in the warmer months.

Lowering the value of k to 1/7 and T_0 to 24.75 lowered the consumption and improved the indoor temperature. Lowering the value of T_0 also meant, in the unlikely event that the average temperature goes below zero for an extended period, T_{slab} does not exceed the allowed range.

Change were also made to the air system. Due to lack of flexibility with the comfort thermostat, the air control was changed to the initial reheat system of Strategy 1. Figure 69 shows the room temperature before and after the changes. It is worth noting that the improved reheat system of Strategy 1 increased the energy transfer in this strategy.

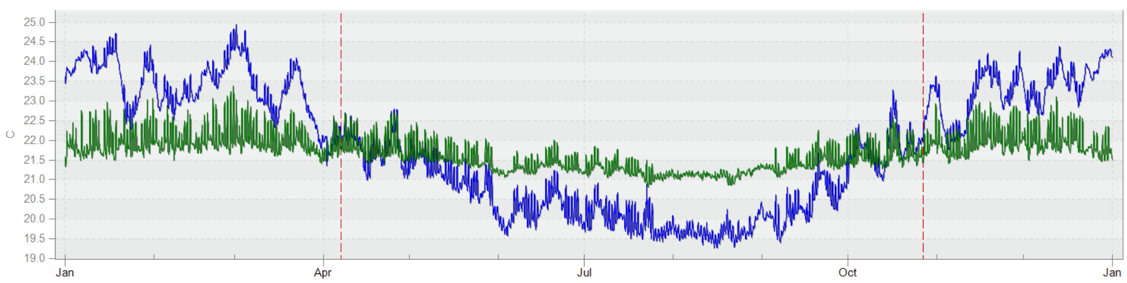


Figure 69 - Different settings of Strategy E air control

Blue: Thermal Comfort Thermostat control, Green: Reheat

In the end, the Strategy E controls in the reheat mode managed to maintain a more consistent temperature profile throughout the year than the baseline and all other strategies but with higher load transfer than most. 7944 hours were comfortable in this strategy.

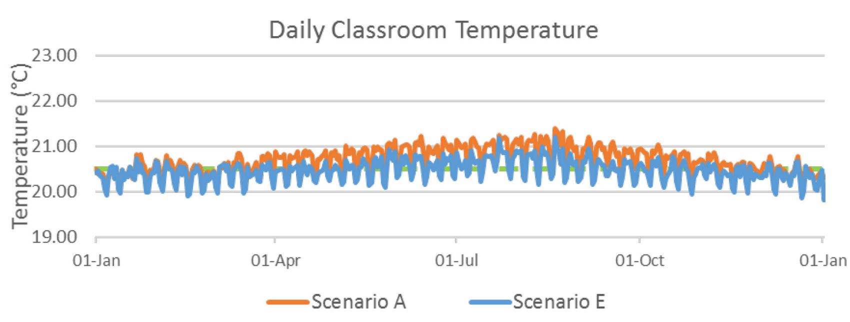


Figure 70 - Strategy E room temperature compared to the baseline

8.5 Peak-shaving

Peak-shaving was mentioned during the literature review for its positive effect on the indoor environment and the cost of HVAC operation [98]. After ensuring the systems have the proper response to high loads, room precooling – as a simple peak-shaving method – was employed. The main goal of experimenting with pre-cooling in this subsection is examining the system lags and how long the effect lasts.

EnergyPlus provides Economizer time-of-day schedules as the method of creating a pre-cooling effect, but for better customization, this task was performed in ERL with the *InternalVarible* of *Hour*. The code added to the slab control is as follows:

```
IF Hour > precool_start && Hour < precool_end,
      SET zone_intended_SP = radiant_max_cooling_T,
ENDIF,
```

Figure 71 - Precooling EMS snippet

Where *precool_start* and *precool_end* were changed for the best results. A similar but independent snippet was added to the air control. To get the desired effect, the precooling must be active in both systems.

For the radiant system, the best results were achieved by having the precooling started more than 3 hours before the load; however, this causes unnecessary work when the load is not occurring (the weekend in Figure 72). To address this issue, the occurrence of the precooling may be further optimized using the InternalVariables such as *Day*, *Month*, *DayOfWeek*, etc. In the case-study building, the pre-cooling operation can be connected to the class schedules.

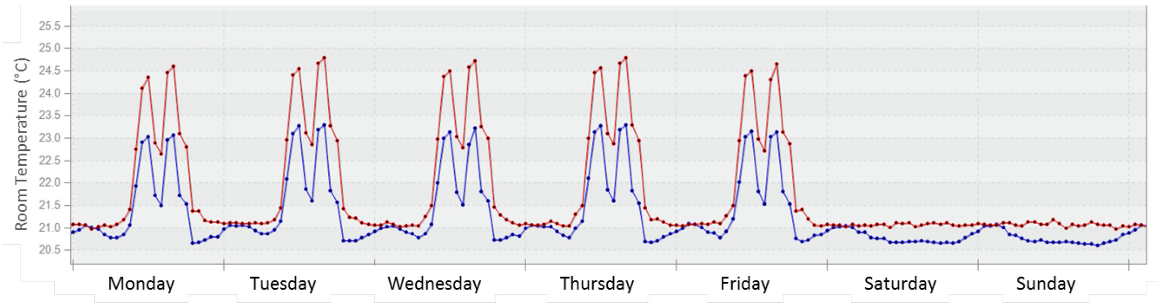


Figure 72 - Peakshaving effect on room temperature

Red: no peakshaving, Blue: peakshaving active

Another possible problem of this practice is when the precooling starts earlier than needed. This was seen when the air system precooling control was added (Figure 73). For a more consistent temperature profile, the precooling time for the air system was set to one hour before the load.

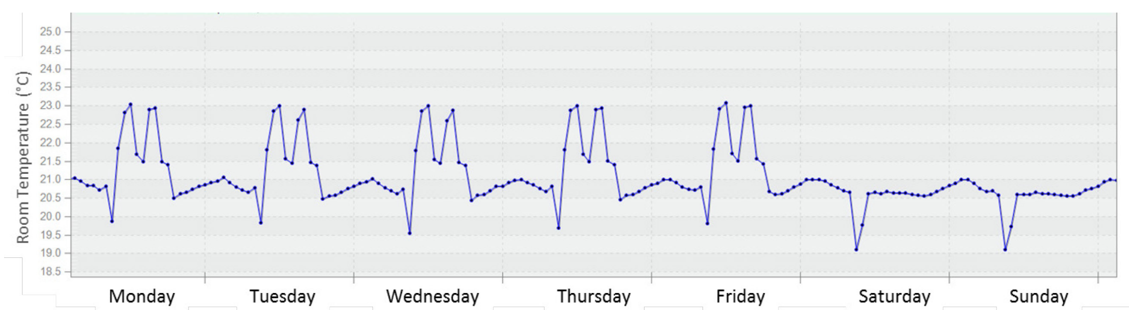


Figure 73 - Effect of early peakshaving on room temperature

8.6 Section Conclusion

In the classroom level simulation model, different control strategies were tested and compared. This demonstrated that the control strategies at this scale greatly impact the magnitude of HVAC load transfer. In the next section, the best performing control (Strategy B) will be tested in a more comprehensive model made from the case-study building.

9 Whole Building Energy Model (WBEM)

With the experience gathered from the performance gap and the classroom level simulation sections, a Whole Building Energy Model was created. The baseline case of the model was calibrated based on the data available from the building.

The model was used to compare the baseline case with an improved condition which is the best performing strategy found in the last section. The comparison shows that the system electricity consumption was reduced by 3.1% and mechanical system gas consumption was reduced by 6.3%.

The following subsections introduce stages of creating and tuning the model.

9.1 Building Shell

The as-built and architectural drawings received from the Vancouver Island University were used to draw the building shell. As it is a common simulation practice [81], [91], some adjacent spaces with similar temperature and loads were merged so that duplications are avoided. There are 26 zones in the model in total.

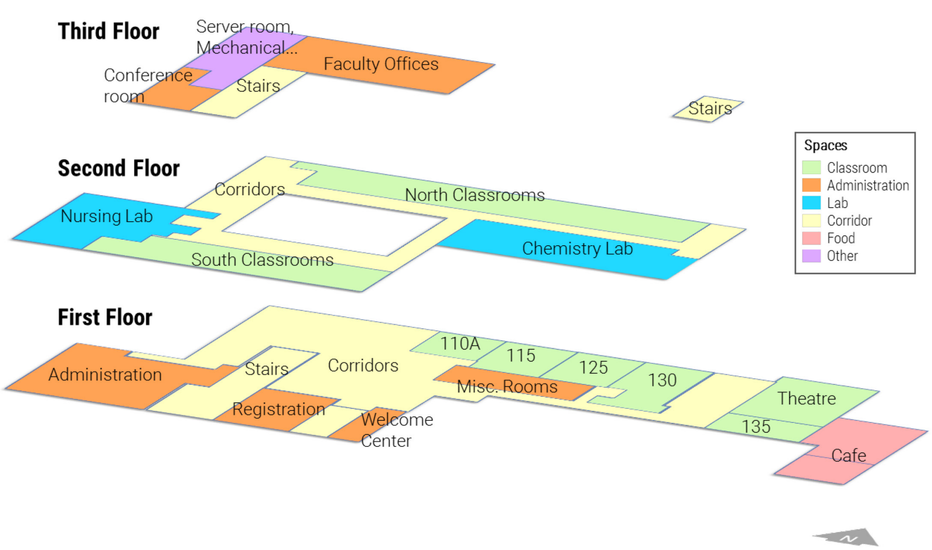


Figure 74 - Modeled Zones

For windows, doors, and vents, the elevation as-builts were used. DesignBuilder does not allow drawing windows on the exterior walls at their intersection with the interior walls. This caused minor changes in the location of the windows.

Angle of solar collector panels was taken from the as-builts as well. These were modeled using the solar collector tool of DesignBuilder on two slopped component blocks. The collectors' connection to the mechanical system is shown in the mechanical system subsection.

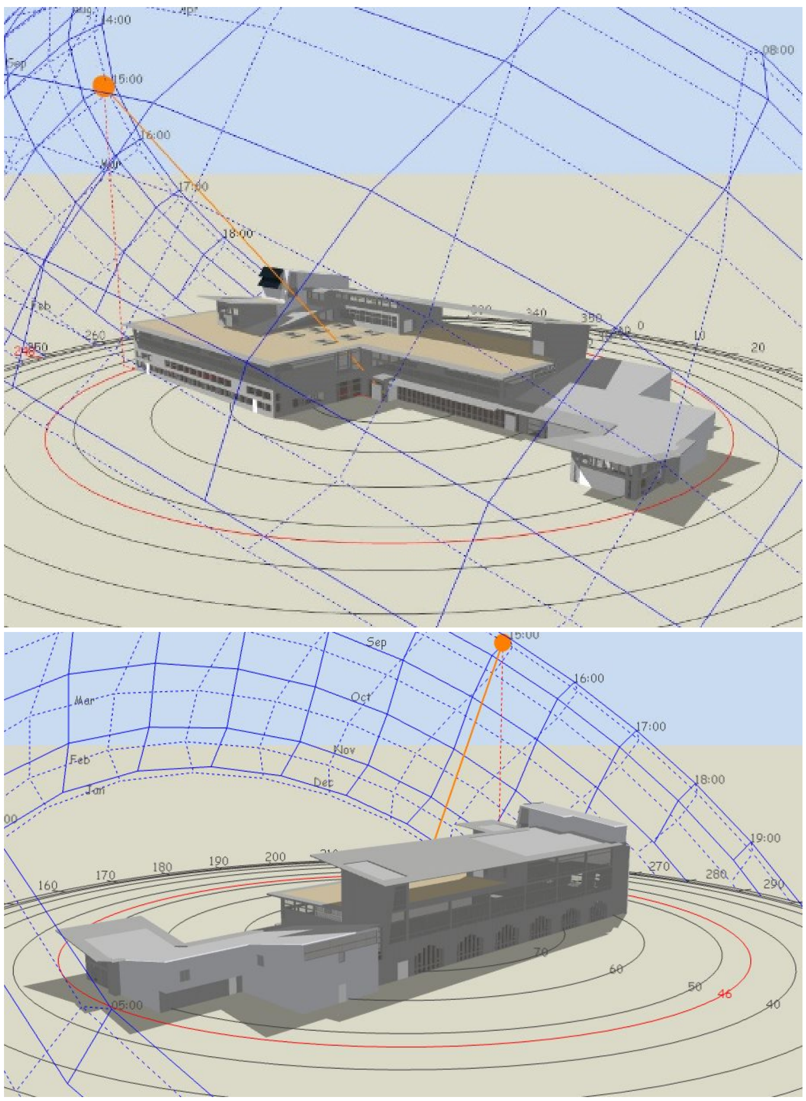


Figure 75 - Building Model in DesignBuilder

To prevent the thermal mass problem described in section 6.4, each construction layer was independently modeled. DesignBuilder can calculate thermal bridging, but the results are not transferred to EnergyPlus. For this reason, the construction layers with thermal bridging (metal roof and the walls) were modeled as separate constructions, then the software calculated values were put as a layer inside the actual construction.

The only remaining unknown in the constructions was the percentage of bridging. It was found that using 0.5% and 2% bridging, respectively for the walls and the metal roof, results in the values identical to what the building's eQUEST modelers had set manually (Figure 76).

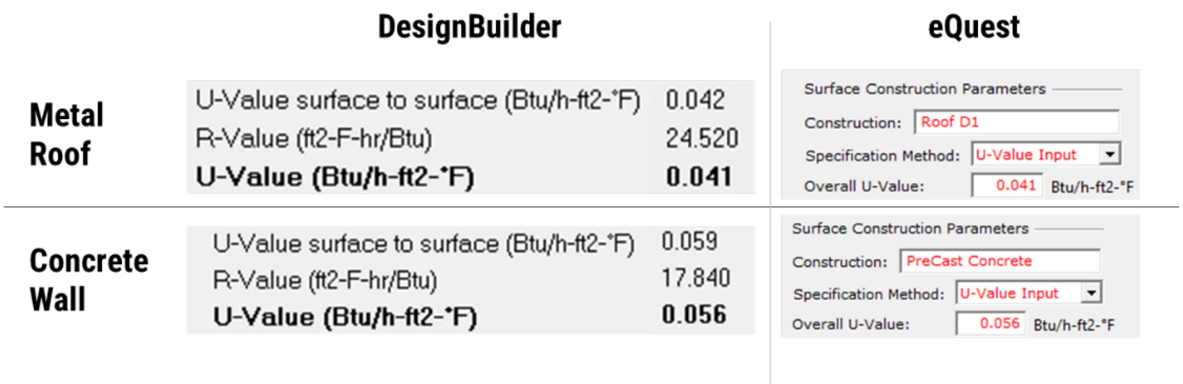


Figure 76 - Comparison of U-Values of WBEMs

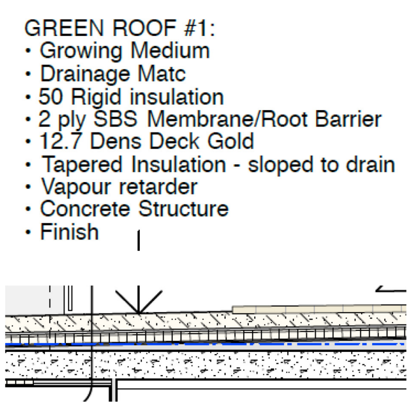
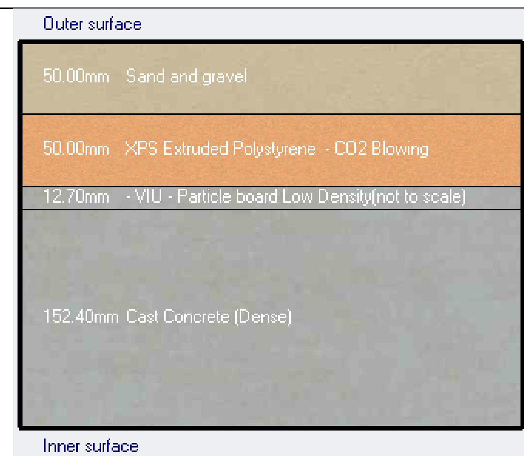
Left: DesignBuilder layer-by-layer result, Right: eQUEST direct input

Window Glazing conductivity and Solar Heat Gain Coefficient (SHGC) were derived from eQUEST since the HPB report specifically mentions the improvement of windows in the model. That said, the eQUEST framing U-values were not used due to inconsistency between similar glazing units on the first floor and the second floor. A corresponding DesignBuilder template was used instead.

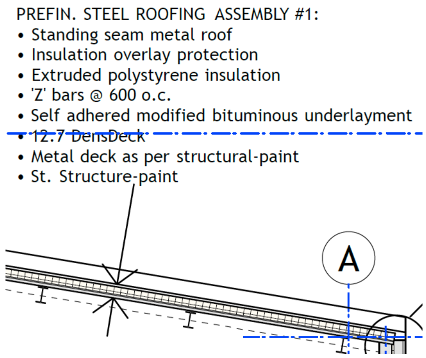
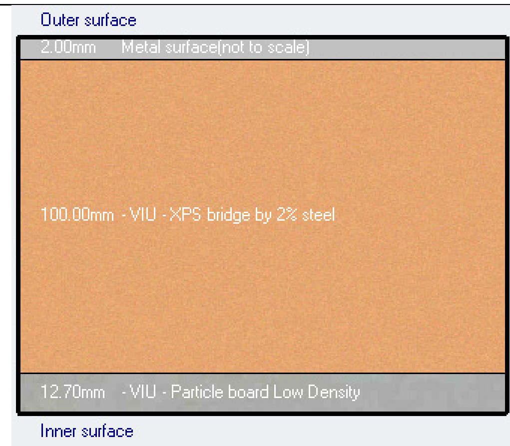
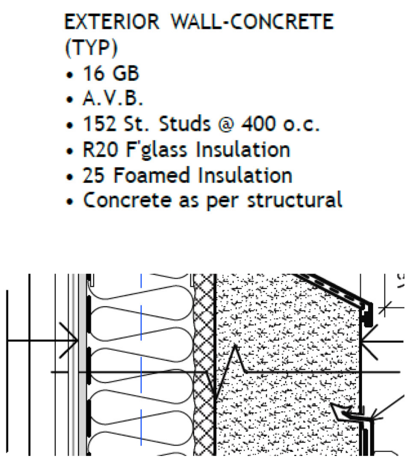
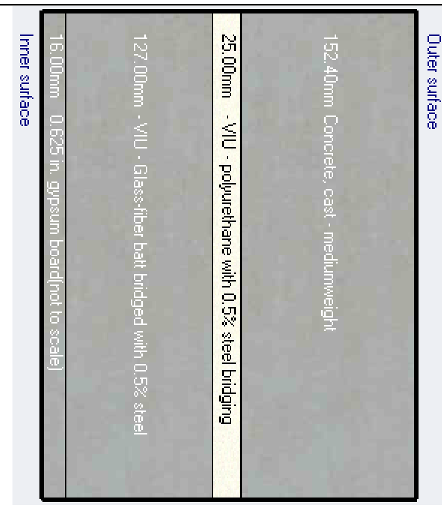
Table 5 provides the details of envelope elements. It is important to note that there are variations to the shown assemblies. Most significantly, the concrete slab thickness change for structural reasons, and the tapered insulation of the green roof, were accommodated by averaging whenever possible or customization within the zones. The same practice was seen in the eQUEST model.

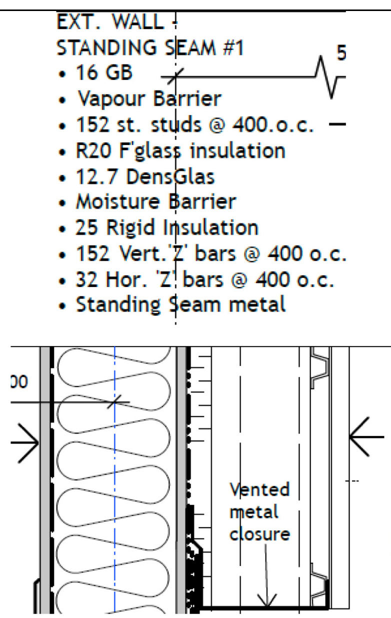
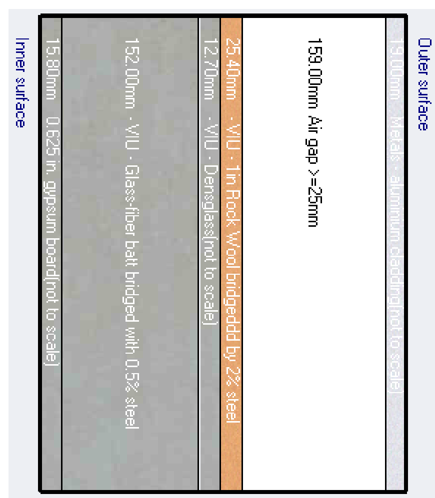
The layers shown for the “Green Roof” construction belong to the planted segment of the roof. The rest of the roof is covered with pavers on the surface and the same materials underneath.

Table 5 – Major assemblies of the case-study building and their modeled properties

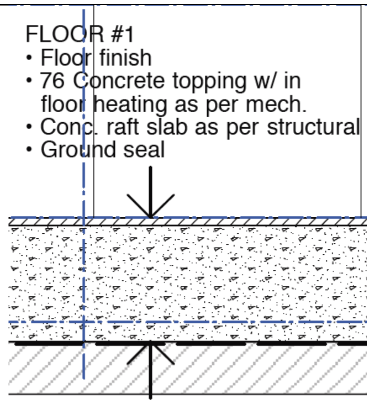
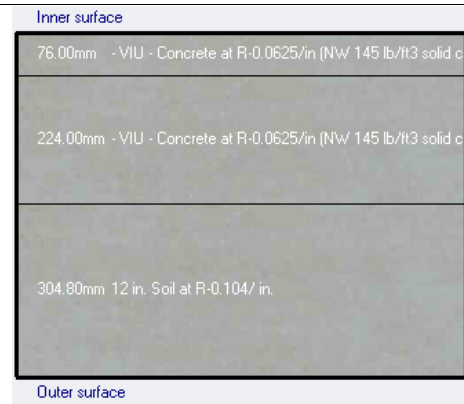
Description	Layers (As-Built)	Layers (DesignBuilder)
Green Roof		

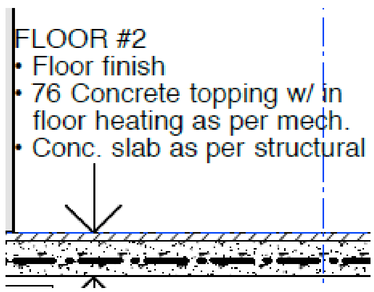
<table>
<tr>
<td>Metal

Roof</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass Wall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal Clad

Wall</td>
<td></td>
<td></td>
</tr>
</table>

<table>
<tr>
<td>Ground

Slab</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Internal

Floor</td>
<td>
</td>
<td>
</td>
</tr>
</table>

9.2 Loads

The case-study building is equipped with an outdoor air temperature sensor; however, the sensor data is only being used for building mode in the GCL control program and is not being recorded. The initial weather file used for the model was the climate data of Victoria International Airport available through DesignBuilder. The climate file is a suitable option for building design but the calibration process of this model requires the weather condition of 2016. This was acquired from [99].

The airport has an approximate distance of 25Km from the building. It was seen that the data lacks the microclimate effects; thus the data from Quamichan Middle School's weather station was retrieved from [100] for the year 2016 and then combined using a

Python script. This weather station has an approximate distance of 600m from the building. Figure 77 shows the improvement this data provides when compared to the airport files.

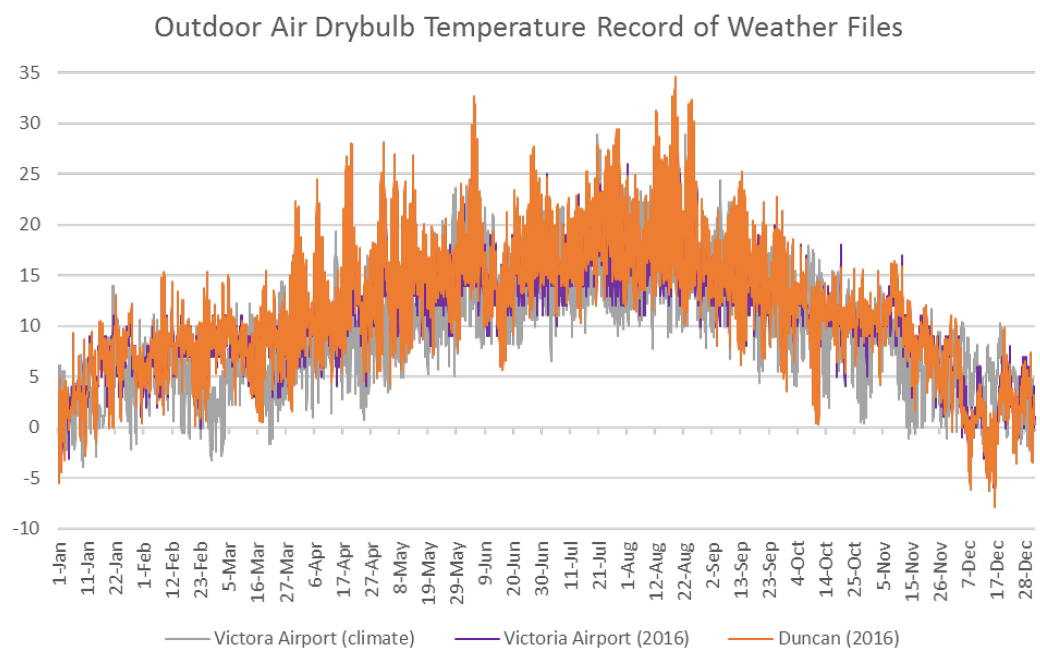


Figure 77 - Effect of microclimate and weather condition of the simulation year

Collected weather data, except for Solar Irradiance, required little processing to match EnergyPlus units and timestep. For solar parameters (direct and diffuse) the [101], [102] splitting method available in EnergyPlus Weather Converter auxiliary program was used [86]. The weather file was then reviewed in Elements software [103].

Simulation schedules are available in Appendix A. These were initially taken from the High-Performance Building Report and the eQUEST model. The exact operation hours were then taken from the building operation logs and added to the data. Most schedules remained unchanged during the modeling and calibration process. For lighting, a minor simplification improved the simulated electricity consumption profile compared to the logged data.

For infiltration, a core-perimeter model was available in eQUEST. In the first step, an average infiltration, weighted by zone square meter, was put in DesignBuilder. The infiltration rate was increased after the removal of mixed mode mechanical operation (hybrid ventilation) for the same reason described in the classroom level simulation section. The method of finding infiltration values were the same as that section.

Comparison of the model's load with the eQUEST energy model shows that while the trends are close for components such as windows, for the reasons mentioned in the subsection 6.4 (e.g. neglecting the thermal mass) for walls and roofs significant discrepancies can be seen during the warm months. Figure 78 provides examples.

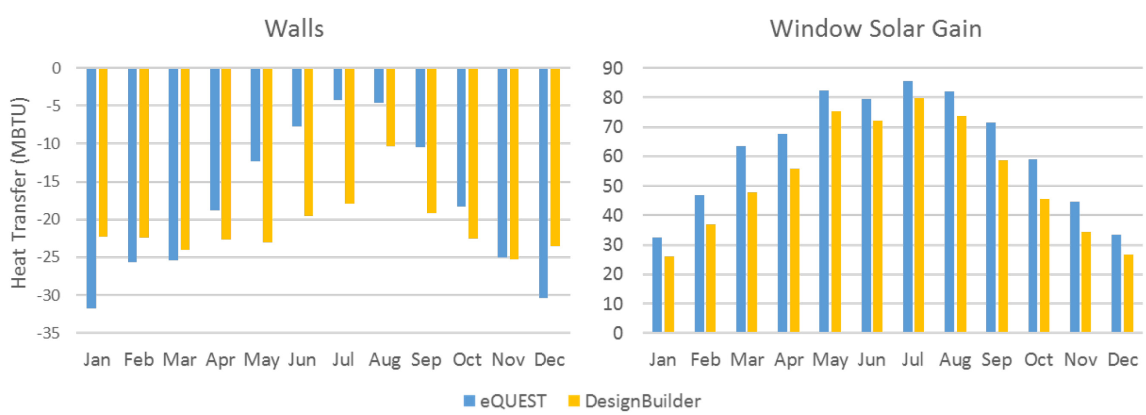


Figure 78 - Load difference between eQUEST and DesignBuilder models

9.3 Mechanical System

Based on the mechanical as-built drawings, the mechanical system was implemented in the detailed HVAC mode of the DesignBuilder. Figure 79 provides an overview of the actual system. Different components of the mechanical system are marked and their corresponding regions in the modeled mechanical system are shown in Figure 80.

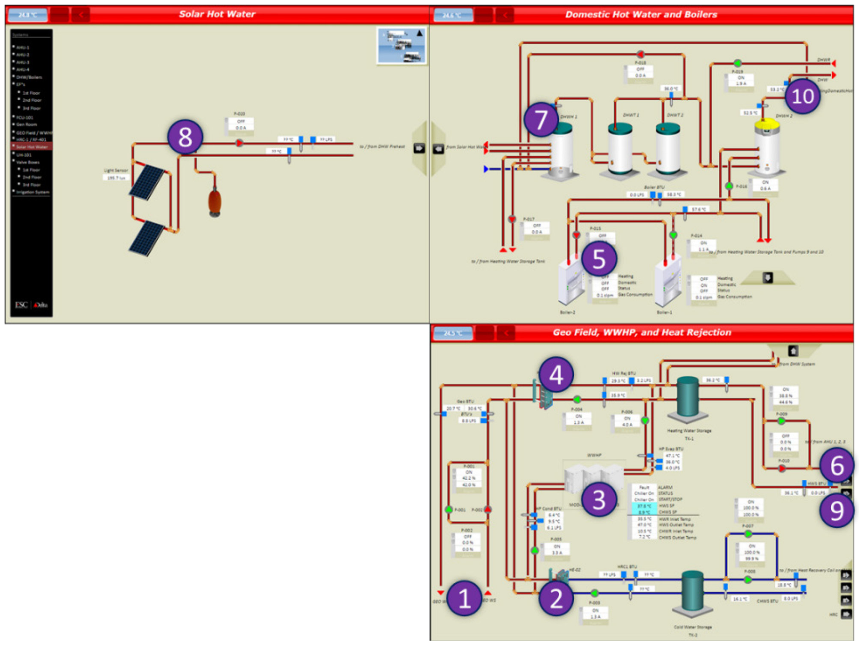


Figure 79 - Case-study building mechanical system supply side

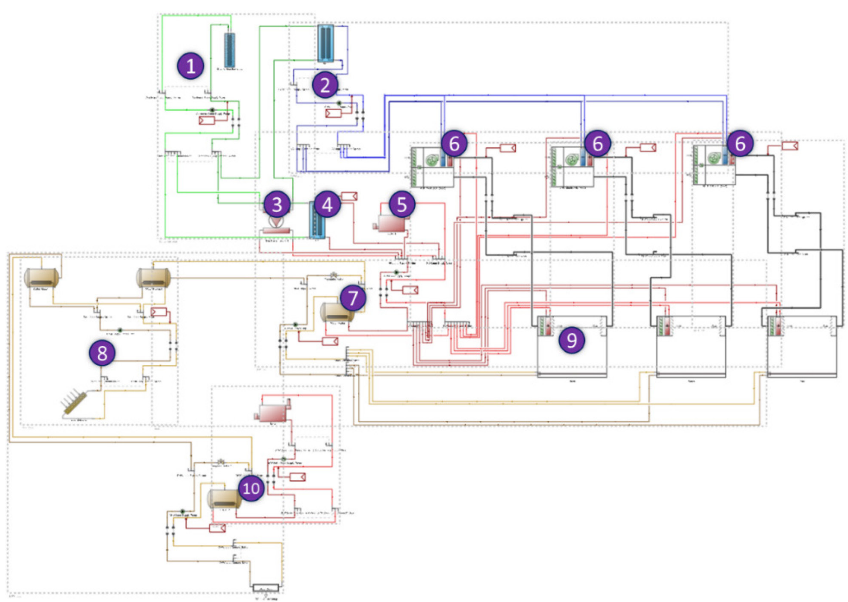


Figure 80 - DesignBuilder mechanical scheme

The ground source bore hole structure (1) connects to the cooling side heat exchanger (2) and from there to the heat pump (3). The other heat exchanger (4) is available only for heat rejection if the hot water loop temperature goes beyond a seasonal threshold. The boiler (5) provides additional heating in case heat pump is not capable of reaching the setpoint temperature. Hot water and chilled water are connected to the air handling units (6) and zone VAVs.

This setup is also assisted by the solar loop (8). DesignBuilder connects the solar loop and the low-temperature radiant systems only to the domestic hot water loops, therefore (7) is necessary to connect those to other systems. For simplifying the scheme, all the zones (9) connected to a AHU are put under one zone group. This was later customized for each zone in EnergyPlus. The typical zone has a radiant cooling system, a radiant heating system, a VAV input with reheat, and ducted exhaust.

The Domestic Hot Water (DHW) outlet (10) is connected to the solar loop as well a as hot water loop. In the case-study building the two boilers can change mode to satisfy the DHW demand or increase the hot water loop temperature. To keep the track of boiler operation and since boiler mode could not be replicated in EnergyPlus, one boiler was positioned on the hot water loop and another on the domestic hot water loop.

Since the boilers in the case-study building have lead-lag operation pattern, only one boiler is expected to run; therefore, the capacity of one boiler was divided between the two boilers. In the simulation, similar to what has been observed the case-study building, most of the boiler operation is related to the domestic hot water.

In an alternative of the above scheme, the DHW related systems were removed. This did not cause a noticeable change in the operation of other systems. Another simplified mechanical scheme with fewer hot water tanks and a single boiler was also compared with this scheme that shows similar overall consumption, but does not provide insights on the boiler mode of operation.

This scheme as shown in Figure 80 cannot be simulated in DesignBuilder. Given that the zones have both chilled ceiling and heated floor, slabs between two floors will embody both systems. This causes termination of the EnergyPlus simulation. The mechanical system was drawn this way because DesignBuilder does not support simultaneous slab heating and cooling, but this file can be slightly modified in EnergyPlus for this purpose.

9.4 EnergyPlus Modifications

The DesignBuilder environment had the following limitations:

1. For this research the default control tools of EnergyPlus, available in DesingBuilder, needed to be further expanded using the “EnergyManagementSystem” feature.
2. While the software provides a “Heated Slab” option, there is no option for simultaneous slab heating and cooling at different zones. This option is available in EnergyPlus.
3. Some external files cannot be used in the simulation.
4. DesignBuilder result reporting did not provide the flexibility needed for extracting the results.
5. The EnergyPlus “CentralHeatPump” object may better represent the heat pump system of the building, compared to the generic heat pump DesingBuilder provides.

We encountered the Limitation 1 while modeling the radiant slabs of the building. As per the actual controls, the slabs have temperature equal or above 18.8 °C in cooling mode, and equal or below 25 °C in heating mode. This type of control causes an overlap error in EnergyPlus as the software expects to have a heating setpoint below cooling setpoint. As a result, a workaround was necessary to add the control. This is further discussed in EnergyManagementSystem section.

To solve the above, the EnergyPlus IDF file was exported from DesignBuilder and was manipulated directly. The disadvantage of making direct changes in the EnergyPlus input file is that it creates a point of no return. No error fix or modification can be performed in DesignBuilder after exporting the file.

The first problem that needed to be addressed was the proper implementation of the radiant system. The method provided in the appendix of [87] was used for implementation of slab heating and cooling: for each zone, the chilled ceilings were removed and their branch nodes were connected to the heated floor instead.

The operation schedule of the case-study building taken from the building's online interface, did not follow a pattern as it was regularly changed manually. Inputting the data directly in EnergyPlus was not feasible so the schedule was entered as an external file using the Schedule:File object (limitation 3). This method makes it possible to take advantage of a spreadsheet software to prepare the data for simulations. For building operation hours, the data from the building was recorded on change of value (COV) basis. Using Microsoft Excel, these values were converted to 8760 rows of hourly values in the span of one year, for EnergyPlus.

For getting the simulation outputs, the DesignBuilder support team suggested directly reviewing the ESO file generated by EnergyPlus after simulation. The DesignBuilder's native output viewer does not generate the ideal results in some cases (limitation 4). Also, the output viewer is designed only for the year 2002 and simulation for other years may not be shown as expected. Selecting specific outputs to be included in the ESO file was only possible by directly modifying the EnergyPlus input file.

The last item (limitation 5) is more complex than the rest. EnergyPlus includes a *CentralHeatPump* object that may better represent the three-way interaction of the heat pump system with the heating, cooling, and condenser loops. On the downside, that configuration could not replicate the cooling loop's free cooling as in the DesignBuilder's model. As previously mentioned, a unique design feature of the mechanical system is the evaporator side of the heat pump unit (Figure 81). The advantage of the design is allowing the cooling loop to have free cooling from the ground loop and reject the heat to be harvested by the heat pump for the heating loop.

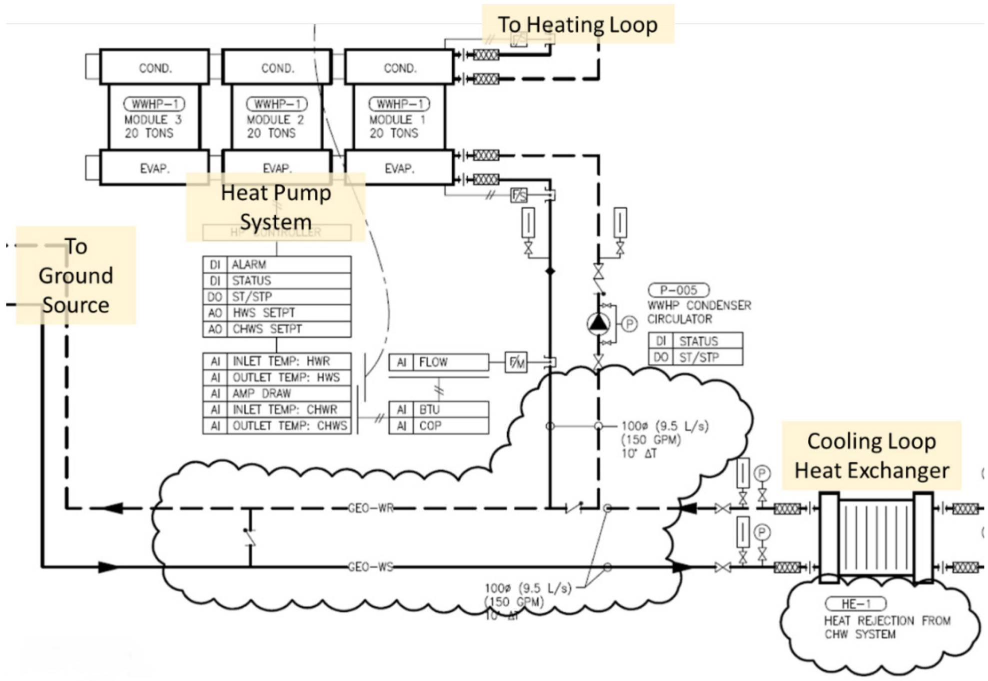


Figure 81 - Connection of the ground loop to heating and cooling loops

Thus, both alternatives, CentralHeatPump object and the DesignBuilder's heat pump (EquationFit heat pump), were modeled and compared. The EnergyPlus CentralHeatPump object includes a number of heat pump modules that can change their loop connections based on the demand. This is shown in Figure 82: by closing specific valves (shown with crosses) the water of each loop can get exposed to the modules and exchange heat with another loop; therefore, the three loops (ground, hot water, and chilled water) must be connected to the object separately. Figure 83 shows the difference of this loop connection with the other alternative. It is notable that due to the lead-lag operation of the heat pump in the building, only one of the heat pump modules is active during the building operation, and therefore in the model. This means the CentralHeatPump as shown in Figure 82 can only exchange heat between two loops at any given time.

Diagram of chiller-heater bank with one module in heat recovery mode, two in cooling only mode.

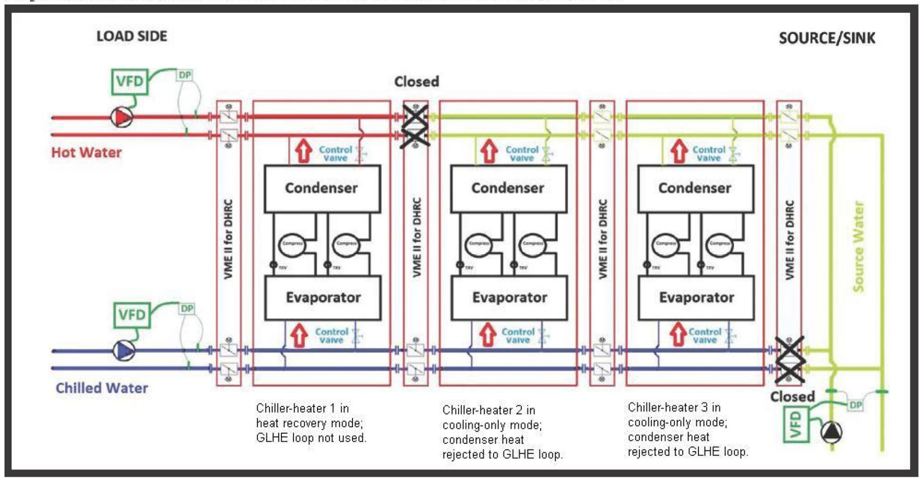


Diagram of chiller-heater bank with 2 modules in heat recovery mode and 1 module in heating only mode.

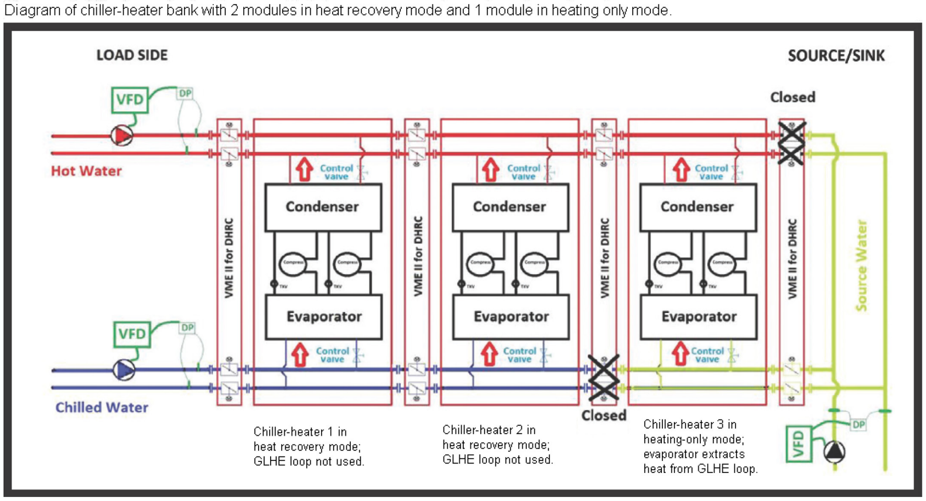


Figure 82 - EnergyPlus CentralHeatPump object

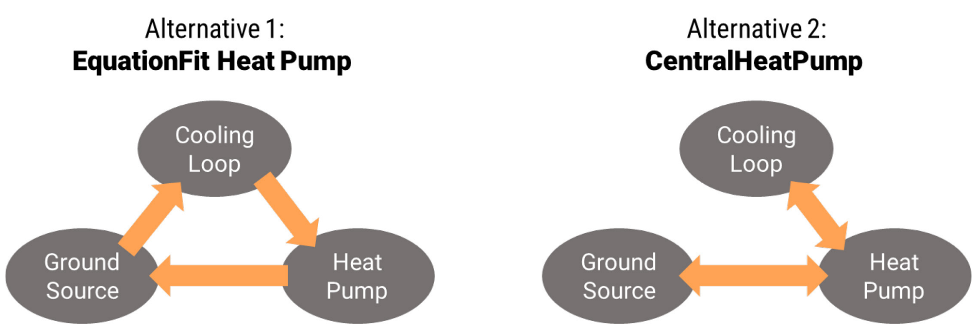


Figure 83 - Heat Pump Model Alternatives

For the implementation of the CentralHeatPump, a new loop was defined between the heat pump and the cooling side heat exchanger. Figure 84 shows the connection diagrams of the CentralHeatPump object and the added loop in EnergyPlus.

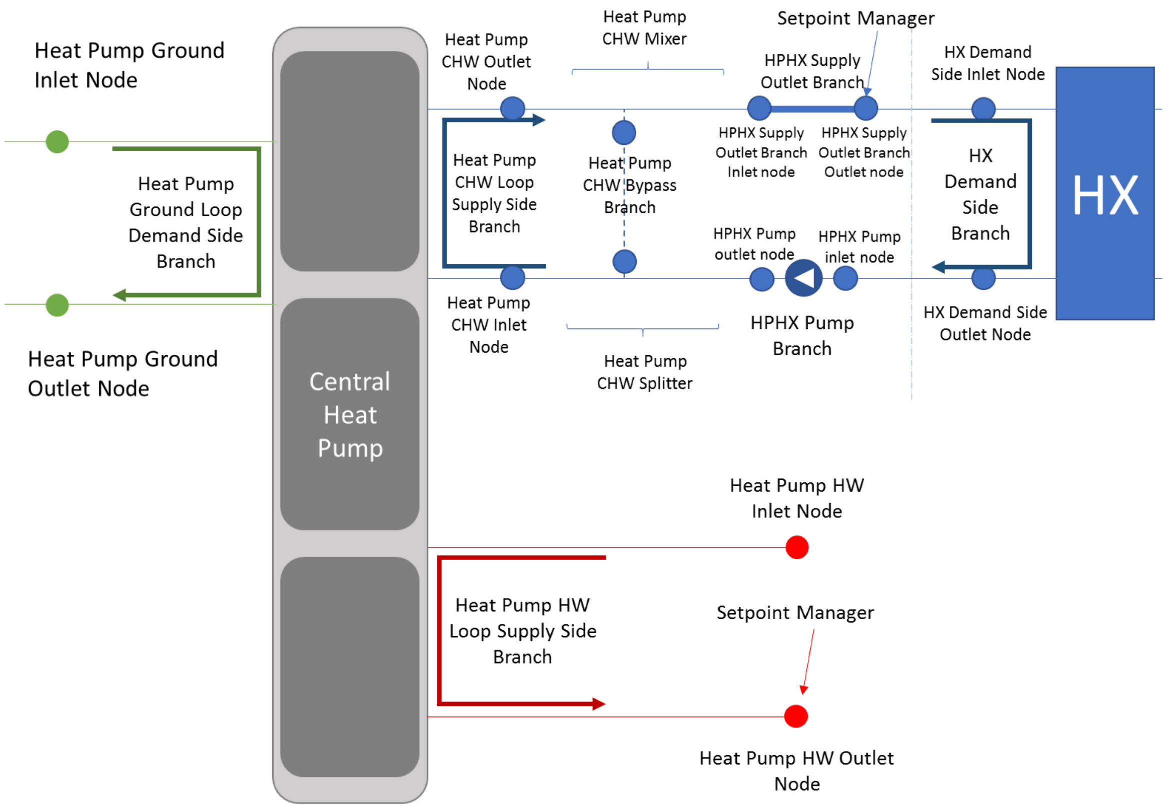


Figure 84 - CentralHeatPump connections

It was found that the free cooling feature of the mechanical system is crucial; thus, the EquationFit model (alt. 1) better represents the mechanical system of the building. While the CentralHeatPump (alt. 2) had very similar electricity consumption profile and demand-side temperatures, its dependence on the boilers was more than what has been seen in the case-study building.

None of the alterations made to the CentralHeatPump system (alt. 2) brought down the gas consumption to comparable levels. Most notably, the alterations included experimenting with different performance curves (*actual*, *typical*, *ideal*). The *actual* Biquadric curves were generated by the Table object of EnergyPlus. Later, [104] was used for curve fitting to speed up the simulation.

9.5 Calibration

The building model was calibrated as per ASHRAE 14-2014. The energy consumption data gathered from the BAS was cumulative and the consumption values were recorded with a precision of 10 which posed a challenge to calibration (Figure 85).

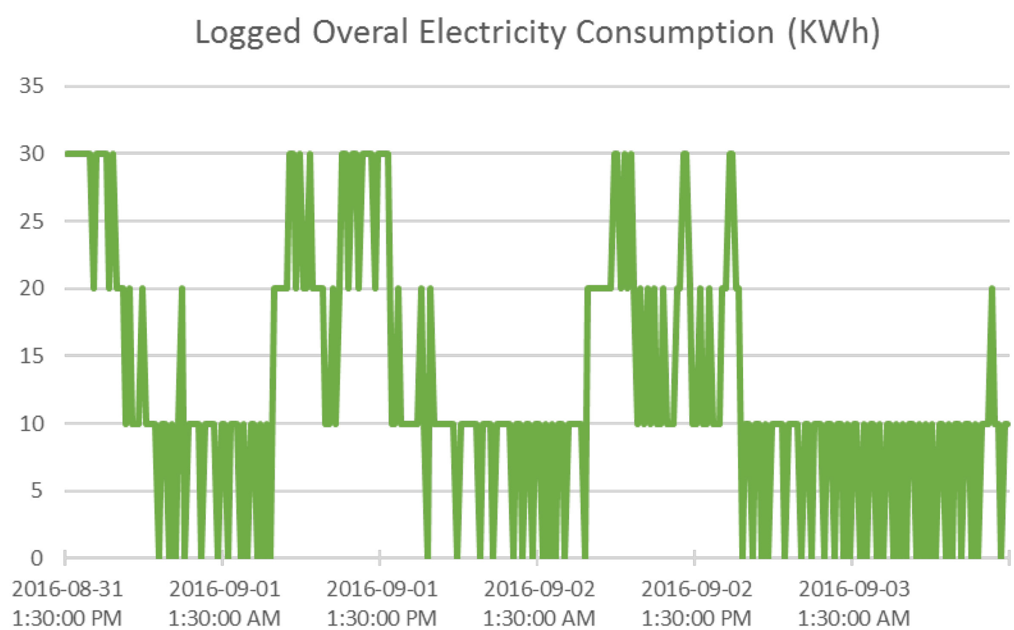


Figure 85 - Three days of logged consumption data (15-minute interval)

To better understand the data trends, Savitzky-Golay denoising method [105], [106] was used. Within the available literature, [107] benefited from this method to denoise the HVAC sensor readings. The main advantage of this denoising method is keeping the total consumption the same as the original data.

For the smoothing process, small windows of data (8 neighboring values) were used so that the smoothed path retains the sudden rise and fall of consumption at the start and the end of the daily operation (Figure 86).

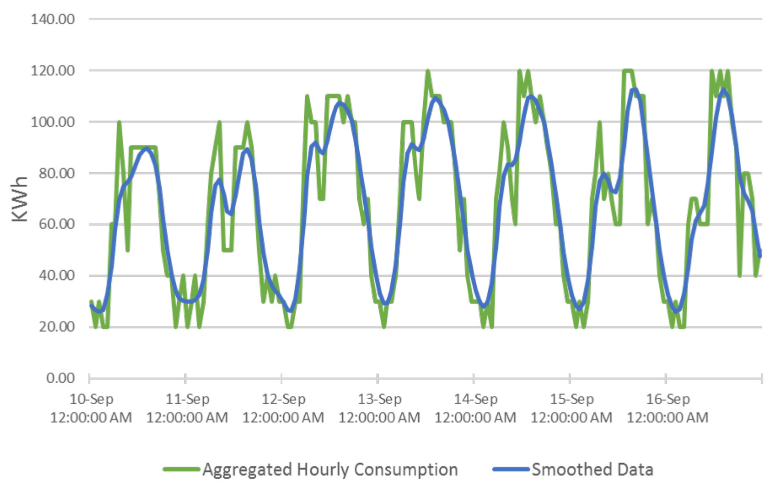


Figure 86 - hourly aggregated electricity consumption vs its smoothed profile

Typical week of the case-study buildling

For the typical weeks, Figure 87 presents the electricity consumption simulation output and the result of consumption smoothing.

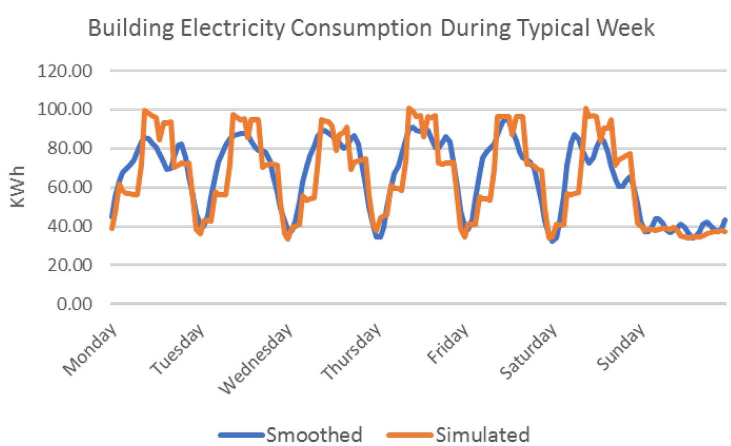


Figure 87 - Simulated electricity consumption compared to the data

Using the controls designed for the previous section (classroom level simulation), with the modifications for scaling that were described in the previous subsection, the simulated classroom interior condition is similar to the classroom level simulation, and thus, to the actual classrooms.

The simulated and actual air and radiant setpoints in a classroom are graphed in Figure 88 for the months of July and August. The figure shows that the simulated mechanical system and the actual data have comparable patterns; notwithstanding, a few days during this period show significant contrast in response. This could be due to occasional activities in the case-study building.

Figure 88 - Simulated mechanical system response compared to the actual data Classroom 225

It is important to note that the simulation result shown in Figure 88 is for a merged zone which also includes the classroom 225. This should not impact the radiant system results as all the spaces in the zone are connected to one valve box. The spaces are also connected to the same AHU but different VAVs; thus, the air setpoint is for all the spaces.

Comparing the simulation output with the smoothed energy consumption data shows Root Mean Square Error (RMSE) is below 30% and Mean Bias Error (MBE) is below 10% in hourly resolution. Most of the error arises from the periods which lack data consumption patterns.

9.6 Modified Controls

The demand-side controls of the calibrated model were changed to the controls described as “Strategy B” in the previous section (classroom level simulation). The control has altered ramps for air and radiant systems, and directly uses the room temperature to setpoint difference rather than a PI controller. The modification is done in the Subroutines; therefore, the zone programs remain the same.

The main goal of this modification is generating more stable system setpoints for the slab and air system, thus reducing the load transfer and utility operation.

Although the scope of observations were the classrooms, the change covered all the zones served by the AHUs of north and south and all the slabs in the building. This was done because having distinct control methods in adjacent spaces may affect the observed zone.

For the classrooms, this change increases the stability of setpoints for both air and radiant systems. The radiant system changes within the same limits but more consistently than the baseline (Figure 89). The air system control maintains a higher setpoint at the lower limit and more gradually increases it when necessary (Figure 90).

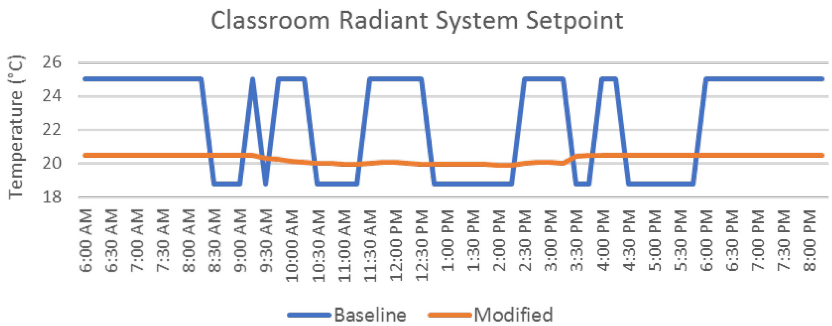


Figure 89 - Improved radiant system classroom setpoint compared to the baseline

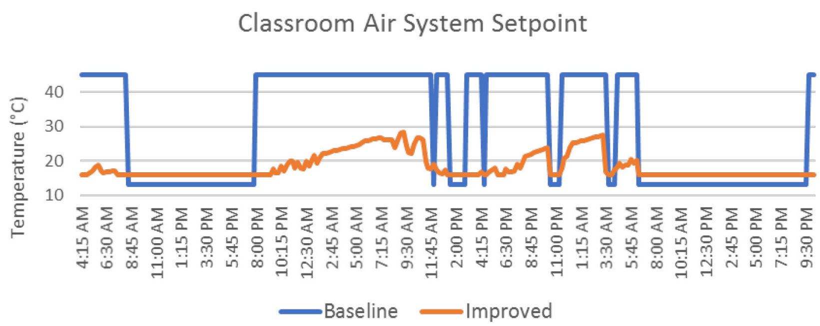


Figure 90 - Improved air system classroom setpoint compared to the baseline

Naturally, the effect of the modification can be seen in the room temperature but the difference is normally less than 1°C (Figure 91). The noticeable difference is in the winter where the modified controls allow about 1°C increase of temperature inside the comfort zone during the peak hours. At these times, the baseline air and radiant system have the setpoint temperatures of 13°C and 25°C respectively while the setpoints in modified case are 16°C and 21°C.

The classrooms in the WBEM show the same response pattern as the classroom model. The difference is that the room temperature in the WBEM is less responsive to the modification of the air and radiant systems than the classroom level simulation. This kept the setpoints at their bounds more often than previously seen. The higher thermal inertia of rooms also reduced the effect of pre-cooling thus, longer periods of precooling are needed to see its effect.

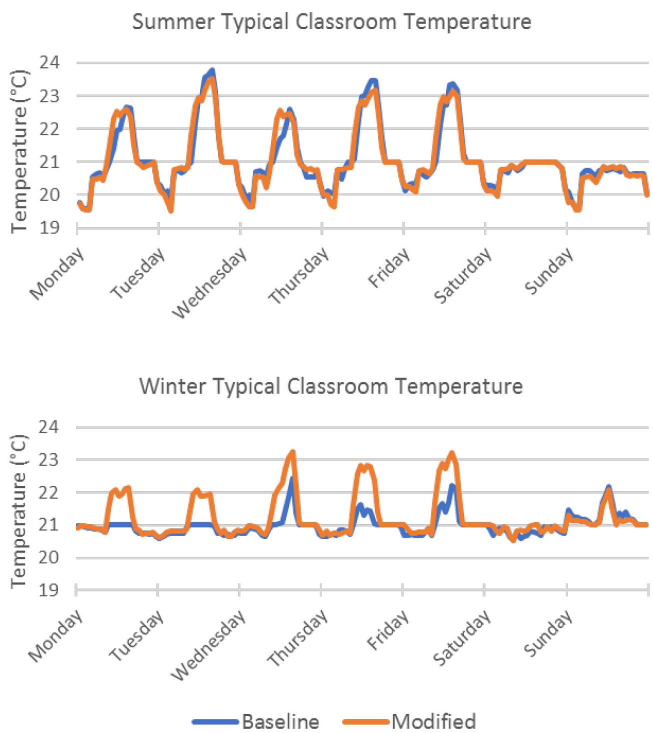


Figure 91 - Baseline and modified temperature control in typical classroom

Figure 92 compares the electricity consumption of two controls and Figure 93 magnifies the consumption comparison for two months. The electricity consumption is steadily lower due to the smaller mechanical system demand. The trend is continuous throughout the year. The pattern is more complex for gas consumption. Non-DHW gas consumption is insignificant and can only be seen in cold months. In total, the modified controls demand lower gas consumption but, as it can be seen, sometimes higher consumption during a specific hour.

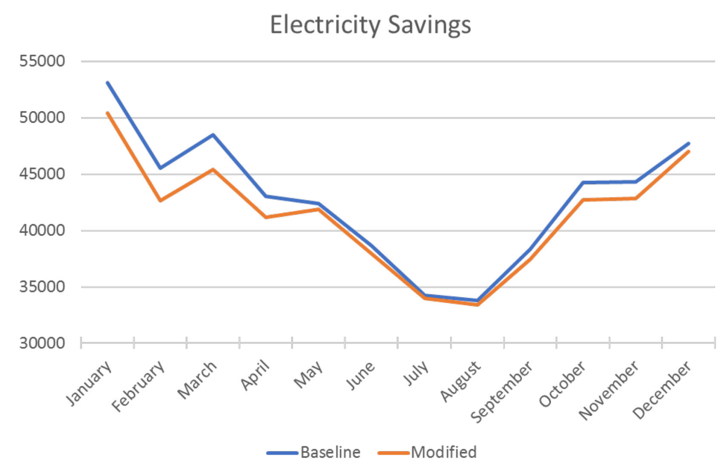


Figure 92 - Electricity savings as a result of control modification

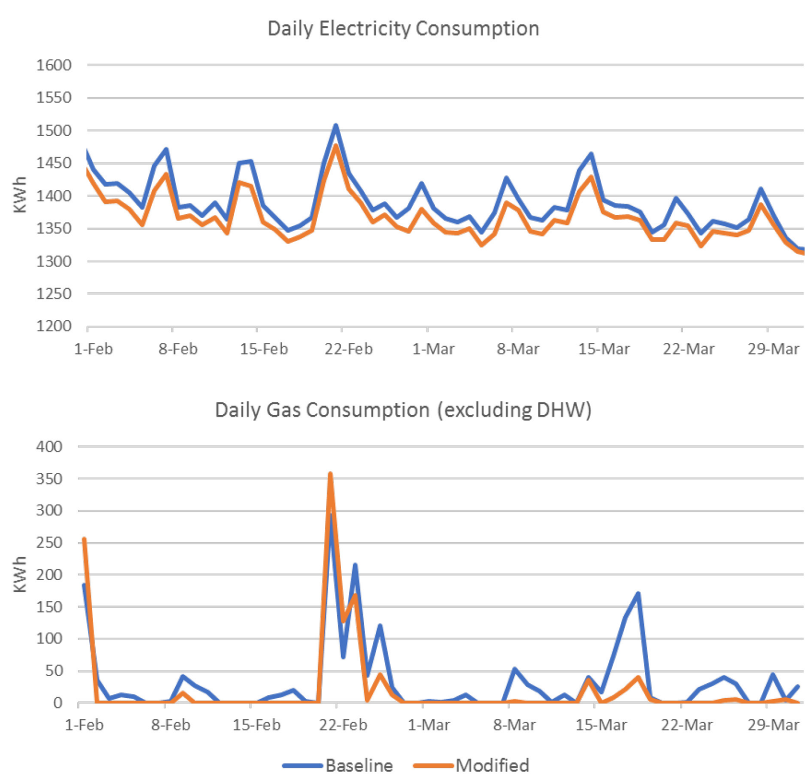


Figure 93 - Energy consumption of modified controls vs baseline

As for what causes the savings, the answer appears to be a combination of elements. Correlating energy savings with the outdoor air temperature (Figure 96), fan and pump operation (Figure 94), the time of the year or day (Figure 95), and the occupancy level (Figure 97), reveal certain patterns in the saving amount. High occupancy times have experienced the highest savings. This could show the benefit of tweaking performed on the controls in the previous section for high loads. Moreover, the most significant savings are achieved when the outdoor air temperature is around 10 °C.

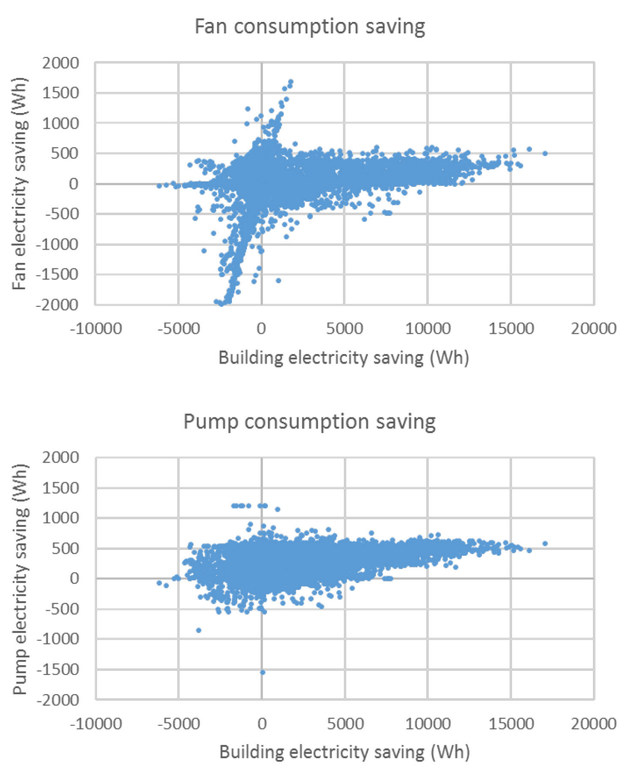


Figure 94 - Correlation of fan and pump consumption reduction and overall savings

Each dot represents the condition in one hour of the year

Figure 94 shows that the level of savings in fans and pumps correlate with the overall energy savings; the modified controls decrease the work of both systems. Increasing the data resolution to hourly shows that while modified control may show poor electricity use for some hours of the day, it has better overall performance for 298 days of the year. The same can be seen for the fan and pump operation.

Two crossed linear patterns can be identified in the fan's savings graph of Figure 94. The points on the near-vertical line show the times when the fan operation has caused the biggest change. At the same time, these points have very close values on X and Y axes which means, at these times, the main reducer or increaser of electricity consumption have been the fans. Typically, the said condition occurs on the afternoons, from mid-May to mid-September, when the dampers should be open to remove excess heat. The total number of these incidents does not exceed 200 hours.

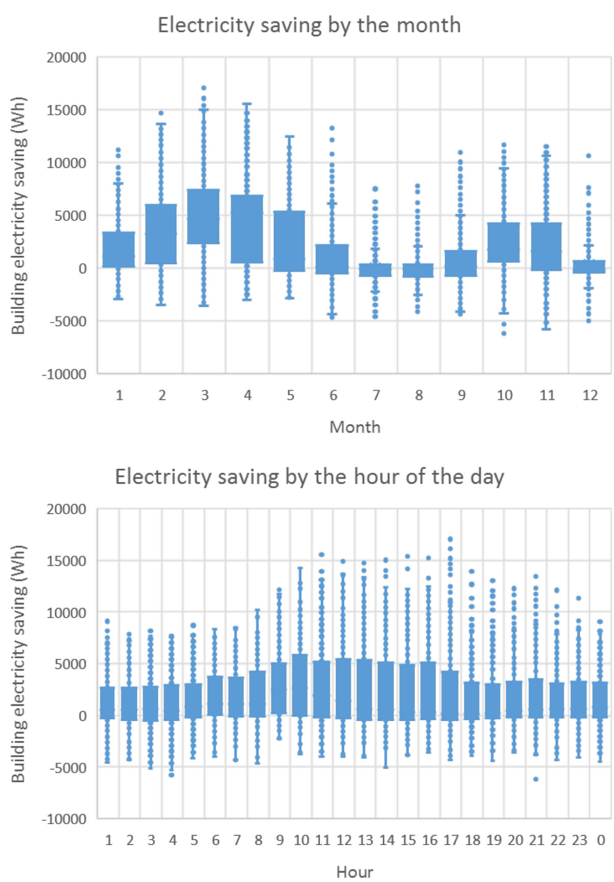


Figure 95 - The magnitude of energy saving at different time periods

Each dot represents the condition in one hour of the year

Further to Figure 92, Figure 95 shows that the savings are strong during the shoulder seasons. These are the periods that the outdoor weather is fluctuating and the baseline controls lack an operation pattern. This is also confirmed by Figure 96 which shows that the modified controls are better for the lower temperatures, but the same cannot be said about electricity consumption at temperatures above 18 °C. That is where the baseline control enters the cooling mode and keeps the slabs at a constant temperature. Until when the outdoor air temperature is not near its annual peak, this strategy works better energy-wise than the modified control.

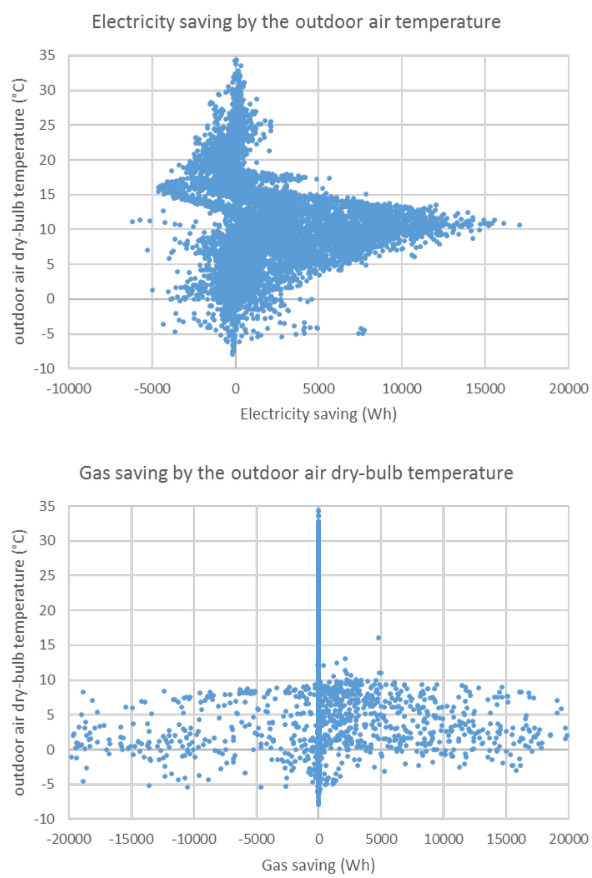


Figure 96 - Correlation of OAT and the energy saved by the modified control

Each dot represents the condition in one hour of the year

Figure 97 shows the savings at different levels of classrooms' occupancy. At high occupancy (mornings and afternoons on school days), the modified controls perform far better than the baseline. At low occupancy, boiler operation is variant and gas consumption saving could not be demonstrated. These are typically the idle times during the cold months when the mechanical system attempts to compensate for the temperature loss of the spaces.

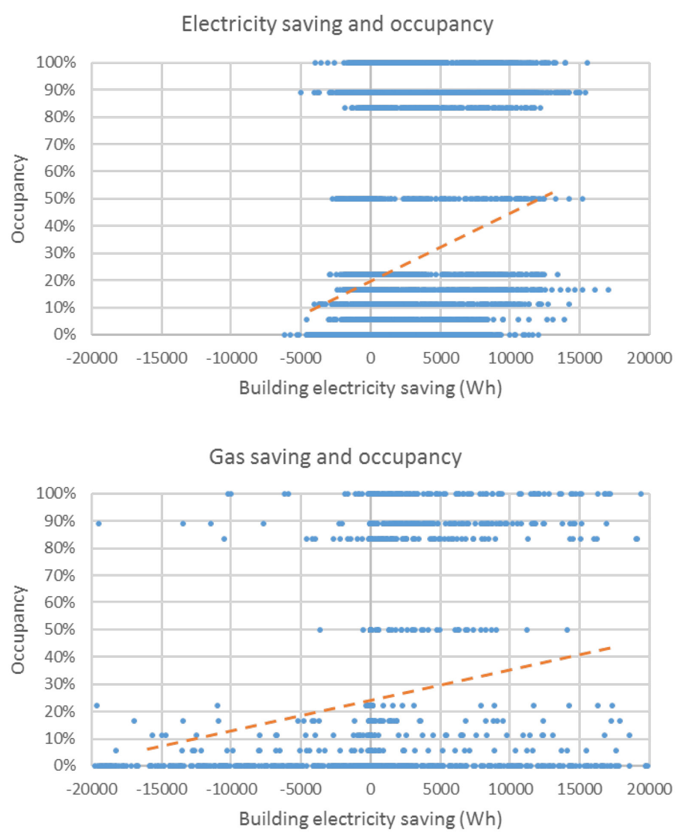


Figure 97 - Correlation of occupancy and the energy saved by the modified control

Each dot represents the condition in one hour of the year, orange dashes are the trendlines

In total, the building's electricity consumption was reduced by 3.1% and the gas consumption was reduced by 6.3%, with the majority of the reduction at times that the occupant activity in the building is high. That is during the school period at day time.

9.7 Section Conclusion

Several items play key roles in the process of building modeling. It is important to ensure the construction, the mechanical system, and the loads represent the real building. Thus, data gathered from the building played an essential role in reaching the satisfactory level of accuracy. The data processing methods, aggregation and path-smoothing made the energy consumption profile more understandable and possibly closer to reality. For uncertainties, alternatives were implemented and evaluated with the building data.

The calibrated WBEM shows that the modified control, taken from the classroom-level model, positively impacts the building's consumption without compromising the indoor temperature. The consumption reduction is relatively more at the high occupancy times of the building and during the shoulder season.

10 Summary and Conclusion

This study described the process of improving the demand-side controls of a case-study High-Performance Academic Building (HPAB) with the assistance of the control modeling options in EnergyPlus. The overarching goal of the study was addressing the Performance Gap, between predicted and actual performance, in the building. The focus was on improving the demand-side controls at the classroom level, where the previous research shows the indoor environment quality impacts student performance.

Reviewing the original Whole Building Energy Model (WBEM) that was made available by the designers, revealed three potential causes of discrepancy that may have contributed to the Performance Gap in the case-study building. These areas are: the ability of the software to model complex mechanical systems and controls existing in the building, the modeled building shell, and the model constructions. A new WBEM of the building was created as part of this study, and calibrated as per ASHRAE Guideline 14-2014, to rectify these problems and help evaluate the whole-building energy performance impacts of improved demand-side controls.

A challenge in the case-study building was working with two independent terminal systems on the demand-side of the mechanical system: the radiant slabs as well as the air systems, serving spaces at the same time. This means that the two systems are interacting with each other while their controls have no connection. For using building simulation in this context, accurate representation of the controls within the simulation environment is critical; therefore, customized building control options of the simulation software, EnergyPlus, were utilized to simulate the control responses within the model.

To observe the interaction of the two systems in a small scale, a classroom level model was created and calibrated. Five operation strategies were tested in this model which included using a thermal comfort model, average outdoor air reset, and constant temperatures. A strategy with temperature reset showed the best performance for the defined metrics.

The best strategy found of the classroom level model was implemented in the WBEM. The strategy reduced the overall electricity and gas consumption largely by more efficient energy delivery to the terminal systems and stable operation during the most active hours of the building.

10.1 Further Work

To improve and validate the proposed classroom-level controls, and for overcoming the possible weaknesses of the research (e.g. the detailed occupancy data), the use and operation of representative selected classrooms should be closely monitored, including its boundary conditions. The monitoring should include sensors to track: indoor occupancy presence and number, indoor environmental conditions, radiant floor, air supply, and window temperatures, and windows and room door open/close operation. Site testing of air supply flow rate and temperature from the VAVs and room pressure differentials at the door under various VAV airflow conditions would also help better define the boundary conditions for the classrooms models. All these measurements could be coupled with satisfaction questionnaires to the room occupants. This will also help engage the students and faculty and learn how the indoor environment may affect their learning.

The fact that this building was designed for mixed-mode ventilation (all classrooms have operable windows) brings several questions: how are these windows being operated by occupants? How is this operation affecting the indoor environment and the terminal systems operation? How is it impacting whole building energy performance? Answering these questions requires classroom level monitoring as described above. Assessing building performance under mixed-mode ventilation is an active subject of research. This will help improving the classroom level controls to account for such occupants' interactions with windows, and ultimately help develop more advanced control strategies that consider the active role of occupants in affecting the indoor environment. Anecdotal evidence from our visits to the building revealed that when the room radiant and air systems were not making occupants comfortable, during high occupancy, they opened the windows to achieve comfort even in the cold months.

References

[1] IBM, “Smarter Buildings: Using data to drive optimised building performance,” 2012.

[2] Office of Energy Efficiency Natural Resources Canada, *Commercial and Institutional Consumption of Energy Survey, Summary Report 2005*, no. June 2007. 2010.

[3] I. Korolija, L. Marjanovic-Halburd, Y. Zhang, and V. I. Hanby, “Influence of building parameters and HVAC systems coupling on building energy performance,” *Energy Build.*, vol. 43, no. 6, pp. 1247–1253, 2011.

[4] P. De Wilde, “The gap between predicted and measured energy performance of buildings: A framework for investigation,” *Autom. Constr.*, vol. 41, pp. 40–49, 2014.

[5] C. Miller, Z. Z. Nagy, and A. Schlueter, “Automated daily pattern filtering of measured building performance data,” *Autom. Constr.*, vol. 49, no. PA, pp. 1–17, 2015.

[6] B. D. Hunn, J. Bochat, and I. Process, “Measurement Of Commercial Building Performance,” *ASHRAE J.*, no. July, pp. 66–72, 2012.

[7] S. H. Cho and M. Zaheer-uddin, “Predictive Control of intermittently operated radiant floor heating system,” *Energy Convers. Manag.*, vol. 49, pp. 1333–1342, 2003.

[8] T. I. Salsbury and S. Ashish, “Control System Commissioning for Enhanced Building Operations,” *Proc. 3rd Int. Conf. Enhanc. Build. Oper. Oct. 13-15*, vol. 1, no. 414, pp. 1–9, 2003.

[9] Pacific Gas & Electric Company, “A General Commissioning Acceptance Procedure for DDC Systems.” 2002.

[10] M. A. Hatton, T. Sullivan, and L. Newlands, "Optimizing building controls during commissioning," *ASHRAE J.*, vol. 52, no. 12, pp. 22–27, 2010.

[11] K. Horsley, "CIBSE Case Study : Innovative Ground - Source Energy System in University," no. August, 2013.

[12] M. Donnelly, "Building Energy Management : Using Data as a Tool, Issue Brief," *Inst. Build. Effic.*, p. 9, 2012.

[13] D. M. Ogoli, "Predicting indoor temperatures in closed buildings with high thermal mass," *Energy Build.*, vol. 35, no. 9, pp. 851–862, 2003.

[14] T. Lu, M. Viljanen, Tao Lu, and M. Viljanen, "Prediction of indoor temperature and relative humidity using neural network models: model comparison," *Neural Comput. Appl.*, vol. 18, no. 4, pp. 345–57, 2009.

[15] A. E. Ruano, E. M. Crispim, E. Z. E. Conceição, and M. M. J. R. Lúcio, "Prediction of building's temperature using neural networks models," *Energy Build.*, vol. 38, no. 6, pp. 682–694, 2006.

[16] B. Dirkes, James V. ; Weaver, "Modeled performance isn't actual performance," *ASHRAE J.*, 2016.

[17] S. Urlaub, G. Grün, P. Foldbjerg, and K. P. Sedlbauer, "The impact of ventilation and daylight on learning in schools – a summary of the actual state of knowledge," 2016.

[18] M. Turunen, U. Haverinen-shaughnessy, O. Toyinbo, R. Shaughnessy, M. Turunen, T. Putus, J. Metsämuuronen, J. Kurnitski, and U. Haverinen-shaughnessy, "Building characteristics, indoor environmental quality, and mathematics achievement in

Finnish elementary schools," *Build. Environ.*, vol. 104, no. May, pp. 114–121, 2016.

[19] U. Haverinen-Shaughnessy and R. J. Shaughnessy, "Effects of classroom ventilation rate and temperature on students' test scores," *PLoS One*, vol. 10, no. 8, 2015.

[20] T. Hoyt, K. H. Lee, H. Zhang, E. Arens, and TomWebster, "Energy savings from extended air temperature setpoints and reductions in room air mixing," 2005.

[21] M. J. Mendell, E. A. Eliseeva, M. M. Davies, M. Spears, A. Lobscheid, W. J. Fisk, and M. G. Apte, *Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools*, vol. 23, no. 6. 2013.

[22] University of Saskatchewan Facilities Management Division, "University of Saskatchewan Design Manual." .

[23] Daikin, "School HVAC Design Guide," 2007.

[24] Toronto District School Board, "Regular Meeting of June 17, 2015."

[25] Stanford University, "Stanford University Server / Telecom Rooms Design Guide." pp. 1–29, 2011.

[26] E. M. Sterling, J. F. Steeves, and C. D. Wrigley, "Building Performance Database," in *International Conference on Building Use and Safety Technology*, 1986, pp. 218–222.

[27] Lawrence Berkeley National Laboratory, "Building Performance Database," 2017. [Online]. Available: bpd.lbl.gov.

[28] B. K. Tannahill and M. Jamshidi, "System of Systems and Big Data analytics – Bridging the gap," *Comput. Electr. Eng.*, vol. 40, no. 1, pp. 2–15, 2014.

[29] K. W. Kim and B. W. Olesen, “Radiant Heating and Cooling Systems: Part two,” *Ashrae J.*, vol. 57, no. 3, pp. 34–42, 2015.

[30] E. Fabrizio, S. P. Corgnati, F. Causone, and M. Filippi, “Numerical comparison between energy and comfort performances of radiant heating and cooling systems versus air systems,” *HVAC&R Res.*, vol. 18, pp. 37–41, 2013.

[31] St. A. Mumma, “HVAC: the next generation,” 2003.

[32] M. S. Addison, “Cooling via Underfloor Air Distribution : Current Design Issues and Analysis Options,” 2001.

[33] B. Dong and K. P. Lam, “A real-time model predictive control for building heating and cooling systems based on the occupancy behavior pattern detection and local weather forecasting,” *Build. Simul.*, vol. 7, no. 1, pp. 89–106, 2014.

[34] S. Privara, J. Cigler, Z. Vana, F. Oldewurtel, C. Sagerschnig, and E. Zacekova, “Building modeling as a crucial part for building predictive control,” *Energy Build.*, vol. 56, pp. 8–22, 2013.

[35] D. Kriksciuniene, T. Pitner, A. Kučera, and V. Sakalauskas, “Data Analysis in the Intelligent Building Environment,” *Int. J. Comput. Sci. Appl.*, vol. 11, no. 1, pp. 1–17, 2014.

[36] U. Habib, K. Hayat, and G. Zucker, “Complex building’s energy system operation patterns analysis using bag of words representation with hierarchical clustering,” *Complex Adapt. Syst. Model.*, vol. 4, no. 1, p. 8, 2016.

[37] J. Moffat, *Complexity Theory and Netowkr Centric Warfare*. 2003.

[38] B. Lehmann, V. Dorer, M. Gwerder, F. Renggli, and J. Tödtli, “Thermally activated

building systems (TABS): Energy efficiency as a function of control strategy, hydronic circuit topology and (cold) generation system," *Appl. Energy*, vol. 88, no. 1, pp. 180–191, 2011.

[39] M. Gwerder, J. Tödtli, B. Lehmann, F. Renggli, and V. Dorer, "Control of Thermally Activated Building Systems," *9th REHVA World Congr. Build. Technol.*, vol. 85, no. 7, 2007.

[40] D. Westphalen and S. Koszalinski, "Energy Consumption Characteristics of Commercial Building HVAC Systems. Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation," *Arthur D. Little Inc*, vol. 20, no. October, 1999.

[41] Control Solutions Inc., "The Utimate Guide to Building Automation," 2015. [Online]. Available: http://controlyourbuilding.com/blog/entry/the-ultimate-guide-to-building-automation. [Accessed: 30-Nov-2016].

[42] Hathaway Dinwiddie, "HVAC Sequences of Operation Stanford SEQ2 - Rev. 1," 2007.

[43] M. Hydeman and B. Eubanks, "ASHRAE RP-1455 : Advanced Control Sequences for HVAC Systems Phase I," 2014.

[44] PRISM Engineers, "4th Annual PUMA Benchmarking Summary For BC Advanced Education: 2016 Calendar Year," 2016.

[45] E. Baskin, "Evaluation of Hydronic Forced-Air and Radiant Siab Heating and Cooling Systems," *ASHRAE Trans*, pp. 525–534, 2005.

[46] K. Haddad, J. Purdy, and A. Laouadi, "Comparison of the Performance of a Forced-Air and a Radiant Floor Residential Heating System Connected to Solar Collectors," *J. Sol. Energy Eng.*, vol. 129, no. November, pp. 465–72, 2007.

[47] G. SASTRY and P. RUMSEY, “VAV vs . Radiant Side-by-Side Comparison,” *ASHRAE J.*, no. May, 2014.

[48] U. Frossell and P. Lindskog, “Combining semi-physical and neural network modeling: An example of its usefulness,” *Proc. 11th IFAC Symp. Syst. Identif.*, vol. 24, pp. 795–798, 1997.

[49] N. Nassif, S. Moujaes, and M. Zaheeruddin, “Self-tuning dynamic models of HVAC system components,” *Energy Build.*, vol. 40, no. 9, pp. 1709–1720, 2008.

[50] Y. Kwak, D. Seo, C. Jang, and J. H. Huh, “Feasibility study on a novel methodology for short-term real-time energy demand prediction using weather forecasting data,” *Energy Build.*, vol. 57, pp. 250–260, 2013.

[51] H. Huang, L. Chen, and E. Hu, “A new model predictive control scheme for energy and cost savings in commercial buildings: An airport terminal building case study,” *Build. Environ.*, vol. 89, pp. 203–216, 2015.

[52] B. Thomas and M. Soleimani-Mohseni, “Artificial neural network models for indoor temperature prediction: Investigations in two buildings,” *Neural Comput. Appl.*, vol. 16, no. 1, pp. 81–89, 2007.

[53] M. W. Ahmad, M. Mourshed, B. Yuce, and Y. Rezgui, “Computational intelligence techniques for HVAC systems: A review,” *Build. Simul.*, vol. 9, no. 4, pp. 359–398, 2016.

[54] D. H. Wolpert and W. G. Macready, “No free lunch theorems for optimization,” *IEEE Trans. Evol. Comput.*, vol. 1, no. 1, pp. 67–82, 1997.

[55] Z. Yu, B. C. M. Fung, and F. Haghighat, “Extracting knowledge from building-related

data - A data mining framework," *Build. Simul.*, vol. 6, no. 2, pp. 207–222, 2013.

[56] S. C. Bengea, A. D. Kelman, F. Borrelli, and R. Taylor, "Model Predictive Control for Mid-Size Commercial Building HVAC : Implementation , Results and Energy Savings," *HVAC&R Res.*, vol. 20, pp. 979–986, 2014.

[57] F. Oldewurtel, A. Parisio, C. N. Jones, D. Gyalistras, M. Gwerder, V. Stauch, B. Lehmann, and M. Morari, "Use of model predictive control and weather forecasts for energy efficient building climate control," *Energy Build.*, vol. 45, pp. 15–27, 2012.

[58] J. Cigler, D. Gyalistras, J. Siroky, V.-N. Tiet, and L. Ferkl, "Beyond Theory: the Challenge of Implementing Model Predictive Control in Buildings," in *Clima 2013 - 11th REHVA World Congress & 8th International Conference on IAQVEC - "Energy Efficient, Smart and Healthy Buildings,"* 2013, pp. 1008–1018.

[59] J. . A. Clarke, J. Cockroft, S. Conner, J. W. Hand, N. J. Kelly, R. Moore, T. O. Brien, P. Strachan, T. O'Brien, and P. Strachan, "Simulation-assisted control in building energy management systems," *Energy Build.*, vol. 34, no. 9, pp. 933–940, 2002.

[60] S. Prívara, Z. Váňa, E. Žáčeková, and J. Cigler, "Building modeling: Selection of the most appropriate model for predictive control," *Energy Build.*, vol. 55, pp. 341–350, 2012.

[61] S. Privara, Z. Vana, D. Gyalistras, J. Cigler, C. Sagerschnig, M. Morari, and L. Ferkl, "Modeling and identification of a large multi-zone office building," *Int. Conf. Control Appl.*, no. September, pp. 55–60, 2011.

[62] X. Li, J. Wen, and E. W. Bai, "Developing a whole building cooling energy forecasting model for on-line operation optimization using proactive system identification,"

Appl. Energy, vol. 164, no. August, pp. 69–88, 2016.

[63] C. Sagerschnig, D. Gyalistras, A. Seerig, S. Privara, and Z. Vana, “Co-simulation for building controller development: the case study of a modern office building,” *Proc. CISBAT*, no. 2005, pp. 955–960, 2011.

[64] D. B. Crawley, J. W. Hand, M. Kummert, and B. T. Griffith, “Contrasting the capabilities of building energy performance simulation programs,” *Build. Environ.*, vol. 43, no. 4, pp. 661–673, 2008.

[65] S. Prívara, “Building Modeling and Identification for Predictive Control,” Czech Technical University in Prague, 2013.

[66] O. Baumann, “Design and Optimization of Control Strategies and Parameters by Building and System Simulation,” 2003.

[67] M. Gwerder, D. Gyalistras, F. Oldewurtel, B. Lehmann, V. Stauch, and J. Tödtli, “Potential Assessment of Rule-Based Control for Integrated Room Automation,” *10th REHVA World Congr.*, pp. 9–12, 2010.

[68] Y. Ma, A. Kelman, A. Daly, and F. Borrelli, “Predictive Control for Energy Efficient Buildings with Thermal Storage: Modeling, Stimulation, and Experiments,” *IEEE Control Syst.*, vol. 32, no. 1, pp. 44–64, 2012.

[69] B. Boardass and A. Leaman, “CIBSE Case Study : Investigation of 90s Building for Energy Performance,” *CIBSE J.*, 2012.

[70] A. A. Argiriou, I. Bellas-Velidis, and C. A. Balaras, “Development of a neural network heating controller for solar buildings,” *Neural Networks*, vol. 13, no. 7, pp. 811–820, 2000.

[71] ABB Group, “Application information (PID Control), 2104301-001-rev. AB.” 2011.

[72] R. Rogers, “Building a Benchtop PID Controller,” *Keithley Instruments*, no. 3243, 2013.

[73] Q. Bi, W. J. Cai, Q. G. Wang, C. C. Hang, Eng-Lock Lee, Y. Sun, K. D. Liu, Y. Zhang, and B. Zou, “Advanced controller auto-tuning and its application in HVAC systems,” *Control Eng. Pract.*, vol. 8, no. 6, pp. 633–644, 2000.

[74] A. Afram and F. Janabi-Sharifi, “Theory and applications of HVAC control systems - A review of model predictive control (MPC),” *Build. Environ.*, vol. 72, 2014.

[75] L. Smith, “Strategies for Sustainablity,” *ASHRAE Journal'*, pp. 34–38, 2013.

[76] G. Tardioli, R. Kerrigan, M. Oates, J. O‘Donnell, and D. Finn, “Data Driven Approaches for Prediction of Building Energy Consumption at Urban Level,” *Energy Procedia*, vol. 78, pp. 3378–3383, 2015.

[77] IPMVP, “Concepts and Options for Determining energy and Water Savings,” *Int. Perform. Meas. Verif. Protoc.*, vol. 1, 2002.

[78] M. Gruber, A. Truschel, and J. O. Dalenback, “Combining performance and implementability of model-based controllers for indoor climate control in office environments,” *Build. Environ.*, vol. 82, pp. 228–236, 2014.

[79] A. Kusiak and M. Li, “Optimal decision making in ventilation control,” *Energy*, vol. 34, no. 11, pp. 1835–1845, 2009.

[80] X. Xu, S. Wang, Z. Sun, and F. Xiao, “A model-based optimal ventilation control strategy of multi-zone VAV air-conditioning systems,” *Appl. Therm. Eng.*, vol. 29, no. 1, pp. 91–104, 2009.

[81] Y. Wang, J. Kuckelkorn, F. Y. Zhao, D. Liu, A. Kirschbaum, and J. L. Zhang, “Evaluation on classroom thermal comfort and energy performance of passive school building by optimizing HVAC control systems,” *Build. Environ.*, vol. 89, pp. 86–106, 2015.

[82] L. M. Candanedo and V. Feldheim, “Accurate occupancy detection of an office room from light, temperature, humidity and CO2 measurements using statistical learning models,” *Energy Build.*, vol. 112, pp. 28–39, 2016.

[83] Y. Zhao, W. Zeiler, G. Boxem, and T. Labeodan, “Virtual occupancy sensors for real-time occupancy information in buildings,” *Build. Environ.*, vol. 93, pp. 9–20, 2015.

[84] J. Lund, B. Sanner, L. Rybach, R. Curtis, and G. Hellström, “Geothermal (Ground-Source) Heat Pumps a World Overview,” *Geo-Heat Cent. Q. Bull.*, 2004.

[85] P. Raftery, M. Keane, and A. Costa, “Calibrating whole building energy models: Detailed case study using hourly measured data,” *Energy Build.*, vol. 43, no. 12, pp. 3666–3679, 2011.

[86] U.S. Department of Energy, *EnergyPlus Engineering Reference: The Reference to EnergyPlus Calculations*. 2015.

[87] A. Tzoulis, “Performance assessment of building energy modelling programs and control optimization of thermally activated building systems,” *Delft Univ. Technol.*, 2014.

[88] ASHRAE, *Guideline 14-2014: Measurement of energy and demand savings*. 2014.

[89] M. Royapoor and T. Roskilly, “Building model calibration using energy and environmental data,” *Energy Build.*, vol. 94, pp. 109–120, 2015.

[90] R. Troncoso, “A hybrid monitoring-modeling procedure for analyzing the performance of large central chilling plants,” *Proc. 6th Int. IBPSA Conf.*, vol. 97, pp. 421–428, 1997.

[91] U.S. Depratment of Energy, *Input Output Reference, EnergyPlus Version 8.7 Documentation*. 2016.

[92] Vancouver Island University, “Timetable.” [Online]. Available: https://isapp.viu.ca/srs/timetable.htm. [Accessed: 19-Dec-2017].

[93] D. Wahlers, “Payback analysis for ground source heat pump retrofits using eQuest modeling software,” 2011.

[94] S. Srivastava-Modi, “Evaluating the ability of eQUEST software to simulate low-energy buildings in a cold climate region.,” 2011.

[95] Lawrence Berkeley National Laboratory and Group Q-11, *DOE-2 Engineers Manual, Version 2.1A*. Berkeley, CA, 1982.

[96] U.S. Department of Energy, *Application Guide for EMS, EnergyPlus Version 8.7 Documentaion*. 2016.

[97] ASHRAE, *Guideline 36P: High Performance Sequences of Operation for HVAC Systems, First Public Review*. 2016.

[98] T. X. Nghiem, G. J. Pappas, and R. Mangharam, “Event-based Green Scheduling of Radiant Systems in Buildings.”

[99] The Weather Company LLC, “Weather History for Victoria, Canada | Weather Underground.” [Online]. Available: https://www.wunderground.com/history/airport/CYYJ/. [Accessed: 11-Jun-2017].

[100] School-Based Weather Station Network, “Quamichan Middle School Weather Data,” *April 8, 2016*. [Online]. Available: http://www.victoriaweather.ca/station.php?id=126. [Accessed: 12-Jun-2017].

[101] R. Perez, P. Ineichen, E. Maxwell, R. Seals, and A. Zelenka, “Dynamic global-to-direct irradiance conversion models,” *ASHRAE Trans.*, vol. 98, no. 1, pp. 354–369, 1992.

[102] R. . Perez, R.; Ineichen, P.; Seals, R.; Michalasky, J.; Stewart, “Modeling daylight availability and irradiance components from direct and global irradiance,” *Sol. Energy*, vol. 44, no. 5, pp. 271–289, 1990.

[103] Big Ladder Software, “Elements,” *May 24, 2017*. [Online]. Available: http://bigladdersoftware.com/projects/elements/. [Accessed: 12-Jun-2017].

[104] M. J. Witte, “Example Biquadratic Curve Fit using LINEST function,” *GARD Analytics, Inc.* [Online]. Available: energyplus.helpserve.com/Knowledgebase/Article/GetAttachment/135/5844. [Accessed: 03-Oct-2017].

[105] A. Savitzky and M. J. E. Golay, “Smoothing and Differentiation of Data by Simplified Least Squares Procedures,” *Anal. Chem.*, vol. 36, no. 8, pp. 1627–1639, 1964.

[106] R. W. Schafer, “What is a savitzky-golay filter?,” *IEEE Signal Process. Mag.*, vol. 28, no. 4, pp. 111–117, 2011.

[107] W. Liang, “Modeling and Control of AHUs in Building HVAC Systems,” 2014.

```
Schedule:Compact,
  On 24/7,              !- Name
  Any Number,           !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: AllDays,         !- Field 2
  Until: 24:00,         !- Field 3
  1;                    !- Field 4
Schedule:Compact,
  Summer (Northern Hemisphere),  !- Name
  Fraction,             !- Schedule Type Limits Name
  Through: 1 Apr,       !- Field 1
  For: AllDays,         !- Field 2
  Until: 24:00,         !- Field 3
  0,                    !- Field 4
  Through: 30 Sep,      !- Field 5
  For: AllDays,         !- Field 6
  Until: 24:00,         !- Field 7
  1,                    !- Field 8
  Through: 31 Dec,      !- Field 9
  For: AllDays,         !- Field 10
  Until: 24:00,         !- Field 11
  0;                    !- Field 12
Schedule:Compact,
  Thermostat Cooling set point schedule,  !- Name
  Any Number,           !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: AllDays,         !- Field 2
  Until: 24:00,         !- Field 3
  20.5;                 !- Field 4
Schedule:Compact,
  Thermostat Heating set point schedule,  !- Name
  Any Number,           !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: AllDays,         !- Field 2
  Until: 24:00,         !- Field 3
  20.5;                 !- Field 4
Schedule:Compact,
  Control type schedule: Always 4,  !- Name
  Any Number,           !- Schedule Type Limits Name
  Through: 12/31,       !- Field 1
  For: AllDays,         !- Field 2
  Until: 24:00,         !- Field 3
  4;                    !- Field 4
Schedule:Compact,
- VIU - eQuest infiltration,  !- Name
Fraction,             !- Schedule Type Limits Name
Through: 06 Jan,      !- Field 1
For: AllDays,         !- Field 2
Until: 24:00,         !- Field 3
0.874174775,          !- Field 4
Through: 26 Jun,      !- Field 5
For: Weekdays,        !- Field 6
Until: 5:00,          !- Field 7
0.874174775,          !- Field 8
Until: 6:00,          !- Field 9
0.889359653,          !- Field 10
Until: 7:00,          !- Field 11
1,                    !- Field 12
Until: 9:00,          !- Field 13
0.83951348,           !- Field 14
Until: 10:00,         !- Field 15
0.511831327,          !- Field 16
Until: 11:00,         !- Field 17
0.518055517,          !- Field 18
Until: 12:00,         !- Field 19
0.513870286,          !- Field 20
Until: 13:00,         !- Field 21
0.437087388,          !- Field 22
Until: 14:00,         !- Field 23
0.496646449,          !- Field 24
Until: 16:00,         !- Field 25
0.83951348,           !- Field 26
Until: 17:00,         !- Field 27
0.621666822,          !- Field 28
Until: 18:00,         !- Field 29
0.903632365,          !- Field 30
Until: 19:00,         !- Field 31
0.885925617,          !- Field 32
Until: 20:00,         !- Field 33
0.958040373,          !- Field 34
Until: 21:00,         !- Field 35
0.97038144,           !- Field 36
Until: 22:00,         !- Field 37
0.924343895,          !- Field 38
Until: 23:00,         !- Field 39
0.884476883,          !- Field 40
Until: 24:00,         !- Field 41
0.874174775,          !- Field 42
```

For: AllOtherDays, !- Field 43
Until: 6:00, !- Field 44
0.874174775, !- Field 45
Until: 7:00, !- Field 46
0.966837301, !- Field 47
Until: 8:00, !- Field 48
0.986069146, !- Field 49
Until: 9:00, !- Field 50
0.874174775, !- Field 51
Until: 10:00, !- Field 52
0.437087388, !- Field 53
Until: 14:00, !- Field 54
0.536743312, !- Field 55
Until: 15:00, !- Field 56
0.437087388, !- Field 57
Until: 16:00, !- Field 58
0.874174775, !- Field 59
Until: 18:00, !- Field 60
0.947605456, !- Field 61
Until: 24:00, !- Field 62
0.874174775, !- Field 63
Through: 28 Jun, !- Field 64
For: AllDays, !- Field 65
Until: 24:00, !- Field 66
0.874174775, !- Field 67
Through: 4 Sep, !- Field 68
For: Weekdays, !- Field 69
Until: 8:00, !- Field 70
0.874174775, !- Field 71
Until: 9:00, !- Field 72
0.512703506, !- Field 73
Until: 10:00, !- Field 74
0.45675632, !- Field 75
Until: 17:00, !- Field 76
0.437087388, !- Field 77
Until: 24:00, !- Field 78
0.874174775, !- Field 79
For: AllOtherDays, !- Field 80
Until: 6:00, !- Field 81
0.874174775, !- Field 82
Until: 7:00, !- Field 83
0.898651669, !- Field 84
Until: 8:00, !- Field 85
0.908267591, !- Field 86
Until: 16:00, !- Field 87
0.874174775, !- Field 88
Until: 17:00, !- Field 89
0.889035746, !- Field 90
Until: 18:00, !- Field 91
0.889035746, !- Field 92
Until: 24:00, !- Field 93
0.874174775, !- Field 94
Through: 06 Sep, !- Field 95
For: AllDays, !- Field 96
Until: 24:00, !- Field 97
0.874174775, !- Field 98
Through: 18 Dec, !- Field 99
For: Weekdays, !- Field 100
Until: 5:00, !- Field 101
0.874174775, !- Field 102
Until: 6:00, !- Field 103
0.889359653, !- Field 104
Until: 7:00, !- Field 105
1, !- Field 106
Until: 9:00, !- Field 107
0.83951348, !- Field 108
Until: 10:00, !- Field 109
0.511831327, !- Field 110
Until: 11:00, !- Field 111
0.518055517, !- Field 112
Until: 12:00, !- Field 113
0.513870286, !- Field 114
Until: 13:00, !- Field 115
0.437087388, !- Field 116
Until: 14:00, !- Field 117
0.496646449, !- Field 118
Until: 16:00, !- Field 119
0.83951348, !- Field 120
Until: 17:00, !- Field 121
0.621666822, !- Field 122
Until: 18:00, !- Field 123
0.903632365, !- Field 124
Until: 19:00, !- Field 125
0.885925617, !- Field 126
Until: 20:00, !- Field 127
0.958040373, !- Field 128
Until: 21:00, !- Field 129
0.97038144, !- Field 130

```
    Until: 22:00,          !- Field 131
    0.924343895,           !- Field 132
    Until: 23:00,          !- Field 133
    0.884476883,           !- Field 134
    Until: 24:00,          !- Field 135
    0.874174775,           !- Field 136
    For: AllOtherDays,     !- Field 137
    Until: 6:00,           !- Field 138
    0.874174775,           !- Field 139
    Until: 7:00,           !- Field 140
    0.966837301,           !- Field 141
    Until: 8:00,           !- Field 142
    0.986069146,           !- Field 143
    Until: 9:00,           !- Field 144
    0.874174775,           !- Field 145
    Until: 10:00,          !- Field 146
    0.437087388,           !- Field 147
    Until: 14:00,          !- Field 148
    0.536743312,           !- Field 149
    Until: 15:00,          !- Field 150
    0.437087388,           !- A153
    Until: 16:00,          !- A154
    0.874174775,           !- A155
    Until: 18:00,          !- A156
    0.947605456,           !- A157
    Until: 24:00,          !- A158
    0.874174775,           !- A159
    Through: 31 Dec,       !- A160
    For: AllDays,          !- A161
    Until: 24:00,          !- A162
    0.874174775;           !- A163
Schedule:Compact,
    - VIU - tweaked lights,  !- Name
    Fraction,              !- Schedule Type Limits Name
    Through: 1 July,       !- Field 1
    For: Weekdays,         !- Field 2
    Until: 07:00,          !- Field 3
    0.18,                  !- Field 4
    Until: 08:00,          !- Field 5
    0.454,                 !- Field 6
    Until: 12:00,          !- Field 7
    0.9,                   !- Field 8
    Until: 13:00,          !- Field 9
    0.75,                  !- Field 10
    Until: 16:00,          !- Field 11
    0.9,                   !- Field 12
    Until: 21:00,          !- Field 13
    0.5,                   !- Field 14
    Until: 22:00,          !- Field 15
    0.1869,                !- Field 16
    Until: 23:00,          !- Field 17
    0.0824,                !- Field 18
    Until: 24:00,          !- Field 19
    0.0531,                !- Field 20
    For: AllOtherDays,     !- Field 21
    Until: 24:00,          !- Field 22
    0.5,                   !- Field 23
    Through: 1 Dec,        !- Field 24
    For: Monday Tuesday Wednesday Thursday Friday Sunday,  !- Field 25
    Until: 07:00,          !- Field 26
    0.18,                  !- Field 27
    Until: 08:00,          !- Field 28
    0.454,                 !- Field 29
    Until: 12:00,          !- Field 30
    0.9,                   !- Field 31
    Until: 13:00,          !- Field 32
    0.75,                  !- Field 33
    Until: 16:00,          !- Field 34
    0.9,                   !- Field 35
    Until: 21:00,          !- Field 36
    0.5,                   !- Field 37
    Until: 22:00,          !- Field 38
    0.1869,                !- Field 39
    Until: 23:00,          !- Field 40
    0.0824,                !- Field 41
    Until: 24:00,          !- Field 42
    0.0531,                !- Field 43
    For: Saturday,         !- Field 44
    Until: 24:00,          !- Field 45
    0.05,                  !- Field 46
    For: AllOtherDays,     !- Field 47
    Until: 24:00,          !- Field 48
    0.5,                   !- Field 49
    Through: 21 Dec,       !- Field 50
    For: Alldays,          !- Field 51
    Until: 24:00,          !- Field 52
    .5,                    !- Field 53
    Through: 31 Dec,       !- Field 54
```

```
    For: Alldays,          !- Field 55
    Until: 06:00,          !- Field 56
    0.05,                  !- Field 57
    Until: 07:00,          !- Field 58
    0.051,                 !- Field 59
    Until: 08:00,          !- Field 60
    0.0535,                !- Field 61
    Until: 16:00,          !- Field 62
    0.054,                 !- Field 63
    Until: 17:00,          !- Field 64
    0.0535,                !- Field 65
    Until: 18:00,          !- Field 66
    0.0521,                !- Field 67
    Until: 20:00,          !- Field 68
    0.0512,                !- Field 69
    Until: 22:00,          !- Field 70
    0.0502,                !- Field 71
    Until: 24:00,          !- Field 72
    0.05;                  !- Field 73
Schedule:Compact,
    - VIU - eQuest exterior lighting,  !- Name
    Fraction,              !- Schedule Type Limits Name
    Through: 31 Dec,       !- Field 1
    For: AllDays,          !- Field 2
    Until: 7:00,           !- Field 3
    0.603,                 !- Field 4
    Until: 17:00,          !- Field 5
    0,                     !- Field 6
    Until: 18:00,          !- Field 7
    0.504,                 !- Field 8
    Until: 22:00,          !- Field 9
    0.9,                   !- Field 10
    Until: 23:00,          !- Field 11
    0.801,                 !- Field 12
    Until: 24:00,          !- Field 13
    0.702;                 !- Field 14
Schedule:Compact,
    - VIU - HW loop Warm months 35 cold months 58,  !- Name
    Any Number,            !- Schedule Type Limits Name
    Through: 5/1,          !- Field 1
    For: AllDays,          !- Field 2
    Until: 24:00,          !- Field 3
    58,                    !- Field 4
    Through: 10/01,        !- Field 5
    For: AllDays,          !- Field 6
    Until: 24:00,          !- Field 7
    35,                    !- Field 8
    Through: 12/31,        !- Field 9
    For: AllDays,          !- Field 10
    Until: 24:00,          !- Field 11
    58;                    !- Field 12
Schedule:Compact,
    - VIU - High Slab 25.5,  !- Name
    Any Number,            !- Schedule Type Limits Name
    Through: 12/31,        !- Field 1
    For: AllDays,          !- Field 2
    Until: 24:00,          !- Field 3
    25.5;                  !- Field 4
! Schedule: - VIU - Low slab 18.8
Schedule:Compact,
    - VIU - Low slab 18.8,   !- Name
    Any Number,            !- Schedule Type Limits Name
    Through: 12/31,        !- Field 1
    For: AllDays,          !- Field 2
    Until: 24:00,          !- Field 3
    18.8;                  !- Field 4
Schedule:Compact,
    Clothing Insulation Calculation Schedule,  !- Name
    Any Number,            !- Schedule Type Limits Name
    Through: 31 Dec,       !- Field 9
    For: AllDays,          !- Field 10
    Until: 24:00,          !- Field 11
    2;                     !- Field 12
Schedule:Compact,
    ASHRAE 90.1 Occupancy - School,  !- Name
    Fraction,              !- Schedule Type Limits Name
    Through: 31 Dec,       !- Field 1
    For: Weekdays,         !- Field 2
    Until: 07:00,          !- Field 3
    0,                     !- Field 4
    Until: 08:00,          !- Field 5
    0.05,                  !- Field 6
    Until: 09:00,          !- Field 7
    0.75,                  !- Field 8
    Until: 11:00,          !- Field 9
    0.90,                  !- Field 10
    Until: 15:00,          !- Field 11
    0.80,                  !- Field 12
```

```
Until: 16:00,          !- Field 13
0.45,                  !- Field 14
Until: 17:00,          !- Field 15
0.15,                  !- Field 16
Until: 18:00,          !- Field 17
0.05,                  !- Field 18
Until: 19:00,          !- Field 19
0.15,                  !- Field 20
Until: 21:00,          !- Field 21
0.20,                  !- Field 22
Until: 22:00,          !- Field 23
0.10,                  !- Field 24
Until: 24:00,          !- Field 25
0.00,                  !- Field 26
For: Saturday,         !- Field 27
Until: 08:00,          !- Field 28
0,                     !- Field 29
Until: 13:00,          !- Field 30
0.10,                  !- Field 31
Until: 24:00,          !- Field 32
0.00,                  !- Field 33
For: Sunday,           !- Field 34
Until: 24:00,          !- Field 35
0,                     !- Field 36
For: SummerDesignDay,  !- Field 37
Until: 08:00,          !- Field 38
0,                     !- Field 39
Until: 23:00,          !- Field 40
1,                     !- Field 41
Until: 24:00,          !- Field 42
0,                     !- Field 43
For: AllOtherDays,     !- Field 44
Until: 24:00,          !- Field 45
0;                     !- Field 46
```

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

Version,
    8.8;                     !- Version Identifier

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

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

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

Building,
    Classroom,               !- Name
    0,                       !- North Axis {deg}
    Suburbs,                 !- Terrain
    0.04,                    !- Loads Convergence Tolerance Value
    0.4,                     !- Temperature Convergence Tolerance Value {deltaC}
    FullExterior,            !- Solar Distribution
    25,                      !- Maximum Number of Warmup Days
    6;                       !- Minimum Number of Warmup Days

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

ShadowCalculation,
    AverageOverDaysInFrequency,  !- Calculation Method
    20,                      !- Calculation Frequency
    15000,                   !- Maximum Figures in Shadow Overlap Calculations
    SutherlandHodgman,       !- Polygon Clipping Algorithm
    SimpleSkyDiffuseModeling;!- Sky Diffuse Modeling Algorithm

!-   =========== ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:INSIDE ===========

SurfaceConvectionAlgorithm:Inside,
    TARP;                    !- Algorithm

!-   =========== ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:OUTSIDE ===========

SurfaceConvectionAlgorithm:Outside,
    DOE-2;                   !- Algorithm

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

HeatBalanceAlgorithm,
    ConductionTransferFunction,  !- Algorithm
    2000;                    !- Surface Temperature Upper Limit {C}

!-   =========== ALL OBJECTS IN CLASS: ZONECAPACITANCEMULTIPLIER:RESEARCHSPECIAL ===========

ZoneCapacitanceMultiplier:ResearchSpecial,
    Multiplier,              !- Name
    ,                        !- Zone or ZoneList Name
    1,                       !- Temperature Capacity Multiplier
    1.0,                     !- Humidity Capacity Multiplier
    1.0,                     !- Carbon Dioxide Capacity Multiplier
    1.0;                     !- Generic Contaminant Capacity Multiplier

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

Timestep,
    6;                       !- Number of Timesteps per Hour

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

ConvergenceLimits,
    1,                       !- Minimum System Timestep {minutes}
    25;                      !- Maximum HVAC Iterations

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

Site:Location,
    Site (01-01:31-12)  (01-01:31-12),  !- Name
    48.65,                   !- Latitude {deg}
    -123.43,                 !- Longitude {deg}
    -8,                      !- Time Zone {hr}
    20;                      !- Elevation {m}

!-   =========== ALL OBJECTS IN CLASS: SIZINGPERIOD:DESIGNDAY ===========

SizingPeriod:DesignDay,
    Summer Design Day in Site (01-01:31-12) Jul,  !- Name
    7,                       !- Month
    22,                      !- Day of Month
    SummerDesignDay,         !- Day Type
    29,                      !- Maximum Dry-Bulb Temperature {C}
    14,                      !- Daily Dry-Bulb Temperature Range {deltaC}
    ,                        !- Dry-Bulb Temperature Range Modifier Type
    ,                        !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    WetBulb,                 !- Humidity Condition Type
    17.6,                    !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                        !- Humidity Condition Day Schedule Name
    ,                        !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
    ,                        !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                        !- Daily Wet-Bulb Temperature Range {deltaC}
    101085,                  !- Barometric Pressure {Pa}
    0,                       !- Wind Speed {m/s}
    0,                       !- Wind Direction {deg}
    No,                      !- Rain Indicator
    No,                      !- Snow Indicator
    Yes,                     !- Daylight Saving Time Indicator
    ,                        !- Solar Model Indicator
    ,                        !- Beam Solar Day Schedule Name
```

```
,                  !- Diffuse Solar Day Schedule Name
,                  !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
,                  !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
0.98;              !- Sky Clearness

SizingPeriod:DesignDay,
  Winter Design Day in Site (01-01:31-12),  !- Name
  1,                 !- Month
  10,                !- Day of Month
  WinterDesignDay,   !- Day Type
  -3.5,              !- Maximum Dry-Bulb Temperature {C}
  8,                 !- Daily Dry-Bulb Temperature Range {deltaC}
  ,                  !- Dry-Bulb Temperature Range Modifier Type
  ,                  !- Dry-Bulb Temperature Range Modifier Day Schedule Name
  WetBulb,           !- Humidity Condition Type
  -4.2,              !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
  ,                  !- Humidity Condition Day Schedule Name
  ,                  !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
  ,                  !- Enthalpy at Maximum Dry-Bulb {J/kg}
  ,                  !- Daily Wet-Bulb Temperature Range {deltaC}
  101085,            !- Barometric Pressure {Pa}
  11.9,              !- Wind Speed {m/s}
  0,                 !- Wind Direction {deg}
  No,                !- Rain Indicator
  No,                !- Snow Indicator
  No,                !- Daylight Saving Time Indicator
  ,                  !- Solar Model Indicator
  ,                  !- Beam Solar Day Schedule Name
  ,                  !- Diffuse Solar Day Schedule Name
  ,                  !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
  ,                  !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
  0;                 !- Sky Clearness

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

RunPeriod,
  Site (01-01:31-12),  !- Name
  1,                 !- Begin Month
  1,                 !- Begin Day of Month
  12,                !- End Month
  31,                !- End Day of Month
  UseWeatherFile,    !- Day of Week for Start Day
  No,                !- Use Weather File Holidays and Special Days
  No,                !- Use Weather File Daylight Saving Period
  Yes,               !- Apply Weekend Holiday Rule
  Yes,               !- Use Weather File Rain Indicators
  Yes,               !- Use Weather File Snow Indicators
  1;                 !- Number of Times Runperiod to be Repeated

!-   ===========  ALL OBJECTS IN CLASS: RUNPERIODCONTROL:DAYLIGHTSAVINGTIME ===========

RunPeriodControl:DaylightSavingTime,
  1st Sunday in April,     !- Start Date
  Last Sunday in October;  !- End Date

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

Site:GroundTemperature:BuildingSurface,
  18,                !- January Ground Temperature {C}
  18,                !- February Ground Temperature {C}
  18,                !- March Ground Temperature {C}
  18,                !- April Ground Temperature {C}
  18,                !- May Ground Temperature {C}
  18,                !- June Ground Temperature {C}
  18,                !- July Ground Temperature {C}
  18,                !- August Ground Temperature {C}
  18,                !- September Ground Temperature {C}
  18,                !- October Ground Temperature {C}
  18,                !- November Ground Temperature {C}
  18;                !- December Ground Temperature {C}

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

Site:GroundTemperature:FCfactorMethod,
  4.52,              !- January Ground Temperature {C}
  4.02,              !- February Ground Temperature {C}
  4.90,              !- March Ground Temperature {C}
  6.28,              !- April Ground Temperature {C}
  9.89,              !- May Ground Temperature {C}
  12.68,             !- June Ground Temperature {C}
  14.55,             !- July Ground Temperature {C}
  15.13,             !- August Ground Temperature {C}
  14.15,             !- September Ground Temperature {C}
  11.99,             !- October Ground Temperature {C}
  9.10,              !- November Ground Temperature {C}
  6.42;              !- December Ground Temperature {C}

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

Site:GroundTemperature:Shallow,
  14,                !- January Surface Ground Temperature {C}
  14,                !- February Surface Ground Temperature {C}
  14,                !- March Surface Ground Temperature {C}
  14,                !- April Surface Ground Temperature {C}
```

```
    14,                      !- May Surface Ground Temperature {C}
    14,                      !- June Surface Ground Temperature {C}
    14,                      !- July Surface Ground Temperature {C}
    14,                      !- August Surface Ground Temperature {C}
    14,                      !- September Surface Ground Temperature {C}
    14,                      !- October Surface Ground Temperature {C}
    14,                      !- November Surface Ground Temperature {C}
    14;                      !- December Surface Ground Temperature {C}

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

Site:GroundTemperature:Deep,
    14,                      !- January Deep Ground Temperature {C}
    14,                      !- February Deep Ground Temperature {C}
    14,                      !- March Deep Ground Temperature {C}
    14,                      !- April Deep Ground Temperature {C}
    14,                      !- May Deep Ground Temperature {C}
    14,                      !- June Deep Ground Temperature {C}
    14,                      !- July Deep Ground Temperature {C}
    14,                      !- August Deep Ground Temperature {C}
    14,                      !- September Deep Ground Temperature {C}
    14,                      !- October Deep Ground Temperature {C}
    14,                      !- November Deep Ground Temperature {C}
    14;                      !- December Deep Ground Temperature {C}

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

Site:GroundReflectance,
    0.2,                     !- January Ground Reflectance {dimensionless}
    0.2,                     !- February Ground Reflectance {dimensionless}
    0.2,                     !- March Ground Reflectance {dimensionless}
    0.2,                     !- April Ground Reflectance {dimensionless}
    0.2,                     !- May Ground Reflectance {dimensionless}
    0.2,                     !- June Ground Reflectance {dimensionless}
    0.2,                     !- July Ground Reflectance {dimensionless}
    0.2,                     !- August Ground Reflectance {dimensionless}
    0.2,                     !- September Ground Reflectance {dimensionless}
    0.2,                     !- October Ground Reflectance {dimensionless}
    0.2,                     !- November Ground Reflectance {dimensionless}
    0.2;                     !- December Ground Reflectance {dimensionless}

!-   =========== ALL OBJECTS IN CLASS: SITE:GROUNDREFLECTANCE:SNOWMODIFIER ===========

Site:GroundReflectance:SnowModifier,
    2.0,                     !- Ground Reflected Solar Modifier
    2.0;                     !- Daylighting Ground Reflected Solar Modifier

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

ScheduleTypeLimits,
    Any Number;              !- Name

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

ScheduleTypeLimits,
    Temperature,             !- Name
    -60,                     !- Lower Limit Value
    200,                     !- Upper Limit Value
    CONTINUOUS;              !- Numeric Type

ScheduleTypeLimits,
    Control Type,            !- Name
    0,                       !- Lower Limit Value
    4,                       !- Upper Limit Value
    DISCRETE;                !- Numeric Type

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

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

Schedule:Compact,
    AHU Temperature Setpoint,!- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    16;                      !- Field 4

Schedule:Compact,
    Boundary AHU Temperature Setpoint,  !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    21;                      !- Field 4

Schedule:Compact,
    Cooling set point schedule,  !- Name
    Temperature,             !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllOtherDays,       !- Field 2
    Until: 24:00,            !- Field 3
    22;                      !- Field 4
```

```
Schedule:Compact,
  Heating set point schedule,  !- Name
  Temperature,           !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllOtherDays,     !- Field 2
  Until: 24:00,          !- Field 3
  22;                    !- Field 4
Schedule:Compact,
  Radiant Heating set point schedule,  !- Name
  Temperature,           !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  19.25;                 !- Field 4
Schedule:Compact,
  Radiant Cooling set point schedule,  !- Name
  Temperature,           !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  24.75;                 !- Field 4
Schedule:Compact,
  On,                    !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  1;                     !- Field 4
Schedule:Compact,
  Off,                   !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  0;                     !- Field 4
Schedule:Compact,
  Work efficiency,       !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  0;                     !- Field 4
Schedule:Compact,
  Zone Comfort Control Type Sched,  !- Name
  Control Type,          !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  4;                     !- Field 4
Schedule:Compact,
  AirVelocitySchedule,   !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  .136999898404958;      !- Field 4
Schedule:Compact,
  On 24/7,               !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  1;                     !- Field 4
Schedule:Compact,
  Off 24/7,              !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  0;                     !- Field 4
Schedule:Compact,
  Chilled water flow set point temperature: Always 6 C,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  6;                     !- Field 4
Schedule:Compact,
  Cooling low water temperature schedule: Always 10.00,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,          !- Field 3
  10;                    !- Field 4
Schedule:Compact,
  Domestic hot water setpoint temperature: Always 55.00,  !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
```

```
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    55;                      !- Field 4
Schedule:Compact,
    Boundary air setpoint temperature,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    55;                      !- Field 4
Schedule:Compact,
    Water heater ambient temperature schedule: Always 20.00,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    20;                      !- Field 4
Schedule:Compact,
    Underfloor heating setpoint temperature: Always 40.00,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    40;                      !- Field 4
Schedule:Compact,
    HVAC Operation Schedule, !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    1;                       !- Field 4
Schedule:Compact,
    ASHRAE 90.1 Occupancy,   !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays,           !- Field 2
    Until: 07:00,            !- Field 3
    0,                       !- Field 4
    Until: 08:00,            !- Field 5
    0.05,                    !- Field 6
    Until: 09:00,            !- Field 7
    0.75,                    !- Field 8
    Until: 11:00,            !- Field 9
    0.90,                    !- Field 10
    Until: 15:00,            !- Field 11
    0.80,                    !- Field 12
    Until: 16:00,            !- Field 13
    0.45,                    !- Field 14
    Until: 17:00,            !- Field 15
    0.15,                    !- Field 16
    Until: 18:00,            !- Field 17
    0.05,                    !- Field 18
    Until: 19:00,            !- Field 19
    0.15,                    !- Field 20
    Until: 21:00,            !- Field 21
    0.20,                    !- Field 22
    Until: 22:00,            !- Field 23
    0.10,                    !- Field 24
    Until: 24:00,            !- Field 25
    0.00,                    !- Field 26
    For: Saturday,           !- Field 27
    Until: 08:00,            !- Field 28
    0,                       !- Field 29
    Until: 13:00,            !- Field 30
    0.10,                    !- Field 31
    Until: 24:00,            !- Field 32
    0.00,                    !- Field 33
    For: Sunday,             !- Field 34
    Until: 24:00,            !- Field 35
    0,                       !- Field 36
    For: SummerDesignDay,    !- Field 37
    Until: 08:00,            !- Field 38
    0,                       !- Field 39
    Until: 23:00,            !- Field 40
    1,                       !- Field 41
    Until: 24:00,            !- Field 42
    0,                       !- Field 43
    For: AllOtherDays,       !- Field 44
    Until: 24:00,            !- Field 45
    0;                       !- Field 46
Schedule:Compact,
    ASHRAE 90.1 Lighting,    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 31 Dec,         !- Field 1
    For: Weekdays,           !- Field 2
    Until: 07:00,            !- Field 3
    0.05,                    !- Field 4
    Until: 08:00,            !- Field 5
```

```
    0.30,                    !- Field 6
    Until: 09:00,            !- Field 7
    0.85,                    !- Field 8
    Until: 12:00,            !- Field 9
    0.95,                    !- Field 10
    Until: 15:00,            !- Field 11
    0.80,                    !- Field 12
    Until: 16:00,            !- Field 13
    0.70,                    !- Field 14
    Until: 18:00,            !- Field 15
    0.50,                    !- Field 16
    Until: 21:00,            !- Field 17
    0.35,                    !- Field 18
    Until: 22:00,            !- Field 19
    0.30,                    !- Field 20
    Until: 24:00,            !- Field 21
    0.05,                    !- Field 22
    For: Saturday,           !- Field 23
    Until: 07:00,            !- Field 24
    0.05,                    !- Field 25
    Until: 13:00,            !- Field 26
    0.15,                    !- Field 27
    Until: 24:00,            !- Field 28
    0.05,                    !- Field 29
    For: Sunday,             !- Field 30
    Until: 24:00,            !- Field 31
    0.05,                    !- Field 32
    For: SummerDesignDay,    !- Field 33
    Until: 08:00,            !- Field 34
    0,                       !- Field 35
    Until: 23:00,            !- Field 36
    1,                       !- Field 37
    Until: 24:00,            !- Field 38
    0,                       !- Field 39
    For: AllOtherDays,       !- Field 40
    Until: 24:00,            !- Field 41
    0;                       !- Field 42
Schedule:Compact,
    Activity Schedule 588,   !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    110.7;                   !- Field 4
Schedule:Compact,
    Control type schedule: Always 4,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    4;                       !- Field 4
Schedule:Compact,
    AHU Minimum OA Fraction Sch,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    0.2;                     !- Field 4
Schedule:Compact,
    AHU Maximum OA Fraction Sch,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 6/1,            !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    1,                       !- Field 4
    Through: 8/31,           !- Field 5
    For: AllDays,            !- Field 6
    Until: 24:00,            !- Field 7
    0.2,                     !- Field 8
    Through: 12/31,          !- Field 9
    For: AllDays,            !- Field 10
    Until: 24:00,            !- Field 11
    1;                       !- Field 12
Schedule:Compact,
    Ventilation control mode schedule Boundary Air Loop,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    1;                       !- Field 4
Schedule:Compact,
    Heating Cooling PMV Setpoints,  !- Name
    Any Number,              !- Schedule Type Limits Name
    Through:  1 Apr,         !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    -1,                      !- Field 4
    Through:  1 Oct,         !- Field 5
```

```
    For: AllDays,           !- Field 6
    Until: 24:00,           !- Field 7
    1,                      !- Field 8
    Through:  31 Dec,       !- Field 9
    For: AllDays,           !- Field 10
    Until: 24:00,           !- Field 11
    -1;                     !- Field 12
Schedule:Compact,
    Heating Cooling PMV Setpoints,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through:  31 Dec,       !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    0;                      !- Field 4
Schedule:Compact,
    Thermal Comfort Control Type SCHEDULE: Always 3,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    3;                      !- Field 4
Schedule:Compact,
    Work efficiency sch,    !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    0.01;                   !- Field 4
Schedule:Compact,
    Activity Level Schedule, !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    110.7;                  !- Field 4
Schedule:Compact,
    Clothing Insulation Calculation Schedule,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 31 Dec,        !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    2;                      !- Field 4
Schedule:Compact,
    Clothing Insulation Schedule,  !- Name
    Any Number,             !- Schedule Type Limits Name
    Through: 1 Apr,         !- Field 1
    For: AllDays,           !- Field 2
    Until: 24:00,           !- Field 3
    0.54,                   !- Field 4
    Through: 30 Sep,        !- Field 5
    For: AllDays,           !- Field 6
    Until: 24:00,           !- Field 7
    0.96,                   !- Field 8
    Through: 31 Dec,        !- Field 9
    For: AllDays,           !- Field 10
    Until: 24:00,           !- Field 11
    0.54;                   !- Field 12
!-   ===========  ALL OBJECTS IN CLASS: MATERIAL ===========
Material,
    R-55 board Insulation (Glass fiber board)_0.3099,  !- Name
    Rough,                  !- Roughness
    0.3099,                 !- Thickness {m}
    0.036,                  !- Conductivity {W/m-K}
    160,                    !- Density {kg/m3}
    840,                    !- Specific Heat {J/kg-K}
    0.9,                    !- Thermal Absorptance
    0.7,                    !- Solar Absorptance
    0.7;                    !- Visible Absorptance
Material,
    6 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.1524,  !-
Name
    Rough,                  !- Roughness
    0.1524,                 !- Thickness {m}
    2.27,                   !- Conductivity {W/m-K}
    2321.4,                 !- Density {kg/m3}
    837.36,                 !- Specific Heat {J/kg-K}
    0.9,                    !- Thermal Absorptance
    0.7,                    !- Solar Absorptance
    0.7;                    !- Visible Absorptance
Material,
    Board insulation (Glass fiber board)_0.3913,  !- Name
    Rough,                  !- Roughness
    0.3913,                 !- Thickness {m}
    0.036,                  !- Conductivity {W/m-K}
    160,                    !- Density {kg/m3}
    840,                    !- Specific Heat {J/kg-K}
    0.9,                    !- Thermal Absorptance
    0.7,                    !- Solar Absorptance
```

```
  0.7;                !- Visible Absorptance
Material,
  Metal deck_0.01,        !- Name
  Rough,                !- Roughness
  0.01,                 !- Thickness {m}
  45.28,                !- Conductivity {W/m-K}
  7824,                 !- Density {kg/m3}
  500,                  !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  Gypsum Plasterboard_0.025,  !- Name
  Rough,                !- Roughness
  0.025,                !- Thickness {m}
  0.25,                 !- Conductivity {W/m-K}
  900,                  !- Density {kg/m3}
  1000,                 !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.5,                  !- Solar Absorptance
  0.5;                  !- Visible Absorptance
Material,
  8 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.2032,  !-
Name
  Rough,                !- Roughness
  0.2032,               !- Thickness {m}
  2.3,                  !- Conductivity {W/m-K}
  2321.4,               !- Density {kg/m3}
  837.36,               !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  R-60 board Insulation (Glass fiber board)_0.3886,  !- Name
  Rough,                !- Roughness
  0.3886,               !- Thickness {m}
  0.036,                !- Conductivity {W/m-K}
  160,                  !- Density {kg/m3}
  840,                  !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  0.5 in. (12.7 mm) gypsum board_0.0127,  !- Name
  Rough,                !- Roughness
  0.0127,               !- Thickness {m}
  0.16,                 !- Conductivity {W/m-K}
  640,                  !- Density {kg/m3}
  1150,                 !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  Painted Oak_0.035,      !- Name
  Rough,                !- Roughness
  0.035,                !- Thickness {m}
  0.19,                 !- Conductivity {W/m-K}
  700,                  !- Density {kg/m3}
  2390,                 !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.5,                  !- Solar Absorptance
  0.5;                  !- Visible Absorptance
Material,
  4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.1016,  !-
Name
  Rough,                !- Roughness
  0.1016,               !- Thickness {m}
  2.3,                  !- Conductivity {W/m-K}
  2321.4,               !- Density {kg/m3}
  837.36,               !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  3 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.0508,  !-
Name
  Rough,                !- Roughness
  0.076,                !- Thickness {m}
  2.21,                 !- Conductivity {W/m-K}
  2321.4,               !- Density {kg/m3}
  837.36,               !- Specific Heat {J/kg-K}
  0.9,                  !- Thermal Absorptance
  0.7,                  !- Solar Absorptance
  0.7;                  !- Visible Absorptance
Material,
  Sand and gravel_0.05,    !- Name
  Rough,                !- Roughness
  0.05,                 !- Thickness {m}
  2,                    !- Conductivity {W/m-K}
```

```
  1950,              !- Density {kg/m3}
  1045,              !- Specific Heat {J/kg-K}
  0.9,               !- Thermal Absorptance
  0.3,               !- Solar Absorptance
  0.3;               !- Visible Absorptance
Material,
  XPS Extruded Polystyrene  - CO2 Blowing_0.05,  !- Name
  Rough,             !- Roughness
  0.05,              !- Thickness {m}
  0.034,             !- Conductivity {W/m-K}
  35,                !- Density {kg/m3}
  1400,              !- Specific Heat {J/kg-K}
  0.9,               !- Thermal Absorptance
  0.6,               !- Solar Absorptance
  0.6;               !- Visible Absorptance
Material,
  Plasterboard_0.02,      !- Name
  Rough,             !- Roughness
  0.02,              !- Thickness {m}
  0.25,              !- Conductivity {W/m-K}
  2800,              !- Density {kg/m3}
  896,               !- Specific Heat {J/kg-K}
  0.9,               !- Thermal Absorptance
  0.5,               !- Solar Absorptance
  0.5;               !- Visible Absorptance
Material,
  Cast Concrete (Dense)_0.15,  !- Name
  Rough,             !- Roughness
  0.15,              !- Thickness {m}
  1.4,               !- Conductivity {W/m-K}
  2100,              !- Density {kg/m3}
  840,               !- Specific Heat {J/kg-K}
  0.9,               !- Thermal Absorptance
  0.6,               !- Solar Absorptance
  0.6;               !- Visible Absorptance
Material,
  14_2_3510,         !- Name
  Rough,             !- Roughness
  0.0797,            !- Thickness {m}
  0.0355,            !- Conductivity {W/m-K}
  10,                !- Density {kg/m3}
  1470,              !- Specific Heat {J/kg-K}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
  0.7;               !- Visible Absorptance
!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:NOMASS ===========
Material:NoMass,
  LinearBridgingLayer,    !- Name
  Rough,             !- Roughness
  0.6267,            !- Thermal Resistance {m2-K/W}
  0.0100000,         !- Thermal Absorptance
  0.0100000,         !- Solar Absorptance
  0.0100000;         !- Visible Absorptance
Material:NoMass,
  1_RVAL_1,          !- Name
  Rough,             !- Roughness
  0.2201375,         !- Thermal Resistance {m2-K/W}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
  0.7;               !- Visible Absorptance
Material:NoMass,
  4_RVAL_2,          !- Name
  Rough,             !- Roughness
  0.15,              !- Thermal Resistance {m2-K/W}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
  0.7;               !- Visible Absorptance
Material:NoMass,
  5_RVAL_2,          !- Name
  Rough,             !- Roughness
  0.15,              !- Thermal Resistance {m2-K/W}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
  0.7;               !- Visible Absorptance
Material:NoMass,
  10_RVAL_1,         !- Name
  Rough,             !- Roughness
  0.2201375,         !- Thermal Resistance {m2-K/W}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
  0.7;               !- Visible Absorptance
Material:NoMass,
  11_RVAL_3,         !- Name
  Rough,             !- Roughness
  0.2201375,         !- Thermal Resistance {m2-K/W}
  0.9,               !- Thermal Absorptance
  0.7,               !- Solar Absorptance
```

0.7;   !- Visible Absorptance

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

Material:InfraredTransparent,

IRTMaterial;   !- Name

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

WindowMaterial:Glazing,

3,   !- 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}

1;   !- Dirt Correction Factor for Solar and Visible Transmittance

WindowMaterial:Glazing,

42,   !- Name

SpectralAverage,   !- Optical Data Type

,   !- Window Glass Spectral Data Set Name

0.006,   !- Thickness {m}

0.600,   !- Solar Transmittance at Normal Incidence

0.170,   !- Front Side Solar Reflectance at Normal Incidence

0.220,   !- Back Side Solar Reflectance at Normal Incidence

0.840,   !- Visible Transmittance at Normal Incidence

0.055,   !- Front Side Visible Reflectance at Normal Incidence

0.078,   !- Back Side Visible Reflectance at Normal Incidence

0.0,   !- Infrared Transmittance at Normal Incidence

0.84,   !- Front Side Infrared Hemispherical Emissivity

0.10,   !- Back Side Infrared Hemispherical Emissivity

0.9,   !- Conductivity {W/m-K}

1;   !- Dirt Correction Factor for Solar and Visible Transmittance

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

WindowMaterial:Gas,

1004,   !- Name

Argon,   !- Gas Type

0.013;   !- Thickness {m}

WindowMaterial:Gas,

Half thickness 1004,   !- Name

Argon,   !- Gas Type

0.0065;   !- Thickness {m}

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

Construction,

Roof Ins Entirely above Deck R-60 (10.4) U-0.016 (0.091), !- Name

Board insulation (Glass fiber board)_0.3913, !- Outside Layer

Metal deck_0.01;   !- Layer 2

Construction,

Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity, !- Name

Gypsum Plasterboard_0.025, !- Outside Layer

4_RVAL_2,   !- Layer 2

Gypsum Plasterboard_0.025; !- Layer 3

Construction,

Wall Mass R-60.0 (10.56) U-0.016 (0.09), !- Name

8 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.2032, !- Outside Layer

R-60 board Insulation (Glass fiber board)_0.3886, !- Layer 2

0.5 in. (12.7 mm) gypsum board_0.0127; !- Layer 3

Construction,

Internal door,   !- Name

Painted Oak_0.035;   !- Outside Layer

Construction,

Internal door_Rev,   !- Name

Painted Oak_0.035;   !- Outside Layer

Construction,

Wall Mass R-17.5 (3.08) U-0.069 (0.39), !- Name

8 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.2032, !- Outside Layer

14_2_3510,   !- Layer 2

0.5 in. (12.7 mm) gypsum board_0.0127; !- Layer 3

Construction,

1001,   !- Name

42,   !- Outside Layer

1004,   !- Layer 2

3;   !- Layer 3

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

Construction:FfactorGroundFloor,

Slab-On-Grade Unheated Fully Insulated R-55.0 (9.7) F-0.161 (0.28) - 1, !- Name

0.28,   !- F-Factor {W/m-K}

225,   !- Area {m2}

60;   !- PerimeterExposed {m}

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

Construction:InternalSource,

  - VIU Floor,            !- Name

  2,                      !- Source Present After Layer Number

  2,                      !- Temperature Calculation Requested After Layer Number

  1,                      !- Dimensions for the CTF Calculation

  0.2999740000012,        !- Tube Spacing {m}

  10_RVAL_1,              !- Outside Layer

  4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.1016,  !- Layer 2

  3 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete)_0.0508;  !- Layer 3

Construction:InternalSource,

  - VIU - Green Roof,     !- Name

  3,                      !- Source Present After Layer Number

  3,                      !- Temperature Calculation Requested After Layer Number

  1,                      !- Dimensions for the CTF Calculation

  0.2999740000012,        !- Tube Spacing {m}

  Sand and gravel_0.05,   !- Outside Layer

  XPS Extruded Polystyrene  - CO2 Blowing_0.05,  !- Layer 2

  Plasterboard_0.02,      !- Layer 3

  Cast Concrete (Dense)_0.15;  !- Layer 4

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

GlobalGeometryRules,

  LowerLeftCorner,        !- Starting Vertex Position

  CounterClockWise,       !- Vertex Entry Direction

  Relative;               !- Coordinate System

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

Zone,

  Block:boundary,         !- Name

  0,                      !- Direction of Relative North {deg}

  0,                      !- X Origin {m}

  0,                      !- Y Origin {m}

  0,                      !- Z Origin {m}

  1,                      !- Type

  1,                      !- Multiplier

  ,                       !- Ceiling Height {m}

  628,                    !- Volume {m3}

  157,                    !- Floor Area {m2}

  TARP,                   !- Zone Inside Convection Algorithm

  ,                       !- Zone Outside Convection Algorithm

  Yes;                    !- Part of Total Floor Area

Zone,

  Block:Test,             !- Name

  0,                      !- Direction of Relative North {deg}

  0,                      !- X Origin {m}

  0,                      !- Y Origin {m}

  0,                      !- Z Origin {m}

  1,                      !- Type

  1,                      !- Multiplier

  ,                       !- Ceiling Height {m}

  272,                    !- Volume {m3}

  68,                     !- Floor Area {m2}

  TARP,                   !- Zone Inside Convection Algorithm

  ,                       !- Zone Outside Convection Algorithm

  Yes;                    !- Part of Total Floor Area

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

BuildingSurface:Detailed,

  Block:boundary_GroundFloor_0_0_0,  !- Name

  Floor,                  !- Surface Type

  Slab-On-Grade Unheated Fully Insulated R-55.0 (9.7) F-0.161 (0.28) - 1,  !- Construction Name

  Block:boundary,         !- Zone Name

  GroundFCfactorMethod,   !- Outside Boundary Condition

  ,                       !- Outside Boundary Condition Object

  NoSun,                  !- Sun Exposure

  NoWind,                 !- Wind Exposure

  AutoCalculate,          !- View Factor to Ground

  4,                      !- Number of Vertices

  5.1680357464,           !- Vertex 1 X-coordinate {m}

  7.6951745012,           !- Vertex 1 Y-coordinate {m}

  0,                      !- Vertex 1 Z-coordinate {m}

  1.6680357464,           !- Vertex 2 X-coordinate {m}

  7.6951745012,           !- Vertex 2 Y-coordinate {m}

  0,                      !- Vertex 2 Z-coordinate {m}

  1.6680357464,           !- Vertex 3 X-coordinate {m}

  16.1951745012,          !- Vertex 3 Y-coordinate {m}

  0,                      !- Vertex 3 Z-coordinate {m}

  5.1680357464,           !- Vertex 4 X-coordinate {m}

  16.1951745012,          !- Vertex 4 Y-coordinate {m}

  0;                      !- Vertex 4 Z-coordinate {m}

BuildingSurface:Detailed,

  Block:boundary_GroundFloor_0_0_1,  !- Name

  Floor,                  !- Surface Type

  Slab-On-Grade Unheated Fully Insulated R-55.0 (9.7) F-0.161 (0.28) - 1,  !- Construction Name

  Block:boundary,         !- Zone Name

  GroundFCfactorMethod,   !- Outside Boundary Condition
```

```
    ,                    !- Outside Boundary Condition Object
    NoSun,               !- Sun Exposure
    NoWind,              !- Wind Exposure
    AutoCalculate,       !- View Factor to Ground
    4,                   !- Number of Vertices
    13.1680357464,       !- Vertex 1 X-coordinate {m}
    1.1951745012,        !- Vertex 1 Y-coordinate {m}
    0,                   !- Vertex 1 Z-coordinate {m}
    1.6680357464,        !- Vertex 2 X-coordinate {m}
    1.1951745012,        !- Vertex 2 Y-coordinate {m}
    0,                   !- Vertex 2 Z-coordinate {m}
    1.6680357464,        !- Vertex 3 X-coordinate {m}
    7.6951745012,        !- Vertex 3 Y-coordinate {m}
    0,                   !- Vertex 3 Z-coordinate {m}
    13.1680357464,       !- Vertex 4 X-coordinate {m}
    7.6951745012,        !- Vertex 4 Y-coordinate {m}
    0;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
    Block:boundary_GroundFloor_0_0_2,  !- Name
    Floor,               !- Surface Type
    Slab-On-Grade Unheated Fully Insulated R-55.0 (9.7) F-0.161 (0.28) - 1,  !- Construction Name
    Block:boundary,      !- Zone Name
    GroundFCfactorMethod,    !- Outside Boundary Condition
    ,                    !- Outside Boundary Condition Object
    NoSun,               !- Sun Exposure
    NoWind,              !- Wind Exposure
    AutoCalculate,       !- View Factor to Ground
    4,                   !- Number of Vertices
    16.6680357464,       !- Vertex 1 X-coordinate {m}
    1.1951745012,        !- Vertex 1 Y-coordinate {m}
    0,                   !- Vertex 1 Z-coordinate {m}
    13.1680357464,       !- Vertex 2 X-coordinate {m}
    1.1951745012,        !- Vertex 2 Y-coordinate {m}
    0,                   !- Vertex 2 Z-coordinate {m}
    13.1680357464,       !- Vertex 3 X-coordinate {m}
    16.1951745012,       !- Vertex 3 Y-coordinate {m}
    0,                   !- Vertex 3 Z-coordinate {m}
    16.6680357464,       !- Vertex 4 X-coordinate {m}
    16.1951745012,       !- Vertex 4 Y-coordinate {m}
    0;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
    Block:boundary_Roof_1_0_0,  !- Name
    Roof,                !- Surface Type
    Roof Ins Entirely above Deck R-60 (10.4) U-0.016 (0.091),  !- Construction Name
    Block:boundary,      !- Zone Name
    Outdoors,            !- Outside Boundary Condition
    ,                    !- Outside Boundary Condition Object
    SunExposed,          !- Sun Exposure
    WindExposed,         !- Wind Exposure
    AutoCalculate,       !- View Factor to Ground
    4,                   !- Number of Vertices
    13.1680357464,       !- Vertex 1 X-coordinate {m}
    7.6951745012,        !- Vertex 1 Y-coordinate {m}
    4,                   !- Vertex 1 Z-coordinate {m}
    16.6680357464,       !- Vertex 2 X-coordinate {m}
    7.6951745012,        !- Vertex 2 Y-coordinate {m}
    4,                   !- Vertex 2 Z-coordinate {m}
    16.6680357464,       !- Vertex 3 X-coordinate {m}
    16.1951745012,       !- Vertex 3 Y-coordinate {m}
    4,                   !- Vertex 3 Z-coordinate {m}
    13.1680357464,       !- Vertex 4 X-coordinate {m}
    16.1951745012,       !- Vertex 4 Y-coordinate {m}
    4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
    Block:boundary_Roof_1_0_1,  !- Name
    Roof,                !- Surface Type
    Roof Ins Entirely above Deck R-60 (10.4) U-0.016 (0.091),  !- Construction Name
    Block:boundary,      !- Zone Name
    Outdoors,            !- Outside Boundary Condition
    ,                    !- Outside Boundary Condition Object
    SunExposed,          !- Sun Exposure
    WindExposed,         !- Wind Exposure
    AutoCalculate,       !- View Factor to Ground
    4,                   !- Number of Vertices
    5.1680357464,        !- Vertex 1 X-coordinate {m}
    1.1951745012,        !- Vertex 1 Y-coordinate {m}
    4,                   !- Vertex 1 Z-coordinate {m}
    16.6680357464,       !- Vertex 2 X-coordinate {m}
    1.1951745012,        !- Vertex 2 Y-coordinate {m}
    4,                   !- Vertex 2 Z-coordinate {m}
    16.6680357464,       !- Vertex 3 X-coordinate {m}
    7.6951745012,        !- Vertex 3 Y-coordinate {m}
    4,                   !- Vertex 3 Z-coordinate {m}
    5.1680357464,        !- Vertex 4 X-coordinate {m}
    7.6951745012,        !- Vertex 4 Y-coordinate {m}
    4;                   !- Vertex 4 Z-coordinate {m}
```

```
BuildingSurface:Detailed,
  Block:boundary_Roof_1_0_2,  !- Name
  Roof,                !- Surface Type
  Roof Ins Entirely above Deck R-60 (10.4) U-0.016 (0.091),  !- Construction Name
  Block:boundary,         !- Zone Name
  Outdoors,             !- Outside Boundary Condition
  ,                    !- Outside Boundary Condition Object
  SunExposed,           !- Sun Exposure
  WindExposed,          !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                   !- Number of Vertices
  1.6680357464,          !- Vertex 1 X-coordinate {m}
  1.1951745012,          !- Vertex 1 Y-coordinate {m}
  4,                   !- Vertex 1 Z-coordinate {m}
  5.1680357464,          !- Vertex 2 X-coordinate {m}
  1.1951745012,          !- Vertex 2 Y-coordinate {m}
  4,                   !- Vertex 2 Z-coordinate {m}
  5.1680357464,          !- Vertex 3 X-coordinate {m}
  16.1951745012,         !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  1.6680357464,          !- Vertex 4 X-coordinate {m}
  16.1951745012,         !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Partition_2_0_0,  !- Name
  Wall,                !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity,  !- Construction Name
  Block:boundary,         !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:Test_Partition_4_0_10000,  !- Outside Boundary Condition Object
  NoSun,               !- Sun Exposure
  NoWind,              !- Wind Exposure
  0,                   !- View Factor to Ground
  4,                   !- Number of Vertices
  5.1680357464,          !- Vertex 1 X-coordinate {m}
  7.6951745,            !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  5.1680357464,          !- Vertex 2 X-coordinate {m}
  16.1951745,           !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
  5.1680357464,          !- Vertex 3 X-coordinate {m}
  16.1951745,           !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  5.1680357464,          !- Vertex 4 X-coordinate {m}
  7.6951745,            !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_Partition_4_0_10000,  !- Name
  Wall,                !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity_Rev,  !- Construction Name
  Block:Test,           !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:boundary_Partition_2_0_0, !- Outside Boundary Condition Object
  NoSun,               !- Sun Exposure
  NoWind,              !- Wind Exposure
  0,                   !- View Factor to Ground
  4,                   !- Number of Vertices
  5.1680357464,          !- Vertex 1 X-coordinate {m}
  16.1951745,           !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  5.1680357464,          !- Vertex 2 X-coordinate {m}
  7.6951745,            !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
  5.1680357464,          !- Vertex 3 X-coordinate {m}
  7.6951745,            !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  5.1680357464,          !- Vertex 4 X-coordinate {m}
  16.1951745,           !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Wall_3_0_0,  !- Name
  Wall,                !- Surface Type
  Wall Mass R-60.0 (10.56) U-0.016 (0.09),  !- Construction Name
  Block:boundary,         !- Zone Name
  Outdoors,             !- Outside Boundary Condition
  ,                    !- Outside Boundary Condition Object
  SunExposed,           !- Sun Exposure
  WindExposed,          !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                   !- Number of Vertices
  5.1680357464,          !- Vertex 1 X-coordinate {m}
  16.1951745012,         !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  1.6680357464,          !- Vertex 2 X-coordinate {m}
  16.1951745012,         !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
```

```
  1.6680357464,          !- Vertex 3 X-coordinate {m}
  16.1951745012,         !- Vertex 3 Y-coordinate {m}
  4,                     !- Vertex 3 Z-coordinate {m}
  5.1680357464,          !- Vertex 4 X-coordinate {m}
  16.1951745012,         !- Vertex 4 Y-coordinate {m}
  4;                     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Wall_4_0_0,  !- Name
  Wall,                  !- Surface Type
  Wall Mass R-60.0 (10.56) U-0.016 (0.09),  !- Construction Name
  Block:boundary,        !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  1.6680357464,          !- Vertex 1 X-coordinate {m}
  16.1951745012,         !- Vertex 1 Y-coordinate {m}
  0,                     !- Vertex 1 Z-coordinate {m}
  1.6680357464,          !- Vertex 2 X-coordinate {m}
  1.1951745012,          !- Vertex 2 Y-coordinate {m}
  0,                     !- Vertex 2 Z-coordinate {m}
  1.6680357464,          !- Vertex 3 X-coordinate {m}
  1.1951745012,          !- Vertex 3 Y-coordinate {m}
  4,                     !- Vertex 3 Z-coordinate {m}
  1.6680357464,          !- Vertex 4 X-coordinate {m}
  16.1951745012,         !- Vertex 4 Y-coordinate {m}
  4;                     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Wall_5_0_0,  !- Name
  Wall,                  !- Surface Type
  Wall Mass R-60.0 (10.56) U-0.016 (0.09),  !- Construction Name
  Block:boundary,        !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  1.6680357464,          !- Vertex 1 X-coordinate {m}
  1.1951745012,          !- Vertex 1 Y-coordinate {m}
  0,                     !- Vertex 1 Z-coordinate {m}
  16.6680357464,         !- Vertex 2 X-coordinate {m}
  1.1951745012,          !- Vertex 2 Y-coordinate {m}
  0,                     !- Vertex 2 Z-coordinate {m}
  16.6680357464,         !- Vertex 3 X-coordinate {m}
  1.1951745012,          !- Vertex 3 Y-coordinate {m}
  4,                     !- Vertex 3 Z-coordinate {m}
  1.6680357464,          !- Vertex 4 X-coordinate {m}
  1.1951745012,          !- Vertex 4 Y-coordinate {m}
  4;                     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Wall_6_0_0,  !- Name
  Wall,                  !- Surface Type
  Wall Mass R-60.0 (10.56) U-0.016 (0.09),  !- Construction Name
  Block:boundary,        !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  16.6680357464,         !- Vertex 1 X-coordinate {m}
  1.1951745012,          !- Vertex 1 Y-coordinate {m}
  0,                     !- Vertex 1 Z-coordinate {m}
  16.6680357464,         !- Vertex 2 X-coordinate {m}
  16.1951745012,         !- Vertex 2 Y-coordinate {m}
  0,                     !- Vertex 2 Z-coordinate {m}
  16.6680357464,         !- Vertex 3 X-coordinate {m}
  16.1951745012,         !- Vertex 3 Y-coordinate {m}
  4,                     !- Vertex 3 Z-coordinate {m}
  16.6680357464,         !- Vertex 4 X-coordinate {m}
  1.1951745012,          !- Vertex 4 Y-coordinate {m}
  4;                     !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Wall_7_0_0,  !- Name
  Wall,                  !- Surface Type
  Wall Mass R-60.0 (10.56) U-0.016 (0.09),  !- Construction Name
  Block:boundary,        !- Zone Name
  Outdoors,              !- Outside Boundary Condition
  ,                      !- Outside Boundary Condition Object
  SunExposed,            !- Sun Exposure
  WindExposed,           !- Wind Exposure
  AutoCalculate,         !- View Factor to Ground
  4,                     !- Number of Vertices
  16.6680357464,         !- Vertex 1 X-coordinate {m}
  16.1951745012,         !- Vertex 1 Y-coordinate {m}
```

```
  0,                    !- Vertex 1 Z-coordinate {m}
  13.1680357464,        !- Vertex 2 X-coordinate {m}
  16.1951745012,        !- Vertex 2 Y-coordinate {m}
  0,                    !- Vertex 2 Z-coordinate {m}
  13.1680357464,        !- Vertex 3 X-coordinate {m}
  16.1951745012,        !- Vertex 3 Y-coordinate {m}
  4,                    !- Vertex 3 Z-coordinate {m}
  16.6680357464,        !- Vertex 4 X-coordinate {m}
  16.1951745012,        !- Vertex 4 Y-coordinate {m}
  4;                    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Partition_8_0_0,  !- Name
  Wall,                 !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity,  !- Construction Name
  Block:boundary,       !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:Test_Partition_2_0_10001,  !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,               !- Wind Exposure
  0,                    !- View Factor to Ground
  4,                    !- Number of Vertices
  13.1680357464,        !- Vertex 1 X-coordinate {m}
  16.1951745,           !- Vertex 1 Y-coordinate {m}
  0,                    !- Vertex 1 Z-coordinate {m}
  13.1680357464,        !- Vertex 2 X-coordinate {m}
  7.6951745,            !- Vertex 2 Y-coordinate {m}
  0,                    !- Vertex 2 Z-coordinate {m}
  13.1680357464,        !- Vertex 3 X-coordinate {m}
  7.6951745,            !- Vertex 3 Y-coordinate {m}
  4,                    !- Vertex 3 Z-coordinate {m}
  13.1680357464,        !- Vertex 4 X-coordinate {m}
  16.1951745,           !- Vertex 4 Y-coordinate {m}
  4;                    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_Partition_2_0_10001,  !- Name
  Wall,                 !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity_Rev,  !- Construction Name
  Block:Test,           !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:boundary_Partition_8_0_0, !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,               !- Wind Exposure
  0,                    !- View Factor to Ground
  4,                    !- Number of Vertices
  13.1680357464,        !- Vertex 1 X-coordinate {m}
  7.6951745,            !- Vertex 1 Y-coordinate {m}
  0,                    !- Vertex 1 Z-coordinate {m}
  13.1680357464,        !- Vertex 2 X-coordinate {m}
  16.1951745,           !- Vertex 2 Y-coordinate {m}
  0,                    !- Vertex 2 Z-coordinate {m}
  13.1680357464,        !- Vertex 3 X-coordinate {m}
  16.1951745,           !- Vertex 3 Y-coordinate {m}
  4,                    !- Vertex 3 Z-coordinate {m}
  13.1680357464,        !- Vertex 4 X-coordinate {m}
  7.6951745,            !- Vertex 4 Y-coordinate {m}
  4;                    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:boundary_Partition_9_0_0,  !- Name
  Wall,                 !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity,  !- Construction Name
  Block:boundary,       !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:Test_Partition_5_0_10002,  !- Outside Boundary Condition Object
  NoSun,                !- Sun Exposure
  NoWind,               !- Wind Exposure
  0,                    !- View Factor to Ground
  4,                    !- Number of Vertices
  13.16803575,          !- Vertex 1 X-coordinate {m}
  7.6951745012,         !- Vertex 1 Y-coordinate {m}
  0,                    !- Vertex 1 Z-coordinate {m}
  5.16803575,           !- Vertex 2 X-coordinate {m}
  7.6951745012,         !- Vertex 2 Y-coordinate {m}
  0,                    !- Vertex 2 Z-coordinate {m}
  5.16803575,           !- Vertex 3 X-coordinate {m}
  7.6951745012,         !- Vertex 3 Y-coordinate {m}
  4,                    !- Vertex 3 Z-coordinate {m}
  13.16803575,          !- Vertex 4 X-coordinate {m}
  7.6951745012,         !- Vertex 4 Y-coordinate {m}
  4;                    !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_Partition_5_0_10002,  !- Name
  Wall,                 !- Surface Type
  Partition - 2 x 1 in. (2x25mm) gypsum plasterboard with 4 in. (100mm) cavity_Rev,  !- Construction Name
  Block:Test,           !- Zone Name
  Surface,              !- Outside Boundary Condition
  Block:boundary_Partition_9_0_0, !- Outside Boundary Condition Object
```

```
  NoSun,               !- Sun Exposure
  NoWind,              !- Wind Exposure
  0,                   !- View Factor to Ground
  4,                   !- Number of Vertices
  5.16803575,          !- Vertex 1 X-coordinate {m}
  7.6951745012,        !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  13.16803575,         !- Vertex 2 X-coordinate {m}
  7.6951745012,        !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
  13.16803575,         !- Vertex 3 X-coordinate {m}
  7.6951745012,        !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  5.16803575,          !- Vertex 4 X-coordinate {m}
  7.6951745012,        !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_GroundFloor_0_0_0,  !- Name
  Floor,               !- Surface Type
  - VIU Floor,         !- Construction Name
  Block:Test,          !- Zone Name
  Ground,              !- Outside Boundary Condition
  ,                    !- Outside Boundary Condition Object
  NoSun,               !- Sun Exposure
  NoWind,              !- Wind Exposure
  AutoCalculate,       !- View Factor to Ground
  4,                   !- Number of Vertices
  13.1680357464,       !- Vertex 1 X-coordinate {m}
  7.6951745012,        !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  5.1680357464,        !- Vertex 2 X-coordinate {m}
  7.6951745012,        !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
  5.1680357464,        !- Vertex 3 X-coordinate {m}
  16.1951745012,       !- Vertex 3 Y-coordinate {m}
  0,                   !- Vertex 3 Z-coordinate {m}
  13.1680357464,       !- Vertex 4 X-coordinate {m}
  16.1951745012,       !- Vertex 4 Y-coordinate {m}
  0;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_Roof_1_0_0,  !- Name
  Roof,                !- Surface Type
  - VIU - Green Roof,  !- Construction Name
  Block:Test,          !- Zone Name
  Outdoors,            !- Outside Boundary Condition
  ,                    !- Outside Boundary Condition Object
  SunExposed,          !- Sun Exposure
  WindExposed,         !- Wind Exposure
  AutoCalculate,       !- View Factor to Ground
  4,                   !- Number of Vertices
  5.1680357464,        !- Vertex 1 X-coordinate {m}
  7.6951745012,        !- Vertex 1 Y-coordinate {m}
  4,                   !- Vertex 1 Z-coordinate {m}
  13.1680357464,       !- Vertex 2 X-coordinate {m}
  7.6951745012,        !- Vertex 2 Y-coordinate {m}
  4,                   !- Vertex 2 Z-coordinate {m}
  13.1680357464,       !- Vertex 3 X-coordinate {m}
  16.1951745012,       !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  5.1680357464,        !- Vertex 4 X-coordinate {m}
  16.1951745012,       !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
BuildingSurface:Detailed,
  Block:Test_Wall_3_0_0,  !- Name
  Wall,                !- Surface Type
  Wall Mass R-17.5 (3.08) U-0.069 (0.39),  !- Construction Name
  Block:Test,          !- Zone Name
  Outdoors,            !- Outside Boundary Condition
  ,                    !- Outside Boundary Condition Object
  SunExposed,          !- Sun Exposure
  WindExposed,         !- Wind Exposure
  AutoCalculate,       !- View Factor to Ground
  4,                   !- Number of Vertices
  13.1680357464,       !- Vertex 1 X-coordinate {m}
  16.1951745012,       !- Vertex 1 Y-coordinate {m}
  0,                   !- Vertex 1 Z-coordinate {m}
  5.1680357464,        !- Vertex 2 X-coordinate {m}
  16.1951745012,       !- Vertex 2 Y-coordinate {m}
  0,                   !- Vertex 2 Z-coordinate {m}
  5.1680357464,        !- Vertex 3 X-coordinate {m}
  16.1951745012,       !- Vertex 3 Y-coordinate {m}
  4,                   !- Vertex 3 Z-coordinate {m}
  13.1680357464,       !- Vertex 4 X-coordinate {m}
  16.1951745012,       !- Vertex 4 Y-coordinate {m}
  4;                   !- Vertex 4 Z-coordinate {m}
!- =========== ALL OBJECTS IN CLASS: FENESTRATIONSURFACE:DETAILED ===========
FenestrationSurface:Detailed,
```

```
  Block:boundary_Partition_9_0_0_0_0_0_Door,  !- Name
  Door,                    !- Surface Type
  Internal door,           !- Construction Name
  Block:boundary_Partition_9_0_0,  !- Building Surface Name
  Block:Test_Partition_5_0_0_0_0_0_Door_10004,   !- Outside Boundary Condition Object
  0,                       !- View Factor to Ground
  ,                        !- Shading Control Name
  ,                        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  8.4781947,               !- Vertex 1 X-coordinate {m}
  11.1951745012,           !- Vertex 1 Y-coordinate {m}
  0.002,                   !- Vertex 1 Z-coordinate {m}
  7.48391321,              !- Vertex 2 X-coordinate {m}
  11.1951745012,           !- Vertex 2 Y-coordinate {m}
  0.002,                   !- Vertex 2 Z-coordinate {m}
  7.48391321,              !- Vertex 3 X-coordinate {m}
  11.1951745012,           !- Vertex 3 Y-coordinate {m}
  2.19853942,              !- Vertex 3 Z-coordinate {m}
  8.4781947,               !- Vertex 4 X-coordinate {m}
  11.1951745012,           !- Vertex 4 Y-coordinate {m}
  2.19853942;              !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
  Block:Test_Partition_5_0_0_0_0_0_Door_10004,  !- Name
  Door,                    !- Surface Type
  Internal door_Rev,       !- Construction Name
  Block:Test_Partition_5_0_10002,  !- Building Surface Name
  Block:boundary_Partition_9_0_0_0_0_0_Door,    !- Outside Boundary Condition Object
  0,                       !- View Factor to Ground
  ,                        !- Shading Control Name
  ,                        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  7.48391321,              !- Vertex 1 X-coordinate {m}
  11.1951745012,           !- Vertex 1 Y-coordinate {m}
  0.002,                   !- Vertex 1 Z-coordinate {m}
  8.4781947,               !- Vertex 2 X-coordinate {m}
  11.1951745012,           !- Vertex 2 Y-coordinate {m}
  0.002,                   !- Vertex 2 Z-coordinate {m}
  8.4781947,               !- Vertex 3 X-coordinate {m}
  11.1951745012,           !- Vertex 3 Y-coordinate {m}
  2.19853942,              !- Vertex 3 Z-coordinate {m}
  7.48391321,              !- Vertex 4 X-coordinate {m}
  11.1951745012,           !- Vertex 4 Y-coordinate {m}
  2.19853942;              !- Vertex 4 Z-coordinate {m}
FenestrationSurface:Detailed,
  Block:Test_Wall_3_0_0_0_0_0_Win,  !- Name
  Window,                  !- Surface Type
  1001,                    !- Construction Name
  Block:Test_Wall_3_0_0,   !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  AutoCalculate,           !- View Factor to Ground
  ,                        !- Shading Control Name
  ,                        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  11.12803575,             !- Vertex 1 X-coordinate {m}
  16.1951745012,           !- Vertex 1 Y-coordinate {m}
  1.04,                    !- Vertex 1 Z-coordinate {m}
  7.20803575,              !- Vertex 2 X-coordinate {m}
  16.1951745012,           !- Vertex 2 Y-coordinate {m}
  1.04,                    !- Vertex 2 Z-coordinate {m}
  7.20803575,              !- Vertex 3 X-coordinate {m}
  16.1951745012,           !- Vertex 3 Y-coordinate {m}
  2.96,                    !- Vertex 3 Z-coordinate {m}
  11.12803575,             !- Vertex 4 X-coordinate {m}
  16.1951745012,           !- Vertex 4 Y-coordinate {m}
  2.96;                    !- Vertex 4 Z-coordinate {m}
!-   ===========  ALL OBJECTS IN CLASS: SHADING:BUILDING:DETAILED ===========
Shading:Building:Detailed,
  5,                       !- Name
  ,                        !- Transmittance Schedule Name
  4,                       !- Number of Vertices
  7.16803575,              !- Vertex 1 X-coordinate {m}
  16.6951745012,           !- Vertex 1 Y-coordinate {m}
  3,                       !- Vertex 1 Z-coordinate {m}
  11.16803575,             !- Vertex 2 X-coordinate {m}
  16.6951745012,           !- Vertex 2 Y-coordinate {m}
  3,                       !- Vertex 2 Z-coordinate {m}
  11.16803575,             !- Vertex 3 X-coordinate {m}
  16.1951745012,           !- Vertex 3 Y-coordinate {m}
  3,                       !- Vertex 3 Z-coordinate {m}
  7.16803575,              !- Vertex 4 X-coordinate {m}
  16.1951745012,           !- Vertex 4 Y-coordinate {m}
  3;                       !- Vertex 4 Z-coordinate {m}
!-   ===========  ALL OBJECTS IN CLASS: PEOPLE ===========
```

People,

People Block:boundary, !- Name

Block:boundary, !- Zone or ZoneList Name

ASHRAE 90.1 Occupancy, !- Number of People Schedule Name

People, !- Number of People Calculation Method

0, !- Number of People

, !- People per Zone Floor Area {person/m2}

, !- Zone Floor Area per Person {m2/person}

0.3, !- Fraction Radiant

AutoCalculate, !- Sensible Heat Fraction

Activity Schedule 588, !- Activity Level Schedule Name

0.0000000382, !- Carbon Dioxide Generation Rate {m3/s-W}

No, !- Enable ASHRAE 55 Comfort Warnings

ZoneAveraged, !- Mean Radiant Temperature Calculation Type

, !- Surface Name/Angle Factor List Name

Work efficiency, !- Work Efficiency Schedule Name

ClothingInsulationSchedule, !- Clothing Insulation Calculation Method

, !- Clothing Insulation Calculation Method Schedule Name

Clothing Schedule 588, !- Clothing Insulation Schedule Name

AirVelocitySchedule; !- Air Velocity Schedule Name

People,

People Block:Test, !- Name

Block:Test, !- Zone or ZoneList Name

ASHRAE 90.1 Occupancy, !- Number of People Schedule Name

People, !- Number of People Calculation Method

20, !- Number of People

, !- People per Zone Floor Area {person/m2}

, !- Zone Floor Area per Person {m2/person}

0.3, !- Fraction Radiant

AutoCalculate, !- Sensible Heat Fraction

Activity Level Schedule, !- Activity Level Schedule Name

0.0000000382, !- Carbon Dioxide Generation Rate {m3/s-W}

Yes, !- Enable ASHRAE 55 Comfort Warnings

ZoneAveraged, !- Mean Radiant Temperature Calculation Type

, !- Surface Name/Angle Factor List Name

work efficiency sch, !- Work Efficiency Schedule Name

ClothingInsulationSchedule, !- Clothing Insulation Calculation Method

Clothing Insulation Calculation Schedule, !- Clothing Insulation Calculation Method Schedule Name

Clothing Insulation Schedule, !- Clothing Insulation Schedule Name

AirVelocitySchedule, !- Air Velocity Schedule Name

Fanger; !- Thermal Comfort Model 1 Type

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

Lights,

Block:Test General lighting, !- Name

Block:Test, !- Zone or ZoneList Name

ASHRAE 90.1 Lighting, !- Schedule Name

LightingLevel, !- Design Level Calculation Method

1000, !- Lighting Level {W}

, !- Watts per Zone Floor Area {W/m2}

, !- Watts per Person {W/person}

0.86, !- Return Air Fraction

0.04, !- Fraction Radiant

0.10, !- Fraction Visible

1, !- Fraction Replaceable

ELECTRIC EQUIPMENT#Block:Test#GeneralLights; !- End-Use Subcategory

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

ZoneInfiltration:DesignFlowRate,

Block:Test Infiltration, !- Name

Block:Test, !- Zone or ZoneList Name

On 24/7, !- Schedule Name

Flow/zone, !- Design Flow Rate Calculation Method

0.07, !- Design Flow Rate {m3/s}

, !- Flow per Zone Floor Area {m3/s-m2}

, !- Flow per Exterior Surface Area {m3/s-m2}

, !- Air Changes per Hour {1/hr}

1, !- Constant Term Coefficient

0, !- Temperature Term Coefficient

0, !- Velocity Term Coefficient

0; !- Velocity Squared Term Coefficient

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

ZoneVentilation:DesignFlowRate,

Block:Test Nat Vent, !- Name

Block:Test, !- Zone or ZoneList Name

On, !- Schedule Name

Flow/zone, !- Design Flow Rate Calculation Method

0.138889, !- Design Flow Rate {m3/s}

, !- Flow Rate per Zone Floor Area {m3/s-m2}

, !- Flow Rate per Person {m3/s-person}

, !- Air Changes per Hour {1/hr}

NATURAL, !- Ventilation Type

0, !- Fan Pressure Rise {Pa}

1, !- Fan Total Efficiency

1, !- Constant Term Coefficient

0, !- Temperature Term Coefficient

0, !- Velocity Term Coefficient

```
  0,                   !- Velocity Squared Term Coefficient
  24,                  !- Minimum Indoor Temperature {C}
  ,                    !- Minimum Indoor Temperature Schedule Name
  100,                 !- Maximum Indoor Temperature {C}
  ,                    !- Maximum Indoor Temperature Schedule Name
  0,                   !- Delta Temperature {deltaC}
  ,                    !- Delta Temperature Schedule Name
  12,                  !- 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: DESIGNSPECIFICATION:OUTDOORAIR ===========

DesignSpecification:OutdoorAir,
  Block:Test Design Specification Outdoor Air Object,  !- Name
  Flow/Person,         !- Outdoor Air Method
  0.009440,            !- Outdoor Air Flow per Person {m3/s-person}
  0.000000,            !- Outdoor Air Flow per Zone Floor Area {m3/s-m2}
  0.000000,            !- Outdoor Air Flow per Zone {m3/s}
  0.000000,            !- Outdoor Air Flow Air Changes per Hour {1/hr}
  On 24/7;             !- Outdoor Air Schedule Name


DesignSpecification:OutdoorAir,
  Block:boundary Design Specification Outdoor Air Object,  !- Name
  Flow/Person,         !- Outdoor Air Method
  0,                   !- Outdoor Air Flow per Person {m3/s-person}
  0.000000,            !- Outdoor Air Flow per Zone Floor Area {m3/s-m2}
  0.000000,            !- Outdoor Air Flow per Zone {m3/s}
  0.000000,            !- Outdoor Air Flow Air Changes per Hour {1/hr}
  Off;                 !- Outdoor Air Schedule Name

!-   =========== ALL OBJECTS IN CLASS: DESIGNSPECIFICATION:ZONEAIRDISTRIBUTION ===========

DesignSpecification:ZoneAirDistribution,
  Block:Test Design Specification Zone Air Distribution Object,  !- Name
  1.0000,              !- Zone Air Distribution Effectiveness in Cooling Mode {dimensionless}
  1.0000,              !- Zone Air Distribution Effectiveness in Heating Mode {dimensionless}
  ,                    !- Zone Air Distribution Effectiveness Schedule Name
  0.0000;              !- Zone Secondary Recirculation Fraction {dimensionless}

DesignSpecification:ZoneAirDistribution,
  Block:boundary Design Specification Zone Air Distribution Object,  !- Name
  1.0000,              !- Zone Air Distribution Effectiveness in Cooling Mode {dimensionless}
  1.0000,              !- Zone Air Distribution Effectiveness in Heating Mode {dimensionless}
  ,                    !- Zone Air Distribution Effectiveness Schedule Name
  0.0000;              !- Zone Secondary Recirculation Fraction {dimensionless}

!-   =========== ALL OBJECTS IN CLASS: SIZING:PARAMETERS ===========

Sizing:Parameters,
  1,                   !- Heating Sizing Factor
  1.3,                 !- Cooling Sizing Factor
  6;                   !- Timesteps in Averaging Window

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

Sizing:Zone,
  Block:Test,          !- Zone or ZoneList Name
  SupplyAirTemperature,  !- Zone Cooling Design Supply Air Temperature Input Method
  13.00,               !- Zone Cooling Design Supply Air Temperature {C}
  5.00,                !- Zone Cooling Design Supply Air Temperature Difference {deltaC}
  SupplyAirTemperature,  !- Zone Heating Design Supply Air Temperature Input Method
  45.00,               !- Zone Heating Design Supply Air Temperature {C}
  25.00,               !- Zone Heating Design Supply Air Temperature Difference {deltaC}
  0.0090,              !- Zone Cooling Design Supply Air Humidity Ratio {kgWater/kgDryAir}
  0.0040,              !- Zone Heating Design Supply Air Humidity Ratio {kgWater/kgDryAir}
  Block:Test Design Specification Outdoor Air Object,  !- Design Specification Outdoor Air Object Name
  ,                    !- Zone Heating Sizing Factor
  ,                    !- Zone Cooling Sizing Factor
  DesignDay,           !- Cooling Design Air Flow Method
  0.000000,            !- Cooling Design Air Flow Rate {m3/s}
  0.000760,            !- Cooling Minimum Air Flow per Zone Floor Area {m3/s-m2}
  0.000000,            !- Cooling Minimum Air Flow {m3/s}
  0.00,                !- Cooling Minimum Air Flow Fraction
  DesignDay,           !- Heating Design Air Flow Method
  0.000000,            !- Heating Design Air Flow Rate {m3/s}
  0.002030,            !- Heating Maximum Air Flow per Zone Floor Area {m3/s-m2}
  0.141580,            !- Heating Maximum Air Flow {m3/s}
  0.43,                !- Heating Maximum Air Flow Fraction
  Block:Test Design Specification Zone Air Distribution Object;  !- Design Specification Zone Air Distribution Object Name

Sizing:Zone,
  Block:boundary,      !- Zone or ZoneList Name
  SupplyAirTemperature,  !- Zone Cooling Design Supply Air Temperature Input Method
  12.00,               !- Zone Cooling Design Supply Air Temperature {C}
```

5.00, !- Zone Cooling Design Supply Air Temperature Difference {deltaC}

SupplyAirTemperature, !- Zone Heating Design Supply Air Temperature Input Method

55.00, !- Zone Heating Design Supply Air Temperature {C}

15.00, !- Zone Heating Design Supply Air Temperature Difference {deltaC}

0.0090, !- Zone Cooling Design Supply Air Humidity Ratio {kgWater/kgDryAir}

0.0040, !- Zone Heating Design Supply Air Humidity Ratio {kgWater/kgDryAir}

Block:boundary Design Specification Outdoor Air Object, !- Design Specification Outdoor Air Object Name

1.25, !- Zone Heating Sizing Factor

1.15, !- Zone Cooling Sizing Factor

DesignDay, !- Cooling Design Air Flow Method

0.000000, !- Cooling Design Air Flow Rate {m3/s}

0.000760, !- Cooling Minimum Air Flow per Zone Floor Area {m3/s-m2}

0.000000, !- Cooling Minimum Air Flow {m3/s}

0.00, !- Cooling Minimum Air Flow Fraction

DesignDay, !- Heating Design Air Flow Method

0.000000, !- Heating Design Air Flow Rate {m3/s}

0.002030, !- Heating Maximum Air Flow per Zone Floor Area {m3/s-m2}

0.141580, !- Heating Maximum Air Flow {m3/s}

0.30, !- Heating Maximum Air Flow Fraction

Block:boundary Design Specification Zone Air Distribution Object; !- Design Specification Zone Air Distribution Object Name

!- =========== ALL OBJECTS IN CLASS: SIZING:SYSTEM ===========

Sizing:System,

Air Loop, !- AirLoop Name

Sensible, !- Type of Load to Size On

0.072835, !- Design Outdoor Air Flow Rate {m3/s}

1.00, !- Central Heating Maximum System Air Flow Ratio

5.00, !- Preheat Design Temperature {C}

0.00800, !- Preheat Design Humidity Ratio {kgWater/kgDryAir}

25.00, !- Precool Design Temperature {C}

0.00800, !- Precool Design Humidity Ratio {kgWater/kgDryAir}

12.00, !- Central Cooling Design Supply Air Temperature {C}

55, !- Central Heating Design Supply Air Temperature {C}

Noncoincident, !- Type of Zone Sum to Use

No, !- 100% Outdoor Air in Cooling

No, !- 100% Outdoor Air in Heating

0.00800, !- Central Cooling Design Supply Air Humidity Ratio {kgWater/kgDryAir}

0.00800, !- Central Heating Design Supply Air Humidity Ratio {kgWater/kgDryAir}

Designday, !- Cooling Supply Air Flow Rate Method

, !- Cooling Supply Air Flow Rate {m3/s}

, !- Cooling Supply Air Flow Rate Per Floor Area {m3/s-m2}

, !- Cooling Fraction of Autosized Cooling Supply Air Flow Rate

, !- Cooling Supply Air Flow Rate Per Unit Cooling Capacity {m3/s-W}

Designday, !- Heating Supply Air Flow Rate Method

, !- Heating Supply Air Flow Rate {m3/s}

, !- Heating Supply Air Flow Rate Per Floor Area {m3/s-m2}

, !- Heating Fraction of Autosized Heating Supply Air Flow Rate

, !- Heating Fraction of Autosized Cooling Supply Air Flow Rate

, !- Heating Supply Air Flow Rate Per Unit Heating Capacity {m3/s-W}

ZoneSum, !- System Outdoor Air Method

1.0000, !- Zone Maximum Outdoor Air Fraction {dimensionless}

CoolingDesignCapacity, !- Cooling Design Capacity Method

2000, !- Cooling Design Capacity {W}

, !- Cooling Design Capacity Per Floor Area {W/m2}

, !- Fraction of Autosized Cooling Design Capacity

HeatingDesignCapacity, !- Heating Design Capacity Method

6000, !- Heating Design Capacity {W}

, !- Heating Design Capacity Per Floor Area {W/m2}

, !- Fraction of Autosized Heating Design Capacity

OnOff; !- Central Cooling Capacity Control Method

Sizing:System,

Boundary Air Loop, !- AirLoop Name

Sensible, !- Type of Load to Size On

0.042932, !- Design Outdoor Air Flow Rate {m3/s}

1.00, !- Central Heating Maximum System Air Flow Ratio

10.00, !- Preheat Design Temperature {C}

0.00800, !- Preheat Design Humidity Ratio {kgWater/kgDryAir}

11.00, !- Precool Design Temperature {C}

0.00800, !- Precool Design Humidity Ratio {kgWater/kgDryAir}

12.00, !- Central Cooling Design Supply Air Temperature {C}

48.89, !- Central Heating Design Supply Air Temperature {C}

Noncoincident, !- Type of Zone Sum to Use

No, !- 100% Outdoor Air in Cooling

No, !- 100% Outdoor Air in Heating

0.00800, !- Central Cooling Design Supply Air Humidity Ratio {kgWater/kgDryAir}

0.00800, !- Central Heating Design Supply Air Humidity Ratio {kgWater/kgDryAir}

Designday, !- Cooling Supply Air Flow Rate Method

, !- Cooling Supply Air Flow Rate {m3/s}

, !- Cooling Supply Air Flow Rate Per Floor Area {m3/s-m2}

```
    ,                    !- Cooling Fraction of Autosized Cooling Supply Air Flow Rate
    ,                    !- Cooling Supply Air Flow Rate Per Unit Cooling Capacity {m3/s-W}
    Designday,           !- Heating Supply Air Flow Rate Method
    ,                    !- Heating Supply Air Flow Rate {m3/s}
    ,                    !- Heating Supply Air Flow Rate Per Floor Area {m3/s-m2}
    ,                    !- Heating Fraction of Autosized Heating Supply Air Flow Rate
    ,                    !- Heating Fraction of Autosized Cooling Supply Air Flow Rate
    ,                    !- Heating Supply Air Flow Rate Per Unit Heating Capacity {m3/s-W}
    ZoneSum,             !- System Outdoor Air Method
    1.0000,              !- Zone Maximum Outdoor Air Fraction {dimensionless}
    CoolingDesignCapacity,  !- Cooling Design Capacity Method
    1000,                !- Cooling Design Capacity {W}
    ,                    !- Cooling Design Capacity Per Floor Area {W/m2}
    ,                    !- Fraction of Autosized Cooling Design Capacity
    HeatingDesignCapacity,  !- Heating Design Capacity Method
    2000,                !- Heating Design Capacity {W}
    ,                    !- Heating Design Capacity Per Floor Area {W/m2}
    ,                    !- Fraction of Autosized Heating Design Capacity
    OnOff;               !- Central Cooling Capacity Control Method

!-   ===========  ALL OBJECTS IN CLASS: SIZING:PLANT ===========

Sizing:Plant,
    HW Loop,             !- Plant or Condenser Loop Name
    Heating,             !- Loop Type
    58,                  !- Design Loop Exit Temperature {C}
    5.56;                !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    Condenser Loop,      !- Plant or Condenser Loop Name
    Condenser,           !- Loop Type
    10.00,               !- Design Loop Exit Temperature {C}
    5.56;                !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    CHW Loop,            !- Plant or Condenser Loop Name
    Cooling,             !- Loop Type
    6.00,                !- Design Loop Exit Temperature {C}
    4.00;                !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    boundary HW Loop,    !- Plant or Condenser Loop Name
    Heating,             !- Loop Type
    58,                  !- Design Loop Exit Temperature {C}
    3;                   !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    boundary Condenser Loop, !- Plant or Condenser Loop Name
    Condenser,           !- Loop Type
    10.00,               !- Design Loop Exit Temperature {C}
    5.56;                !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    boundary CHW Loop,   !- Plant or Condenser Loop Name
    Cooling,             !- Loop Type
    6.00,                !- Design Loop Exit Temperature {C}
    4.00;                !- Loop Design Temperature Difference {deltaC}

Sizing:Plant,
    DHW Loop,            !- Plant or Condenser Loop Name
    Heating,             !- Loop Type
    58,                  !- Design Loop Exit Temperature {C}
    5.00;                !- Loop Design Temperature Difference {deltaC}

!-   ===========  ALL OBJECTS IN CLASS: ZONECONTROL:THERMOSTAT ===========

ZoneControl:Thermostat,
    Block:Test Thermostat,   !- Name
    Block:Test,          !- Zone or ZoneList Name
    Control type schedule: Always 4,  !- Control Type Schedule Name
    ThermostatSetpoint:DualSetpoint,  !- Control 1 Object Type
    Block:Test Dual SP;     !- Control 1 Name

ZoneControl:Thermostat,
    Block:boundary Thermostat,  !- Name
    Block:boundary,         !- Zone or ZoneList Name
    Control type schedule: Always 4,  !- Control Type Schedule Name
    ThermostatSetpoint:DualSetpoint,  !- Control 1 Object Type
    Block:boundary Dual SP;  !- Control 1 Name

!-   ===========  ALL OBJECTS IN CLASS: ZONECONTROL:THERMOSTAT:THERMALCOMFORT ===========

! UNCOMMENT FOR THERMAL COMFORT THERMOSTAT
! ZoneControl:Thermostat:ThermalComfort,
   ! Scenario 4 thermal comfort controller,  !- Name
   ! Block:Test,           !- Zone or ZoneList Name
   ! ,                     !- Averaging Method
   ! ,                     !- Specific People Name
   ! 16,                   !- Minimum Dry-Bulb Temperature Setpoint {C}
   ! 33,                   !- Maximum Dry-Bulb Temperature Setpoint {C}
   ! Thermal Comfort Control Type SCHEDULE: Always 3,   !- Thermal Comfort Control Type Schedule Name
   ! ThermostatSetpoint:ThermalComfort:Fanger:SingleHeatingOrCooling,  !- Thermal Comfort Control 1 Object Type
   ! Heating Cooling Comfort Setpoint; !- Thermal Comfort Control 1 Name

!-   ===========  ALL OBJECTS IN CLASS: THERMOSTATSETPOINT:DUALSETPOINT ===========

ThermostatSetpoint:DualSetpoint,
```

Block:Test Dual SP, !- Name

Heating set point schedule, !- Heating Setpoint Temperature Schedule Name

Cooling set point schedule; !- Cooling Setpoint Temperature Schedule Name

ThermostatSetpoint:DualSetpoint,

Block:boundary Dual SP, !- Name

Heating set point schedule, !- Heating Setpoint Temperature Schedule Name

Cooling set point schedule; !- Cooling Setpoint Temperature Schedule Name

!- =========== ALL OBJECTS IN CLASS: THERMOSTATSETPOINT:THERMALCOMFORT:FANGER:SINGLEHEATINGORCOOLING ===========

ThermostatSetpoint:ThermalComfort:Fanger:SingleHeatingOrCooling,

Heating Cooling Comfort Setpoint, !- Name

Heating Cooling PMV Setpoints; !- Fanger Thermal Comfort Schedule Name

!- =========== ALL OBJECTS IN CLASS: ZONEHVAC:LOWTEMPERATURERADIANT:VARIABLEFLOW ===========

ZoneHVAC:LowTemperatureRadiant:VariableFlow,

Block:Test Heated Floor, !- Name

HVAC Operation Schedule, !- Availability Schedule Name

Block:Test, !- Zone Name

Block:Test Heated Floor Radiant Surface List, !- Surface Name or Radiant Surface Group Name

0.0130, !- Hydronic Tubing Inside Diameter {m}

453.33, !- Hydronic Tubing Length {m}

MeanRadiantTemperature, !- Temperature Control Type

HeatingDesignCapacity, !- Heating Design Capacity Method

2500, !- Heating Design Capacity {W}

, !- Heating Design Capacity Per Floor Area {W/m2}

, !- Fraction of Autosized Heating Design Capacity

0.001, !- Maximum Hot Water Flow {m3/s}

Block:Test Heated Floor Hot Water Inlet Node, !- Heating Water Inlet Node Name

Block:Test Heated Floor Hot Water Outlet Node, !- Heating Water Outlet Node Name

1.50, !- Heating Control Throttling Range {deltaC}

Radiant Heating set point schedule, !- Heating Control Temperature Schedule Name

CoolingDesignCapacity, !- Cooling Design Capacity Method

1000, !- Cooling Design Capacity {W}

, !- Cooling Design Capacity Per Floor Area {W/m2}

, !- Fraction of Autosized Cooling Design Capacity

0.000098, !- Maximum Cold Water Flow {m3/s}

Block:Test Chilled Ceiling CHW Water Inlet Node, !- Cooling Water Inlet Node Name

Block:Test Chilled Ceiling CHW Water Outlet Node, !- Cooling Water Outlet Node Name

1.50, !- Cooling Control Throttling Range {deltaC}

Radiant Cooling set point schedule, !- Cooling Control Temperature Schedule Name

SimpleOff, !- Condensation Control Type

1.00, !- Condensation Control Dewpoint Offset {C}

OnePerSurface, !- Number of Circuits

106.700; !- Circuit Length {m}

!- =========== ALL OBJECTS IN CLASS: ZONEHVAC:LOWTEMPERATURERADIANT:SURFACEGROUP ===========

ZoneHVAC:LowTemperatureRadiant:SurfaceGroup,

Block:Test Heated Floor Radiant Surface List, !- Name

Block:Test_GroundFloor_0_0_0, !- Surface 1 Name

1; !- Flow Fraction for Surface 1

!- =========== ALL OBJECTS IN CLASS: AIRTERMINAL:SINGLEDUCT:UNCONTROLLED ===========

AirTerminal:SingleDuct:Uncontrolled,

Block:Test Direct Air, !- Name

HVAC Operation Schedule, !- Availability Schedule Name

Air Loop Zone Splitter Outlet Node 1, !- Zone Supply Air Node Name

0.072835; !- Maximum Air Flow Rate {m3/s}

AirTerminal:SingleDuct:Uncontrolled,

Block:boundary Direct Air, !- Name

On 24/7, !- Availability Schedule Name

Boundary Air Loop Zone Splitter Outlet Node 1, !- Zone Supply Air Node Name

0.042958; !- Maximum Air Flow Rate {m3/s}

!- =========== ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTLIST ===========

ZoneHVAC:EquipmentList,

Block:Test Equipment, !- Name

ZoneHVAC:LowTemperatureRadiant:VariableFlow, !- Zone Equipment 1 Object Type

Block:Test Heated Floor, !- Zone Equipment 1 Name

1, !- Zone Equipment 1 Cooling Sequence

1, !- Zone Equipment 1 Heating or No-Load Sequence

AirTerminal:SingleDuct:Uncontrolled, !- Zone Equipment 2 Object Type

Block:Test Direct Air, !- Zone Equipment 2 Name

2, !- Zone Equipment 2 Cooling Sequence

2; !- Zone Equipment 2 Heating or No-Load Sequence

ZoneHVAC:EquipmentList,

Block:boundary Equipment,!- Name

AirTerminal:SingleDuct:Uncontrolled, !- Zone Equipment 1 Object Type

Block:boundary Direct Air, !- Zone Equipment 1 Name

1, !- Zone Equipment 1 Cooling Sequence

1; !- Zone Equipment 1 Heating or No-Load Sequence

!- =========== ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTCONNECTIONS ===========

```
ZoneHVAC:EquipmentConnections,
  Block:Test,           !- Zone Name
  Block:Test Equipment,   !- Zone Conditioning Equipment List Name
  Block:Test Air Inlet Node List,  !- Zone Air Inlet Node or NodeList Name
  ,                 !- Zone Air Exhaust Node or NodeList Name
  Block:Test Zone Air Node,!- Zone Air Node Name
  Air Loop Zone Mixer Inlet Node 1;  !- Zone Return Air Node or NodeList Name
ZoneHVAC:EquipmentConnections,
  Block:boundary,        !- Zone Name
  Block:boundary Equipment,!- Zone Conditioning Equipment List Name
  Block:boundary Air Inlet Node List,  !- Zone Air Inlet Node or NodeList Name
  ,                 !- Zone Air Exhaust Node or NodeList Name
  Block:boundary Zone Air Node,  !- Zone Air Node Name
  Boundary Air Loop Zone Mixer Inlet Node 1;  !- Zone Return Air Node or NodeList Name
!-   ===========  ALL OBJECTS IN CLASS: FAN:VARIABLEVOLUME ===========
Fan:VariableVolume,
  Air Loop AHU Supply Fan, !- Name
  On,               !- Availability Schedule Name
  0.70,             !- Fan Total Efficiency
  600.00,            !- Pressure Rise {Pa}
  0.072835,           !- Maximum Flow Rate {m3/s}
  Fraction,           !- Fan Power Minimum Flow Rate Input Method
  0.2500,            !- Fan Power Minimum Flow Fraction
  0.000000,           !- Fan Power Minimum Air Flow Rate {m3/s}
  0.90,             !- Motor Efficiency
  1.00,             !- Motor In Airstream Fraction
  0.3507122300,        !- Fan Power Coefficient 1
  0.3085053500,        !- Fan Power Coefficient 2
  -0.5413736400,       !- Fan Power Coefficient 3
  0.8719882300,        !- Fan Power Coefficient 4
  0.0000000000,        !- Fan Power Coefficient 5
  Air Loop AHU Mixed Air Outlet,  !- Air Inlet Node Name
  Air Loop AHU Supply Fan Air Outlet Node,  !- Air Outlet Node Name
  General;           !- End-Use Subcategory
Fan:VariableVolume,
  Boundary Air Loop AHU Supply Fan,  !- Name
  On,               !- Availability Schedule Name
  0.70,             !- Fan Total Efficiency
  600.00,            !- Pressure Rise {Pa}
  0.04,             !- Maximum Flow Rate {m3/s}
  Fraction,           !- Fan Power Minimum Flow Rate Input Method
  0.2500,            !- Fan Power Minimum Flow Fraction
  0.000000,           !- Fan Power Minimum Air Flow Rate {m3/s}
  0.90,             !- Motor Efficiency
  1.00,             !- Motor In Airstream Fraction
  0.3507122300,        !- Fan Power Coefficient 1
  0.3085053500,        !- Fan Power Coefficient 2
  -0.5413736400,       !- Fan Power Coefficient 3
  0.8719882300,        !- Fan Power Coefficient 4
  0.0000000000,        !- Fan Power Coefficient 5
  Boundary Air Loop AHU Mixed Air Outlet,  !- Air Inlet Node Name
  Boundary Air Loop AHU Supply Fan Air Outlet Node,  !- Air Outlet Node Name
  General;           !- End-Use Subcategory
!-   ===========  ALL OBJECTS IN CLASS: COIL:COOLING:WATER ===========
Coil:Cooling:Water,
  Air Loop AHU Cooling Coil,  !- Name
  On 24/7,            !- Availability Schedule Name
  0.000088,           !- Design Water Flow Rate {m3/s}
  0.01,             !- Design Air Flow Rate {m3/s}
  6.00,             !- Design Inlet Water Temperature {C}
  26.62,             !- Design Inlet Air Temperature {C}
  12.00,             !- Design Outlet Air Temperature {C}
  0.007935,           !- Design Inlet Air Humidity Ratio {kgWater/kgDryAir}
  0.007864,          !- Design Outlet Air Humidity Ratio {kgWater/kgDryAir}
  Air Loop AHU Cooling Coil Water Inlet Node,  !- Water Inlet Node Name
  Air Loop AHU Cooling Coil Water Outlet Node,  !- Water Outlet Node Name
  Air Loop AHU Heating Coil Air Outlet Node,  !- Air Inlet Node Name
  Air Loop Supply Side Outlet 1,  !- Air Outlet Node Name
  SimpleAnalysis,        !- Type of Analysis
  CrossFlow;           !- Heat Exchanger Configuration
Coil:Cooling:Water,
  Boundary Air Loop AHU Cooling Coil,  !- Name
  On 24/7,            !- Availability Schedule Name
  0.000038,           !- Design Water Flow Rate {m3/s}
  0.042932,           !- Design Air Flow Rate {m3/s}
  6.00,             !- Design Inlet Water Temperature {C}
  25.08,             !- Design Inlet Air Temperature {C}
  12.00,             !- Design Outlet Air Temperature {C}
  0.009000,           !- Design Inlet Air Humidity Ratio {kgWater/kgDryAir}
  0.007864,          !- Design Outlet Air Humidity Ratio {kgWater/kgDryAir}
  Boundary Air Loop AHU Cooling Coil Water Inlet Node,  !- Water Inlet Node Name
  Boundary Air Loop AHU Cooling Coil Water Outlet Node,  !- Water Outlet Node Name
  Boundary Air Loop AHU Heating Coil Air Outlet Node,  !- Air Inlet Node Name
```

```
    Boundary Air Loop Supply Side Outlet 1,  !- Air Outlet Node Name
    SimpleAnalysis,          !- Type of Analysis
    CrossFlow;               !- Heat Exchanger Configuration

!-   ===========  ALL OBJECTS IN CLASS: COIL:HEATING:WATER ===========

Coil:Heating:Water,
    Air Loop AHU Heating Coil,  !- Name
    On 24/7,                 !- Availability Schedule Name
    288.73,                  !- U-Factor Times Area Value {W/K}
    0.000206,                !- Maximum Water Flow Rate {m3/s}
    Air Loop AHU Heating Coil Water Inlet Node,  !- Water Inlet Node Name
    Air Loop AHU Heating Coil Water Outlet Node,  !- Water Outlet Node Name
    Air Loop AHU Supply Fan Air Outlet Node,  !- Air Inlet Node Name
    Air Loop AHU Heating Coil Air Outlet Node,  !- Air Outlet Node Name
    UFactorTimesAreaAndDesignWaterFlowRate,  !- Performance Input Method
    5000,                    !- Rated Capacity {W}
    80,                      !- Rated Inlet Water Temperature {C}
    16,                      !- Rated Inlet Air Temperature {C}
    70,                      !- Rated Outlet Water Temperature {C}
    35,                      !- Rated Outlet Air Temperature {C}
    0.50;                    !- Rated Ratio for Air and Water Convection

Coil:Heating:Water,
    Boundary Air Loop AHU Heating Coil,  !- Name
    On 24/7,                 !- Availability Schedule Name
    76.12,                   !- U-Factor Times Area Value {W/K}
    0.000111,                !- Maximum Water Flow Rate {m3/s}
    Boundary Air Loop AHU Heating Coil Water Inlet Node,  !- Water Inlet Node Name
    Boundary Air Loop AHU Heating Coil Water Outlet Node,  !- Water Outlet Node Name
    Boundary Air Loop AHU Supply Fan Air Outlet Node,  !- Air Inlet Node Name
    Boundary Air Loop AHU Heating Coil Air Outlet Node, !- Air Outlet Node Name
    UFactorTimesAreaAndDesignWaterFlowRate,  !- Performance Input Method
    1500,                    !- Rated Capacity {W}
    80,                      !- Rated Inlet Water Temperature {C}
    16,                      !- Rated Inlet Air Temperature {C}
    70,                      !- Rated Outlet Water Temperature {C}
    35,                      !- Rated Outlet Air Temperature {C}
    0.50;                    !- Rated Ratio for Air and Water Convection

!-   ===========  ALL OBJECTS IN CLASS: CONTROLLER:WATERCOIL ===========

Controller:WaterCoil,
    Air Loop AHU Heating Coil Controller,  !- Name
    Temperature,             !- Control Variable
    Normal,                  !- Action
    Flow,                    !- Actuator Variable
    Air Loop AHU Heating Coil Air Outlet Node,  !- Sensor Node Name
    Air Loop AHU Heating Coil Water Inlet Node,  !- Actuator Node Name
    0.001000,                !- Controller Convergence Tolerance {deltaC}
    0.000206,                !- Maximum Actuated Flow {m3/s}
    0.000000;                !- Minimum Actuated Flow {m3/s}


Controller:WaterCoil,
    Air Loop AHU Cooling Coil Controller,  !- Name
    Temperature,             !- Control Variable
    Reverse,                 !- Action
    Flow,                    !- Actuator Variable
    Air Loop Supply Side Outlet 1,  !- Sensor Node Name
    Air Loop AHU Cooling Coil Water Inlet Node,  !- Actuator Node Name
    0.001000,                !- Controller Convergence Tolerance {deltaC}
    0.000088,                !- Maximum Actuated Flow {m3/s}
    0.000000;                !- Minimum Actuated Flow {m3/s}

Controller:WaterCoil,
    Boundary Air Loop AHU Heating Coil Controller,  !- Name
    Temperature,             !- Control Variable
    Normal,                  !- Action
    Flow,                    !- Actuator Variable
    Boundary Air Loop AHU Heating Coil Air Outlet Node,  !- Sensor Node Name
    Boundary Air Loop AHU Heating Coil Water Inlet Node,  !- Actuator Node Name
    0.001000,                !- Controller Convergence Tolerance {deltaC}
    0.000111,                !- Maximum Actuated Flow {m3/s}
    0.000000;                !- Minimum Actuated Flow {m3/s}

Controller:WaterCoil,
    Boundary Air Loop AHU Cooling Coil Controller,  !- Name
    Temperature,             !- Control Variable
    Reverse,                 !- Action
    Flow,                    !- Actuator Variable
    Boundary Air Loop Supply Side Outlet 1,  !- Sensor Node Name
    Boundary Air Loop AHU Cooling Coil Water Inlet Node,  !- Actuator Node Name
    0.001000,                !- Controller Convergence Tolerance {deltaC}
    0.000038,                !- Maximum Actuated Flow {m3/s}
    0.000000;                !- Minimum Actuated Flow {m3/s}

!-   ===========  ALL OBJECTS IN CLASS: CONTROLLER:OUTDOORAIR ===========

Controller:OutdoorAir,
    Air Loop AHU  Outdoor Air Controller,  !- Name
```

```
  Air Loop AHU Relief Air Outlet,  !- Relief Air Outlet Node Name
  Air Loop Supply Side Inlet,  !- Return Air Node Name
  Air Loop AHU Mixed Air Outlet,  !- Mixed Air Node Name
  Air Loop AHU Outdoor Air Inlet,  !- Actuator Node Name
  0.014567,             !- Minimum Outdoor Air Flow Rate {m3/s}
  0.014567,             !- Maximum Outdoor Air Flow Rate {m3/s}
  NoEconomizer,         !- Economizer Control Type
  ModulateFlow,         !- Economizer Control Action Type
  ,                     !- Economizer Maximum Limit Dry-Bulb Temperature {C}
  ,                     !- Economizer Maximum Limit Enthalpy {J/kg}
  ,                     !- Economizer Maximum Limit Dewpoint Temperature {C}
  ,                     !- Electronic Enthalpy Limit Curve Name
  ,                     !- Economizer Minimum Limit Dry-Bulb Temperature {C}
  NoLockout,            !- Lockout Type
  FixedMinimum,         !- Minimum Limit Type
  ,                     !- Minimum Outdoor Air Schedule Name
  AHU Minimum OA Fraction Sch,  !- Minimum Fraction of Outdoor Air Schedule Name
  AHU Maximum OA Fraction Sch,  !- Maximum Fraction of Outdoor Air Schedule Name
  ,                     !- Mechanical Ventilation Controller Name
  ,                     !- Time of Day Economizer Control Schedule Name
  No,                   !- High Humidity Control
  ,                     !- Humidistat Control Zone Name
  1,                    !- High Humidity Outdoor Air Flow Ratio
  Yes,                  !- Control High Indoor Humidity Based on Outdoor Humidity Ratio
  BypassWhenWithinEconomizerLimits;  !- Heat Recovery Bypass Control Type

Controller:OutdoorAir,
  Boundary Air Loop AHU  Outdoor Air Controller,  !- Name
  Boundary Air Loop AHU Relief Air Outlet,  !- Relief Air Outlet Node Name
  Boundary Air Loop Supply Side Inlet,  !- Return Air Node Name
  Boundary Air Loop AHU Mixed Air Outlet,  !- Mixed Air Node Name
  Boundary Air Loop AHU Outdoor Air Inlet,  !- Actuator Node Name
  0,                    !- Minimum Outdoor Air Flow Rate {m3/s}
  0,                    !- Maximum Outdoor Air Flow Rate {m3/s}
  NoEconomizer,         !- Economizer Control Type
  ModulateFlow,         !- Economizer Control Action Type
  ,                     !- Economizer Maximum Limit Dry-Bulb Temperature {C}
  ,                     !- Economizer Maximum Limit Enthalpy {J/kg}
  ,                     !- Economizer Maximum Limit Dewpoint Temperature {C}
  ,                     !- Electronic Enthalpy Limit Curve Name
  ,                     !- Economizer Minimum Limit Dry-Bulb Temperature {C}
  NoLockout,            !- Lockout Type
  FixedMinimum,         !- Minimum Limit Type
  ,                     !- Minimum Outdoor Air Schedule Name
  ,                     !- Minimum Fraction of Outdoor Air Schedule Name
  ,                     !- Maximum Fraction of Outdoor Air Schedule Name
  ,                     !- Mechanical Ventilation Controller Name
  ,                     !- Time of Day Economizer Control Schedule Name
  No,                   !- High Humidity Control
  ,                     !- Humidistat Control Zone Name
  1,                    !- High Humidity Outdoor Air Flow Ratio
  Yes,                  !- Control High Indoor Humidity Based on Outdoor Humidity Ratio
  BypassWhenWithinEconomizerLimits;  !- Heat Recovery Bypass Control Type

!-   =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:CONTROLLERLIST ===========

AirLoopHVAC:ControllerList,
  Air Loop AHU  Outside air Controller List,  !- Name
  Controller:OutdoorAir,   !- Controller 1 Object Type
  Air Loop AHU  Outdoor Air Controller;  !- Controller 1 Name

AirLoopHVAC:ControllerList,
  Boundary Air Loop AHU  Outside air Controller List,  !- Name
  Controller:OutdoorAir,   !- Controller 1 Object Type
  Boundary Air Loop AHU  Outdoor Air Controller;  !- Controller 1 Name

AirLoopHVAC:ControllerList,
  Air Loop Controllers,    !- Name
  Controller:WaterCoil,    !- Controller 1 Object Type
  Air Loop AHU Heating Coil Controller,  !- Controller 1 Name
  Controller:WaterCoil,    !- Controller 2 Object Type
  Air Loop AHU Cooling Coil Controller;  !- Controller 2 Name

AirLoopHVAC:ControllerList,
  Boundary Air Loop Controllers,  !- Name
  Controller:WaterCoil,    !- Controller 1 Object Type
  Boundary Air Loop AHU Heating Coil Controller,  !- Controller 1 Name
  Controller:WaterCoil,    !- Controller 2 Object Type
  Boundary Air Loop AHU Cooling Coil Controller;  !- Controller 2 Name

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

AirLoopHVAC,
  Air Loop,             !- Name
  Air Loop Controllers,    !- Controller List Name
  Air Loop AvailabilityManager List,  !- Availability Manager List Name
  0.072835,             !- Design Supply Air Flow Rate {m3/s}
  Air Loop Branches,       !- Branch List Name
  ,                     !- Connector List Name
  Air Loop Supply Side Inlet,  !- Supply Side Inlet Node Name
  Air Loop Demand Side Outlet,  !- Demand Side Outlet Node Name
```

Air Loop Demand Side Inlet List, !- Demand Side Inlet Node Names

Air Loop Supply Side Outlet List; !- Supply Side Outlet Node Names

AirLoopHVAC,

Boundary Air Loop, !- Name

Boundary Air Loop Controllers, !- Controller List Name

Boundary Air Loop AvailabilityManager List, !- Availability Manager List Name

0.042932, !- Design Supply Air Flow Rate {m3/s}

Boundary Air Loop Branches, !- Branch List Name

, !- Connector List Name

Boundary Air Loop Supply Side Inlet, !- Supply Side Inlet Node Name

Boundary Air Loop Demand Side Outlet, !- Demand Side Outlet Node Name

Boundary Air Loop Demand Side Inlet List, !- Demand Side Inlet Node Names

Boundary Air Loop Supply Side Outlet List; !- Supply Side Outlet Node Names

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:OUTDOORAIRSYSTEM:EQUIPMENTLIST ===========

AirLoopHVAC:OutdoorAirSystem:EquipmentList,

Air Loop AHU Outside air Equipment List, !- Name

OutdoorAir:Mixer, !- Component 1 Object Type

Air Loop AHU Outdoor Air Mixer; !- Component 1 Name

AirLoopHVAC:OutdoorAirSystem:EquipmentList,

Boundary Air Loop AHU Outside air Equipment List, !- Name

OutdoorAir:Mixer, !- Component 1 Object Type

Boundary Air Loop AHU Outdoor Air Mixer; !- Component 1 Name

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:OUTDOORAIRSYSTEM ===========

AirLoopHVAC:OutdoorAirSystem,

Air Loop AHU Outside air system, !- Name

Air Loop AHU Outside air Controller List, !- Controller List Name

Air Loop AHU Outside air Equipment List; !- Outdoor Air Equipment List Name

AirLoopHVAC:OutdoorAirSystem,

Boundary Air Loop AHU Outside air system, !- Name

Boundary Air Loop AHU Outside air Controller List, !- Controller List Name

Boundary Air Loop AHU Outside air Equipment List; !- Outdoor Air Equipment List Name

!- =========== ALL OBJECTS IN CLASS: OUTDOORAIR:MIXER ===========

OutdoorAir:Mixer,

Air Loop AHU Outdoor Air Mixer, !- Name

Air Loop AHU Mixed Air Outlet, !- Mixed Air Node Name

Air Loop AHU Outdoor Air Inlet, !- Outdoor Air Stream Node Name

Air Loop AHU Relief Air Outlet, !- Relief Air Stream Node Name

Air Loop Supply Side Inlet; !- Return Air Stream Node Name

OutdoorAir:Mixer,

Boundary Air Loop AHU Outdoor Air Mixer, !- Name

Boundary Air Loop AHU Mixed Air Outlet, !- Mixed Air Node Name

Boundary Air Loop AHU Outdoor Air Inlet, !- Outdoor Air Stream Node Name

Boundary Air Loop AHU Relief Air Outlet, !- Relief Air Stream Node Name

Boundary Air Loop Supply Side Inlet; !- Return Air Stream Node Name

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:ZONESPLITTER ===========

AirLoopHVAC:ZoneSplitter,

Air Loop Zone Splitter, !- Name

Air Loop Demand Side Inlet 1, !- Inlet Node Name

Air Loop Zone Splitter Outlet Node 1; !- Outlet 1 Node Name

AirLoopHVAC:ZoneSplitter,

Boundary Air Loop Zone Splitter, !- Name

Boundary Air Loop Demand Side Inlet 1, !- Inlet Node Name

Boundary Air Loop Zone Splitter Outlet Node 1; !- Outlet 1 Node Name

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:SUPPLYPATH ===========

AirLoopHVAC:SupplyPath,

Air Loop Demand Side Supply Path 1, !- Name

Air Loop Demand Side Inlet 1, !- Supply Air Path Inlet Node Name

AirLoopHVAC:ZoneSplitter,!- Component 1 Object Type

Air Loop Zone Splitter; !- Component 1 Name

AirLoopHVAC:SupplyPath,

Boundary Air Loop Demand Side Supply Path 1, !- Name

Boundary Air Loop Demand Side Inlet 1, !- Supply Air Path Inlet Node Name

AirLoopHVAC:ZoneSplitter,!- Component 1 Object Type

Boundary Air Loop Zone Splitter; !- Component 1 Name

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:ZONEMIXER ===========

AirLoopHVAC:ZoneMixer,

Air Loop Zone Mixer, !- Name

Air Loop Demand Side Outlet, !- Outlet Node Name

Air Loop Zone Mixer Inlet Node 1; !- Inlet 1 Node Name

AirLoopHVAC:ZoneMixer,

Boundary Air Loop Zone Mixer, !- Name

Boundary Air Loop Demand Side Outlet, !- Outlet Node Name

Boundary Air Loop Zone Mixer Inlet Node 1; !- Inlet 1 Node Name

!- =========== ALL OBJECTS IN CLASS: AIRLOOPHVAC:RETURNPATH ===========

AirLoopHVAC:ReturnPath,

Air Loop Demand Side Return Path, !- Name

Air Loop Demand Side Outlet, !- Return Air Path Outlet Node Name

AirLoopHVAC:ZoneMixer, !- Component 1 Object Type

Air Loop Zone Mixer;   !- Component 1 Name

AirLoopHVAC:ReturnPath,

Boundary Air Loop Demand Side Return Path, !- Name

Boundary Air Loop Demand Side Outlet, !- Return Air Path Outlet Node Name

AirLoopHVAC:ZoneMixer,   !- Component 1 Object Type

Boundary Air Loop Zone Mixer; !- Component 1 Name

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

Branch,

Air Loop AHU Main Branch,!- Name

,   !- Pressure Drop Curve Name

AirLoopHVAC:OutdoorAirSystem, !- Component 1 Object Type

Air Loop AHU Outside air system, !- Component 1 Name

Air Loop Supply Side Inlet, !- Component 1 Inlet Node Name

Air Loop AHU Mixed Air Outlet, !- Component 1 Outlet Node Name

Fan:VariableVolume,   !- Component 2 Object Type

Air Loop AHU Supply Fan, !- Component 2 Name

Air Loop AHU Mixed Air Outlet, !- Component 2 Inlet Node Name

Air Loop AHU Supply Fan Air Outlet Node, !- Component 2 Outlet Node Name

Coil:Heating:Water,   !- Component 3 Object Type

Air Loop AHU Heating Coil, !- Component 3 Name

Air Loop AHU Supply Fan Air Outlet Node, !- Component 3 Inlet Node Name

Air Loop AHU Heating Coil Air Outlet Node,   !- Component 3 Outlet Node Name

Coil:Cooling:Water,   !- Component 4 Object Type

Air Loop AHU Cooling Coil, !- Component 4 Name

Air Loop AHU Heating Coil Air Outlet Node, !- Component 4 Inlet Node Name

Air Loop Supply Side Outlet 1; !- Component 4 Outlet Node Name

Branch,

Boundary Air Loop AHU Main Branch, !- Name

,   !- Pressure Drop Curve Name

AirLoopHVAC:OutdoorAirSystem, !- Component 1 Object Type

Boundary Air Loop AHU Outside air system, !- Component 1 Name

Boundary Air Loop Supply Side Inlet, !- Component 1 Inlet Node Name

Boundary Air Loop AHU Mixed Air Outlet, !- Component 1 Outlet Node Name

Fan:VariableVolume,   !- Component 2 Object Type

Boundary Air Loop AHU Supply Fan, !- Component 2 Name

Boundary Air Loop AHU Mixed Air Outlet, !- Component 2 Inlet Node Name

Boundary Air Loop AHU Supply Fan Air Outlet Node, !- Component 2 Outlet Node Name

Coil:Heating:Water,   !- Component 3 Object Type

Boundary Air Loop AHU Heating Coil, !- Component 3 Name

Boundary Air Loop AHU Supply Fan Air Outlet Node, !- Component 3 Inlet Node Name

Boundary Air Loop AHU Heating Coil Air Outlet Node, !- Component 3 Outlet Node Name

Coil:Cooling:Water,   !- Component 4 Object Type

Boundary Air Loop AHU Cooling Coil, !- Component 4 Name

Boundary Air Loop AHU Heating Coil Air Outlet Node, !- Component 4 Inlet Node Name

Boundary Air Loop Supply Side Outlet 1; !- Component 4 Outlet Node Name

Branch,

HW Loop Demand Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

HW Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

HW Loop Demand Side Inlet, !- Component 1 Inlet Node Name

HW Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

HW Loop Demand Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

HW Loop Demand Side Bypass Pipe, !- Component 1 Name

HW Loop Demand Side Bypass Pipe Inlet Node,   !- Component 1 Inlet Node Name

HW Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Air Loop AHU Heating Coil HW Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

Coil:Heating:Water,   !- Component 1 Object Type

Air Loop AHU Heating Coil, !- Component 1 Name

Air Loop AHU Heating Coil Water Inlet Node, !- Component 1 Inlet Node Name

Air Loop AHU Heating Coil Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

DHW Loop Water Heater HW Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

WaterHeater:Mixed,   !- Component 1 Object Type

DHW Loop Water Heater,   !- Component 1 Name

DHW Loop Water Heater Heating Inlet Node, !- Component 1 Inlet Node Name

DHW Loop Water Heater Heating Outlet Node; !- Component 1 Outlet Node Name

Branch,

HW Loop Demand Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

HW Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

HW Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

HW Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

HW Loop Supply Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pump:VariableSpeed, !- Component 1 Object Type

HW Loop Supply Pump, !- Component 1 Name

HW Loop Supply Side Inlet, !- Component 1 Inlet Node Name

HW Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

HW Loop Supply Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

HW Loop Supply Side Bypass Pipe, !- Component 1 Name

HW Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

HW Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Heating HW Loop Supply Side Branch, !- Name

, !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Heating, !- Component 1 Object Type

Heat Pump Heating, !- Component 1 Name

Heat Pump Heating HW Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Heating HW Outlet Node; !- Component 1 Outlet Node Name

Branch,

HW Loop Supply Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

HW Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

HW Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

HW Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Demand Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

Condenser Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

Condenser Loop Demand Side Inlet, !- Component 1 Inlet Node Name

Condenser Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Demand Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

Condenser Loop Demand Side Bypass Pipe, !- Component 1 Name

Condenser Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

Condenser Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Cooling Condenser Loop Demand Side Branch, !- Name

, !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Component 1 Object Type

Heat Pump Cooling, !- Component 1 Name

Heat Pump Cooling Condenser Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Cooling Condenser Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Heating Condenser Loop Demand Side Branch, !- Name

, !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Heating, !- Component 1 Object Type

Heat Pump Heating, !- Component 1 Name

Heat Pump Heating Condenser Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Heating Condenser Outlet Node; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Demand Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

Condenser Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

Condenser Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

Condenser Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Supply Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pump:VariableSpeed, !- Component 1 Object Type

Condenser Loop Supply Pump, !- Component 1 Name

Condenser Loop Supply Side Inlet, !- Component 1 Inlet Node Name

Condenser Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Supply Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

Condenser Loop Supply Side Bypass Pipe, !- Component 1 Name

Condenser Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

Condenser Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Ground Heat Exchanger Condenser Loop Supply Side Branch, !- Name

, !- Pressure Drop Curve Name

GroundHeatExchanger:Vertical, !- Component 1 Object Type

Ground Heat Exchanger, !- Component 1 Name

Ground Heat Exchanger Water Inlet Node, !- Component 1 Inlet Node Name

Ground Heat Exchanger Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

Condenser Loop Supply Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

Condenser Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

Condenser Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

Condenser Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

CHW Loop Demand Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

CHW Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

CHW Loop Demand Side Inlet, !- Component 1 Inlet Node Name

CHW Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

CHW Loop Demand Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

CHW Loop Demand Side Bypass Pipe, !- Component 1 Name

CHW Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

CHW Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Air Loop AHU Cooling Coil CHW Loop Demand Side Branch, !- Name

, !- Pressure Drop Curve Name

Coil:Cooling:Water, !- Component 1 Object Type

Air Loop AHU Cooling Coil, !- Component 1 Name

Air Loop AHU Cooling Coil Water Inlet Node, !- Component 1 Inlet Node Name

Air Loop AHU Cooling Coil Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

Block:Test Chilled Ceiling CHW Loop Demand Side Branch, !- Name

, !- Pressure Drop Curve Name

ZoneHVAC:LowTemperatureRadiant:VariableFlow, !- Component 1 Object Type

Block:Test Heated Floor, !- Component 1 Name

Block:Test Chilled Ceiling CHW Water Inlet Node, !- Component 1 Inlet Node Name

Block:Test Chilled Ceiling CHW Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

CHW Loop Demand Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

CHW Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

CHW Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

CHW Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

CHW Loop Supply Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pump:VariableSpeed, !- Component 1 Object Type

CHW Loop Supply Pump, !- Component 1 Name

CHW Loop Supply Side Inlet, !- Component 1 Inlet Node Name

CHW Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

CHW Loop Supply Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

CHW Loop Supply Side Bypass Pipe, !- Component 1 Name

CHW Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

CHW Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Cooling CHW Loop Supply Side Branch, !- Name

, !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Component 1 Object Type

Heat Pump Cooling, !- Component 1 Name

Heat Pump Cooling CHW Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Cooling CHW Outlet Node; !- Component 1 Outlet Node Name

Branch,

CHW Loop Supply Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

CHW Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

CHW Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

CHW Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Demand Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary HW Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

boundary HW Loop Demand Side Inlet, !- Component 1 Inlet Node Name

boundary HW Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Demand Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary HW Loop Demand Side Bypass Pipe, !- Component 1 Name

boundary HW Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary HW Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Boundary Air Loop AHU Heating Coil boundary HW Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

Coil:Heating:Water,   !- Component 1 Object Type

Boundary Air Loop AHU Heating Coil, !- Component 1 Name

Boundary Air Loop AHU Heating Coil Water Inlet Node, !- Component 1 Inlet Node Name

Boundary Air Loop AHU Heating Coil Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Demand Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary HW Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

boundary HW Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

boundary HW Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Supply Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pump:VariableSpeed,   !- Component 1 Object Type

boundary HW Loop Supply Pump, !- Component 1 Name

boundary HW Loop Supply Side Inlet, !- Component 1 Inlet Node Name

boundary HW Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Supply Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary HW Loop Supply Side Bypass Pipe, !- Component 1 Name

boundary HW Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary HW Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Heating 1 boundary HW Loop Supply Side Branch, !- Name

,   !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Heating, !- Component 1 Object Type

Heat Pump Heating 1,   !- Component 1 Name

Heat Pump Heating 1 HW Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Heating 1 HW Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary HW Loop Supply Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary HW Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

boundary HW Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

boundary HW Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Demand Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary Condenser Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

boundary Condenser Loop Demand Side Inlet, !- Component 1 Inlet Node Name

boundary Condenser Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Demand Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary Condenser Loop Demand Side Bypass Pipe, !- Component 1 Name

boundary Condenser Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary Condenser Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Cooling 1 boundary Condenser Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Component 1 Object Type

Heat Pump Cooling 1,   !- Component 1 Name

Heat Pump Cooling 1 Condenser Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Cooling 1 Condenser Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Heating 1 boundary Condenser Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Heating, !- Component 1 Object Type

Heat Pump Heating 1,   !- Component 1 Name

Heat Pump Heating 1 Condenser Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Heating 1 Condenser Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Demand Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary Condenser Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

boundary Condenser Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

boundary Condenser Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Supply Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pump:VariableSpeed,   !- Component 1 Object Type

boundary Condenser Loop Supply Pump, !- Component 1 Name

boundary Condenser Loop Supply Side Inlet, !- Component 1 Inlet Node Name

boundary Condenser Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Supply Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary Condenser Loop Supply Side Bypass Pipe, !- Component 1 Name

boundary Condenser Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary Condenser Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Ground Heat Exchanger 1 boundary Condenser Loop Supply Side Branch, !- Name

,   !- Pressure Drop Curve Name

GroundHeatExchanger:Vertical, !- Component 1 Object Type

Ground Heat Exchanger 1, !- Component 1 Name

Ground Heat Exchanger 1 Water Inlet Node, !- Component 1 Inlet Node Name

Ground Heat Exchanger 1 Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary Condenser Loop Supply Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary Condenser Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

boundary Condenser Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

boundary Condenser Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Demand Side Inlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary CHW Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

boundary CHW Loop Demand Side Inlet, !- Component 1 Inlet Node Name

boundary CHW Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Demand Side Bypass Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary CHW Loop Demand Side Bypass Pipe, !- Component 1 Name

boundary CHW Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary CHW Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Boundary Air Loop AHU Cooling Coil boundary CHW Loop Demand Side Branch, !- Name

,   !- Pressure Drop Curve Name

Coil:Cooling:Water,   !- Component 1 Object Type

Boundary Air Loop AHU Cooling Coil, !- Component 1 Name

Boundary Air Loop AHU Cooling Coil Water Inlet Node, !- Component 1 Inlet Node Name

Boundary Air Loop AHU Cooling Coil Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Demand Side Outlet Branch, !- Name

,   !- Pressure Drop Curve Name

Pipe:Adiabatic,   !- Component 1 Object Type

boundary CHW Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

boundary CHW Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name boundary CHW Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Supply Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pump:VariableSpeed, !- Component 1 Object Type

boundary CHW Loop Supply Pump, !- Component 1 Name

boundary CHW Loop Supply Side Inlet, !- Component 1 Inlet Node Name

boundary CHW Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Supply Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

boundary CHW Loop Supply Side Bypass Pipe, !- Component 1 Name

boundary CHW Loop Supply Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

boundary CHW Loop Supply Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Heat Pump Cooling 1 boundary CHW Loop Supply Side Branch, !- Name

, !- Pressure Drop Curve Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Component 1 Object Type

Heat Pump Cooling 1, !- Component 1 Name

Heat Pump Cooling 1 CHW Inlet Node, !- Component 1 Inlet Node Name

Heat Pump Cooling 1 CHW Outlet Node; !- Component 1 Outlet Node Name

Branch,

boundary CHW Loop Supply Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

boundary CHW Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

boundary CHW Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

boundary CHW Loop Supply Side Outlet; !- Component 1 Outlet Node Name

Branch,

DHW Loop Demand Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

DHW Loop Demand Side Inlet Branch Pipe, !- Component 1 Name

DHW Loop Demand Side Inlet, !- Component 1 Inlet Node Name

DHW Loop Demand Side Inlet Branch Pipe Outlet; !- Component 1 Outlet Node Name

Branch,

DHW Loop Demand Side Bypass Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

DHW Loop Demand Side Bypass Pipe, !- Component 1 Name

DHW Loop Demand Side Bypass Pipe Inlet Node, !- Component 1 Inlet Node Name

DHW Loop Demand Side Bypass Pipe Outlet Node; !- Component 1 Outlet Node Name

Branch,

Block:Test Heated Floor DHW Loop Demand Side Branch, !- Name

, !- Pressure Drop Curve Name

ZoneHVAC:LowTemperatureRadiant:VariableFlow, !- Component 1 Object Type

Block:Test Heated Floor, !- Component 1 Name

Block:Test Heated Floor Hot Water Inlet Node, !- Component 1 Inlet Node Name

Block:Test Heated Floor Hot Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

DHW Loop Demand Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

DHW Loop Demand Side Outlet Branch Pipe, !- Component 1 Name

DHW Loop Demand Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

DHW Loop Demand Side Outlet; !- Component 1 Outlet Node Name

Branch,

DHW Loop Supply Side Inlet Branch, !- Name

, !- Pressure Drop Curve Name

Pump:VariableSpeed, !- Component 1 Object Type

DHW Loop Supply Pump, !- Component 1 Name

DHW Loop Supply Side Inlet, !- Component 1 Inlet Node Name

DHW Loop Supply Pump Water Outlet Node; !- Component 1 Outlet Node Name

Branch,

DHW Loop Water Heater DHW Loop Supply Side Branch, !- Name

, !- Pressure Drop Curve Name

WaterHeater:Mixed, !- Component 1 Object Type

DHW Loop Water Heater, !- Component 1 Name

DHW Loop Water Heater DHW Inlet Node, !- Component 1 Inlet Node Name

DHW Loop Water Heater DHW Outlet Node; !- Component 1 Outlet Node Name

Branch,

DHW Loop Supply Side Outlet Branch, !- Name

, !- Pressure Drop Curve Name

Pipe:Adiabatic, !- Component 1 Object Type

DHW Loop Supply Side Outlet Branch Pipe, !- Component 1 Name

DHW Loop Supply Side Outlet Branch Pipe Inlet, !- Component 1 Inlet Node Name

DHW Loop Supply Side Outlet; !- Component 1 Outlet Node Name

```
!-   ===========  ALL OBJECTS IN CLASS: BRANCHLIST ===========

BranchList,
    Air Loop Branches,       !- Name
    Air Loop AHU Main Branch;!- Branch 1 Name

BranchList,
    Boundary Air Loop Branches,  !- Name
    Boundary Air Loop AHU Main Branch;  !- Branch 1 Name

BranchList,
    HW Loop Demand Side Branches,  !- Name
    HW Loop Demand Side Inlet Branch,  !- Branch 1 Name
    HW Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Air Loop AHU Heating Coil HW Loop Demand Side Branch,  !- Branch 3 Name
    DHW Loop Water Heater HW Loop Demand Side Branch,  !- Branch 4 Name
    HW Loop Demand Side Outlet Branch;  !- Branch 5 Name

BranchList,
    HW Loop Supply Side Branches,  !- Name
    HW Loop Supply Side Inlet Branch,  !- Branch 1 Name
    HW Loop Supply Side Bypass Branch,  !- Branch 2 Name
    Heat Pump Heating HW Loop Supply Side Branch,  !- Branch 3 Name
    HW Loop Supply Side Outlet Branch;  !- Branch 4 Name

BranchList,
    Condenser Loop Demand Side Branches,  !- Name
    Condenser Loop Demand Side Inlet Branch,  !- Branch 1 Name
    Condenser Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Heat Pump Cooling Condenser Loop Demand Side Branch,  !- Branch 3 Name
    Heat Pump Heating Condenser Loop Demand Side Branch,  !- Branch 4 Name
    Condenser Loop Demand Side Outlet Branch;  !- Branch 5 Name

BranchList,
    Condenser Loop Supply Side Branches,  !- Name
    Condenser Loop Supply Side Inlet Branch,  !- Branch 1 Name
    Condenser Loop Supply Side Bypass Branch,  !- Branch 2 Name
    Ground Heat Exchanger Condenser Loop Supply Side Branch,  !- Branch 3 Name
    Condenser Loop Supply Side Outlet Branch;  !- Branch 4 Name

BranchList,
    CHW Loop Demand Side Branches,  !- Name
    CHW Loop Demand Side Inlet Branch,  !- Branch 1 Name
    CHW Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Air Loop AHU Cooling Coil CHW Loop Demand Side Branch,  !- Branch 3 Name
    Block:Test Chilled Ceiling CHW Loop Demand Side Branch,  !- Branch 4 Name
    CHW Loop Demand Side Outlet Branch;  !- Branch 5 Name

BranchList,
    CHW Loop Supply Side Branches,  !- Name
    CHW Loop Supply Side Inlet Branch,  !- Branch 1 Name
    CHW Loop Supply Side Bypass Branch,  !- Branch 2 Name
    Heat Pump Cooling CHW Loop Supply Side Branch,  !- Branch 3 Name
    CHW Loop Supply Side Outlet Branch;  !- Branch 4 Name


BranchList,
    boundary HW Loop Demand Side Branches,  !- Name
    boundary HW Loop Demand Side Inlet Branch,  !- Branch 1 Name
    boundary HW Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Boundary Air Loop AHU Heating Coil boundary HW Loop Demand Side Branch,  !- Branch 3 Name
    boundary HW Loop Demand Side Outlet Branch;  !- Branch 4 Name

BranchList,
    boundary HW Loop Supply Side Branches,  !- Name
    boundary HW Loop Supply Side Inlet Branch,  !- Branch 1 Name
    boundary HW Loop Supply Side Bypass Branch,  !- Branch 2 Name
    Heat Pump Heating 1 boundary HW Loop Supply Side Branch,  !- Branch 3 Name
    boundary HW Loop Supply Side Outlet Branch;  !- Branch 4 Name

BranchList,
    boundary Condenser Loop Demand Side Branches,  !- Name
    boundary Condenser Loop Demand Side Inlet Branch,  !- Branch 1 Name
    boundary Condenser Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Heat Pump Cooling 1 boundary Condenser Loop Demand Side Branch,  !- Branch 3 Name
    Heat Pump Heating 1 boundary Condenser Loop Demand Side Branch,  !- Branch 4 Name
    boundary Condenser Loop Demand Side Outlet Branch;  !- Branch 5 Name

BranchList,
    boundary Condenser Loop Supply Side Branches,  !- Name
    boundary Condenser Loop Supply Side Inlet Branch,  !- Branch 1 Name
    boundary Condenser Loop Supply Side Bypass Branch,  !- Branch 2 Name
    Ground Heat Exchanger 1 boundary Condenser Loop Supply Side Branch,  !- Branch 3 Name
    boundary Condenser Loop Supply Side Outlet Branch;  !- Branch 4 Name

BranchList,
    boundary CHW Loop Demand Side Branches,  !- Name
    boundary CHW Loop Demand Side Inlet Branch,  !- Branch 1 Name
    boundary CHW Loop Demand Side Bypass Branch,  !- Branch 2 Name
    Boundary Air Loop AHU Cooling Coil boundary CHW Loop Demand Side Branch,  !- Branch 3 Name
    boundary CHW Loop Demand Side Outlet Branch;  !- Branch 4 Name

BranchList,
    boundary CHW Loop Supply Side Branches,  !- Name
```

boundary CHW Loop Supply Side Inlet Branch, !- Branch 1 Name

boundary CHW Loop Supply Side Bypass Branch, !- Branch 2 Name

Heat Pump Cooling 1 boundary CHW Loop Supply Side Branch, !- Branch 3 Name

boundary CHW Loop Supply Side Outlet Branch; !- Branch 4 Name

BranchList,

DHW Loop Demand Side Branches, !- Name

DHW Loop Demand Side Inlet Branch, !- Branch 1 Name

DHW Loop Demand Side Bypass Branch, !- Branch 2 Name

Block:Test Heated Floor DHW Loop Demand Side Branch, !- Branch 3 Name

DHW Loop Demand Side Outlet Branch; !- Branch 4 Name

BranchList,

DHW Loop Supply Side Branches, !- Name

DHW Loop Supply Side Inlet Branch, !- Branch 1 Name

DHW Loop Water Heater DHW Loop Supply Side Branch, !- Branch 2 Name

DHW Loop Supply Side Outlet Branch; !- Branch 3 Name

!- =========== ALL OBJECTS IN CLASS: CONNECTOR:SPLITTER ===========

Connector:Splitter,

HW Loop Demand Splitter, !- Name

HW Loop Demand Side Inlet Branch, !- Inlet Branch Name

HW Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Air Loop AHU Heating Coil HW Loop Demand Side Branch, !- Outlet Branch 2 Name

DHW Loop Water Heater HW Loop Demand Side Branch; !- Outlet Branch 3 Name

Connector:Splitter,

HW Loop Supply Splitter, !- Name

HW Loop Supply Side Inlet Branch, !- Inlet Branch Name

HW Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Heating HW Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

Condenser Loop Demand Splitter, !- Name

Condenser Loop Demand Side Inlet Branch, !- Inlet Branch Name

Condenser Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Cooling Condenser Loop Demand Side Branch, !- Outlet Branch 2 Name

Heat Pump Heating Condenser Loop Demand Side Branch; !- Outlet Branch 3 Name

Connector:Splitter,

Condenser Loop Supply Splitter, !- Name

Condenser Loop Supply Side Inlet Branch, !- Inlet Branch Name

Condenser Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Ground Heat Exchanger Condenser Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

CHW Loop Demand Splitter,!- Name

CHW Loop Demand Side Inlet Branch, !- Inlet Branch Name

CHW Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Air Loop AHU Cooling Coil CHW Loop Demand Side Branch, !- Outlet Branch 2 Name

Block:Test Chilled Ceiling CHW Loop Demand Side Branch; !- Outlet Branch 3 Name

Connector:Splitter,

CHW Loop Supply Splitter,!- Name

CHW Loop Supply Side Inlet Branch, !- Inlet Branch Name

CHW Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Cooling CHW Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

boundary HW Loop Demand Splitter, !- Name

boundary HW Loop Demand Side Inlet Branch, !- Inlet Branch Name

boundary HW Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Boundary Air Loop AHU Heating Coil boundary HW Loop Demand Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

boundary HW Loop Supply Splitter, !- Name

boundary HW Loop Supply Side Inlet Branch, !- Inlet Branch Name

boundary HW Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Heating 1 boundary HW Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

boundary Condenser Loop Demand Splitter, !- Name

boundary Condenser Loop Demand Side Inlet Branch, !- Inlet Branch Name

boundary Condenser Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Cooling 1 boundary Condenser Loop Demand Side Branch, !- Outlet Branch 2 Name

Heat Pump Heating 1 boundary Condenser Loop Demand Side Branch; !- Outlet Branch 3 Name

Connector:Splitter,

boundary Condenser Loop Supply Splitter, !- Name

boundary Condenser Loop Supply Side Inlet Branch, !- Inlet Branch Name

boundary Condenser Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Ground Heat Exchanger 1 boundary Condenser Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

boundary CHW Loop Demand Splitter, !- Name

boundary CHW Loop Demand Side Inlet Branch, !- Inlet Branch Name

boundary CHW Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Boundary Air Loop AHU Cooling Coil boundary CHW Loop Demand Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

boundary CHW Loop Supply Splitter, !- Name

boundary CHW Loop Supply Side Inlet Branch, !- Inlet Branch Name

boundary CHW Loop Supply Side Bypass Branch, !- Outlet Branch 1 Name

Heat Pump Cooling 1 boundary CHW Loop Supply Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

DHW Loop Demand Splitter,!- Name

DHW Loop Demand Side Inlet Branch, !- Inlet Branch Name

DHW Loop Demand Side Bypass Branch, !- Outlet Branch 1 Name

Block:Test Heated Floor DHW Loop Demand Side Branch; !- Outlet Branch 2 Name

Connector:Splitter,

DHW Loop Supply Splitter,!- Name

DHW Loop Supply Side Inlet Branch, !- Inlet Branch Name

DHW Loop Water Heater DHW Loop Supply Side Branch; !- Outlet Branch 1 Name

!- =========== ALL OBJECTS IN CLASS: CONNECTOR:MIXER ===========

Connector:Mixer,

HW Loop Demand Mixer, !- Name

HW Loop Demand Side Outlet Branch, !- Outlet Branch Name

DHW Loop Water Heater HW Loop Demand Side Branch, !- Inlet Branch 1 Name

HW Loop Demand Side Bypass Branch, !- Inlet Branch 2 Name

Air Loop AHU Heating Coil HW Loop Demand Side Branch; !- Inlet Branch 3 Name

Connector:Mixer,

HW Loop Supply Mixer, !- Name

HW Loop Supply Side Outlet Branch, !- Outlet Branch Name

Heat Pump Heating HW Loop Supply Side Branch, !- Inlet Branch 1 Name

HW Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

Condenser Loop Demand Mixer, !- Name

Condenser Loop Demand Side Outlet Branch, !- Outlet Branch Name

Condenser Loop Demand Side Bypass Branch, !- Inlet Branch 1 Name

Heat Pump Cooling Condenser Loop Demand Side Branch, !- Inlet Branch 2 Name

Heat Pump Heating Condenser Loop Demand Side Branch; !- Inlet Branch 3 Name

Connector:Mixer,

Condenser Loop Supply Mixer, !- Name

Condenser Loop Supply Side Outlet Branch, !- Outlet Branch Name

Ground Heat Exchanger Condenser Loop Supply Side Branch, !- Inlet Branch 1 Name

Condenser Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

CHW Loop Demand Mixer, !- Name

CHW Loop Demand Side Outlet Branch, !- Outlet Branch Name

Block:Test Chilled Ceiling CHW Loop Demand Side Branch, !- Inlet Branch 1 Name

CHW Loop Demand Side Bypass Branch, !- Inlet Branch 2 Name

Air Loop AHU Cooling Coil CHW Loop Demand Side Branch; !- Inlet Branch 3 Name

Connector:Mixer,

CHW Loop Supply Mixer, !- Name

CHW Loop Supply Side Outlet Branch, !- Outlet Branch Name

Heat Pump Cooling CHW Loop Supply Side Branch, !- Inlet Branch 1 Name

CHW Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

boundary HW Loop Demand Mixer, !- Name

boundary HW Loop Demand Side Outlet Branch, !- Outlet Branch Name

boundary HW Loop Demand Side Bypass Branch, !- Inlet Branch 1 Name

Boundary Air Loop AHU Heating Coil boundary HW Loop Demand Side Branch; !- Inlet Branch 2 Name

Connector:Mixer,

boundary HW Loop Supply Mixer, !- Name

boundary HW Loop Supply Side Outlet Branch, !- Outlet Branch Name

Heat Pump Heating 1 boundary HW Loop Supply Side Branch, !- Inlet Branch 1 Name

boundary HW Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

boundary Condenser Loop Demand Mixer, !- Name

boundary Condenser Loop Demand Side Outlet Branch, !- Outlet Branch Name

boundary Condenser Loop Demand Side Bypass Branch, !- Inlet Branch 1 Name

Heat Pump Cooling 1 boundary Condenser Loop Demand Side Branch, !- Inlet Branch 2 Name

Heat Pump Heating 1 boundary Condenser Loop Demand Side Branch; !- Inlet Branch 3 Name

Connector:Mixer,

boundary Condenser Loop Supply Mixer, !- Name

boundary Condenser Loop Supply Side Outlet Branch, !- Outlet Branch Name

Ground Heat Exchanger 1 boundary Condenser Loop Supply Side Branch, !- Inlet Branch 1 Name

boundary Condenser Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

boundary CHW Loop Demand Mixer, !- Name

boundary CHW Loop Demand Side Outlet Branch, !- Outlet Branch Name

boundary CHW Loop Demand Side Bypass Branch, !- Inlet Branch 1 Name

Boundary Air Loop AHU Cooling Coil boundary CHW Loop Demand Side Branch; !- Inlet Branch 2 Name

Connector:Mixer,

boundary CHW Loop Supply Mixer, !- Name

boundary CHW Loop Supply Side Outlet Branch, !- Outlet Branch Name

Heat Pump Cooling 1 boundary CHW Loop Supply Side Branch, !- Inlet Branch 1 Name

boundary CHW Loop Supply Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

DHW Loop Demand Mixer,   !- Name

DHW Loop Demand Side Outlet Branch, !- Outlet Branch Name

Block:Test Heated Floor DHW Loop Demand Side Branch, !- Inlet Branch 1 Name

DHW Loop Demand Side Bypass Branch; !- Inlet Branch 2 Name

Connector:Mixer,

DHW Loop Supply Mixer,   !- Name

DHW Loop Supply Side Outlet Branch, !- Outlet Branch Name

DHW Loop Water Heater DHW Loop Supply Side Branch; !- Inlet Branch 1 Name

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

ConnectorList,

HW Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

HW Loop Demand Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

HW Loop Demand Mixer;   !- Connector 2 Name

ConnectorList,

HW Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

HW Loop Supply Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

HW Loop Supply Mixer;   !- Connector 2 Name

ConnectorList,

Condenser Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

Condenser Loop Demand Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

Condenser Loop Demand Mixer; !- Connector 2 Name

ConnectorList,

Condenser Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

Condenser Loop Supply Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

Condenser Loop Supply Mixer; !- Connector 2 Name

ConnectorList,

CHW Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

CHW Loop Demand Splitter,!- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

CHW Loop Demand Mixer;   !- Connector 2 Name

ConnectorList,

CHW Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

CHW Loop Supply Splitter,!- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

CHW Loop Supply Mixer;   !- Connector 2 Name

ConnectorList,

boundary HW Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary HW Loop Demand Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary HW Loop Demand Mixer; !- Connector 2 Name

ConnectorList,

boundary HW Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary HW Loop Supply Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary HW Loop Supply Mixer; !- Connector 2 Name

ConnectorList,

boundary Condenser Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary Condenser Loop Demand Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary Condenser Loop Demand Mixer; !- Connector 2 Name

ConnectorList,

boundary Condenser Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary Condenser Loop Supply Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary Condenser Loop Supply Mixer; !- Connector 2 Name

ConnectorList,

boundary CHW Loop Demand Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary CHW Loop Demand Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary CHW Loop Demand Mixer; !- Connector 2 Name

ConnectorList,

boundary CHW Loop Supply Side Connectors, !- Name

Connector:Splitter,   !- Connector 1 Object Type

boundary CHW Loop Supply Splitter, !- Connector 1 Name

Connector:Mixer,   !- Connector 2 Object Type

boundary CHW Loop Supply Mixer; !- Connector 2 Name

ConnectorList,

DHW Loop Demand Side Connectors, !- Name

```
    Connector:Splitter,      !- Connector 1 Object Type
    DHW Loop Demand Splitter,!- Connector 1 Name
    Connector:Mixer,         !- Connector 2 Object Type
    DHW Loop Demand Mixer;   !- Connector 2 Name
ConnectorList,
    DHW Loop Supply Side Connectors,  !- Name
    Connector:Splitter,      !- Connector 1 Object Type
    DHW Loop Supply Splitter,!- Connector 1 Name
    Connector:Mixer,         !- Connector 2 Object Type
    DHW Loop Supply Mixer;   !- Connector 2 Name
!-   ===========  ALL OBJECTS IN CLASS: NODELIST ===========
NodeList,
    Air Loop Demand Side Inlet List,  !- Name
    Air Loop Demand Side Inlet 1;  !- Node 1 Name
NodeList,
    Air Loop Supply Side Outlet List,  !- Name
    Air Loop Supply Side Outlet 1;  !- Node 1 Name
NodeList,
    Boundary Air Loop Demand Side Inlet List,  !- Name
    Boundary Air Loop Demand Side Inlet 1;  !- Node 1 Name
NodeList,
    Boundary Air Loop Supply Side Outlet List,  !- Name
    Boundary Air Loop Supply Side Outlet 1;  !- Node 1 Name
NodeList,
    Block:Test Air Inlet Node List,  !- Name
    Air Loop Zone Splitter Outlet Node 1;  !- Node 1 Name
NodeList,
    Block:boundary Air Inlet Node List,  !- Name
    Boundary Air Loop Zone Splitter Outlet Node 1;  !- Node 1 Name
NodeList,
    HW Loop Setpoint Manager Node List,  !- Name
    HW Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    Condenser Loop Setpoint Manager Node List,  !- Name
    Condenser Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    CHW Loop Setpoint Manager Node List,  !- Name
    CHW Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    Air Loop Setpoint Manager Node List,  !- Name
    Air Loop Supply Side Outlet 1,  !- Node 1 Name
    Air Loop AHU Heating Coil Air Outlet Node;  !- Node 2 Name
NodeList,
    HW Loop 1 Setpoint Manager Node List,  !- Name
    boundary HW Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    Condenser Loop 1 Setpoint Manager Node List,  !- Name
    boundary Condenser Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    CHW Loop 1 Setpoint Manager Node List,  !- Name
    boundary CHW Loop Supply Side Outlet;  !- Node 1 Name
NodeList,
    Boundary Air Loop Setpoint Manager Node List,  !- Name
    Boundary Air Loop Supply Side Outlet 1,  !- Node 1 Name
    Boundary Air Loop AHU Heating Coil Air Outlet Node;  !- Node 2 Name
NodeList,
    DHW Loop Setpoint Manager Node List,  !- Name
    DHW Loop Supply Side Outlet;  !- Node 1 Name
!-   ===========  ALL OBJECTS IN CLASS: OUTDOORAIR:NODELIST ===========
OutdoorAir:NodeList,
    Air Loop AHU Outdoor Air Inlet;  !- Node or NodeList Name 1
OutdoorAir:NodeList,
    Boundary Air Loop AHU Outdoor Air Inlet;  !- Node or NodeList Name 1
OutdoorAir:NodeList,
    DHW Loop Water Heater Outdoor Air Node;  !- Node or NodeList Name 1
!-   ===========  ALL OBJECTS IN CLASS: PIPE:ADIABATIC ===========
Pipe:Adiabatic,
    HW Loop Demand Side Inlet Branch Pipe,  !- Name
    HW Loop Demand Side Inlet,  !- Inlet Node Name
    HW Loop Demand Side Inlet Branch Pipe Outlet;  !- Outlet Node Name
Pipe:Adiabatic,
    HW Loop Demand Side Bypass Pipe,  !- Name
    HW Loop Demand Side Bypass Pipe Inlet Node,  !- Inlet Node Name
    HW Loop Demand Side Bypass Pipe Outlet Node;  !- Outlet Node Name
Pipe:Adiabatic,
    HW Loop Demand Side Outlet Branch Pipe,  !- Name
    HW Loop Demand Side Outlet Branch Pipe Inlet,  !- Inlet Node Name
    HW Loop Demand Side Outlet;  !- Outlet Node Name
Pipe:Adiabatic,
    HW Loop Supply Side Bypass Pipe,  !- Name
    HW Loop Supply Side Bypass Pipe Inlet Node,  !- Inlet Node Name
    HW Loop Supply Side Bypass Pipe Outlet Node;  !- Outlet Node Name
Pipe:Adiabatic,
    HW Loop Supply Side Outlet Branch Pipe,  !- Name
    HW Loop Supply Side Outlet Branch Pipe Inlet,  !- Inlet Node Name
    HW Loop Supply Side Outlet;  !- Outlet Node Name
Pipe:Adiabatic,
```

Condenser Loop Demand Side Inlet Branch Pipe, !- Name

Condenser Loop Demand Side Inlet, !- Inlet Node Name

Condenser Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

Condenser Loop Demand Side Bypass Pipe, !- Name

Condenser Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

Condenser Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

Condenser Loop Demand Side Outlet Branch Pipe, !- Name

Condenser Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

Condenser Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

Condenser Loop Supply Side Bypass Pipe, !- Name

Condenser Loop Supply Side Bypass Pipe Inlet Node, !- Inlet Node Name

Condenser Loop Supply Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

Condenser Loop Supply Side Outlet Branch Pipe, !- Name

Condenser Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name

Condenser Loop Supply Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

CHW Loop Demand Side Inlet Branch Pipe, !- Name

CHW Loop Demand Side Inlet, !- Inlet Node Name

CHW Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

CHW Loop Demand Side Bypass Pipe, !- Name

CHW Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

CHW Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

CHW Loop Demand Side Outlet Branch Pipe, !- Name

CHW Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

CHW Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

CHW Loop Supply Side Bypass Pipe, !- Name

CHW Loop Supply Side Bypass Pipe Inlet Node, !- Inlet Node Name

CHW Loop Supply Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

CHW Loop Supply Side Outlet Branch Pipe, !- Name

CHW Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name

CHW Loop Supply Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary HW Loop Demand Side Inlet Branch Pipe, !- Name

boundary HW Loop Demand Side Inlet, !- Inlet Node Name

boundary HW Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary HW Loop Demand Side Bypass Pipe, !- Name

boundary HW Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary HW Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary HW Loop Demand Side Outlet Branch Pipe, !- Name

boundary HW Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

boundary HW Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary HW Loop Supply Side Bypass Pipe, !- Name

boundary HW Loop Supply Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary HW Loop Supply Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary HW Loop Supply Side Outlet Branch Pipe, !- Name

boundary HW Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name

boundary HW Loop Supply Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary Condenser Loop Demand Side Inlet Branch Pipe, !- Name

boundary Condenser Loop Demand Side Inlet, !- Inlet Node Name

boundary Condenser Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary Condenser Loop Demand Side Bypass Pipe, !- Name

boundary Condenser Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary Condenser Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary Condenser Loop Demand Side Outlet Branch Pipe, !- Name

boundary Condenser Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

boundary Condenser Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary Condenser Loop Supply Side Bypass Pipe, !- Name

boundary Condenser Loop Supply Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary Condenser Loop Supply Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary Condenser Loop Supply Side Outlet Branch Pipe, !- Name

boundary Condenser Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name boundary Condenser Loop Supply Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary CHW Loop Demand Side Inlet Branch Pipe, !- Name

boundary CHW Loop Demand Side Inlet, !- Inlet Node Name

boundary CHW Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary CHW Loop Demand Side Bypass Pipe, !- Name

boundary CHW Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary CHW Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary CHW Loop Demand Side Outlet Branch Pipe, !- Name

boundary CHW Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

boundary CHW Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

boundary CHW Loop Supply Side Bypass Pipe, !- Name

boundary CHW Loop Supply Side Bypass Pipe Inlet Node, !- Inlet Node Name

boundary CHW Loop Supply Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

boundary CHW Loop Supply Side Outlet Branch Pipe, !- Name

boundary CHW Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name

boundary CHW Loop Supply Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

DHW Loop Demand Side Inlet Branch Pipe, !- Name

DHW Loop Demand Side Inlet, !- Inlet Node Name

DHW Loop Demand Side Inlet Branch Pipe Outlet; !- Outlet Node Name

Pipe:Adiabatic,

DHW Loop Demand Side Bypass Pipe, !- Name

DHW Loop Demand Side Bypass Pipe Inlet Node, !- Inlet Node Name

DHW Loop Demand Side Bypass Pipe Outlet Node; !- Outlet Node Name

Pipe:Adiabatic,

DHW Loop Demand Side Outlet Branch Pipe, !- Name

DHW Loop Demand Side Outlet Branch Pipe Inlet, !- Inlet Node Name

DHW Loop Demand Side Outlet; !- Outlet Node Name

Pipe:Adiabatic,

DHW Loop Supply Side Outlet Branch Pipe, !- Name

DHW Loop Supply Side Outlet Branch Pipe Inlet, !- Inlet Node Name

DHW Loop Supply Side Outlet; !- Outlet Node Name

!- =========== ALL OBJECTS IN CLASS: PUMP:VARIABLESPEED ===========

Pump:VariableSpeed,

HW Loop Supply Pump, !- Name

HW Loop Supply Side Inlet, !- Inlet Node Name

HW Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.000951, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

27.08, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Intermittent; !- Pump Control Type

Pump:VariableSpeed,

Condenser Loop Supply Pump, !- Name

Condenser Loop Supply Side Inlet, !- Inlet Node Name

Condenser Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.002210, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

62.96, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Intermittent; !- Pump Control Type

Pump:VariableSpeed,

CHW Loop Supply Pump, !- Name

CHW Loop Supply Side Inlet, !- Inlet Node Name

CHW Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.000131, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

3.72, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Continuous; !- Pump Control Type

Pump:VariableSpeed,

boundary HW Loop Supply Pump, !- Name

boundary HW Loop Supply Side Inlet, !- Inlet Node Name

boundary HW Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.000111, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

3.16, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Intermittent; !- Pump Control Type

Pump:VariableSpeed,

boundary Condenser Loop Supply Pump, !- Name

boundary Condenser Loop Supply Side Inlet, !- Inlet Node Name

boundary Condenser Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.002210, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

62.96, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Intermittent; !- Pump Control Type

Pump:VariableSpeed,

boundary CHW Loop Supply Pump, !- Name

boundary CHW Loop Supply Side Inlet, !- Inlet Node Name

boundary CHW Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.000038, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

1.09, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.3698, !- Coefficient 1 of the Part Load Performance Curve

0.8404, !- Coefficient 2 of the Part Load Performance Curve

-0.2101, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Continuous; !- Pump Control Type

Pump:VariableSpeed,

DHW Loop Supply Pump, !- Name

DHW Loop Supply Side Inlet, !- Inlet Node Name

DHW Loop Supply Pump Water Outlet Node, !- Outlet Node Name

0.000098, !- Design Maximum Flow Rate {m3/s}

20000.00, !- Design Pump Head {Pa}

2.80, !- Design Power Consumption {W}

0.90, !- Motor Efficiency

0.00, !- Fraction of Motor Inefficiencies to Fluid Stream

0.0000, !- Coefficient 1 of the Part Load Performance Curve

1.0000, !- Coefficient 2 of the Part Load Performance Curve

0.0000, !- Coefficient 3 of the Part Load Performance Curve

0.0000, !- Coefficient 4 of the Part Load Performance Curve

0.000000, !- Design Minimum Flow Rate {m3/s}

Intermittent; !- Pump Control Type

!- =========== ALL OBJECTS IN CLASS: HEATPUMP:WATERTOWATER:EQUATIONFIT:HEATING ===========

HeatPump:WaterToWater:EquationFit:Heating,

Heat Pump Heating, !- Name

Heat Pump Heating Condenser Inlet Node, !- Source Side Inlet Node Name

Heat Pump Heating Condenser Outlet Node, !- Source Side Outlet Node Name

Heat Pump Heating HW Inlet Node, !- Load Side Inlet Node Name

Heat Pump Heating HW Outlet Node, !- Load Side Outlet Node Name

0.002210, !- Reference Load Side Flow Rate {m3/s}

0.002210, !- Reference Source Side Flow Rate {m3/s}

50000.0000, !- Reference Heating Capacity {W}

12000.000000000, !- Reference Heating Power Consumption {W}

-1.604163340, !- Heating Capacity Coefficient 1

-0.983064150, !- Heating Capacity Coefficient 2

3.247859850, !- Heating Capacity Coefficient 3

0.099980470, !- Heating Capacity Coefficient 4

0.079842920, !- Heating Capacity Coefficient 5

-2.675705440, !- Heating Compressor Power Coefficient 1

2.692155330, !- Heating Compressor Power Coefficient 2

0.393406910, !- Heating Compressor Power Coefficient 3

0.010877340, !- Heating Compressor Power Coefficient 4

0.014918220; !- Heating Compressor Power Coefficient 5

HeatPump:WaterToWater:EquationFit:Heating,

Heat Pump Heating 1, !- Name

Heat Pump Heating 1 Condenser Inlet Node, !- Source Side Inlet Node Name

Heat Pump Heating 1 Condenser Outlet Node, !- Source Side Outlet Node Name

Heat Pump Heating 1 HW Inlet Node, !- Load Side Inlet Node Name

Heat Pump Heating 1 HW Outlet Node, !- Load Side Outlet Node Name

0.002210,   !- Reference Load Side Flow Rate {m3/s}

0.002210,   !- Reference Source Side Flow Rate {m3/s}

50000.0000,   !- Reference Heating Capacity {W}

12000.000000000,   !- Reference Heating Power Consumption {W}

-1.604163340,   !- Heating Capacity Coefficient 1

-0.983064150,   !- Heating Capacity Coefficient 2

3.247859850,   !- Heating Capacity Coefficient 3

0.099980470,   !- Heating Capacity Coefficient 4

0.079842920,   !- Heating Capacity Coefficient 5

-2.675705440,   !- Heating Compressor Power Coefficient 1

2.692155330,   !- Heating Compressor Power Coefficient 2

0.393406910,   !- Heating Compressor Power Coefficient 3

0.010877340,   !- Heating Compressor Power Coefficient 4

0.014918220;   !- Heating Compressor Power Coefficient 5

!- =========== ALL OBJECTS IN CLASS: HEATPUMP:WATERTOWATER:EQUATIONFIT:COOLING ===========

HeatPump:WaterToWater:EquationFit:Cooling,

Heat Pump Cooling,   !- Name

Heat Pump Cooling Condenser Inlet Node, !- Source Side Inlet Node Name

Heat Pump Cooling Condenser Outlet Node, !- Source Side Outlet Node Name

Heat Pump Cooling CHW Inlet Node, !- Load Side Inlet Node Name

Heat Pump Cooling CHW Outlet Node, !- Load Side Outlet Node Name

0.000570,   !- Reference Load Side Flow Rate {m3/s}

0.000570,   !- Reference Source Side Flow Rate {m3/s}

10800.0000,   !- Reference Cooling Capacity {W}

2900.000000000,   !- Reference Cooling Power Consumption {W}

-1.357165400,   !- Cooling Capacity Coefficient 1

4.789435420,   !- Cooling Capacity Coefficient 2

-2.817065990,   !- Cooling Capacity Coefficient 3

0.082846290,   !- Cooling Capacity Coefficient 4

0.076707730,   !- Cooling Capacity Coefficient 5

-3.701490740,   !- Cooling Compressor Power Coefficient 1

0.181795040,   !- Cooling Compressor Power Coefficient 2

4.007635490,   !- Cooling Compressor Power Coefficient 3

0.008399010,   !- Cooling Compressor Power Coefficient 4

-0.138740540;   !- Cooling Compressor Power Coefficient 5

HeatPump:WaterToWater:EquationFit:Cooling,

Heat Pump Cooling 1,   !- Name

Heat Pump Cooling 1 Condenser Inlet Node, !- Source Side Inlet Node Name

Heat Pump Cooling 1 Condenser Outlet Node, !- Source Side Outlet Node Name

Heat Pump Cooling 1 CHW Inlet Node, !- Load Side Inlet Node Name

Heat Pump Cooling 1 CHW Outlet Node, !- Load Side Outlet Node Name

0.000570,   !- Reference Load Side Flow Rate {m3/s}

0.000570,   !- Reference Source Side Flow Rate {m3/s}

10800.0000,   !- Reference Cooling Capacity {W}

2900.000000000,   !- Reference Cooling Power Consumption {W}

-1.357165400,   !- Cooling Capacity Coefficient 1

4.789435420,   !- Cooling Capacity Coefficient 2

-2.817065990,   !- Cooling Capacity Coefficient 3

0.082846290,   !- Cooling Capacity Coefficient 4

0.076707730,   !- Cooling Capacity Coefficient 5

-3.701490740,   !- Cooling Compressor Power Coefficient 1

0.181795040,   !- Cooling Compressor Power Coefficient 2

4.007635490,   !- Cooling Compressor Power Coefficient 3

0.008399010,   !- Cooling Compressor Power Coefficient 4

-0.138740540;   !- Cooling Compressor Power Coefficient 5

!- =========== ALL OBJECTS IN CLASS: GROUNDHEATEXCHANGER:VERTICAL ===========

GroundHeatExchanger:Vertical,

Ground Heat Exchanger,   !- Name

Ground Heat Exchanger Water Inlet Node, !- Inlet Node Name

Ground Heat Exchanger Water Outlet Node, !- Outlet Node Name

0.003900,   !- Design Flow Rate {m3/s}

32,   !- Number of Bore Holes

75.9866,   !- Bore Hole Length {m}

0.0635,   !- Bore Hole Radius {m}

0.6926,   !- Ground Thermal Conductivity {W/m-K}

2346999.9998,   !- Ground Thermal Heat Capacity {J/m3-K}

13.3750,   !- Ground Temperature {C}

0.6926,   !- Grout Thermal Conductivity {W/m-K}

0.3913,   !- Pipe Thermal Conductivity {W/m-K}

0.02666670,   !- Pipe Out Diameter {m}

0.02286000,   !- U-Tube Distance {m}

0.00241285,   !- Pipe Thickness {m}

1,   !- Maximum Length of Simulation {years}

0.00083600,   !- G-Function Reference Ratio {dimensionless}

76,   !- Number of Data Pairs of the G Function

-15.795833,   !- G-Function Ln(T/Ts) Value 1

-0.868005,   !- G-Function G Value 1

-15.646939,   !- G-Function Ln(T/Ts) Value 2

-0.841532,   !- G-Function G Value 2

-15.498044,   !- G-Function Ln(T/Ts) Value 3

-0.813862,   !- G-Function G Value 3

-15.349150, !- G-Function Ln(T/Ts) Value 4
-0.784824, !- G-Function G Value 4
-15.200255, !- G-Function Ln(T/Ts) Value 5
-0.754311, !- G-Function G Value 5
-15.051361, !- G-Function Ln(T/Ts) Value 6
-0.722260, !- G-Function G Value 6
-14.902466, !- G-Function Ln(T/Ts) Value 7
-0.688635, !- G-Function G Value 7
-14.753571, !- G-Function Ln(T/Ts) Value 8
-0.653424, !- G-Function G Value 8
-14.604677, !- G-Function Ln(T/Ts) Value 9
-0.616633, !- G-Function G Value 9
-14.455782, !- G-Function Ln(T/Ts) Value 10
-0.578288, !- G-Function G Value 10
-14.306888, !- G-Function Ln(T/Ts) Value 11
-0.538426, !- G-Function G Value 11
-14.157993, !- G-Function Ln(T/Ts) Value 12
-0.497093, !- G-Function G Value 12
-14.009099, !- G-Function Ln(T/Ts) Value 13
-0.454339, !- G-Function G Value 13
-13.860204, !- G-Function Ln(T/Ts) Value 14
-0.410206, !- G-Function G Value 14
-13.711310, !- G-Function Ln(T/Ts) Value 15
-0.364726, !- G-Function G Value 15
-13.562415, !- G-Function Ln(T/Ts) Value 16
-0.317904, !- G-Function G Value 16
-13.413520, !- G-Function Ln(T/Ts) Value 17
-0.269714, !- G-Function G Value 17
-13.264626, !- G-Function Ln(T/Ts) Value 18
-0.220096, !- G-Function G Value 18
-13.115731, !- G-Function Ln(T/Ts) Value 19
-0.168953, !- G-Function G Value 19
-12.966837, !- G-Function Ln(T/Ts) Value 20
-0.116163, !- G-Function G Value 20
-12.817942, !- G-Function Ln(T/Ts) Value 21
-0.061585, !- G-Function G Value 21
-12.669048, !- G-Function Ln(T/Ts) Value 22
-0.005079, !- G-Function G Value 22
-12.520153, !- G-Function Ln(T/Ts) Value 23
0.053480, !- G-Function G Value 23
-12.371259, !- G-Function Ln(T/Ts) Value 24
0.114187, !- G-Function G Value 24
-12.222364, !- G-Function Ln(T/Ts) Value 25
0.177098, !- G-Function G Value 25
-12.073469, !- G-Function Ln(T/Ts) Value 26
0.242221, !- G-Function G Value 26
-11.924575, !- G-Function Ln(T/Ts) Value 27
0.309516, !- G-Function G Value 27
-11.775680, !- G-Function Ln(T/Ts) Value 28
0.378895, !- G-Function G Value 28
-11.626786, !- G-Function Ln(T/Ts) Value 29
0.450230, !- G-Function G Value 29
-11.477891, !- G-Function Ln(T/Ts) Value 30
0.523360, !- G-Function G Value 30
-11.328997, !- G-Function Ln(T/Ts) Value 31
0.598093, !- G-Function G Value 31
-11.180102, !- G-Function Ln(T/Ts) Value 32
0.674224, !- G-Function G Value 32
-11.031208, !- G-Function Ln(T/Ts) Value 33
0.751534, !- G-Function G Value 33
-10.882313, !- G-Function Ln(T/Ts) Value 34
0.829805, !- G-Function G Value 34
-10.733418, !- G-Function Ln(T/Ts) Value 35
0.908825, !- G-Function G Value 35
-10.584524, !- G-Function Ln(T/Ts) Value 36
0.988392, !- G-Function G Value 36
-10.435629, !- G-Function Ln(T/Ts) Value 37
1.068324, !- G-Function G Value 37
-10.286735, !- G-Function Ln(T/Ts) Value 38
1.148459, !- G-Function G Value 38
-10.137840, !- G-Function Ln(T/Ts) Value 39
1.228656, !- G-Function G Value 39
-9.988946, !- G-Function Ln(T/Ts) Value 40
1.308799, !- G-Function G Value 40
-9.840051, !- G-Function Ln(T/Ts) Value 41
1.388797, !- G-Function G Value 41
-9.691156, !- G-Function Ln(T/Ts) Value 42
1.468579, !- G-Function G Value 42
-9.542262, !- G-Function Ln(T/Ts) Value 43
1.548092, !- G-Function G Value 43
-9.393367, !- G-Function Ln(T/Ts) Value 44
1.627303, !- G-Function G Value 44
-9.244473, !- G-Function Ln(T/Ts) Value 45
1.706193, !- G-Function G Value 45
-9.095578, !- G-Function Ln(T/Ts) Value 46
1.784752, !- G-Function G Value 46
-8.946684, !- G-Function Ln(T/Ts) Value 47
1.862983, !- G-Function G Value 47

```
-8.797789,          !- G-Function Ln(T/Ts) Value 48
1.940892,           !- G-Function G Value 48
-8.648895,          !- G-Function Ln(T/Ts) Value 49
2.018493,           !- G-Function G Value 49
-8.500000,          !- G-Function Ln(T/Ts) Value 50
2.157703,           !- G-Function G Value 50
-7.800000,          !- G-Function Ln(T/Ts) Value 51
2.501703,           !- G-Function G Value 51
-7.200000,          !- G-Function Ln(T/Ts) Value 52
2.798169,           !- G-Function G Value 52
-6.500000,          !- G-Function Ln(T/Ts) Value 53
3.153701,           !- G-Function G Value 53
-5.900000,          !- G-Function Ln(T/Ts) Value 54
3.508888,           !- G-Function G Value 54
-5.200000,          !- G-Function Ln(T/Ts) Value 55
4.109035,           !- G-Function G Value 55
-4.500000,          !- G-Function Ln(T/Ts) Value 56
5.102711,           !- G-Function G Value 56
-3.963000,          !- G-Function Ln(T/Ts) Value 57
6.142695,           !- G-Function G Value 57
-3.270000,          !- G-Function Ln(T/Ts) Value 58
8.399091,           !- G-Function G Value 58
-2.864000,          !- G-Function Ln(T/Ts) Value 59
10.097311,          !- G-Function G Value 59
-2.577000,          !- G-Function Ln(T/Ts) Value 60
11.476045,          !- G-Function G Value 60
-2.171000,          !- G-Function Ln(T/Ts) Value 61
13.625063,          !- G-Function G Value 61
-1.884000,          !- G-Function Ln(T/Ts) Value 62
15.257542,          !- G-Function G Value 62
-1.191000,          !- G-Function Ln(T/Ts) Value 63
19.275440,          !- G-Function G Value 63
-0.497000,          !- G-Function Ln(T/Ts) Value 64
23.134167,          !- G-Function G Value 64
-0.274000,          !- G-Function Ln(T/Ts) Value 65
24.214672,          !- G-Function G Value 65
-0.051000,          !- G-Function Ln(T/Ts) Value 66
25.205920,          !- G-Function G Value 66
0.196000,           !- G-Function Ln(T/Ts) Value 67
26.169701,          !- G-Function G Value 67
0.419000,           !- G-Function Ln(T/Ts) Value 68
26.931357,          !- G-Function G Value 68
0.642000,           !- G-Function Ln(T/Ts) Value 69
27.584614,          !- G-Function G Value 69
0.873000,           !- G-Function Ln(T/Ts) Value 70
28.157340,          !- G-Function G Value 70
1.112000,           !- G-Function Ln(T/Ts) Value 71
28.642468,          !- G-Function G Value 71
1.335000,           !- G-Function Ln(T/Ts) Value 72
29.004730,          !- G-Function G Value 72
1.679000,           !- G-Function Ln(T/Ts) Value 73
29.417658,          !- G-Function G Value 73
2.028000,           !- G-Function Ln(T/Ts) Value 74
29.698521,          !- G-Function G Value 74
2.275000,           !- G-Function Ln(T/Ts) Value 75
29.835319,          !- G-Function G Value 75
3.003000,           !- G-Function Ln(T/Ts) Value 76
30.061249;          !- G-Function G Value 76
GroundHeatExchanger:Vertical,
  Ground Heat Exchanger 1, !- Name
  Ground Heat Exchanger 1 Water Inlet Node,  !- Inlet Node Name
  Ground Heat Exchanger 1 Water Outlet Node,  !- Outlet Node Name
  0.003900,           !- Design Flow Rate {m3/s}
  32,                 !- Number of Bore Holes
  75.9866,            !- Bore Hole Length {m}
  0.0635,             !- Bore Hole Radius {m}
  0.6926,             !- Ground Thermal Conductivity {W/m-K}
  2346999.9998,       !- Ground Thermal Heat Capacity {J/m3-K}
  13.3750,            !- Ground Temperature {C}
  0.6926,             !- Grout Thermal Conductivity {W/m-K}
  0.3913,             !- Pipe Thermal Conductivity {W/m-K}
  0.02666670,         !- Pipe Out Diameter {m}
  0.02286000,         !- U-Tube Distance {m}
  0.00241285,         !- Pipe Thickness {m}
  1,                  !- Maximum Length of Simulation {years}
  0.00083600,         !- G-Function Reference Ratio {dimensionless}
  76,                 !- Number of Data Pairs of the G Function
  -15.795833,         !- G-Function Ln(T/Ts) Value 1
  -0.868005,          !- G-Function G Value 1
  -15.646939,         !- G-Function Ln(T/Ts) Value 2
  -0.841532,          !- G-Function G Value 2
  -15.498044,         !- G-Function Ln(T/Ts) Value 3
  -0.813862,          !- G-Function G Value 3
  -15.349150,         !- G-Function Ln(T/Ts) Value 4
  -0.784824,          !- G-Function G Value 4
  -15.200255,         !- G-Function Ln(T/Ts) Value 5
  -0.754311,          !- G-Function G Value 5
  -15.051361,         !- G-Function Ln(T/Ts) Value 6
```

```
-0.722260,     !- G-Function G Value 6
-14.902466,    !- G-Function Ln(T/Ts) Value 7
-0.688635,     !- G-Function G Value 7
-14.753571,    !- G-Function Ln(T/Ts) Value 8
-0.653424,     !- G-Function G Value 8
-14.604677,    !- G-Function Ln(T/Ts) Value 9
-0.616633,     !- G-Function G Value 9
-14.455782,    !- G-Function Ln(T/Ts) Value 10
-0.578288,     !- G-Function G Value 10
-14.306888,    !- G-Function Ln(T/Ts) Value 11
-0.538426,     !- G-Function G Value 11
-14.157993,    !- G-Function Ln(T/Ts) Value 12
-0.497093,     !- G-Function G Value 12
-14.009099,    !- G-Function Ln(T/Ts) Value 13
-0.454339,     !- G-Function G Value 13
-13.860204,    !- G-Function Ln(T/Ts) Value 14
-0.410206,     !- G-Function G Value 14
-13.711310,    !- G-Function Ln(T/Ts) Value 15
-0.364726,     !- G-Function G Value 15
-13.562415,    !- G-Function Ln(T/Ts) Value 16
-0.317904,     !- G-Function G Value 16
-13.413520,    !- G-Function Ln(T/Ts) Value 17
-0.269714,     !- G-Function G Value 17
-13.264626,    !- G-Function Ln(T/Ts) Value 18
-0.220096,     !- G-Function G Value 18
-13.115731,    !- G-Function Ln(T/Ts) Value 19
-0.168953,     !- G-Function G Value 19
-12.966837,    !- G-Function Ln(T/Ts) Value 20
-0.116163,     !- G-Function G Value 20
-12.817942,    !- G-Function Ln(T/Ts) Value 21
-0.061585,     !- G-Function G Value 21
-12.669048,    !- G-Function Ln(T/Ts) Value 22
-0.005079,     !- G-Function G Value 22
-12.520153,    !- G-Function Ln(T/Ts) Value 23
0.053480,      !- G-Function G Value 23
-12.371259,    !- G-Function Ln(T/Ts) Value 24
0.114187,      !- G-Function G Value 24
-12.222364,    !- G-Function Ln(T/Ts) Value 25
0.177098,      !- G-Function G Value 25
-12.073469,    !- G-Function Ln(T/Ts) Value 26
0.242221,      !- G-Function G Value 26
-11.924575,    !- G-Function Ln(T/Ts) Value 27
0.309516,      !- G-Function G Value 27
-11.775680,    !- G-Function Ln(T/Ts) Value 28
0.378895,      !- G-Function G Value 28
-11.626786,    !- G-Function Ln(T/Ts) Value 29
0.450230,      !- G-Function G Value 29
-11.477891,    !- G-Function Ln(T/Ts) Value 30
0.523360,      !- G-Function G Value 30
-11.328997,    !- G-Function Ln(T/Ts) Value 31
0.598093,      !- G-Function G Value 31
-11.180102,    !- G-Function Ln(T/Ts) Value 32
0.674224,      !- G-Function G Value 32
-11.031208,    !- G-Function Ln(T/Ts) Value 33
0.751534,      !- G-Function G Value 33
-10.882313,    !- G-Function Ln(T/Ts) Value 34
0.829805,      !- G-Function G Value 34
-10.733418,    !- G-Function Ln(T/Ts) Value 35
0.908825,      !- G-Function G Value 35
-10.584524,    !- G-Function Ln(T/Ts) Value 36
0.988392,      !- G-Function G Value 36
-10.435629,    !- G-Function Ln(T/Ts) Value 37
1.068324,      !- G-Function G Value 37
-10.286735,    !- G-Function Ln(T/Ts) Value 38
1.148459,      !- G-Function G Value 38
-10.137840,    !- G-Function Ln(T/Ts) Value 39
1.228656,      !- G-Function G Value 39
-9.988946,     !- G-Function Ln(T/Ts) Value 40
1.308799,      !- G-Function G Value 40
-9.840051,     !- G-Function Ln(T/Ts) Value 41
1.388797,      !- G-Function G Value 41
-9.691156,     !- G-Function Ln(T/Ts) Value 42
1.468579,      !- G-Function G Value 42
-9.542262,     !- G-Function Ln(T/Ts) Value 43
1.548092,      !- G-Function G Value 43
-9.393367,     !- G-Function Ln(T/Ts) Value 44
1.627303,      !- G-Function G Value 44
-9.244473,     !- G-Function Ln(T/Ts) Value 45
1.706193,      !- G-Function G Value 45
-9.095578,     !- G-Function Ln(T/Ts) Value 46
1.784752,      !- G-Function G Value 46
-8.946684,     !- G-Function Ln(T/Ts) Value 47
1.862983,      !- G-Function G Value 47
-8.797789,     !- G-Function Ln(T/Ts) Value 48
1.940892,      !- G-Function G Value 48
-8.648895,     !- G-Function Ln(T/Ts) Value 49
2.018493,      !- G-Function G Value 49
-8.500000,     !- G-Function Ln(T/Ts) Value 50
```

```
2.157703,        !- G-Function G Value 50
-7.800000,       !- G-Function Ln(T/Ts) Value 51
2.501703,        !- G-Function G Value 51
-7.200000,       !- G-Function Ln(T/Ts) Value 52
2.798169,        !- G-Function G Value 52
-6.500000,       !- G-Function Ln(T/Ts) Value 53
3.153701,        !- G-Function G Value 53
-5.900000,       !- G-Function Ln(T/Ts) Value 54
3.508888,        !- G-Function G Value 54
-5.200000,       !- G-Function Ln(T/Ts) Value 55
4.109035,        !- G-Function G Value 55
-4.500000,       !- G-Function Ln(T/Ts) Value 56
5.102711,        !- G-Function G Value 56
-3.963000,       !- G-Function Ln(T/Ts) Value 57
6.142695,        !- G-Function G Value 57
-3.270000,       !- G-Function Ln(T/Ts) Value 58
8.399091,        !- G-Function G Value 58
-2.864000,       !- G-Function Ln(T/Ts) Value 59
10.097311,       !- G-Function G Value 59
-2.577000,       !- G-Function Ln(T/Ts) Value 60
11.476045,       !- G-Function G Value 60
-2.171000,       !- G-Function Ln(T/Ts) Value 61
13.625063,       !- G-Function G Value 61
-1.884000,       !- G-Function Ln(T/Ts) Value 62
15.257542,       !- G-Function G Value 62
-1.191000,       !- G-Function Ln(T/Ts) Value 63
19.275440,       !- G-Function G Value 63
-0.497000,       !- G-Function Ln(T/Ts) Value 64
23.134167,       !- G-Function G Value 64
-0.274000,       !- G-Function Ln(T/Ts) Value 65
24.214672,       !- G-Function G Value 65
-0.051000,       !- G-Function Ln(T/Ts) Value 66
25.205920,       !- G-Function G Value 66
0.196000,        !- G-Function Ln(T/Ts) Value 67
26.169701,       !- G-Function G Value 67
0.419000,        !- G-Function Ln(T/Ts) Value 68
26.931357,       !- G-Function G Value 68
0.642000,        !- G-Function Ln(T/Ts) Value 69
27.584614,       !- G-Function G Value 69
0.873000,        !- G-Function Ln(T/Ts) Value 70
28.157340,       !- G-Function G Value 70
1.112000,        !- G-Function Ln(T/Ts) Value 71
28.642468,       !- G-Function G Value 71
1.335000,        !- G-Function Ln(T/Ts) Value 72
29.004730,       !- G-Function G Value 72
1.679000,        !- G-Function Ln(T/Ts) Value 73
29.417658,       !- G-Function G Value 73
2.028000,        !- G-Function Ln(T/Ts) Value 74
29.698521,       !- G-Function G Value 74
2.275000,        !- G-Function Ln(T/Ts) Value 75
29.835319,       !- G-Function G Value 75
3.003000,        !- G-Function Ln(T/Ts) Value 76
30.061249;       !- G-Function G Value 76

!- =========== ALL OBJECTS IN CLASS: WATERHEATER:MIXED ===========

WaterHeater:Mixed,
  DHW Loop Water Heater,   !- Name
  0.5,             !- Tank Volume {m3}
  Domestic hot water setpoint temperature: Always 55.00,  !- Setpoint Temperature Schedule Name
  5.00,            !- Deadband Temperature Difference {deltaC}
  80.00,           !- Maximum Temperature Limit {C}
  Cycle,           !- Heater Control Type
  0.0,             !- Heater Maximum Capacity {W}
  0.0,             !- Heater Minimum Capacity {W}
  ,                !- Heater Ignition Minimum Flow Rate {m3/s}
  ,                !- Heater Ignition Delay {s}
  Electricity,     !- Heater Fuel Type
  0.8,             !- Heater Thermal Efficiency
  ,                !- Part Load Factor Curve Name
  ,                !- Off Cycle Parasitic Fuel Consumption Rate {W}
  ,                !- Off Cycle Parasitic Fuel Type
  ,                !- Off Cycle Parasitic Heat Fraction to Tank
  ,                !- On Cycle Parasitic Fuel Consumption Rate {W}
  ,                !- On Cycle Parasitic Fuel Type
  ,                !- On Cycle Parasitic Heat Fraction to Tank
  Schedule,        !- Ambient Temperature Indicator
  Water heater ambient temperature schedule: Always 20.00,  !- Ambient Temperature Schedule Name
  ,                !- Ambient Temperature Zone Name
  DHW Loop Water Heater Outdoor Air Node,  !- Ambient Temperature Outdoor Air Node Name
  0.0000,          !- Off Cycle Loss Coefficient to Ambient Temperature {W/K}
  1.00,            !- Off Cycle Loss Fraction to Zone
  0.0000,          !- On Cycle Loss Coefficient to Ambient Temperature {W/K}
  1.00,            !- On Cycle Loss Fraction to Zone
  0.000000,        !- Peak Use Flow Rate {m3/s}
  ,                !- Use Flow Rate Fraction Schedule Name
  ,                !- Cold Water Supply Temperature Schedule Name
```

DHW Loop Water Heater DHW Inlet Node, !- Use Side Inlet Node Name

DHW Loop Water Heater DHW Outlet Node, !- Use Side Outlet Node Name

1.00, !- Use Side Effectiveness

DHW Loop Water Heater Heating Inlet Node, !- Source Side Inlet Node Name

DHW Loop Water Heater Heating Outlet Node, !- Source Side Outlet Node Name

1.00, !- Source Side Effectiveness

0.000098, !- Use Side Design Flow Rate {m3/s}

0.000745, !- Source Side Design Flow Rate {m3/s}

1.500000, !- Indirect Water Heating Recovery Time {hr}

IndirectHeatPrimarySetpoint, !- Source Side Flow Control Mode

Domestic hot water setpoint temperature: Always 55.00; !- Indirect Alternate Setpoint Temperature Schedule Name

!- =========== ALL OBJECTS IN CLASS: WATERHEATER:SIZING ===========

WaterHeater:Sizing,

DHW Loop Water Heater, !- WaterHeater Name

PeakDraw, !- Design Mode

0.600000, !- Time Storage Can Meet Peak Draw {hr}

0.600000, !- Time for Tank Recovery {hr}

1.000000, !- Nominal Tank Volume for Autosizing Plant Connections {m3}

4, !- Number of Bedrooms

2, !- Number of Bathrooms

0.200000, !- Storage Capacity per Person {m3/person}

0.200000, !- Recovery Capacity per Person {m3/hr-person}

0.020000, !- Storage Capacity per Floor Area {m3/m2}

0.020000, !- Recovery Capacity per Floor Area {m3/hr-m2}

4, !- Number of Units

0.200000, !- Storage Capacity per Unit {m3}

0.200000, !- Recovery Capacity PerUnit {m3/hr}

0.200, !- Storage Capacity per Collector Area {m3/m2}

1.000; !- Height Aspect Ratio

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

PlantLoop,

HW Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

HW Loop Operation, !- Plant Equipment Operation Scheme Name

HW Loop Supply Side Outlet, !- Loop Temperature Setpoint Node Name

100.00, !- Maximum Loop Temperature {C}

10.00, !- Minimum Loop Temperature {C}

0.000951, !- Maximum Loop Flow Rate {m3/s}

0.000000, !- Minimum Loop Flow Rate {m3/s}

0.114077, !- Plant Loop Volume {m3}

HW Loop Supply Side Inlet, !- Plant Side Inlet Node Name

HW Loop Supply Side Outlet, !- Plant Side Outlet Node Name

HW Loop Supply Side Branches, !- Plant Side Branch List Name

HW Loop Supply Side Connectors, !- Plant Side Connector List Name

HW Loop Demand Side Inlet, !- Demand Side Inlet Node Name

HW Loop Demand Side Outlet, !- Demand Side Outlet Node Name

HW Loop Demand Side Branches, !- Demand Side Branch List Name

HW Loop Demand Side Connectors, !- Demand Side Connector List Name

SequentialLoad, !- Load Distribution Scheme

HW Loop AvailabilityManager List, !- Availability Manager List Name

SingleSetpoint, !- Plant Loop Demand Calculation Scheme

None, !- Common Pipe Simulation

None; !- Pressure Simulation Type

PlantLoop,

CHW Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

CHW Loop Operation, !- Plant Equipment Operation Scheme Name

CHW Loop Supply Side Outlet, !- Loop Temperature Setpoint Node Name

80.00, !- Maximum Loop Temperature {C}

0.00, !- Minimum Loop Temperature {C}

0.000131, !- Maximum Loop Flow Rate {m3/s}

0.000000, !- Minimum Loop Flow Rate {m3/s}

0.015686, !- Plant Loop Volume {m3}

CHW Loop Supply Side Inlet, !- Plant Side Inlet Node Name

CHW Loop Supply Side Outlet, !- Plant Side Outlet Node Name

CHW Loop Supply Side Branches, !- Plant Side Branch List Name

CHW Loop Supply Side Connectors, !- Plant Side Connector List Name

CHW Loop Demand Side Inlet, !- Demand Side Inlet Node Name

CHW Loop Demand Side Outlet, !- Demand Side Outlet Node Name

CHW Loop Demand Side Branches, !- Demand Side Branch List Name

CHW Loop Demand Side Connectors, !- Demand Side Connector List Name

SequentialLoad, !- Load Distribution Scheme

CHW Loop AvailabilityManager List, !- Availability Manager List Name

SingleSetpoint, !- Plant Loop Demand Calculation Scheme

None, !- Common Pipe Simulation

None; !- Pressure Simulation Type

PlantLoop,

boundary HW Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

boundary HW Loop Operation, !- Plant Equipment Operation Scheme Name boundary HW Loop Supply Side Outlet, !- Loop Temperature Setpoint Node Name

100.00, !- Maximum Loop Temperature {C}

10.00, !- Minimum Loop Temperature {C}

0.000111, !- Maximum Loop Flow Rate {m3/s}

0.000000, !- Minimum Loop Flow Rate {m3/s}

0.013324, !- Plant Loop Volume {m3}

boundary HW Loop Supply Side Inlet, !- Plant Side Inlet Node Name

boundary HW Loop Supply Side Outlet, !- Plant Side Outlet Node Name

boundary HW Loop Supply Side Branches, !- Plant Side Branch List Name

boundary HW Loop Supply Side Connectors, !- Plant Side Connector List Name

boundary HW Loop Demand Side Inlet, !- Demand Side Inlet Node Name

boundary HW Loop Demand Side Outlet, !- Demand Side Outlet Node Name

boundary HW Loop Demand Side Branches, !- Demand Side Branch List Name

boundary HW Loop Demand Side Connectors, !- Demand Side Connector List Name

SequentialLoad, !- Load Distribution Scheme

boundary HW Loop AvailabilityManager List, !- Availability Manager List Name

SingleSetpoint, !- Plant Loop Demand Calculation Scheme

None, !- Common Pipe Simulation

None; !- Pressure Simulation Type

PlantLoop,

boundary CHW Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

boundary CHW Loop Operation, !- Plant Equipment Operation Scheme Name

boundary CHW Loop Supply Side Outlet, !- Loop Temperature Setpoint Node Name

80.00, !- Maximum Loop Temperature {C}

0.00, !- Minimum Loop Temperature {C}

0.000038, !- Maximum Loop Flow Rate {m3/s}

0.000000, !- Minimum Loop Flow Rate {m3/s}

0.004583, !- Plant Loop Volume {m3}

boundary CHW Loop Supply Side Inlet, !- Plant Side Inlet Node Name

boundary CHW Loop Supply Side Outlet, !- Plant Side Outlet Node Name

boundary CHW Loop Supply Side Branches, !- Plant Side Branch List Name

boundary CHW Loop Supply Side Connectors, !- Plant Side Connector List Name

boundary CHW Loop Demand Side Inlet, !- Demand Side Inlet Node Name

boundary CHW Loop Demand Side Outlet, !- Demand Side Outlet Node Name

boundary CHW Loop Demand Side Branches, !- Demand Side Branch List Name

boundary CHW Loop Demand Side Connectors, !- Demand Side Connector List Name

SequentialLoad, !- Load Distribution Scheme

boundary CHW Loop AvailabilityManager List, !- Availability Manager List Name

SingleSetpoint, !- Plant Loop Demand Calculation Scheme

None, !- Common Pipe Simulation

None; !- Pressure Simulation Type

PlantLoop,

DHW Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

DHW Loop Operation, !- Plant Equipment Operation Scheme Name

DHW Loop Supply Side Outlet, !- Loop Temperature Setpoint Node Name

80.00, !- Maximum Loop Temperature {C}

0.00, !- Minimum Loop Temperature {C}

0.000098, !- Maximum Loop Flow Rate {m3/s}

0.000000, !- Minimum Loop Flow Rate {m3/s}

0.011807, !- Plant Loop Volume {m3}

DHW Loop Supply Side Inlet, !- Plant Side Inlet Node Name

DHW Loop Supply Side Outlet, !- Plant Side Outlet Node Name

DHW Loop Supply Side Branches, !- Plant Side Branch List Name

DHW Loop Supply Side Connectors, !- Plant Side Connector List Name

DHW Loop Demand Side Inlet, !- Demand Side Inlet Node Name

DHW Loop Demand Side Outlet, !- Demand Side Outlet Node Name

DHW Loop Demand Side Branches, !- Demand Side Branch List Name

DHW Loop Demand Side Connectors, !- Demand Side Connector List Name

SequentialLoad, !- Load Distribution Scheme

DHW Loop AvailabilityManager List, !- Availability Manager List Name

SingleSetpoint, !- Plant Loop Demand Calculation Scheme

None, !- Common Pipe Simulation

None; !- Pressure Simulation Type

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

CondenserLoop,

Condenser Loop, !- Name

Water, !- Fluid Type

, !- User Defined Fluid Type

Condenser Loop Operation,!- Condenser Equipment Operation Scheme Name

Condenser Loop Supply Side Outlet, !- Condenser Loop Temperature Setpoint Node Name

50.00, !- Maximum Loop Temperature {C}

5.00, !- Minimum Loop Temperature {C}

0.002210, !- Maximum Loop Flow Rate {m3/s}

0.000000,   !- Minimum Loop Flow Rate {m3/s}

0.265200,   !- Condenser Loop Volume {m3}

Condenser Loop Supply Side Inlet, !- Condenser Side Inlet Node Name

Condenser Loop Supply Side Outlet, !- Condenser Side Outlet Node Name

Condenser Loop Supply Side Branches, !- Condenser Side Branch List Name

Condenser Loop Supply Side Connectors, !- Condenser Side Connector List Name

Condenser Loop Demand Side Inlet, !- Demand Side Inlet Node Name

Condenser Loop Demand Side Outlet, !- Demand Side Outlet Node Name

Condenser Loop Demand Side Branches, !- Condenser Demand Side Branch List Name

Condenser Loop Demand Side Connectors, !- Condenser Demand Side Connector List Name

SequentialLoad,   !- Load Distribution Scheme

None;   !- Pressure Simulation Type

CondenserLoop,

boundary Condenser Loop, !- Name

Water,   !- Fluid Type

,   !- User Defined Fluid Type

boundary Condenser Loop Operation, !- Condenser Equipment Operation Scheme Name

boundary Condenser Loop Supply Side Outlet, !- Condenser Loop Temperature Setpoint Node Name

50.00,   !- Maximum Loop Temperature {C}

5.00,   !- Minimum Loop Temperature {C}

0.002210,   !- Maximum Loop Flow Rate {m3/s}

0.000000,   !- Minimum Loop Flow Rate {m3/s}

0.265200,   !- Condenser Loop Volume {m3}

boundary Condenser Loop Supply Side Inlet, !- Condenser Side Inlet Node Name

boundary Condenser Loop Supply Side Outlet, !- Condenser Side Outlet Node Name

boundary Condenser Loop Supply Side Branches, !- Condenser Side Branch List Name

boundary Condenser Loop Supply Side Connectors, !- Condenser Side Connector List Name

boundary Condenser Loop Demand Side Inlet, !- Demand Side Inlet Node Name

boundary Condenser Loop Demand Side Outlet, !- Demand Side Outlet Node Name

boundary Condenser Loop Demand Side Branches, !- Condenser Demand Side Branch List Name

boundary Condenser Loop Demand Side Connectors, !- Condenser Demand Side Connector List Name

SequentialLoad,   !- Load Distribution Scheme

None;   !- Pressure Simulation Type

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

PlantEquipmentList,

HW Loop Scheme 1 Range 1 Equipment List, !- Name

HeatPump:WaterToWater:EquationFit:Heating, !- Equipment 1 Object Type

Heat Pump Heating;   !- Equipment 1 Name

PlantEquipmentList,

Condenser Loop Scheme 1 Range 1 Equipment List, !- Name

GroundHeatExchanger:Vertical, !- Equipment 1 Object Type

Ground Heat Exchanger;   !- Equipment 1 Name

PlantEquipmentList,

CHW Loop Scheme 1 Range 1 Equipment List, !- Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Equipment 1 Object Type

Heat Pump Cooling;   !- Equipment 1 Name

PlantEquipmentList,

boundary HW Loop Scheme 1 Range 1 Equipment List, !- Name

HeatPump:WaterToWater:EquationFit:Heating, !- Equipment 1 Object Type

Heat Pump Heating 1;   !- Equipment 1 Name

PlantEquipmentList,

boundary Condenser Loop Scheme 1 Range 1 Equipment List, !- Name

GroundHeatExchanger:Vertical, !- Equipment 1 Object Type

Ground Heat Exchanger 1; !- Equipment 1 Name

PlantEquipmentList,

boundary CHW Loop Scheme 1 Range 1 Equipment List, !- Name

HeatPump:WaterToWater:EquationFit:Cooling, !- Equipment 1 Object Type

Heat Pump Cooling 1;   !- Equipment 1 Name

PlantEquipmentList,

DHW Loop Scheme 1 Range 1 Equipment List, !- Name

WaterHeater:Mixed,   !- Equipment 1 Object Type

DHW Loop Water Heater;   !- Equipment 1 Name

!- =========== ALL OBJECTS IN CLASS: PLANTEQUIPMENTOPERATION:COOLINGLOAD ===========

PlantEquipmentOperation:CoolingLoad,

Condenser Loop Scheme 1, !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

Condenser Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

PlantEquipmentOperation:CoolingLoad,

CHW Loop Scheme 1,   !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

CHW Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

PlantEquipmentOperation:CoolingLoad,

boundary Condenser Loop Scheme 1, !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

boundary Condenser Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

PlantEquipmentOperation:CoolingLoad,

boundary CHW Loop Scheme 1, !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

boundary CHW Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

!- =========== ALL OBJECTS IN CLASS: PLANTEQUIPMENTOPERATION:HEATINGLOAD ===========

PlantEquipmentOperation:HeatingLoad,

HW Loop Scheme 1,   !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

HW Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

PlantEquipmentOperation:HeatingLoad,

boundary HW Loop Scheme 1, !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

boundary HW Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

PlantEquipmentOperation:HeatingLoad,

DHW Loop Scheme 1,   !- Name

0.00,   !- Load Range 1 Lower Limit {W}

1000000000000000.00,   !- Load Range 1 Upper Limit {W}

DHW Loop Scheme 1 Range 1 Equipment List; !- Range 1 Equipment List Name

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

PlantEquipmentOperationSchemes,

HW Loop Operation,   !- Name

PlantEquipmentOperation:HeatingLoad,   !- Control Scheme 1 Object Type

HW Loop Scheme 1,   !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

PlantEquipmentOperationSchemes,

CHW Loop Operation,   !- Name

PlantEquipmentOperation:CoolingLoad,   !- Control Scheme 1 Object Type

CHW Loop Scheme 1,   !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

PlantEquipmentOperationSchemes,

boundary HW Loop Operation, !- Name

PlantEquipmentOperation:HeatingLoad,   !- Control Scheme 1 Object Type

boundary HW Loop Scheme 1, !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

PlantEquipmentOperationSchemes,

boundary CHW Loop Operation, !- Name

PlantEquipmentOperation:CoolingLoad,   !- Control Scheme 1 Object Type

boundary CHW Loop Scheme 1, !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

PlantEquipmentOperationSchemes,

DHW Loop Operation,   !- Name

PlantEquipmentOperation:HeatingLoad,   !- Control Scheme 1 Object Type

DHW Loop Scheme 1,   !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

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

CondenserEquipmentOperationSchemes,

Condenser Loop Operation,!- Name

PlantEquipmentOperation:CoolingLoad,   !- Control Scheme 1 Object Type

Condenser Loop Scheme 1, !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

CondenserEquipmentOperationSchemes,

boundary Condenser Loop Operation, !- Name

PlantEquipmentOperation:CoolingLoad,   !- Control Scheme 1 Object Type

boundary Condenser Loop Scheme 1, !- Control Scheme 1 Name

On 24/7;   !- Control Scheme 1 Schedule Name

!- =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:SENSOR ===========

EnergyManagementSystem:Sensor,

OA_Temp,   !- Name

*,   !- Output:Variable or Output:Meter Index Key Name

Site Outdoor Air Drybulb Temperature;   !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,

Air_T,   !- Name

Block:Test,   !- Output:Variable or Output:Meter Index Key Name

Zone Mean Air Temperature; !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,

Air_Room_Heat_SP,   !- Name

Block:Test,   !- Output:Variable or Output:Meter Index Key Name

Zone Thermostat Heating Setpoint Temperature; !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,

Slab_T,   !- Name

Block:Test_GroundFloor_0_0_0,   !- Output:Variable or Output:Meter Index Key Name

Surface Inside Face Temperature; !- Output:Variable or Output:Meter Name

```
!-   =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:ACTUATOR ===========

EnergyManagementSystem:Actuator,

  Air_T_SP,            !- Name

  AHU Temperature Setpoint,!- Actuated Component Unique Name

  Schedule:Compact,      !- Actuated Component Type

  Schedule Value;        !- Actuated Component Control Type

EnergyManagementSystem:Actuator,

  Air_Flow_SP,          !- Name

  Boundary Air Loop AHU SUPPLY FAN AIR OUTLET NODE,  !- Actuated Component Unique Name

  System Node Setpoint,   !- Actuated Component Type

  Mass Flow Rate Setpoint; !- Actuated Component Control Type

EnergyManagementSystem:Actuator,

  Radiant_SP_H,         !- Name

  Radiant Heating Set Point schedule,  !- Actuated Component Unique Name

  Schedule:Compact,      !- Actuated Component Type

  Schedule Value;        !- Actuated Component Control Type

EnergyManagementSystem:Actuator,

  Radiant_SP_C,         !- Name

  Radiant Cooling Set Point schedule,  !- Actuated Component Unique Name

  Schedule:Compact,      !- Actuated Component Type

  Schedule Value;        !- Actuated Component Control Type

!-   =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAMCALLINGMANAGER ===========

! UNCOMMENT EACH SCENARIO TO RUN THAT CASE

!EnergyManagementSystem:ProgramCallingManager,

 ! Scenario1 programs,     !- Name

 ! InsideHVACSystemIterationLoop,  !- EnergyPlus Model Calling Point

 ! Scenario1_Air_Control,  !- Program Name 1

 ! Scenario1_Radiant_Control;  !- Program Name 2

!EnergyManagementSystem:ProgramCallingManager,

!  Scenario2 programs,     !- Name

!  InsideHVACSystemIterationLoop,  !- EnergyPlus Model Calling Point

!  Scenario2_Radiant_Control,  !- Program Name 1

!  Scenario2_Air_Control;  !- Program Name 2

!EnergyManagementSystem:ProgramCallingManager,

!  Scenario3 programs,     !- Name

!  InsideHVACSystemIterationLoop,  !- EnergyPlus Model Calling Point

!  Scenario3_Radiant_Control,  !- Program Name 1

!  Scenario1_Air_Control;  !- Program Name 2

!EnergyManagementSystem:ProgramCallingManager,

 ! Scenario4 programs,     !- Name

 ! InsideHVACSystemIterationLoop,  !- EnergyPlus Model Calling Point

 ! Scenario3_Radiant_Control,  !- Program Name 1

 ! Scenario4_Air_Control;  !- Program Name 2

!EnergyManagementSystem:ProgramCallingManager,

!  Scenario5 programs,     !- Name

!  InsideHVACSystemIterationLoop,  !- EnergyPlus Model Calling Point

!  Scenario5_Radiant_Control,  !- Program Name 1

!  Scenario1_Air_Control;  !- Program Name 2

!-   =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAM ===========

EnergyManagementSystem:Program,

  Scenario1_Air_Control,   !- Name

  SET zone_min_air_flow = 0.05,  !- Program Line 1

  SET zone_max_air_flow = 0.1,  !- Program Line 2

  SET zone_max_air_flow_heating = 0.07,  !- A4

  SET zone_min_air_temp = 16,  !- A5

  SET zone_max_air_temp = 33,  !- A6

  SET precool_start = 7,   !- A7

  SET precool_end = 9,    !- A8

  SET flow_ramp_a1 =  -1,  !- A9

  SET flow_ramp_a2 =  0,  !- A10

  SET flow_ramp_b1 =  2,  !- A11

  SET flow_ramp_b2 =  4,  !- A12

  SET T_ramp_a1 =  0.75,  !- A13

  SET T_ramp_a2 = 2,     !- A14

  SET air_stable_T = air_room_heat_SP,  !- A15

  SET cooling_flow_ramp = zone_min_air_flow-zone_max_air_flow,   !- A16

  SET cooling_flow_ramp = cooling_flow_ramp / (flow_ramp_a2 - flow_ramp_a1),  !- A17

  SET heating_T_ramp = zone_max_air_temp - zone_min_air_temp,  !- A18

  SET heating_T_ramp = heating_T_ramp / (T_ramp_a2-T_ramp_a1),   !- A19

  SET zone_diff = air_stable_T - Air_T,  !- A20

  IF zone_diff < flow_ramp_a2,  !- A21

  SET zone_diff = zone_diff - flow_ramp_a2,  !- A22

  SET Air_Flow_SP = (zone_diff*cooling_flow_ramp)+zone_min_air_flow, !- A23

  SET Air_T_SP = zone_min_air_temp,  !- A24

  ELSEIF zone_diff < T_ramp_a1,  !- A25

  SET Air_T_SP = zone_min_air_temp,  !- A26

  SET Air_Flow_SP = zone_min_air_flow,  !- A27

  ELSEIF zone_diff < T_ramp_a2,  !- A28

  SET zone_diff = zone_diff - T_ramp_a2,  !- A29

  SET Air_T_SP = (zone_diff*heating_T_ramp)+zone_max_air_temp,   !- A30

  SET Air_Flow_SP = zone_min_air_flow,  !- A31

  ELSEIF zone_diff < flow_ramp_b2,  !- A32
```

```
SET zone_diff = zone_diff - flow_ramp_b1,  !- A33
SET Air_T_SP = zone_max_air_temp,  !- A34
SET Air_Flow_SP = (-1*zone_diff*cooling_flow_ramp)+zone_min_air_flow,  !- A35
ELSE,                !- A36
SET zone_diff = flow_ramp_b2-flow_ramp_b1,  !- A37
SET Air_T_SP = zone_max_air_temp,  !- A38
SET Air_Flow_SP = (-1*zone_diff*cooling_flow_ramp)+zone_min_air_flow,  !- A39
SET Air_Flow_SP = @min zone_max_air_flow_heating Air_Flow_SP,  !- A40
ENDIF,                !- A41
IF Hour > precool_start && Hour < precool_end,  !- A42
SET Air_T_SP = zone_min_air_temp,  !- A43
SET Air_Flow_SP = zone_max_air_flow,  !- A44
ENDIF,                !- A45
SET Air_Flow_SP = @min Air_Flow_SP zone_max_air_flow;  !- A46
EnergyManagementSystem:Program,
Scenario1_Radiant_Control,  !- Name
SET radiant_max_cooling_T = 18.8,  !- Program Line 1
SET radiant_max_heating_T = 25,  !- Program Line 2
SET precool_start = 5,   !- A4
SET precool_end = 9,     !- A5
SET radiant_stable_T = air_room_heat_SP,  !- A6
SET radiant_ramp_a1 =  -2,  !- A7
SET radiant_ramp_a2 =  -1,  !- A8
SET radiant_ramp_b1 =  1,!- A9
SET radiant_ramp_b2 =  3.5,  !- A10
SET zone_diff = radiant_stable_T - Air_T,  !- A11
IF zone_diff < radiant_ramp_a1,  !- A12
SET zone_intended_SP = radiant_max_cooling_T,  !- A13
ELSEIF zone_diff < radiant_ramp_a2,  !- A14
SET zone_diff = zone_diff - radiant_ramp_a2,  !- A15
SET radiant_ramp =   radiant_stable_T - radiant_max_cooling_T,  !- A16
SET radiant_ramp = radiant_ramp / ( radiant_ramp_a2 - radiant_ramp_a1),  !- A17
SET zone_intended_SP = (zone_diff*radiant_ramp) + radiant_stable_T,  !- A18
ELSEIF zone_diff < radiant_ramp_b1,  !- A19
SET zone_intended_SP = radiant_stable_T,  !- A20
ELSEIF zone_diff < radiant_ramp_b2,  !- A21
SET zone_diff = zone_diff - radiant_ramp_b2,  !- A22
SET radiant_ramp =  radiant_max_heating_T - radiant_stable_T,  !- A23
SET radiant_ramp = radiant_ramp / ( radiant_ramp_b2 - radiant_ramp_b1),  !- A24
SET zone_intended_SP = (zone_diff*radiant_ramp) + radiant_max_heating_T,  !- A25
ELSE,                !- A26
SET zone_intended_SP = radiant_max_heating_T,  !- A27
ENDIF,                !- A28
IF Hour > precool_start && Hour < precool_end,  !- A29
SET zone_intended_SP = radiant_max_cooling_T,  !- A30
ENDIF,                !- A31
RUN setSlabSPs;         !- A32
EnergyManagementSystem:Program,
Scenario2_Air_Control,   !- Name
SET zone_min_air_flow = 0.05,  !- Program Line 1
SET zone_max_air_flow = 0.1,  !- Program Line 2
SET zone_min_air_temp = 14,  !- A4
SET zone_max_air_temp = 45,  !- A5
SET zone_diff = Air_Room_Heat_SP - Air_T,  !- A6
IF zone_diff > 2.5,      !- A7
SET Air_T_SP = zone_max_air_temp,  !- A8
SET Air_Flow_SP = zone_min_air_flow,  !- A9
ELSEIF zone_diff < 1,     !- A10
SET Air_T_SP = zone_min_air_temp,  !- A11
SET Air_Flow_SP = zone_max_air_flow,  !- A12
ENDIF;                !- A13
EnergyManagementSystem:Program,
Scenario2_Radiant_Control,  !- Name
SET zone_diff_low = -0.5,!- Program Line 1
SET zone_diff_high = 0.5,!- Program Line 2
SET slab_local_low = -1, !- A4
SET slab_local_high = 0.25,  !- A5
SET slab_buffer = 3,     !- A6
SET zone_diff = Air_Room_Heat_SP - Air_T,  !- A7
IF OA_Temp > 18,        !- A8
SET slab_intended_SP = 18.8,  !- A9
ELSEIF OA_Temp < 17,     !- A10
IF zone_diff >  zone_diff_high,  !- A11
SET slab_intended_SP = 25.0,  !- A12
ELSEIF zone_diff < zone_diff_low,  !- A13
SET slab_intended_SP = 18.8,  !- A14
ENDIF,                !- A15
ELSE,                !- A16
SET slab_intended_SP = slab_T,  !- A17
ENDIF,                !- A18
SET slab_local_diff = zone_intended_SP - slab_T,  !- A19
IF slab_local_diff > slab_local_high,  !- A20
SET Radiant_SP_C = Air_T + slab_buffer,  !- A21
SET Radiant_SP_H = Air_T + 0.5,  !- A22
```

```
  ELSEIF slab_local_diff < slab_local_low,  !- A23
  SET Radiant_SP_C = Air_T - 0.75,  !- A24
  SET Radiant_SP_H = Air_T - slab_buffer,  !- A25
  ENDIF;                 !- A26
EnergyManagementSystem:Program,
  Scenario3_Radiant_Control,  !- Name
  SET zone_intended_SP = 23,  !- Program Line 1
  RUN setSlabSPs;         !- Program Line 2
EnergyManagementSystem:Program,
  Scenario4_Air_Control,   !- Name
  SET Air_T_SP = Air_Room_Heat_SP;  !- Program Line 1
EnergyManagementSystem:Program,
  Scenario5_Radiant_Control,  !- Name
  SET averaged_OA = (@TrendSum average_OA_T_72hrs 432) + (@TrendSum average_OA_T_72hrs 144),  !- Program Line 1
  SET averaged_OA = averaged_OA/ (432+144),  !- Program Line 2
  SET zone_intended_SP = 24.75 - (averaged_OA/7),  !- A4
  RUN setSlabSPs;         !- A5
!- =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:SUBROUTINE ===========
EnergyManagementSystem:Subroutine,
  setSlabSPs,            !- Name
  SET slab_buffer = 0.75 + 1,  !- Program Line 1
  SET slab_local_diff = zone_intended_SP - slab_T,  !- Program Line 2
  IF slab_local_diff < -0.75,  !- A4
  SET Radiant_SP_H = Air_T - (slab_buffer*2),  !- A5
  SET Radiant_SP_C = Air_T - slab_buffer,  !- A6
  ELSEIF @abs slab_local_diff < 0.5,  !- A7
  SET Radiant_SP_H = Air_T - slab_buffer,  !- A8
  SET Radiant_SP_C = Air_T + slab_buffer,  !- A9
  ELSEIF slab_local_diff > 0.75,  !- A10
  SET Radiant_SP_H = Air_T + slab_buffer,  !- A11
  SET Radiant_SP_C = Air_T + (slab_buffer*2),  !- A12
  ENDIF;                 !- A13
!- =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:GLOBALVARIABLE ===========
EnergyManagementSystem:GlobalVariable,
  zone_intended_SP,       !- Erl Variable 1 Name
  zone_diff,              !- Erl Variable 2 Name
  zone_min_air_flow,      !- Erl Variable 3 Name
  zone_max_air_flow,      !- A4
  zone_max_flow_heating,   !- A5
  zone_min_air_temp,      !- A6
  zone_max_air_temp,      !- A7
  cooling_flow_ramp,      !- A8
  heating_flow_ramp,      !- A9
  heating_T_ramp,         !- A10
  flow_ramp_a1,           !- A11
  flow_ramp_a2,           !- A12
  flow_ramp_b1,           !- A13
  flow_ramp_b2,           !- A14
  T_ramp_a1,              !- A15
  T_ramp_a2,              !- A16
  air_stable_T;           !- A17
EnergyManagementSystem:GlobalVariable,
  radiant_max_cooling_T,   !- Erl Variable 1 Name
  radiant_max_heating_T,   !- Erl Variable 2 Name
  radiant_stable_T,       !- Erl Variable 3 Name
  radiant_ramp_a1,        !- A4
  radiant_ramp_a2,        !- A5
  radiant_ramp_b1,        !- A6
  radiant_ramp_b2,        !- A7
  radiant_ramp,           !- A8
  precool_start,          !- A9
  precool_end,            !- A10
  zone_diff_low,          !- A11
  zone_diff_high,         !- A12
  slab_local_low,         !- A13
  slab_local_high,        !- A14
  slab_buffer,            !- A15
  slab_local_diff,        !- A16
  slab_intended_SP;       !- A17
EnergyManagementSystem:GlobalVariable,
  averaged_OA;            !- Erl Variable 1 Name
!- =========== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:TRENDVARIABLE ===========
EnergyManagementSystem:TrendVariable,
  average_OA_T_72hrs,     !- Name
  OA_Temp,                !- EMS Variable Name
  432;                    !- Number of Timesteps to be Logged
!- =========== ALL OBJECTS IN CLASS: AVAILABILITYMANAGER:SCHEDULED ===========
AvailabilityManager:Scheduled,
  HW Loop Availability,   !- Name
  On 24/7;                !- Schedule Name
AvailabilityManager:Scheduled,
  Condenser Loop Availability,  !- Name
  On 24/7;                !- Schedule Name
AvailabilityManager:Scheduled,
  CHW Loop Availability,   !- Name
```

```
  On 24/7;               !- Schedule Name
AvailabilityManager:Scheduled,
  Air Loop Availability,   !- Name
  HVAC Operation Schedule; !- Schedule Name
AvailabilityManager:Scheduled,
  boundary HW Loop Availability,  !- Name
  On 24/7;               !- Schedule Name
AvailabilityManager:Scheduled,
  boundary Condenser Loop Availability,  !- Name
  On 24/7;               !- Schedule Name
AvailabilityManager:Scheduled,
  boundary CHW Loop Availability,  !- Name
  On 24/7;               !- Schedule Name
AvailabilityManager:Scheduled,
  Boundary Air Loop Availability,  !- Name
  On 24/7;               !- Schedule Name
AvailabilityManager:Scheduled,
  DHW Loop Availability,   !- Name
  On 24/7;               !- Schedule Name
!- =========== ALL OBJECTS IN CLASS: AVAILABILITYMANAGER:NIGHTCYCLE ===========
AvailabilityManager:NightCycle,
  Air Loop AHU Night Cycle Operation,  !- Name
  On 24/7,               !- Applicability Schedule Name
  On 24/7,               !- Fan Schedule Name
  CycleOnControlZone,      !- Control Type
  6,                   !- Thermostat Tolerance {deltaC}
  FixedRunTime,          !- Cycling Run Time Control Type
  3600,                !- Cycling Run Time {s}
  Block:Test;            !- Control Zone or Zone List Name
!- =========== ALL OBJECTS IN CLASS: AVAILABILITYMANAGERASSIGNMENTLIST ===========
AvailabilityManagerAssignmentList,
  HW Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  HW Loop Availability;    !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  Condenser Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  Condenser Loop Availability;  !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  CHW Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  CHW Loop Availability;   !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  Air Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  Air Loop Availability,   !- Availability Manager 1 Name
  AvailabilityManager:NightCycle,  !- Availability Manager 2 Object Type
  Air Loop AHU Night Cycle Operation;  !- Availability Manager 2 Name
AvailabilityManagerAssignmentList,
  boundary HW Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  boundary HW Loop Availability;  !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  boundary Condenser Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  boundary Condenser Loop Availability;  !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  boundary CHW Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  boundary CHW Loop Availability;  !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  Boundary Air Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  Boundary Air Loop Availability;  !- Availability Manager 1 Name
AvailabilityManagerAssignmentList,
  DHW Loop AvailabilityManager List,  !- Name
  AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
  DHW Loop Availability;   !- Availability Manager 1 Name
!- =========== ALL OBJECTS IN CLASS: SETPOINTMANAGER:SCHEDULED ==========
SetpointManager:Scheduled,
  HW Loop Setpoint Manager,!- Name
  Temperature,           !- Control Variable
  Underfloor heating setpoint temperature: Always 40.00,  !- Schedule Name
  HW Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  Condenser Loop Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Cooling low water temperature schedule: Always 10.00,  !- Schedule Name
  Condenser Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  CHW Loop Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Chilled water flow set point temperature: Always 6 C,  !- Schedule Name
  CHW Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
```

```
SetpointManager:Scheduled,
  Air Loop Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  AHU Temperature Setpoint,!- Schedule Name
  Air Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  HW Loop 1 Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Boundary air setpoint temperature,  !- Schedule Name
  HW Loop 1 Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  Condenser Loop 1 Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Cooling low water temperature schedule: Always 10.00,  !- Schedule Name
  Condenser Loop 1 Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  CHW Loop 1 Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Chilled water flow set point temperature: Always 6 C,  !- Schedule Name
  CHW Loop 1 Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  Boundary Air Loop Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Boundary AHU Temperature Setpoint,  !- Schedule Name
  Boundary Air Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
SetpointManager:Scheduled,
  DHW Loop Setpoint Manager,  !- Name
  Temperature,           !- Control Variable
  Domestic hot water setpoint temperature: Always 55.00,  !- Schedule Name
  DHW Loop Setpoint Manager Node List;  !- Setpoint Node or NodeList Name
!-   =========== ALL OBJECTS IN CLASS: SETPOINTMANAGER:MIXEDAIR ===========
SetpointManager:MixedAir,
  Air Loop AHU  Outside air system Mixed Air Manager,  !- Name
  Temperature,           !- Control Variable
  Air Loop Supply Side Outlet 1,  !- Reference Setpoint Node Name
  Air Loop AHU Mixed Air Outlet,  !- Fan Inlet Node Name
  Air Loop AHU Supply Fan Air Outlet Node,  !- Fan Outlet Node Name
  Air Loop AHU Mixed Air Outlet;  !- Setpoint Node or NodeList Name
SetpointManager:MixedAir,
  Boundary Air Loop AHU  Outside air system Mixed Air Manager,  !- Name
  Temperature,           !- Control Variable
  Boundary Air Loop Supply Side Outlet 1,  !- Reference Setpoint Node Name
  Boundary Air Loop AHU Mixed Air Outlet,  !- Fan Inlet Node Name
  Boundary Air Loop AHU Supply Fan Air Outlet Node,  !- Fan Outlet Node Name
  Boundary Air Loop AHU Mixed Air Outlet;  !- Setpoint Node or NodeList Name
!-   =========== ALL OBJECTS IN CLASS: CURVE:LINEAR ===========
Curve:Linear,
  Opening Factor Function of Wind Speed Curve,  !- Name
  1,                 !- Coefficient1 Constant
  0,                 !- Coefficient2 x
  0,                 !- Minimum Value of x
  1;                 !- Maximum Value of x
!-   =========== ALL OBJECTS IN CLASS: CURVE:CUBIC ===========
Curve:Cubic,
  New style low temperature boiler,  !- Name
  0.83888652,            !- Coefficient1 Constant
  0.132579019,           !- Coefficient2 x
  -0.17028503,           !- Coefficient3 x**2
  0.047468326,           !- Coefficient4 x**3
  0.1,                   !- Minimum Value of x
  1;                     !- Maximum Value of x
Curve:Cubic,
  DefaultFanEffRatioCurve, !- Name
  0.33856828,            !- Coefficient1 Constant
  1.72644131,            !- Coefficient2 x
  -1.49280132,           !- Coefficient3 x**2
  0.42776208,            !- Coefficient4 x**3
  0.5,                   !- Minimum Value of x
  1.5,                   !- Maximum Value of x
  0.3,                   !- Minimum Curve Output
  1.0;                   !- Maximum Curve Output
Curve:Cubic,
  ElectronicEnthalpyCurve, !- Name
  0.01342704,            !- Coefficient1 Constant
  -0.00047892,           !- Coefficient2 x
  0.000053352,           !- Coefficient3 x**2
  -0.0000018103,         !- Coefficient4 x**3
  16.6,                  !- Minimum Value of x
  29.13;                 !- Maximum Value of x
Curve:Cubic,
  PartLoadCurveForGasHeatingCoil,  !- Name
```

```
    0.8,                    !- Coefficient1 Constant
    0.2,                    !- Coefficient2 x
    0.0,                    !- Coefficient3 x**2
    0.0,                    !- Coefficient4 x**3
    0,                      !- Minimum Value of x
    1;                      !- Maximum Value of x

!-   ===========  ALL OBJECTS IN CLASS: CURVE:EXPONENT ===========

Curve:Exponent,
    DefaultFanPowerRatioCurve,  !- Name
    0,                      !- Coefficient1 Constant
    1,                      !- Coefficient2 Constant
    3,                      !- Coefficient3 Constant
    0,                      !- Minimum Value of x
    1.5,                    !- Maximum Value of x
    0.01,                   !- Minimum Curve Output
    1.5;                    !- Maximum Curve Outpu

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

EnvironmentalImpactFactors,
    0.3,                    !- District Heating Efficiency
    3.0,                    !- District Cooling COP {W/W}
    0.25,                   !- Steam Conversion Efficiency
    80.7272,                !- Total Carbon Equivalent Emission Factor From N2O {kg/kg}
    6.2727,                 !- Total Carbon Equivalent Emission Factor From CH4 {kg/kg}
    0.2727;                 !- Total Carbon Equivalent Emission Factor From CO2 {kg/kg}
```