NUS MD6 Level 11

Green Lab Feasibility Study

Surbana Jurong Consultants

Sustainability and Resiliency Office

Phase 2 Report– Revision 1

6th May 2025

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Disclaimer

The findings in this report are based on visual site reviews and the accuracy and completeness of the information provided by NUS. SJ Group did not verify the accuracy or completeness of information and the scope of analysis is limited supplied information. SJ Group is not liable or responsible, either expressed or implied, for an loss or damage arising from the use of the report and/or findings within this report. No part of this report may be disseminated or reproduced or disclosed to other parties without the express, written permission of SJ Group.

1 Introduction

1.1 Project Background and Objective

Surbana Jurong Consultants Pte. Ltd.'s Sustainability and Resilience Office (SRO) was engaged to perform a feasibility study in single laboratory identified by NUS. This was to serve the following objectives:

1. Identify the current mechanical design practice for lab exhaust design
2. To reduce the lab exhaust air change rate without compromising lab safety
3. Determine energy savings potential
4. Estimate the potential costs associated with retrofitting a demand-controlled lab exhaust system

Optimising the lab's energy consumption is a key lever towards the campus' energy reduction plans. Most of the energy use is due to the air conditioning requirements in labs, whereby there is a general fixed air change rate (ACH) of 8 during occupied hours and 4 ACH during unoccupied hours. By implementing a demand-controlled exhaust system by sensing the air quality within the labs and exhaust air stream, air change rates could be reduced and therefore drive down energy consumption.

The project is divided into two phases:

A. Phase 1 – Proposed Scope of Work for Feasibility Study

The objective of Phase 1 is to perform a feasibility study in an identified wet lab within NUS KRC premises on Level 11 of MD6 to implement a variable volume lab exhaust system utilising a Facility Air Quality Monitoring System that monitors lab exhaust air and make up air. A variable volume system based on occupancy schedule shall not be considered for this study. The feasibility study shall include the following:

- Site visit to observe lab equipment and controls that could potentially be impacted by a system upgrade.
- Literature search on existing codes and standards on the implications of implementing a variable volume lab exhaust system.
- Review of existing mechanical and electrical drawings to determine the infrastructure changes necessary to reduce the lab air change rate from 8 to 4. The driving factors between minimum ventilation rate, cooling load, and lab exhaust ACH will be reviewed. An energy model assessment of reduced air change rate is provided.
- Review of existing mechanical and electrical drawings to determine the infrastructure changes necessary to propose energy efficient humidity control methodologies and/or equipment/infrastructure upgrades as compared to the existing Heat Recovery Unit (HRU) and reheat systems to labs. An energy model assessment to inform the feasibility of an alternate strategy is provided.
- Provide a high-level metering and reporting strategy for measurement and verification purposes to track energy consumption.

B. **Phase 2 – Proposed Scope of Work Design Concept report and Costing**

The objective of Phase 2 is to prepare an updated design concept report based on the recommended design solution presented in the Phase 1 feasibility report:

- Design narrative and single line schematic level representation of the system and PDF mark ups of existing drawings identifying any existing infrastructure changes.
- A Rough Order of Magnitude (ROM) cost of the system modifications will be provided for budgetary purposes by the partner manufacturer, Aircuity.
- Final deliverable will be an updated report with costing information and mark ups.

1.2 Information Received for Review

The following documents and data were received for review:

Document	Format	Dated back to
MD6 L11 Architectural Furniture Plan	CAD, PDF	July 2012
MD6 Architectural Sectional Plans	CAD	March 2011
MD6 ACMV L11 Plan	CAD, PDF	Aug 2011
MD6 ACMV L6 Plan	CAD	Aug 2011
MD6 ACMV High Plume Fan & Lab AHU Schedule	CAD	Aug 2011
MD6 ACMV Schematic of Lab (North)	CAD	Aug 2011
MD6 ACMV-VRV & Spilt Unit Schematic	PDF	Aug 2011
Reheat Schematic	BMS Screenshot	Sep 2024
MD6 Electrical Lighting L11 Layout Plan	CAD	Aug 2011
Aircuity Airflow Optimisation Proposal	Word	July 2024
Energy Efficiencies Opportunities Assessment for NUS MD6 by Johnson Controls	PDF	June 2023
MD6 Level 11 BTU Metering Data (3 months)		Jun to Aug 2024
MD6 Level 11 Electrical Metering Data (3 months)		Jun to Aug 2024

It should be noted that all values presented in this study are based on design values derived from available design documents as airside and hydronic balancing reports were not available during the course of the execution of this study. BAS/BMS sensor calibration was also not confirmed during the course of this study.

1.3 Existing Mechanical System Description

The existing mechanical system for air conditioning utilizes a combination of venturi valves, variable air volume (VAV) systems and variable refrigerant flow (VRF) systems to maintain optimal indoor conditions across different spaces. Systems differ depending on the space type served. Refer to Appendix C – Zoning drawing for the division between Laboratory Spaces and Office Spaces. This drawing also establishes the extent of the scope for this study.

<u>Laboratory Spaces</u>

The Level 11 laboratory spaces are served by a single pass system with supply air venturi valves and exhaust venturi valves. Exhaust venturi valves are divided into three categories:

1. General Lab Exhaust
2. Fume Hood Exhaust
3. Biosafety Cabinet/Fume Hood Exhaust

Supply venturi valves are served by a central Constant Air Handling Unit (CAHU) System. Exhaust venturi valves are served by high plume fans with each of the three systems described above on independent exhaust systems.

The CAHUs are composed of a Direct Expansion (DX) pre-cooling coil, fan, filters, and chilled water coil. The DX pre-cooling coil is served by a water-cooled condensing unit (labelled as a heat recovery unit). Collected waste heat is pumped to hot water tanks at the roof of the building which is then pumped throughout the building to supply venturi valve reheat coils for humidity control and supply air temperature control in the labs.

While there are separate shafts for in the North core and South core, make up air systems and exhaust systems are fed to/from manifolded airside systems.

<u>Office Spaces</u>

Office spaces in the North core and South core are served independently by recirculating, variable air volume air handling units. Air handling units contain chilled water coils for cooling.

1.4 Facility Air Quality Monitoring System and Demand Controlled Exhaust System

The **Facility Air Quality System (System 1)** proposed for this study works by continuously sampling air from the exhaust air streams at the lab (general lab exhaust, fume hood exhaust, and biosafety cabinet exhaust). When volatile organic compounds (VOCs) or other contaminants are below the defined set points, the venturi valves will start to reduce the air change rate from 8 ACH to 4 ACH. Normal operating parameters would be 4 ACH during occupied hours and 2 ACH during unoccupied hours. Only when VOCs or contaminants are detected, will the air change rate increase to 8 to dilute the air until set points are met again.

The **Demand Controlled Exhaust System (System 2)** proposed for this study works by continuously sampling air from two key locations: the exhaust fan inlet and the clean supply air location, to measure differential air quality. Both samples are sent to Aircuity's Sensor Suite for analysis, where the measurement is compared against predefined containment thresholds. When volatile organic compounds (VOCs) or other contaminants are below the defined trigger level, the stack velocity is reduced to save energy. If the contaminant levels exceed the limit, fan speeds are increased to ensure safety.

The system also provides data on equipment performance and environmental parameters, helping optimize lab ventilation for both safety and efficiency.

System 1 and the **System 2** can operate independently of one another. The **Facility Air Quality System (System 1)** safely reduces the air change rate of the lab systems to reduce the energy necessary to condition outdoor air necessary for make up of the exhaust systems. The **Demand Controlled Exhaust System (System 2)** monitors the exhaust air from the high plume fans and reduces the amount of by-pass air at the plenum (and therefore dilution) and reduces the fan speed and plume height. For this study, System 1 applies to Level 11 only and System 2 serves the exhaust fans associated to Level 8 to Level 15.

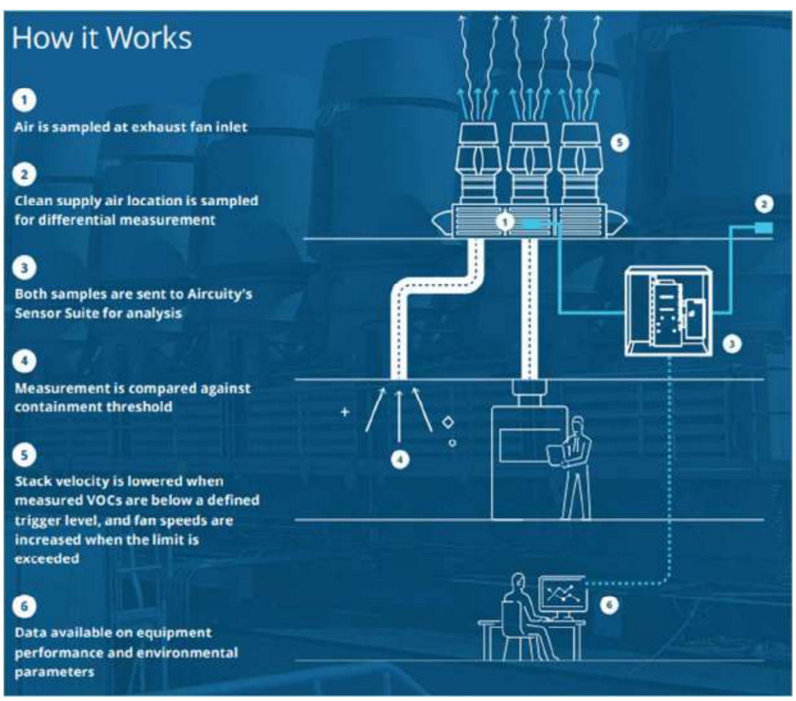

Figure 1: Demand Controlled Exhaust System (Source: Aircuity)

2 Literature Review

To identify the current mechanical design practice for lab exhaust systems and optimise exhaust rates without compromising lab safety, a literature review was conducted, referencing several authoritative sources:

2.1 ASHRAE Laboratory Design Guide

The ASHRAE Laboratory Design Guide provides comprehensive guidelines on ventilation and airflow management in laboratory settings. The guide offers critical information and guidance essential for planning a laboratory building project. Key areas covered include:

- **Risk Assessment:** Identifying potential hazards and assessing the level of risk associated with laboratory processes and equipment.

- **Environmental Requirements:** The lab environment should meet necessary conditions for safe operations, including temperature, humidity, and air quality.
    - **Temperature:** The appropriate temperature control and interlocks should be available to avoid heating or cooling experiments beyond desired limits.
    - **Humidity:** Sensitive electronic instruments may have special minimum humidity requirements prevents static electricity from damaging experiments and equipment.
    - **Air quality:** Proper ventilation minimises potential sources of pollutants and contaminants.

- **Appliances and Occupancy:** Addressing equipment requirements and considering occupancy patterns optimises space use and safety.
    - **Appliance Loads:** HVAC system must remove the sensible and latent heat gains created by equipment, which influences the thermal environment in the room when released.
    - **Lighting:** Lighting heat load depends on the types of ballasts and fixtures used, which vary according to the tasks performed in the area.
    - **Occupants:** Occupant densities, diversities, activities levels and scheduling are the key criteria in determining the occupant load requirements.

- **Pressure Relationships:** Maintaining appropriate pressure differentials to prevent contamination and ensure safe containment of hazardous substances.
    - **Transfer Air:** Transfer air moves from one space to an adjacent space through a transfer grille or other air distribution outlet device
    - **Negative Pressure Room:** A negative pressure room is maintained at a lower pressure than adjacent areas, ensuring that air flows into the room
    - **Positive Pressure Room:** A positive pressure room is maintained at a higher pressure than surrounding spaces, resulting in net airflow out of the room. To achieve this, the supply air volume flow rate must exceed the total exhaust flow rates from all general and equipment exhaust

- **Ventilation & Indoor Air Quality (IAQ):** Air treatment is required to provide the desired air quality by either preventing contaminants from leaving the laboratory and entering the environment or preventing pollutants in the environment from entering the laboratory.

  Active sensing of air quality in individual laboratories is an alternative approach for dealing with the variability of appropriate ventilation rates, particularly when energy efficiency is important or when less may be known about the hazard level. With this approach, the minimum airflow rate is varied based on sensing the laboratory's actual air quality level or air cleanliness. Sensors used to determine air quality should be evaluated for their ability to detect the chemicals being used in the space. When air contaminants are sensed in the laboratory above a given threshold, the minimum air change rate is increased proportionately to an appropriate level to purge the room. When the air is "clean" and contaminants are below the threshold, lower minimum airflow rates may be appropriate.

- **Laboratory Codes, Standard, and References:** Ensuring compliance with relevant codes, standards and best practices for laboratory design and operation
  - **ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality –** referenced for calculation of Minimum Outdoor Air flowrate
  - **ASHRAE Handbook 2021 –** referenced for thermal template (e.g. Activity type, sensible/latent heat gain, etc.)

2.2 NEA Green Fit Out Guideline – Cleantech One

The National Environment Agency (NEA) Green Fit Out Guideline for Cleantech One focuses on sustainable design practices for laboratories, including energy efficiency and green building standards. It encourages the use of energy-efficient exhaust systems, low-emission building materials, and the reduction of environmental impact through optimized design strategies. This guideline helps in aligning lab exhaust designs with environmental sustainability goals.

The guideline recommends a hierarchy of sustainable strategies, starting with the minimisation of design airflow requirements. By reducing the lab's air changes per hour, significant energy savings can be achieved at the lowest cost, making this the most efficient starting point for optimizing energy performance in laboratory environments.

The next step focuses on controlling airflow through demand-based control of lab air change rates, using systems such as Aircuity. Additionally, the use of heat pipes can help minimize dehumidification and reheat energy requirements, further enhancing energy efficiency.

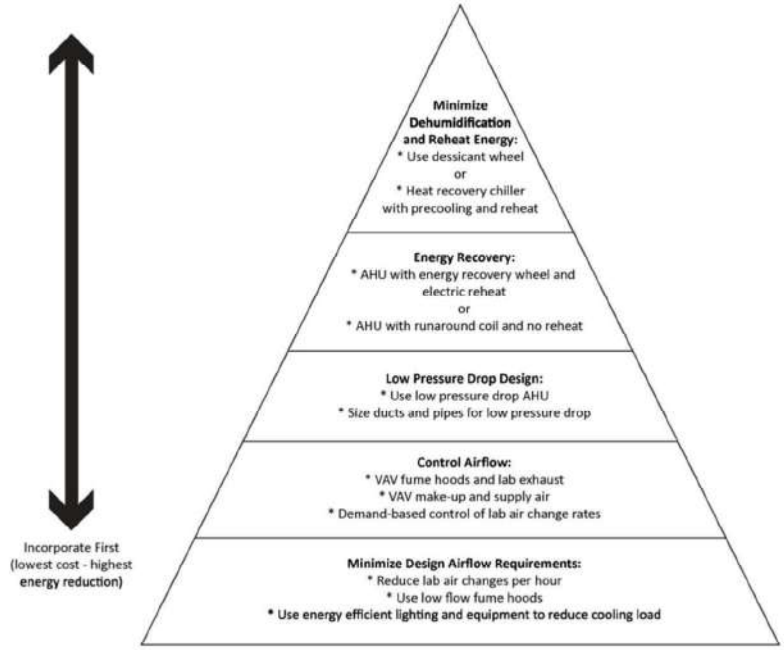

Figure 2: Hierarchy of Sustainable Strategies (Source: NEA Green Fitout Guideline)

2.3 SS641 – Code of Practice for Fire Safety for Laboratories using chemicals

SS641 is a safety standard that outlines the fire safety requirements for laboratories handling chemicals. The code addresses the design, installation, and maintenance of lab exhaust systems to ensure fire safety, particularly when handling flammable or hazardous substances. It emphasizes proper ventilation, exhaust placement, and adherence to fire safety regulations, which are critical to the overall safety of laboratory operations.

Figure 3 elaborates on the operating conditions required to provide adequate ventilation rates, ensuring occupant safety and the safe operation of exhaust devices within the laboratory. Further reduction of the air change rate is permissible down to 4 ACH for sprinklered labs, provided that the Annex B Risk Assessment indicates it is allowable, indoor air quality is not compromised, and the infrastructure has the capability to adjust between occupied and unoccupied modes.

8.3 Ventilation rates

8.3.1 Operating condition

8.3.1.1 Adequate ventilation shall be provided to ensure occupant safety and safe operation of exhaust devices inside the laboratory. The minimum air change rate for laboratories shall be based on Table 4 below, subject to individual operational requirements. Where higher ventilation rates are required due to the use of LEV (e.g. fume cupboards), the total calculated flow rate shall be used to determine the ACH. The calculation to achieve the required ACH can be made using internationally accepted standards (e.g. ASHRAE[6], CIBSE[7])

8.3.1.2 For energy conservation purposes, the air change rate for occupied laboratories can be reduced via the Risk Assessment Flow Chart given in Annex B.

8.3.1.3 There shall be effective means to ensure the ventilation rate is adjusted when the occupancy of the laboratory changes from unoccupied to occupied. In addition, the indoor air quality of the laboratory unit should also be considered when determining the ACH.

Table 4 – Minimum lab ventilation rates

		Sprinkled, air change per hour (ACH)*	Non-sprinkled, air change per hour (ACH)*
Occupied laboratory	Prescribed value	8	12
	Further reduction based on Annex B Risk Assessment	4	8
Non-occupied laboratory	The air change values can be reduced by up to half that of an occupied laboratory, as shown above		

Figure 3: Ventilation Rate in SS641 (Source: SS641)

The ventilation risk assessment flowchart, as shown in Figure 4, is used to analyse the Annex B Risk Assessment of a typical BSL2 lab, where experiments involving gas, vapor, and airborne particles are conducted within fume hoods situated in dedicated, negatively pressurized rooms. It should be noted that this is a sample risk assessment and each lab's risk assessment shall be conducted by a Qualified Professional.

The following are key points to minimise risks:

1. The appropriate Local Exhaust Ventilation (LEV) system must be selected for the lab activities
2. Airborne contaminants must be minimized in open labs by containing hazardous lab activities in dedicated, negatively pressurized rooms with LEVs
3. Design ACH for rooms shall always be for the worst case between cooling supply airflow, LEV airflow, minimum airflow required for IAQ, and 4 ACH

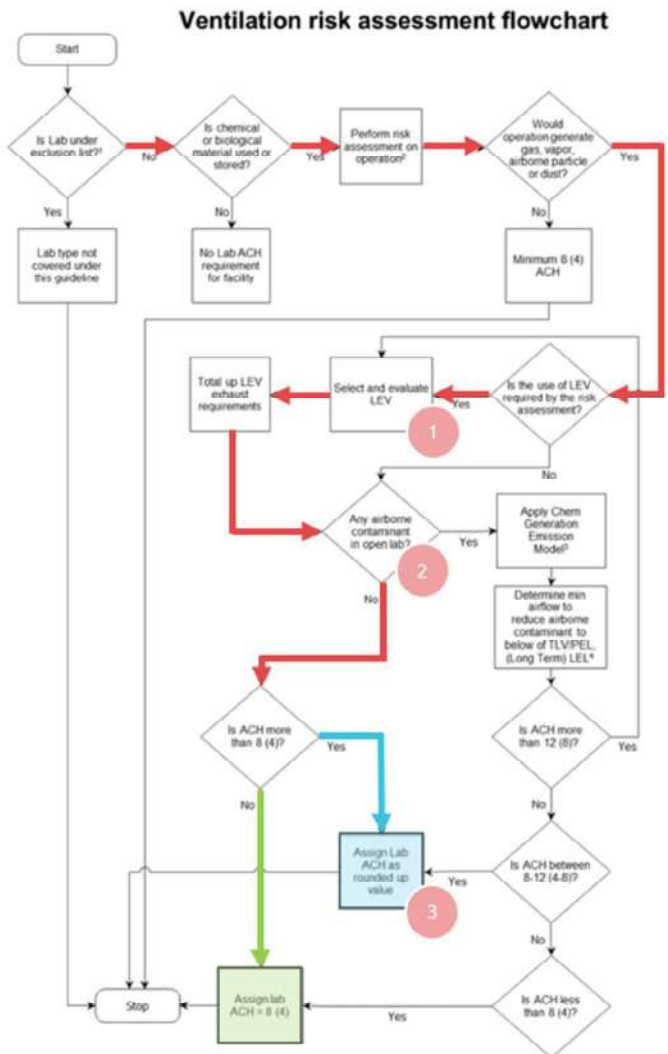

Figure 4: Ventilation Risk Assessment Flowchart

3 Modelling Overview

3.1 IESVE Software

The commercial package IES Virtual Environment (IES-VE) version 2023.5.1.0 was used to construct the building model including materials, glazing and internal loads. The thermal and energy modelling packages Apache and ApacheHVAC were then used to model mechanical systems and to simulate the energy consumption of the base building.

Founded in 1994 by Don Mclean with the first commercial package released in 2000, IES-VE is an energy analysis and thermal load simulation software which meets or exceeds the ANSI/ASHRAE/ACCA Standard 183 by using the Heat Balance (HB) Method to calculate heating and cooling loads to comply with the Standard. The method is detailed in Chapter 18 of the ASHRAE Handbook – Fundamentals as the preferred accurate method for load calculations. The tools also meet the following international standards: BEST TEST, CIBSE TM33, EU EN13791: July 2000, ISO 52000, and ASHRAE 140: 2001, 2004, 2007, 2014, 2017.

The strength of energy simulation software is in its ability to dynamically model the complex heat flows within a building and its zones and simulate how the varied loads interact with the HVAC systems over the course of a year. However, the software is not used to model some energy end uses that are simpler to be estimated using manual calculation (e.g. vertical transportation) and in these cases the energy simulation is supplemented with spreadsheet type calculations and design information. The building model developed to complete the estimated energy simulation includes the following information:

- Geometry and shading by the provided architectural drawings.
- Modelled total floor area was 2,170 m^2 total building area and 2,022 m^2 of conditioned area.
- HVAC systems and equipment set up as documented in accordance with the current mechanical drawings and equipment schedules.
- Lighting power density as documented in the electrical drawings and equipment schedules.

Estimating the base energy consumption using this modelling approach is a powerful tool for assessing energy use. However, it should be noted that there are several assumptions and simplifications that are made that align with the energy modelling guide. All assumptions and their justification are outlined in this report.

3.2 Modelling Approach

The first step of the modelling approach was to determine the capacities of the existing infrastructure through site surveys and a review of the architectural and mechanical drawings.

In order to configure the mechanical system in IESVE, each space was divided into respective thermal zones, served by supply venturi valves or VAV systems identified and zoned accordingly. Additionally, a thermal profile is calculated for each thermal zone, accounting for sensible and latent gains generated from lighting, occupants, and equipment.

A 3D model was constructed in the IESVE software according to the architectural drawings provided. The thermal profiles for each zone are updated and assigned with their respective internal loads and occupancy profiles.

A calculation was made referencing ASHRAE 62.1 and SS 553, considering the worst-case scenario between the ASHRAE 62.1 ventilation requirements, 4 air changes per hour (ACH), and the cooling load supply airflow. This worst case ultimately dictates how low the ACH can be reduced to. This study has found that the cooling load supply airflow is ultimately the determining factor in ACH reduction with results discussed in Section 5

Figure 5 shows the entire modelling workflow in IESVE while Figure *6* and Figure *7* shows the modelled building and floor layout in IESVE.

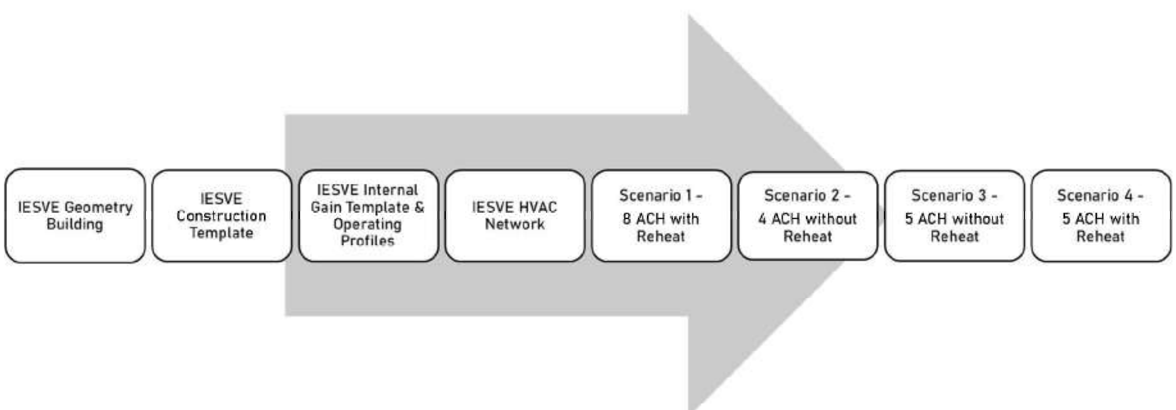

Figure 5: Flowchart of Modelling Approach in IESVE

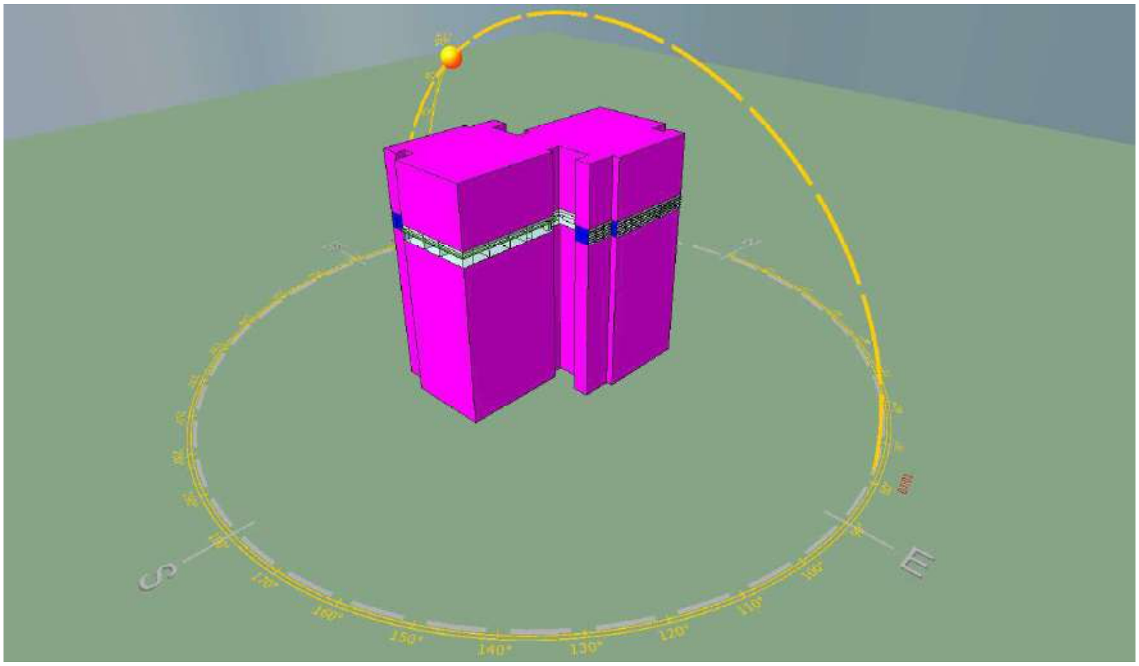

Figure 6: Perspective View of the Building Modelled in IESVE

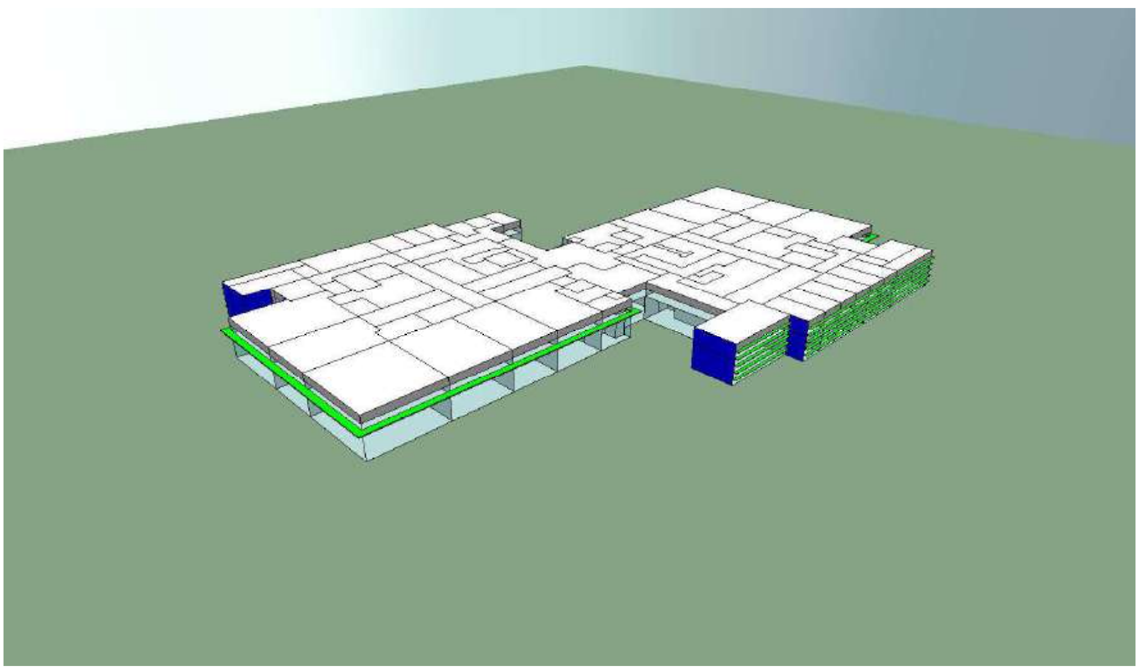

Figure 7: Perspective View of Level 11 Modelled in IESVE

There are 4 scenarios that have been modelled in the IESVE software. The scenarios are as follows:

Scenario 1: 8 ACH with Reheat

- Scenario 1 is the baseline scenario where the existing system is created to be the basis of comparison. In this scenario, the created system will be tweaked to match the current conditions observed during the site visit.

Scenario 2: 4 ACH without Reheat

- Scenario 2 is an exploratory scenario where the existing system airflow is changed from 8 ACH to 4 ACH and turning the reheat component off. In this scenario, the resulting temperature and relative humidity (RH) from the reduction of airflow will be studied and analysed.

Scenario 3: 5 ACH without Reheat

- Scenario 3 is an extension of Scenario 2 where having analyse the Scenario 2 result, it is expected that some of the spaces will be overheated due to the reduction of airflow. These spaces will be identified, and the airflow will be increased to lower down the overheating conditions.
- It is also expected that some of the spaces will be overcooled due to the reheat component being turned off.

Scenario 4: 5 ACH with Reheat

- Scenario 4 is the final scenario where the heating component being turned back on in order to see whether this will make all the spaces at the ideal temperature and RH range.

4 Simulation Input Data

4.1 Simulation Weather File

SingaporeIWEC.fwt weather file that are the default weather file in IESVE for Singapore are used as the simulation weather file. The weather file considered 8,760 hours with hourly timestamp. Figure 8 shows the settings for the simulation weather file in IESVE.

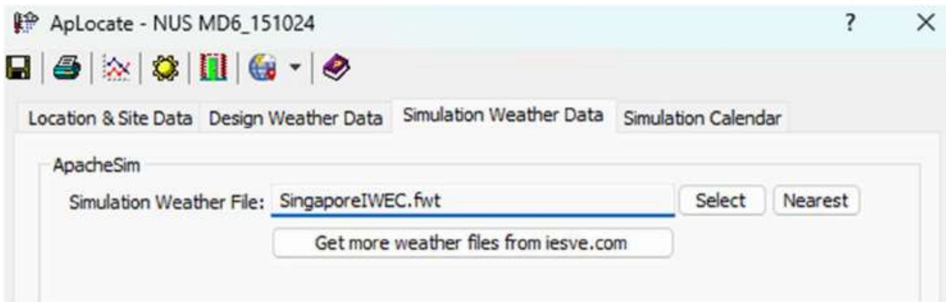

Figure 8: Simulation Weather File Settings in IESVE

4.2 Envelope Parameters

The U-value and shading coefficient of the window glazing are set at 2.19 W/m²K and 0.42, respectively.

4.3 Operational Profiles

The following figures show the operational profiles – occupancy, lights and receptacle that have been set up according to the room typologies.

Labs/Lab Related Areas

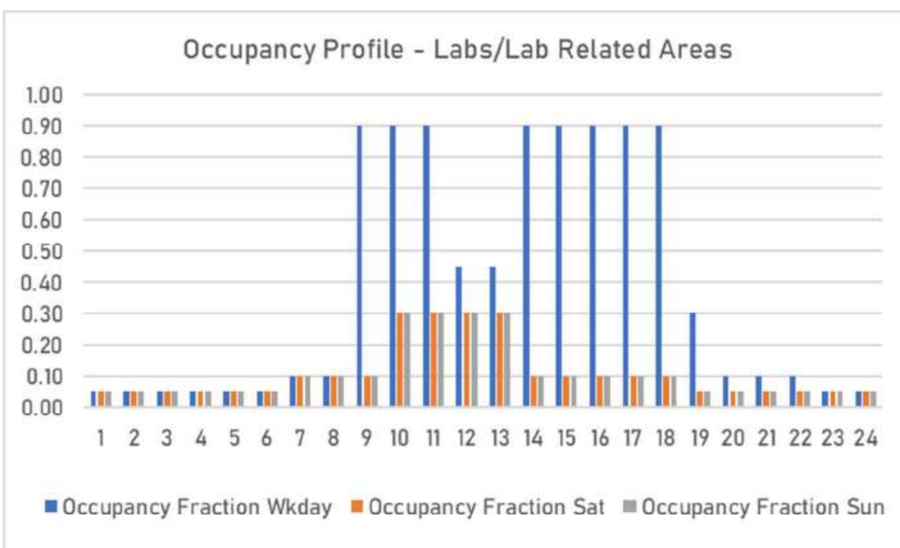

Figure 9: Occupancy Profiles for Labs/Lab Related Areas

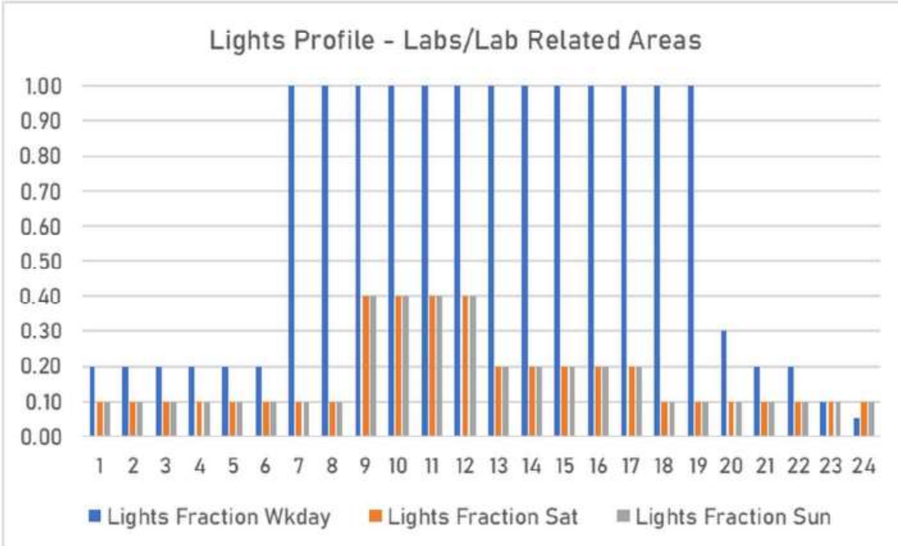

Figure 10: Lights Profile for Lab/Lab Related Areas

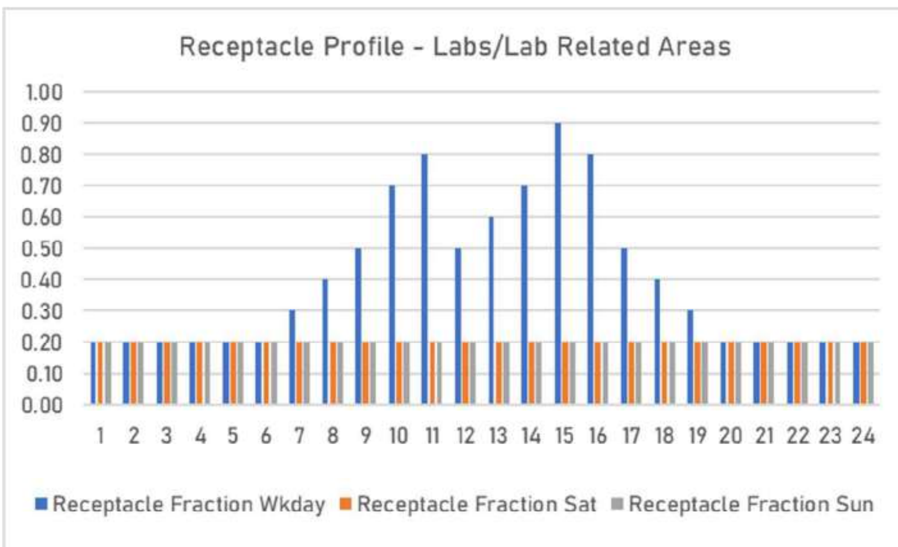

Figure 11: Receptacle Profile for Lab/Labs Related Areas

Office Areas

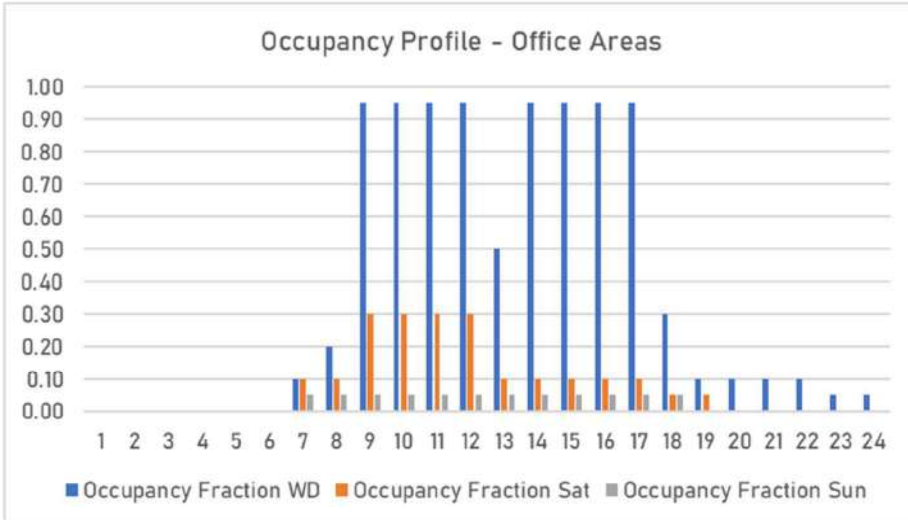

Figure 12: Occupancy Profile for Office Areas

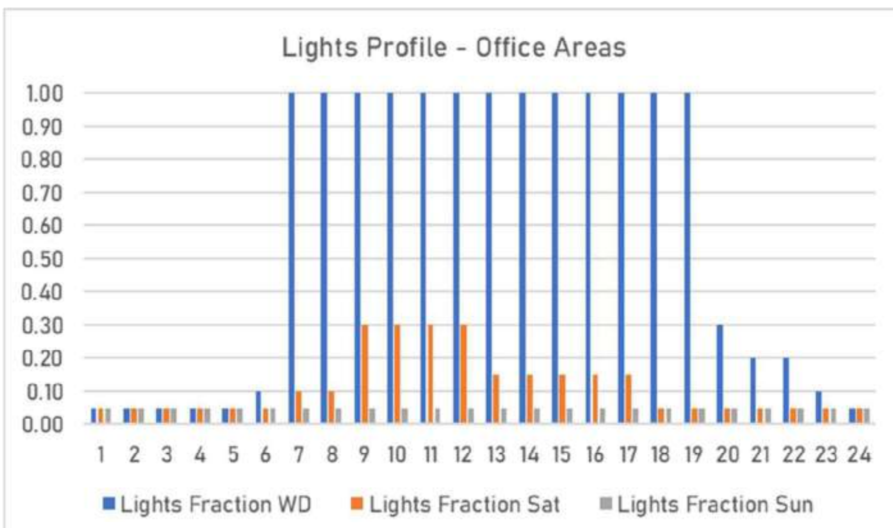

Figure 13: Lights Profile for Office Areas

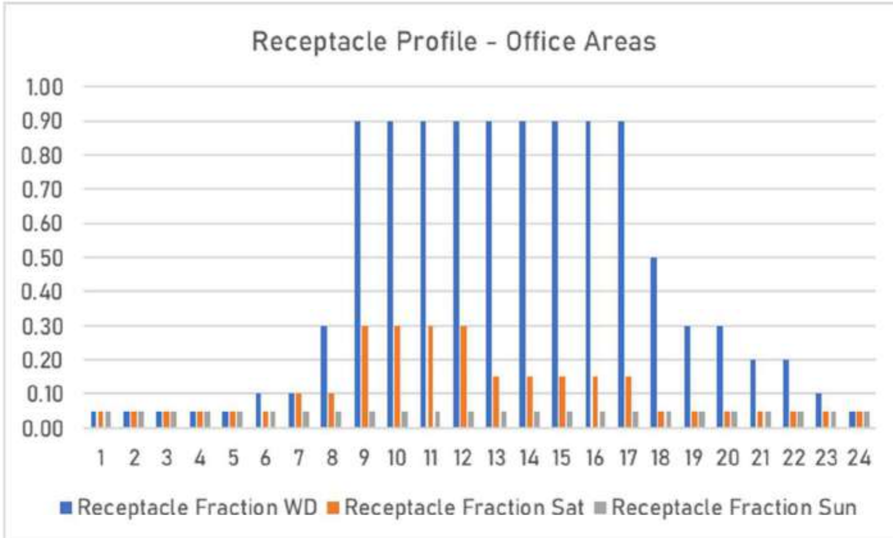

Figure 14: Receptacle Profile for Office Areas

Corridors/Lobbies/Stairs

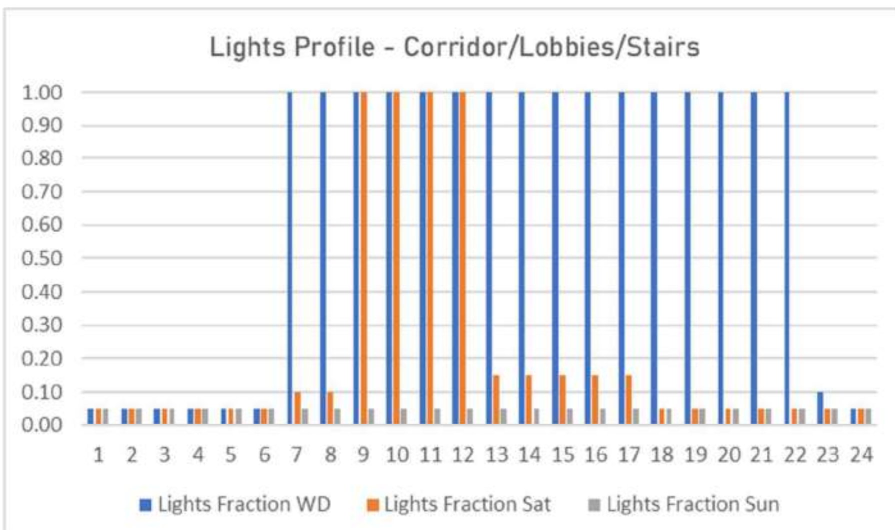

Figure 15: Lights Profile for Corridor/Lobbies/Stairs Areas

MEP/Store

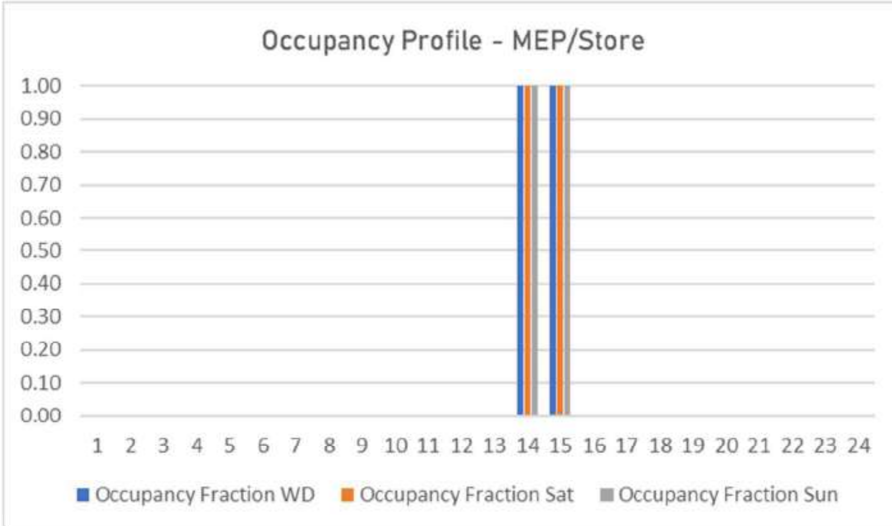

Figure 16: Occupancy Profile for MEP/Store Areas

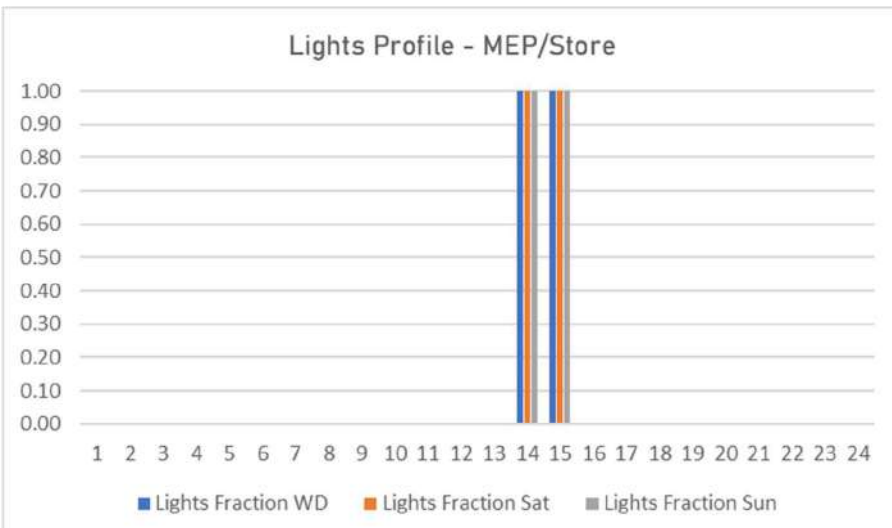

Figure 17: Lights Profile for MEP/Store Areas

4.4 Control Sequences

- **CAHU and Exhaust Fan Schedule**

	Base Case	Optimised Case
Occupied Hours – 0700 to 1900	8 ACH	4 ACH
Unoccupied Hours – 1900 to 0700	4 ACH	2 ACH

- **Reheat Coil Sequence**

System Start	Control valve Open
System Operation	○ Control valve modulates coil flow rate to maintain space temperature set point. ○ Supply air temperature to modulate between 18°C and 21°C.
System Stop	Control valve close

- **Control Input in IESVE**

CAHU with Venturi Valve ApacheHVAC Setup

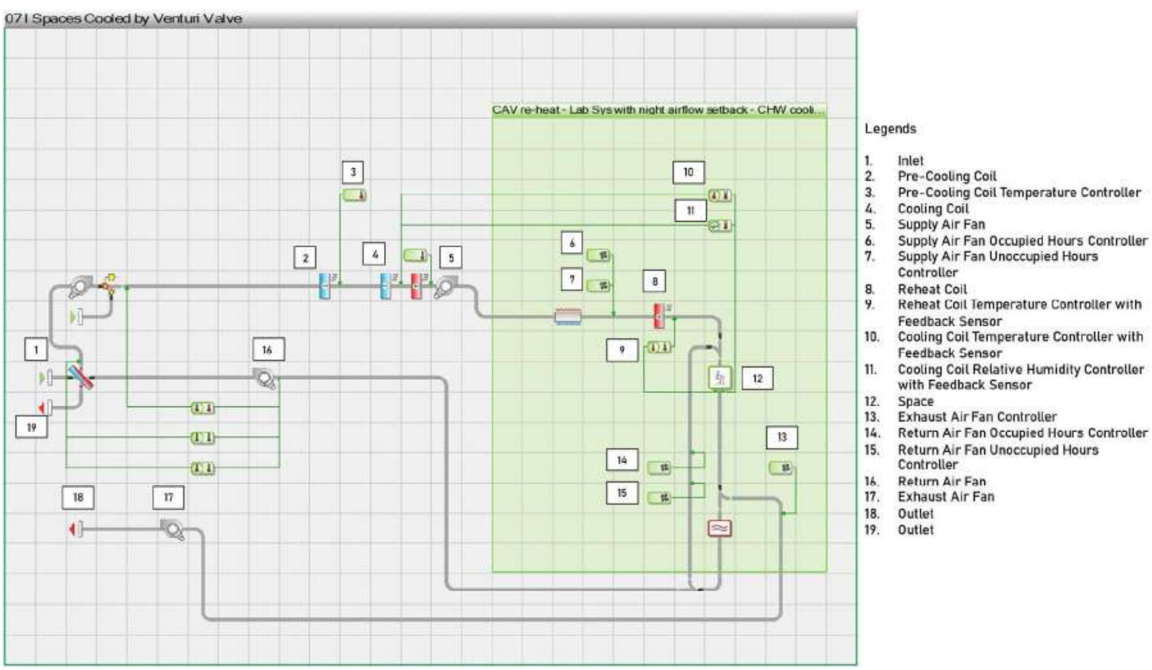

Figure 18: CAHU with Supply Air Venturi Valve Network in ApacheHVAC

Temperature and Air Flow Control Input for Scenario 1

Figure 18 shows the CAHU Venturi Valve ApacheHVAC setup in IESVE. Only the components that are used in the network are shown. Below is all the controller input for Scenario 1. All the other controllers for Scenario 2, 3 and 4 can be found in Appendix C – ApacheHVAC Input.

1. Component 3 (Pre-Cooling Coil Controller)

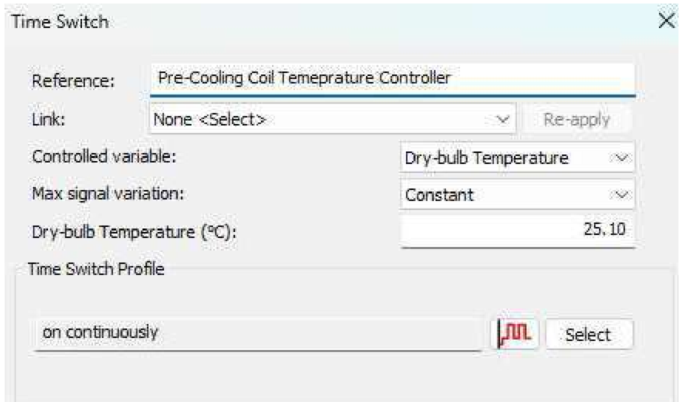

Figure 19: Pre-Cooling Coil Temperature Controller in ApacheHVAC for Scenario 1

2. Component 5 (Supply Air Fan)

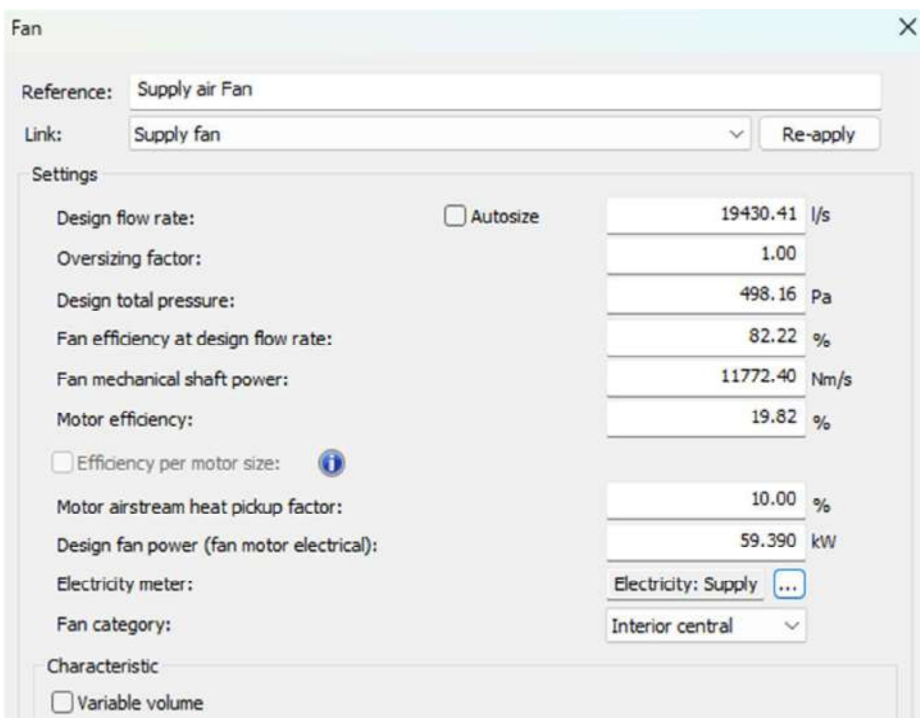

Figure 20: Supply Air Fan Input in ApacheHVAC for Scenario 1

3. Component 6 (Supply Air Fan Occupied Hours Controller)

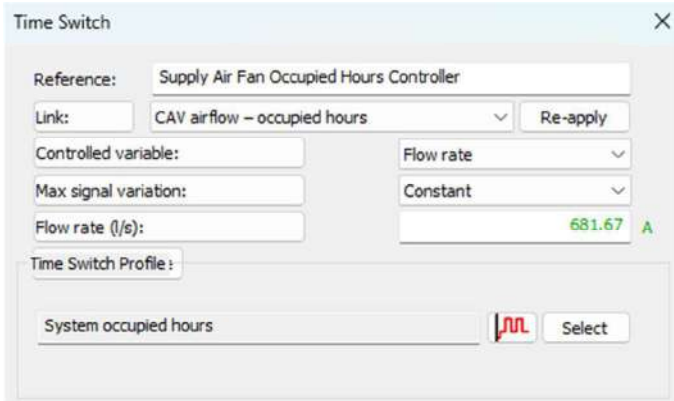

Figure 21: Supply Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 1

4. Component 7 (Supply Air Fan Unoccupied Hours Controller)

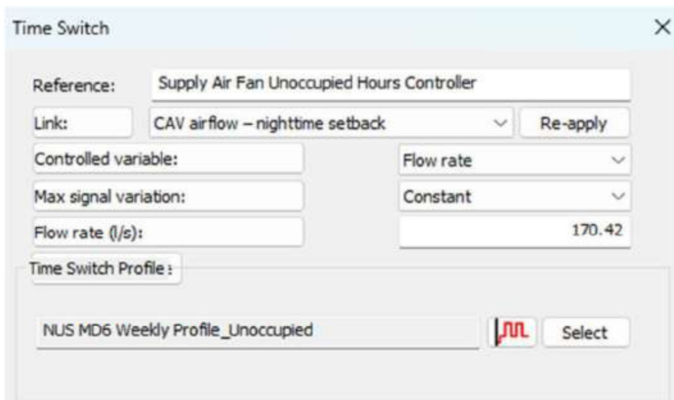

Figure 22: Supply Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 1

5. Component 9 (Reheat Coil Temperature Controller with Feedback Sensor)

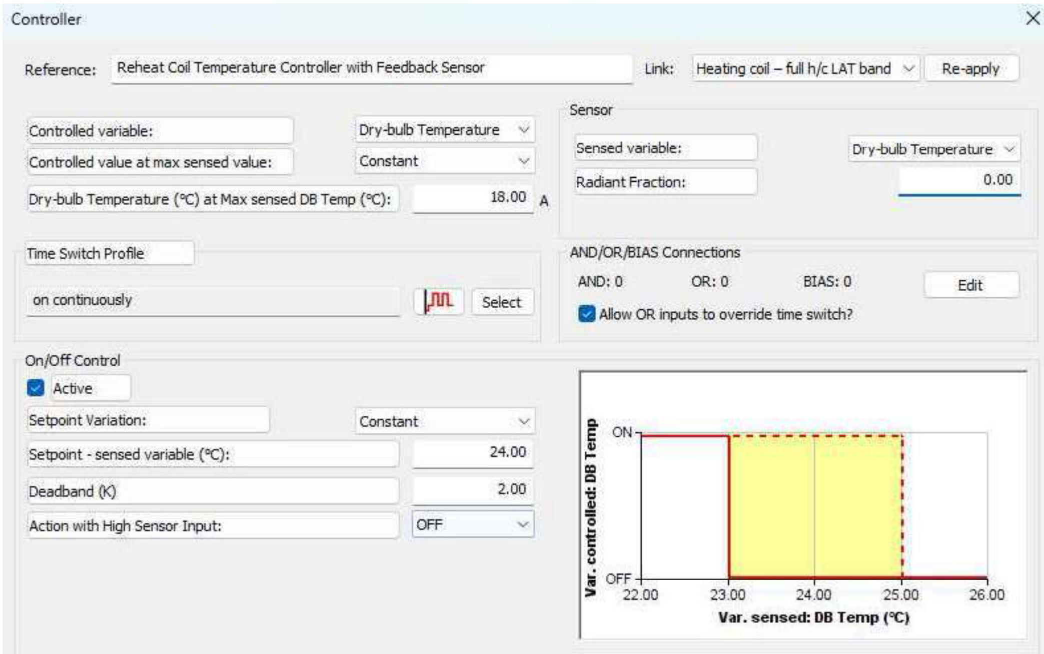

Figure 23: Reheat Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 1

6. Component 10 (Cooling Coil Temperature Controller with Feedback Sensor)

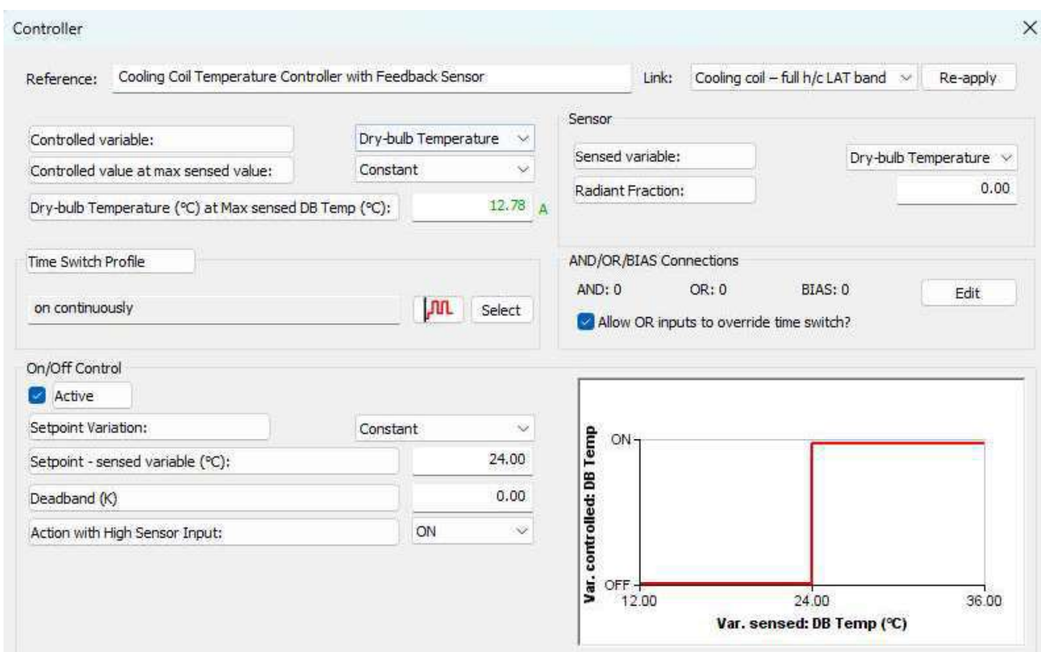

Figure 24: Cooling Coil Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 1

7. Component 11 (Cooling Coil Relative Humidity Controller with Feedback Sensor)

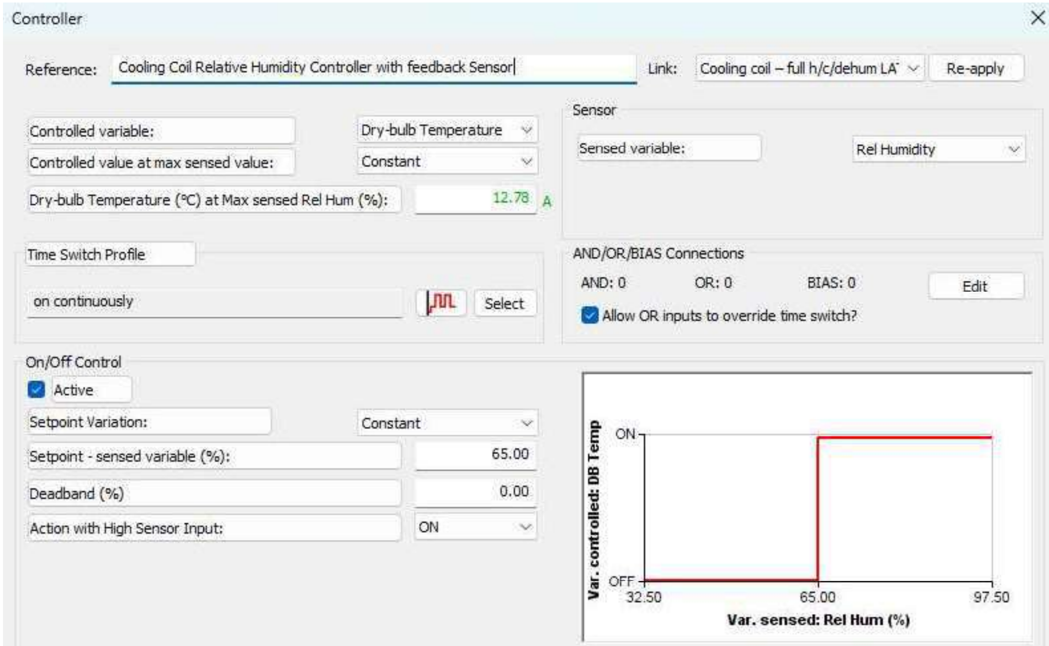

Figure 25: Cooling Coil Relative Humidity Controller with Feedback Sensor in ApacheHVAC for Scenario 1

8. Component 13 (Exhaust Air Fan Controller)

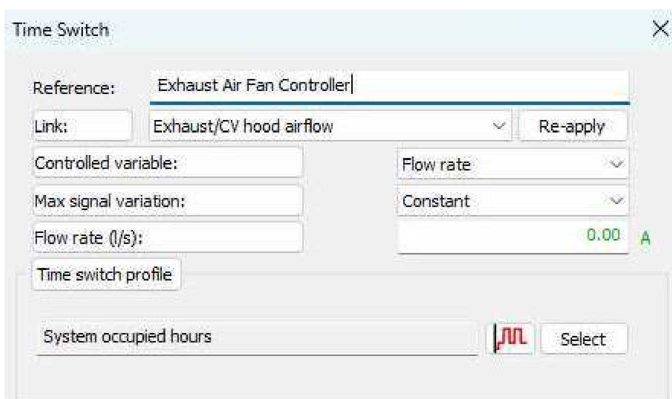

Figure 26: Exhaust Air Fan Controller in ApacheHVAC for Scenario 1

9. Component 14 (Return Air Fan Occupied Hours Controller)

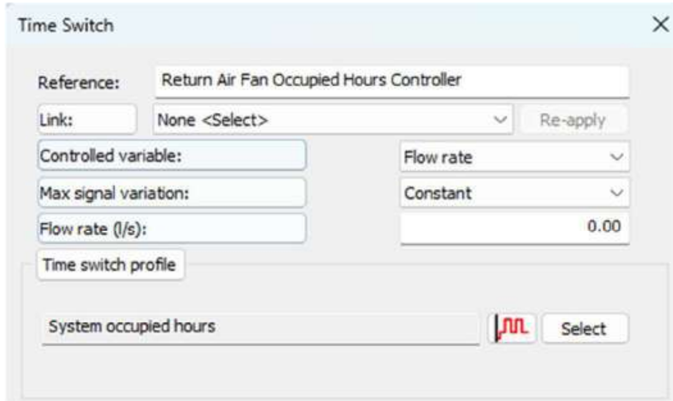

Figure 27: Return Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 1

10. Component 15 (Return Air Unoccupied Hours Controller)

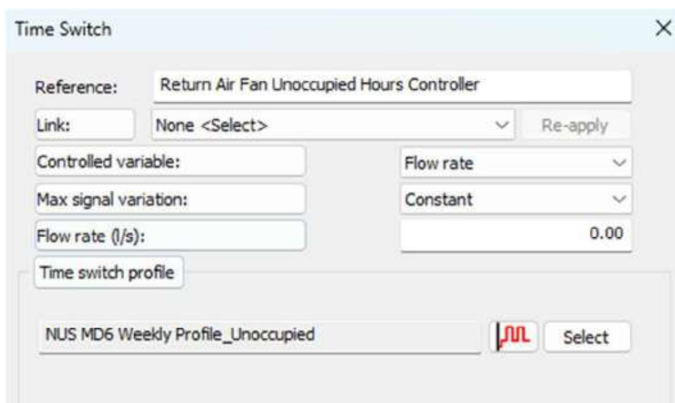

Figure 28: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 1

11. Component 16 (Return Air Fan)

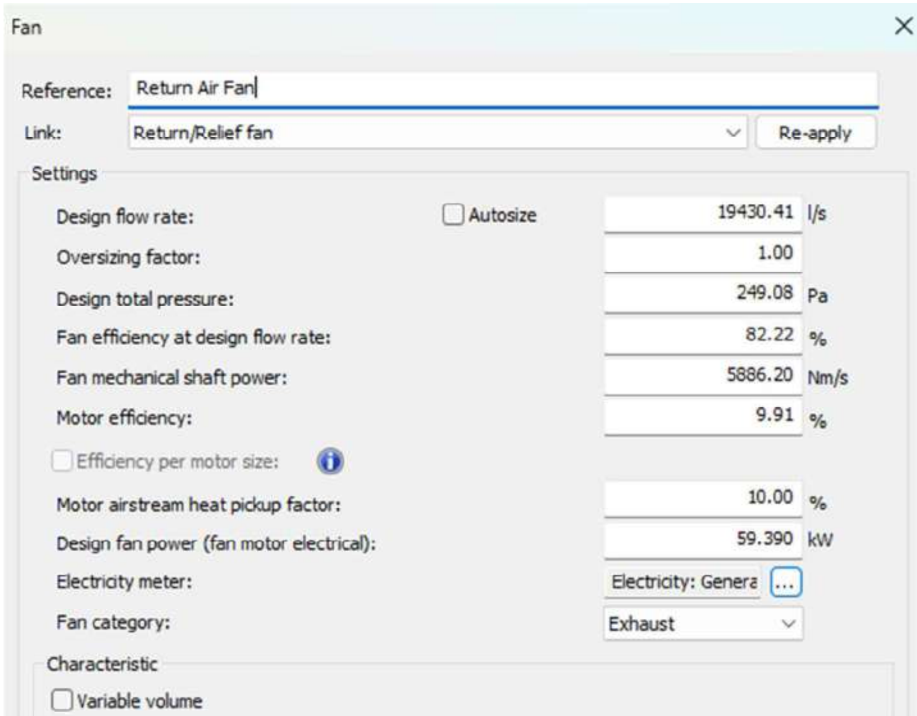

Figure 29: Return Air Fan in ApacheHVAC for Scenario 1

12. Component 17 (Exhaust Air Fan)

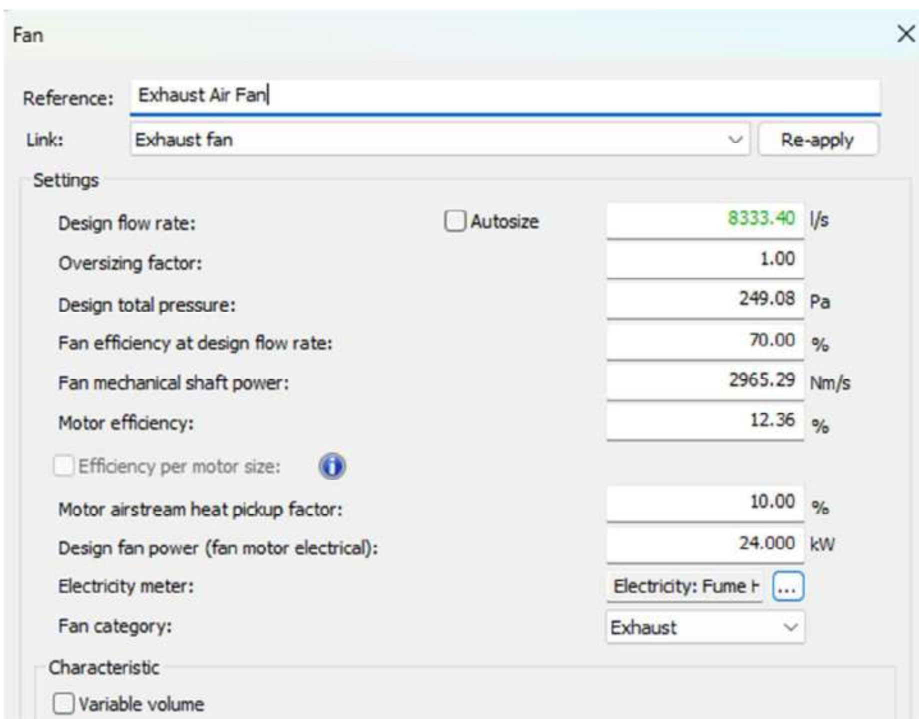

Figure 30: Exhaust Air Fan in ApacheHVAC for Scenario 1

4.5 Space Temperature and Relative Humidity (RH) Set Points

The setpoint for the air-condition areas are set at 24°C ± 1°C for temperature and 60% ± 5% for the RH. These criteria will be the main parameters to look at in the context of this study.

4.6 Lighting

The electrical drawing plan was received, clearly demarcating the light fittings, with the corresponding cutsheet attached. Based on the provided information, the number of light fittings in each zone was counted from the electrical floor plan. Since all lighting fixtures on Level 11 will be replaced in the future, a 40% reduction from the current Lighting Power Budget (LPB) has been assumed.

The lighting power budget is provided in **Appendix A – Lighting Power Budget (LPB).**

4.7 Occupancy

Based on the architectural furniture drawing plan, the number of occupants is assumed to correspond to the number of chairs in each zone. In zones without chairs, the occupancy heat load is assumed to be 0 m^2/person.

For the degree of activity in labs and offices, the work is classified as seated, very light work, as referenced in the 2021 ASHRAE Handbook, with sensible heat at 72 W and latent heat at 45 W per person.

4.8 Lab Equipment (Plug Loads)

Direct cutsheet information for the lab equipment was not provided by NUS, therefore, the equipment's brands and power consumption wattages were researched online. However, to maintain consistency when inputting plug loads, equipment of similar types—such as laptops, freezers, and refrigerators—are assumed to have the same power consumption, regardless of brand. However, not all equipment information was available for every zone, hence a few of the rooms' equipment power consumption was assumed and referenced to a past project of similar space type.

Since the equipment is not continuously in operation, diversity factors were applied to each type to account for their usage variability, as follows:

- Incubators – 1
- Refrigerators – 0.5
- Other equipment – 0.15

The equipment asset list is provided in **Appendix B – Lab Equipment Asset List.**

4.9 Infiltration

Following the CIBSE TM23 standards, the infiltration rate is set at 0.25 ACH.

4.10 Minimum Outdoor Air

The minimum outdoor air ventilation rate was calculated based on the ASHRAE 62.1 standard and applied to spaces served by VAV systems.

5 Results

Table 1 shows an example of how the result for the simulations is tabulated. The table is organized into columns that list the temperature and RH ranges, and rows that indicate the number of hours each range is maintained throughout the year based on the occupied hours (0700 Hours – 1900 Hours) explained in **Section 4.3**. For all zoning tags, refer to **Appendix D – Zoning Drawings.**

Only occupied hours are considered for the result. This is due to the assumption that during the unoccupied hours, lighting, lab equipment (aside from refrigerators and incubators), solar load, and occupancy loads will be low or not present.

Table 1: Example of Tabulated Data

Location	Temperature (°C) – % hours in range			RH (%) – % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	0	100	0	22.7	77.3	0
L11_01_Dark Room	0	100	0	96.7	3.3	0
L11_01_Entry Vestibule	0.8	99.2	0	100	0	0
L11_01_Freezer	2	89.6	8.4	99.1	0.9	0
L11_01_Fume Hood	72.9	27.1	0	36.5	63.5	0
L11_01_Linear Equipment	0	100	0	31.8	68.2	0
L11_01_Mass Spec Lab Large	0	0	100	100	0	0
L11_01_Mass Spec Lab Small	0	0	100	100	0	0
L11_01_Open Laboratory	1.4	44.7	53.9	77.4	22.6	0
L11_01_Tissue Culture	18.9	81.1	0	93.3	6.7	0
L11_01_Virus Room	71.4	28.6	0	35.6	64.4	0
L11_02_Blood Processing Room	0	100	0	15.6	84.4	0
L11_02_Entry Vestibule	3.7	96.3	0	100	0	0
L11_02_Freezer	0	73.5	26.5	100	0	0
L11_02_Fume Hood	68.8	31.2	0	41.7	58.3	0
L11_02_Linear Equipment	0	100	0	95.9	4.1	0
L11_02_Mass Spec Lab Small	0	98.7	1.3	99.5	0.5	0
L11_02_Open Laboratory	3.1	90.5	6.5	34.7	65.3	0
L11_02_Tissue Culture	10.3	89.7	0	96.6	3.4	0
L11_02_Virus Room	79	21	0	24.8	75.2	0
L11_03_Entry Vestibule	3.6	96.4	0	100	0	0
L11_03_Freezer	13.1	71.1	15.9	99.2	0.8	0
L11_03_Open Laboratory	2.3	84.1	13.6	62.5	37.5	0
L11_04_Entry Vestibule	0.1	99.9	0	100	0	0
L11_04_Open Laboratory	0.4	72.8	26.8	54.9	45.1	0
L11_05_Open Laboratory	5	90	5	26.7	73.3	0
L11_06_Open Laboratory	3.7	94	2.3	23.8	76.2	0
L11_07_Open Laboratory	0	87.5	12.5	100	0	0
L11_08_Open Laboratory	0	100	0	60.2	39.8	0
L11_09_Open Laboratory	2.2	94.2	3.6	34.4	65.6	0
L11_10_Open Laboratory	0	77	23	66	34	0
L11_11_Open Laboratory	0	50.9	49.1	83	17	0
L11_12_Open Laboratory	0	98.8	1.2	20.9	79.1	0
L11_13_Open Laboratory	1.6	96	2.4	41.7	58.3	0

The colour coding or shading, highlights areas where conditions fall within or outside the desired range. In the context of the simulation, the colour coding that falls within the desired range is green for both temperature and RH. The ideal conditions should be 90% of the hours within the desired range and 10% of the hours outside of the desired range.

The coloured area highlighted under the location column indicates the areas that is not considered for result analysis. This will be consistent across all of the scenarios simulated.

5.1 Scenario 1: 8 ACH with Reheat

Scenario 1 represents the baseline condition, where the existing system is recreated to serve as a basis for comparison with other scenarios.

5.1.1 Observation

One main observation in Table 2 is that the majority of the areas fall within a temperature range of less than 23°C and within 55% to 65% of RH.

Table 2: Temperature and Relative Humidty (RH) Tabulation for 8 ACH with Reheat

Location	Temperature (°C) – % hours in range			RH (%) – % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	81.8	18.2	0	7.6	92.4	0
L11_01_Dark Room	79.3	20.7	0	51.4	48.6	0
L11_01_Entry Vestibule	100	0	0	0	89.5	10.5
L11_01_Freezer	16.1	83.9	0	100	0	0
L11_01_Fume Hood	100	0	0	0	0.6	99.4
L11_01_Linear Equipment	93	7	0	6.6	93.4	0
L11_01_Mass Spec Lab Large	1.9	98.1	0	97.6	2.4	0
L11_01_Mass Spec Lab Small	0.4	99.6	0	98.6	1.4	0
L11_01_Open Laboratory	21.2	78.8	0	68.7	31.3	0
L11_01_Tissue Culture	100	0	0	0	100	0
L11_01_Virus Room	100	0	0	0	1.7	98.3
L11_02_Blood Processing Room	81.3	18.7	0	6.2	93.8	0
L11_02_Entry Vestibule	100	0	0	0	92.1	7.9
L11_02_Freezer	7.3	92.7	0	99.8	0.2	0
L11_02_Fume Hood	100	0	0	0	1.5	98.5
L11_02_Linear Equipment	100	0	0	0	100	0
L11_02_Mass Spec Lab Small	0	100	0	97.7	2.3	0
L11_02_Open Laboratory	36.1	63.9	0	39.3	60.7	0
L11_02_Tissue Culture	100	0	0	1.9	98.1	0
L11_02_Virus Room	100	0	0	0	0	100
L11_03_Entry Vestibule	100	0	0	0	55	45
L11_03_Freezer	6.2	93.8	0	100	0	0
L11_03_Open Laboratory	34.3	65.7	0	55.8	44.2	0
L11_04_Entry Vestibule	100	0	0	0	79.6	20.4
L11_04_Open Laboratory	26	74	0	57.2	42.8	0
L11_05_Open Laboratory	46.5	53.5	0	31.9	68.1	0
L11_06_Open Laboratory	60.8	39.2	0	24.1	75.9	0
L11_07_Open Laboratory	49.8	50	0.2	63.9	36.1	0
L11_08_Open Laboratory	39.9	60.1	0	58.2	41.8	0
L11_09_Open Laboratory	34.4	65.6	0	42.8	57.2	0
L11_10_Open Laboratory	21.1	78.9	0	63.1	36.9	0
L11_11_Open Laboratory	17	83	0	76.4	23.6	0
L11_12_Open Laboratory	56.7	43.3	0	15.9	84.1	0
L11_13_Open Laboratory	42.8	57.2	0	42.2	57.8	0

The temperature range of less than 23°C indicates that most of the areas are being overcooled.

5.1.2 Discussion

Limitation and Assumptions

As a baseline condition, the team were not able to determine the control sequence of the reheat coils. This is either by finding the sequence in the design documents, operation and maintenance manual or from the control contractors.

The team assumed that the control valve would modulate the flow are according to the space set point with an upper max supply air temperature of 18°C. This can be seen in Figure *23*. There were also no reheat coil schedules available to enter the capacities into the ApacheHVAC network and autosized is the only option in this case.

During one of the site visits, it has also been observed on site that it's possible that the control valves for the reheat coils may not be operating correctly in some spaces.

In terms of the building airside systems and hydronics system, it has not been balanced since the initial construction of the building. There was also no confirmation that the sensors have been recalibrated and the level of sub-metering of the building is not sufficient to do true calibration.

Cause of Overcooling in Scenario 1

In **Section 5.1.1**, it has been observed that the majority of the of the areas falls within a temperature range of less than 23°C and indicates that most of the areas are being overcooled even with reheat. In order to analyse more about this situation, the team looks into one area; 01_Open_Laboratory, plot the temperature and tabulate the space conditions for a day in a year.

Figure 31 shows the temperature plot for 01_Open_Laboratory. Even with reheat, there are still times where the space will be overcooled. This occurs during the early occupied hours of 0730 until 0830 hours.

The reason why this is happening is because the 8 ACH supply air is more than what is required to extract the low sensible and latent gain in the space during this the early morning. Furthermore, the solar gain is also low compared to the rest of the hours in the day as seen in Table 3. The location of the sun at 0730 hours for 01_Open_Laboratory can be seen in Figure 32.

This phenomenon can be mitigated with a variable air volume system where the air can be supplied at just the right temperature to compensate for the low sensible, latent and solar gain in the space.

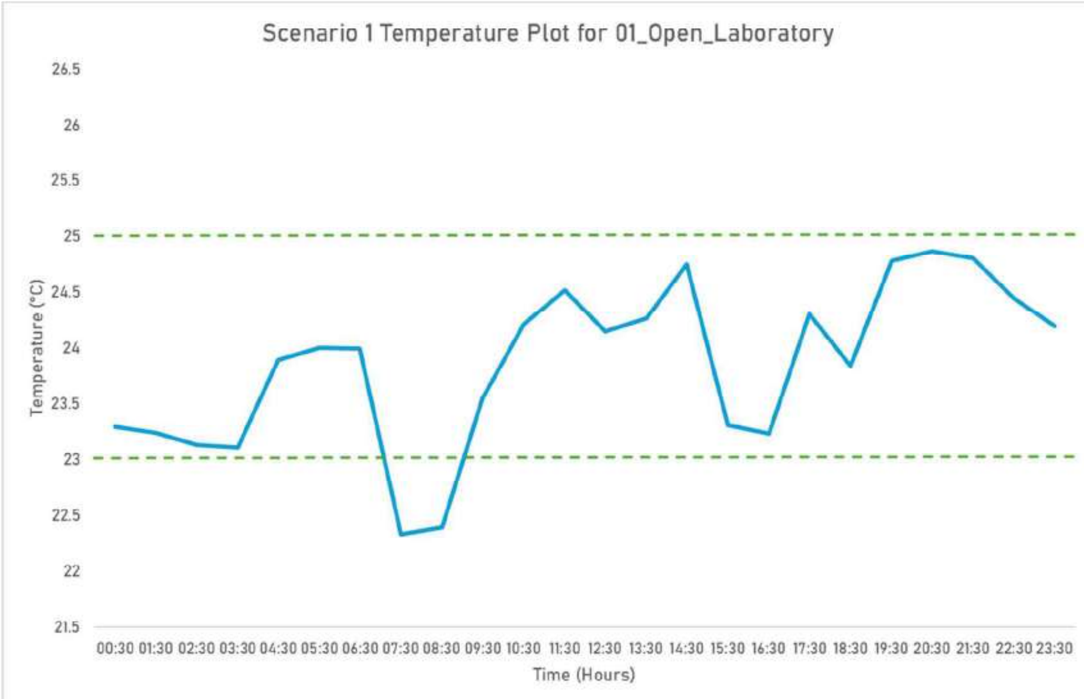

Figure 31: Scenario 1 Temperature Plot for 01_Laboratory for a Day in a Year (22nd April)

Table 3: Scenario 1 Space Conditions for 01_Open_Laboratory on 22nd April

Date	Time	Entering Supply Air Temperature (°C)	Space Air Temperature (°C)	Space Internal Gain (kW)	Space Solar Gain (kW)	Space Air Supply (l/s)
Tue, 22/Apr	00:30	13.47	23.29	0.2739	0	170.42
	01:30	13.47	23.24	0.3969	0	170.42
	02:30	13.47	23.13	0.3969	0	170.42
	03:30	14.38	23.11	0.3969	0	170.42
	04:30	18.00	23.89	0.3969	0	170.42
	05:30	18.00	24	0.3969	0	170.42
	06:30	18.00	23.99	0.3969	0	170.42
	07:30	18.00	22.33	1.2122	0.3929	681.67
	08:30	18.00	22.39	1.2855	1.0223	681.67
	09:30	18.00	23.55	2.7419	1.6337	681.67
	10:30	18.00	24.21	2.8884	2.0642	681.67
	11:30	18.00	24.52	2.9617	2.0026	681.67
	12:30	18.00	24.15	1.9639	1.9944	681.67
	13:30	18.00	24.26	2.0371	2.2664	681.67
	14:30	17.55	24.75	2.8884	2.5483	681.67
	15:30	13.47	23.31	3.0349	3.8097	681.67
	16:30	13.47	23.23	2.9617	4.0239	681.67
	17:30	17.55	24.3	2.7419	2.5965	681.67
	18:30	18.00	23.84	2.6687	0.8423	681.67
	19:30	18.00	24.78	0.9843	0.0739	170.42
	20:30	18.00	24.86	0.8291	0	170.42
	21:30	18.00	24.8	0.8291	0	170.42
	22:30	18.00	24.45	0.4833	0	170.42
	23:30	18.00	24.19	0.3149	0	170.42

Figure 32: The sun location for 01_Open_Loboratory on 22nd April at 0730 hours

5.2 Scenario 2: 4 ACH without Reheat

Taking the result in Scenario 1 as a base case, the team decided to simulate Scenario 2 where the supply air is being halved to 4 ACH and the reheat turned off. This is done to reduce the amount of time most of the spaces are being overcooled and to see whether the reheat is needed.

5.2.1 Observation

The key observation in Table 4 shows that the majority of the areas are still overcooled, indicating that reheating is needed to bring them within the desired temperature range. Three areas stood out, where previously there was no overheating with 8 ACH, but now they are showing signs of overheating with 4 ACH. These areas are highlighted in orange, and it has been decided to change the ventilation to 5 ACH in order to reduce the percentage of hours exceeding 25°C.

Table 4: Temperature and Relative Humidty (RH) Tabulation for 4 ACH without Reheat

Location	Temperature (°C) - % hours in range			RH (%) - % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	87.2	12.8	0	0.2	80.3	19.5
L11_01_Dark Room	98.6	1.4	0	0.7	99.3	0
L11_01_Entry Vestibule	100	0	0	0	3.2	96.8
L11_01_Freezer	49	51	0	99.6	0.4	0
L11_01_Fume Hood	100	0	0	0	5.9	94.1
L11_01_Linear Equipment	93.4	6.6	0	0.1	99.7	0.2
L11_01_Mass Spec Lab Large	0.6	17.7	81.8	98.1	1.9	0
L11_01_Mass Spec Lab Small	14.4	56.8	28.8	75	25	0
L11_01_Open Laboratory	21.6	38.4	39.9	56.9	42.1	1
L11_01_Tissue Culture	100	0	0	0	82.1	17.9
L11_01_Virus Room	100	0	0	0	11	89
L11_02_Blood Processing Room	87.8	12.2	0	0.1	80.7	19.3
L11_02_Entry Vestibule	100	0	0	0	0.7	99.3
L11_02_Freezer	89.9	10.1	0	100	0	0
L11_02_Fume Hood	100	0	0	0	7.6	92.4
L11_02_Linear Equipment	100	0	0	0	93.7	6.3
L11_02_Mass Spec Lab Small	0	100	0	99.9	0.1	0
L11_02_Open Laboratory	45.8	53.1	1.1	6.6	86.2	7.1
L11_02_Tissue Culture	92.9	7.1	0	9.1	83.4	7.4
L11_02_Virus Room	100	0	0	0	2.6	97.4
L11_03_Entry Vestibule	100	0	0	0	0	100
L11_03_Freezer	43.9	56.1	0	99.6	0.4	0
L11_03_Open Laboratory	36.1	59.8	4.1	23.4	73.7	2.9
L11_04_Entry Vestibule	100	0	0	0	1.6	98.4
L11_04_Open Laboratory	29.6	59.6	10.7	22.8	75.9	1.4
L11_05_Open Laboratory	56.4	41.9	1.6	5.2	87.1	7.7
L11_06_Open Laboratory	68.8	30.4	0.8	4	89.9	6.1
L11_07_Open Laboratory	51.6	41.8	6.5	53	45.3	1.7
L11_08_Open Laboratory	69.6	30.4	0	3.4	96.6	0
L11_09_Open Laboratory	43.3	56.3	0.4	6	92.5	1.5
L11_10_Open Laboratory	26.9	68.8	4.3	15.1	84	0.9
L11_11_Open Laboratory	17.1	54.7	28.2	56.2	43.8	0
L11_12_Open Laboratory	65.8	34.1	0.1	0.9	85.9	13.3
L11_13_Open Laboratory	54.8	45.1	0.2	6.8	92.2	1

5.2.2 Discussion

In **Section 5.2.1,** it has been observed that there are spaces highlighted in orange are overheating where previously it is not in Scenario 1. Taking 01_Open_Laboratory to analyse further, the team plots the temperature and tabulate the space conditions for a day in a year.

The overheating occurs at 1130 to 1830 hours where the sensible, latent and solar gain are at the highest as shown in Figure 33 and Table 5. This shows that 4 ACH is not enough to compensate the sensible, latent and solar gain during the time of 1130 to 1830 hours.

The next step in the process to reduce the overheating hours are shown in the next section.

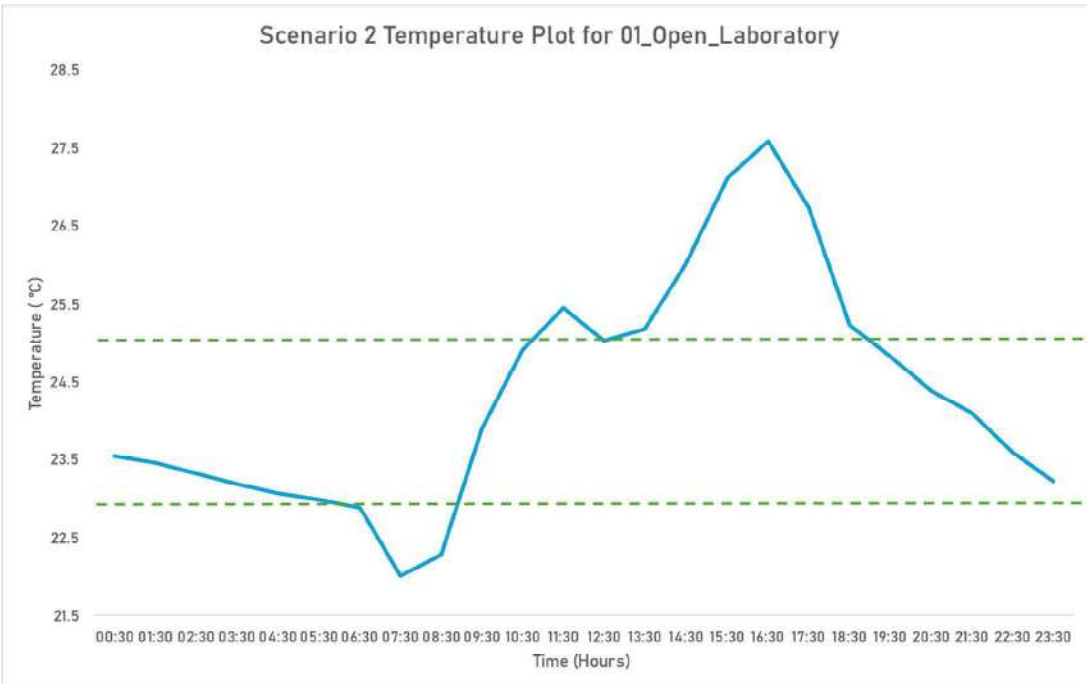

Figure 33: Scenario 2 Temperature Plot for 01_Laboratory for a Day in a Year (22nd April)

Table 5: Scenario 2 Space Conditions for 01_Open_Laboratory on 22nd April

Date	Time	Entering Supply Air Temperature (°C)	Space Air Temperature (°C)	Space Internal Gain (kW)	Space Solar Gain (kW)	Space Air Supply (l/s)
Tue, 22/Apr	00:30	13.47	23.54	0.2739	0	170.42
	01:30	13.47	23.46	0.3969	0	170.42
	02:30	13.47	23.32	0.3969	0	170.42
	03:30	13.47	23.19	0.3969	0	170.42
	04:30	13.47	23.08	0.3969	0	170.42
	05:30	13.47	22.99	0.3969	0	170.42
	06:30	13.47	22.89	0.3969	0	170.42
	07:30	13.47	22.01	1.2122	0.3929	340.84
	08:30	13.47	22.29	1.2855	1.0223	340.84
	09:30	13.47	23.89	2.7419	1.6337	340.84
	10:30	13.47	24.91	2.8884	2.0642	340.84
	11:30	13.47	25.44	2.9617	2.0026	340.84
	12:30	13.47	25.03	1.9639	1.9944	340.84
	13:30	13.47	25.18	2.0371	2.2664	340.84
	14:30	13.47	26	2.8884	2.5483	340.84
	15:30	13.47	27.11	3.0349	3.8097	340.84
	16:30	13.47	27.58	2.9617	4.0239	340.84
	17:30	13.47	26.72	2.7419	2.5965	340.84
	18:30	13.47	25.22	2.6687	0.8423	340.84
	19:30	13.47	24.83	0.9843	0.0739	170.42
	20:30	13.47	24.39	0.8291	0	170.42
	21:30	13.47	24.1	0.8291	0	170.42
	22:30	13.47	23.6	0.4833	0	170.42
	23:30	13.47	23.23	0.3149	0	170.42

5.3 Scenario 3: 5 ACH for Certain Spaces without Reheat

Scenario 3 is an extension of Scenario 2 where the three areas identified in Scenario 2; the air being supplied is changed from 4 ACH to 5 ACH. These areas are 01_Open_Laboratary, 04_Open Laboratory and 11_Open_Laboratory.

5.3.1 Observation

Analysing the result in Table 6, the change to 5 ACH reduces the percentage of overheating hours in these three areas. In terms of the overcooling hours, the team concluded that a reheat component is needed in order to reduce the percentage of the overcooling hours to all the other areas.

Table 6: Temperature and Relative Humidty (RH) Tabulation for 5 ACH without Reheat

Location	Temperature (°C) – % hours in range			RH (%) – % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	87.2	12.8	0	0.2	80.3	19.5
L11_01_Dark Room	98.6	1.4	0	0.7	99.3	0
L11_01_Entry Vestibule	100	0	0	0	3.2	96.8
L11_01_Freezer	49	51	0	99.6	0.4	0
L11_01_Fume Hood	100	0	0	0	5.9	94.1
L11_01_Linear Equipment	93.4	6.6	0	0.1	99.7	0.2
L11_01_Mass Spec Lab Large	0.6	17.7	81.8	98.1	1.9	0
L11_01_Mass Spec Lab Small	14.4	56.8	28.8	75	25	0
L11_01_Open Laboratory	42	52.6	5.3	29.2	62.1	8.7
L11_01_Tissue Culture	100	0	0	0	80.3	19.7
L11_01_Virus Room	100	0	0	0	8.6	91.4
L11_02_Blood Processing Room	88.7	11.3	0	0.1	80.1	19.8
L11_02_Entry Vestibule	100	0	0	0	0.7	99.3
L11_02_Freezer	89.9	10.1	0	100	0	0
L11_02_Fume Hood	100	0	0	0	7.6	92.4
L11_02_Linear Equipment	100	0	0	0	93.7	6.3
L11_02_Mass Spec Lab Small	0	100	0	99.9	0.1	0
L11_02_Open Laboratory	45.8	53.1	1.1	6.6	86.2	7.1
L11_02_Tissue Culture	92.9	7.1	0	9.1	83.4	7.4
L11_02_Virus Room	100	0	0	0	2.6	97.4
L11_03_Entry Vestibule	100	0	0	0	0	100
L11_03_Freezer	43.9	56.1	0	99.6	0.4	0
L11_03_Open Laboratory	36.1	59.8	4.1	23.4	73.7	2.9
L11_04_Entry Vestibule	100	0	0	0	1.6	98.4
L11_04_Open Laboratory	66.7	32.3	1	5.5	83.2	11.3
L11_05_Open Laboratory	56.4	41.9	1.6	5.2	87.1	7.7
L11_06_Open Laboratory	68.8	30.4	0.8	4	89.9	6.1
L11_07_Open Laboratory	51.6	41.8	6.5	53	45.3	1.7
L11_08_Open Laboratory	69.6	30.4	0	3.4	96.6	0
L11_09_Open Laboratory	43.3	56.3	0.4	6	92.5	1.5
L11_10_Open Laboratory	26.9	68.8	4.3	15.1	84	0.9
L11_11_Open Laboratory	39.5	59.2	1.3	21.9	77	1.1
L11_12_Open Laboratory	65.8	34.1	0.1	0.9	85.9	13.3
L11_13_Open Laboratory	54.8	45.1	0.2	6.8	92.2	1

5.3.2 Discussion

The increase to 5 ACH in 01_Open_Laboratory shows some improvement in terms of space temperature. This can be seen by comparing Table 5 and **Error! Reference source not found.**. Previously with 4 ACH the hours of 1130 to 1830 shows that the space is overheating but with 5 ACH, the overheating only occurs during the hours of 1530 to 1730.

On the flipside, the increment to 5 ACH also increases the overcooled hours from 0730 – 0830 in Table 5 to 0730 – 0930 in **Error! Reference source not found.**. It is the same issues that happens in Scenario 1 where the supply air is more than what is required to extract the low sensible, latent and solar gain during the early hours of the occupancy period.

The next step in the process to reduce the overcooling hours are shown in the next section.

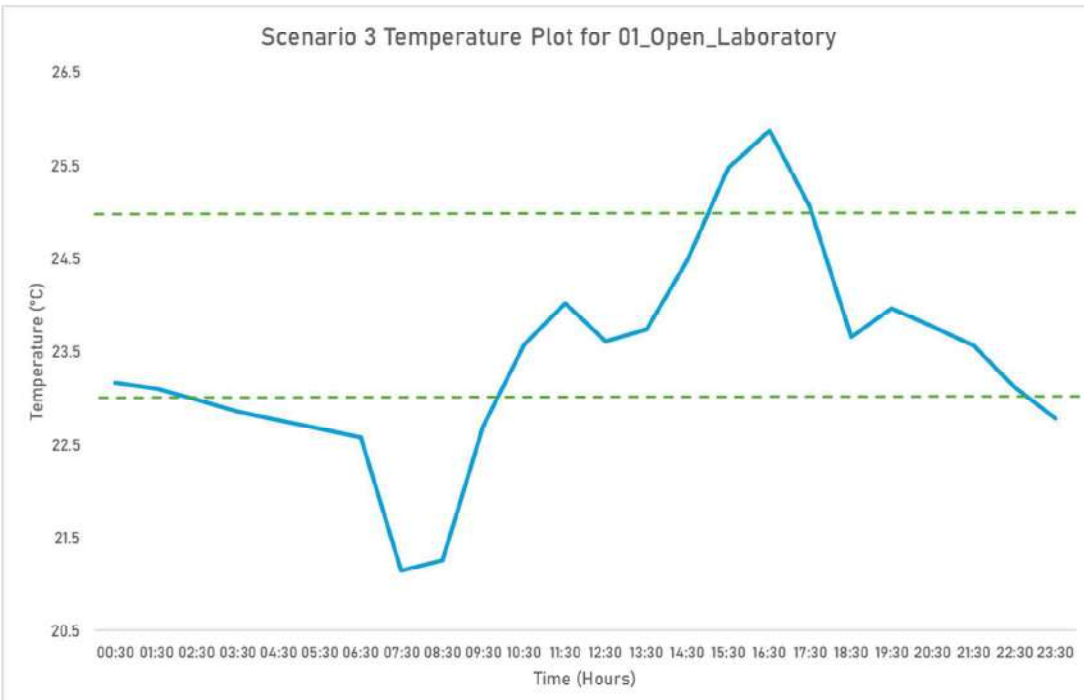

Figure 34: Scenario 2 Temperature Plot for 01_Laboratory for a Day in a Year (22nd April)

Table 7: Scenario 3 Space Conditions for 01_Open_Laboratory on 22nd April

Date	Time	Entering Supply Air Temperature (°C)	Space Air Temperature (°C)	Space Internal Gain (kW)	Space Solar Gain (kW)	Space Air Supply (l/s)
Tue, 22/Apr	00:30	13.47	23.17	0.2739	0	170.42
	01:30	13.47	23.1	0.3969	0	170.42
	02:30	13.47	22.98	0.3969	0	170.42
	03:30	13.47	22.85	0.3969	0	170.42
	04:30	13.47	22.76	0.3969	0	170.42
	05:30	13.47	22.67	0.3969	0	170.42
	06:30	13.47	22.58	0.3969	0	170.42
	07:30	13.47	21.15	1.2122	0.3929	426.04
	08:30	13.47	21.26	1.2855	1.0223	426.04
	09:30	13.47	22.69	2.7419	1.6337	426.04
	10:30	13.47	23.57	2.8884	2.0642	426.04
	11:30	13.47	24.02	2.9617	2.0026	426.04
	12:30	13.47	23.61	1.9639	1.9944	426.04
	13:30	13.47	23.74	2.0371	2.2664	426.04
	14:30	13.47	24.48	2.8884	2.5483	426.04
	15:30	13.47	25.48	3.0349	3.8097	426.04
	16:30	13.47	25.87	2.9617	4.0239	426.04
	17:30	13.47	25.05	2.7419	2.5965	426.04
	18:30	13.47	23.66	2.6687	0.8423	426.04
	19:30	13.47	23.96	0.9843	0.0739	170.42
	20:30	13.47	23.77	0.8291	0	170.42
	21:30	13.47	23.56	0.8291	0	170.42
	22:30	13.47	23.12	0.4833	0	170.42
	23:30	13.47	22.78	0.3149	0	170.42

5.4 Scenario 4: 5 ACH for Certain Spaces with Reheat

5.4.1 Observation

Scenario 4 is a scenario where it is a combination of the conclusion from Scenario 2 and Scenario 3. In Scenario 4, the reheat component is now being turned on in order to control the overcooling percentage hours in all the areas.

Table 8: Temperature and Relative Humidty (RH) Tabulation for 5 ACH with Reheat

Location	Temperature (°C) - % hours in range			RH (%) - % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	0	100	0	12.6	87.4	0
L11_01_Dark Room	0	100	0	100	0	0
L11_01_Entry Vestibule	1.1	98.9	0	100	0	0
L11_01_Freezer	0	91.6	8.4	100	0	0
L11_01_Fume Hood	83.9	16.1	0	28.5	71.5	0
L11_01_Linear Equipment	0	100	0	36.8	63.2	0
L11_01_Mass Spec Lab Large	0	0	100	100	0	0
L11_01_Mass Spec Lab Small	0	0	100	100	0	0
L11_01_Open Laboratory	0	86.9	13.1	59.5	40.5	0
L11_01_Tissue Culture	8	92	0	97	3	0
L11_01_Virus Room	81.9	18.1	0	26.4	73.6	0
L11_02_Blood Processing Room	0	100	0	6.3	93.7	0
L11_02_Entry Vestibule	3.5	96.5	0	100	0	0
L11_02_Freezer	0	88.2	11.8	100	0	0
L11_02_Fume Hood	81.2	18.8	0	34.6	65.4	0
L11_02_Linear Equipment	0	100	0	99.1	0.9	0
L11_02_Mass Spec Lab Small	0	98.2	1.8	99.8	0.2	0
L11_02_Open Laboratory	0	93.8	6.2	29.6	70.4	0
L11_02_Tissue Culture	0	100	0	100	0	0
L11_02_Virus Room	90.2	9.8	0	13.8	86.2	0
L11_03_Entry Vestibule	2.3	97.7	0	100	0	0
L11_03_Freezer	0	90.9	9.1	100	0	0
L11_03_Open Laboratory	0	84.1	15.9	62.6	37.4	0
L11_04_Entry Vestibule	0	100	0	100	0	0
L11_04_Open Laboratory	0	96.3	3.7	26.9	73.1	0
L11_05_Open Laboratory	0	94.9	5.1	20.7	79.3	0
L11_06_Open Laboratory	0	97.3	2.7	22.6	77.4	0
L11_07_Open Laboratory	0	85.1	14.9	100	0	0
L11_08_Open Laboratory	0	100	0	55.4	44.6	0
L11_09_Open Laboratory	0	95.8	4.2	28.8	71.2	0
L11_10_Open Laboratory	0	76.7	23.3	61.1	38.9	0
L11_11_Open Laboratory	0	93.8	6.2	60.1	39.9	0
L11_12_Open Laboratory	0	99.3	0.7	11.8	88.2	0
L11_13_Open Laboratory	0	97.3	2.7	37.3	62.7	0

Table 8 shows the result for Scenario 4. The main takeaway from this scenario is that, with the reheat turned on, it is shown that all the areas are no longer showing any major overcooling indication except for a few special areas which will be discuss further below. This proves that the reheat component is still needed in order to control the temperature and RH in all the areas. An analysis of Table 8 further reveals a few special areas mentioned earlier, namely the Fume Hood room and the Virus room, where overcooling still occurs even with 5 ACH. The team found that with lower ACH, it will deviate more towards overheating and with a higher ACH, it will lead to overcooling.

5.4.2 Discussion

The three areas that are identified earlier in Scenario 3, are now showing sign of not being overcooled anymore. For the area 01_Open_Laboratory, the percentage of hours that it is in the range of more than 25°C is more than 10%. In order to analyse more about this situation, the team looks into the area and plot the temperature for a day in a year.

Figure 35 shows the temperature plot for a day in a year for 01_Open_Laboratory. Majority of the time, it falls within the desired temperature range of 23°C to 25°C except during the hours of 1530 to 1730 in the afternoon.

This is due to the solar heat gain, as from the hours of 1530 to 1730 the sun is on the Western side of the building as shown in Figure 36. The solar heat gain can be seen in Table *9* highlighted in red.

This phenomenon can be mitigated with a variable air volume system where the air can be supplied at just the right temperature to compensate for the spike in space temperature.

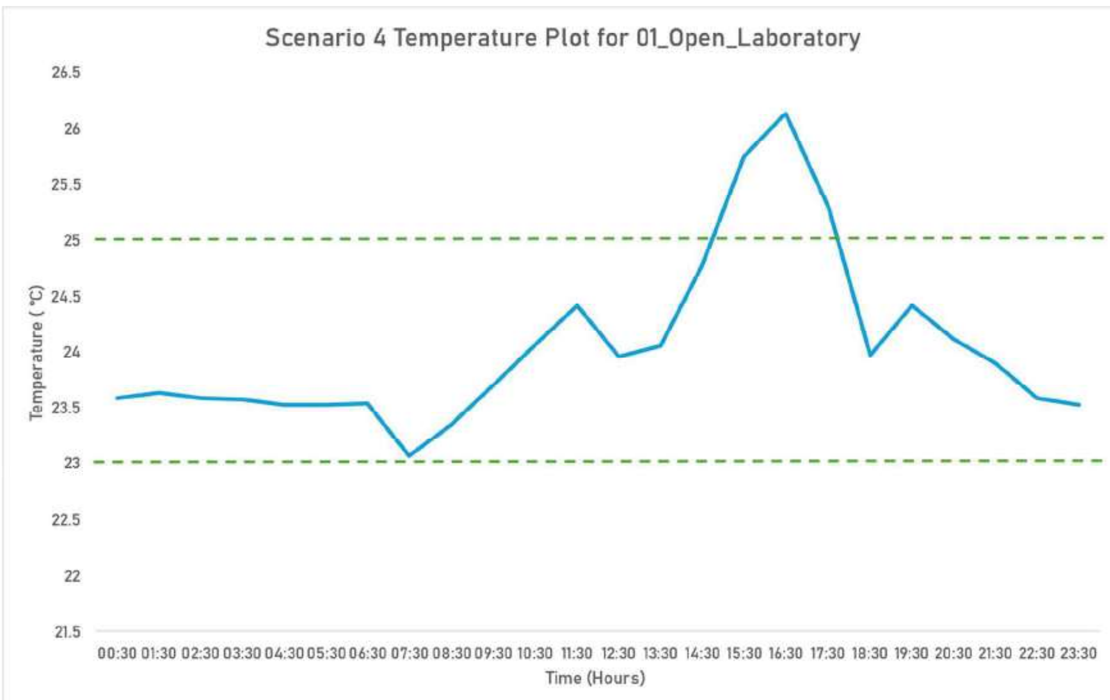

Figure 35: Scenario 4 Temperature Plot for 01_Laboratory for a Day in a Year (22nd April)

Table 9: Scenario 4 Space Conditions for 01_Open_Laboratory on 22nd April

Date	Time	Entering Supply Air Temperature (°C)	Space Air Temperature (°C)	Space Internal Gain (kW)	Space Solar Gain (kW)	Space Air Supply (l/s)
Tue, 22/Apr	00:30	13.92	23.58	0.2739	0	170.42
	01:30	14.38	23.63	0.3969	0	170.42
	02:30	14.83	23.58	0.3969	0	170.42
	03:30	14.83	23.57	0.3969	0	170.42
	04:30	15.28	23.53	0.3969	0	170.42
	05:30	15.28	23.52	0.3969	0	170.42
	06:30	15.74	23.54	0.3969	0	170.42
	07:30	17.55	23.07	1.2122	0.3929	426.04
	08:30	17.09	23.35	1.2855	1.0223	426.04
	09:30	13.92	23.7	2.7419	1.6337	426.04
	10:30	13.47	24.07	2.8884	2.0642	426.04
	11:30	13.47	24.42	2.9617	2.0026	426.04
	12:30	13.47	23.96	1.9639	1.9944	426.04
	13:30	13.47	24.06	2.0371	2.2664	426.04
	14:30	13.47	24.77	2.8884	2.5483	426.04
	15:30	13.47	25.75	3.0349	3.8097	426.04
	16:30	13.47	26.13	2.9617	4.0239	426.04
	17:30	13.47	25.29	2.7419	2.5965	426.04
	18:30	13.92	23.97	2.6687	0.8423	426.04
	19:30	13.47	24.42	0.9843	0.0739	170.42
	20:30	13.47	24.11	0.8291	0	170.42
	21:30	13.47	23.9	0.8291	0	170.42
	22:30	14.38	23.59	0.4833	0	170.42
	23:30	15.28	23.52	0.3149	0	170.42

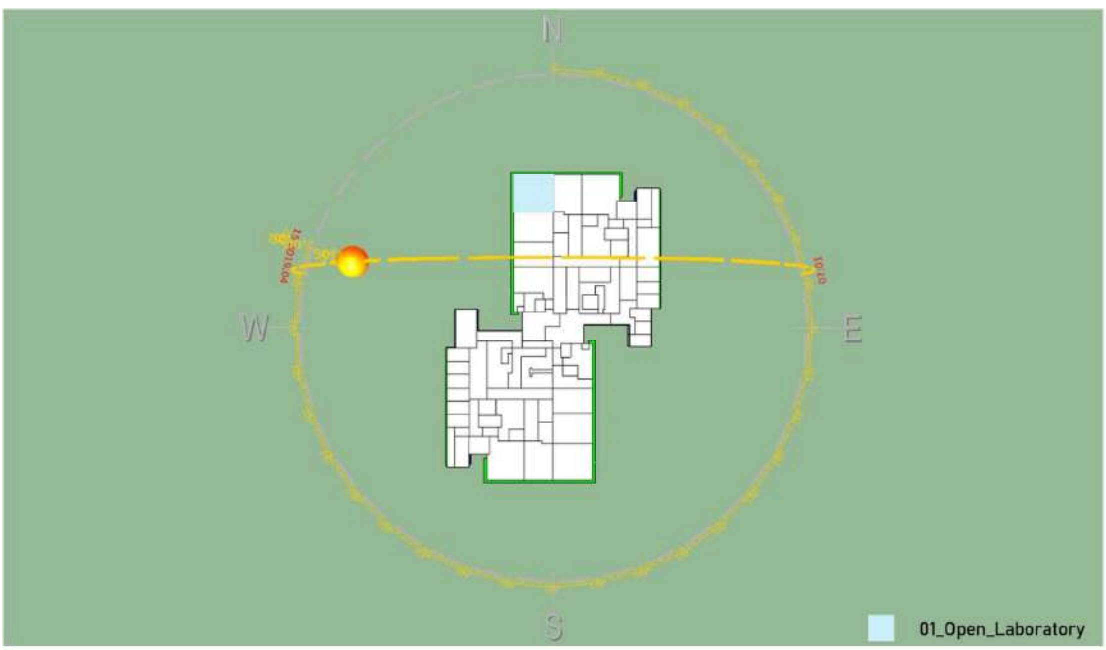

Figure 36: The sun location for 01_Open_Loboratory on 22nd April at 1530 hours

As mentioned in Section 5.3, only 01_Open_Laboratary, 04_Open Laboratory and 11_Open_Laboratory areas that are changed to 5 ACH from 4 ACH. As for the other areas, it remains at 4 ACH. The supplied air weighted average is 4.17 ACH.

5.5 Energy Savings Potential with 5 ACH for Certain Spaces with Reheat

Table 10 shows the percentage hours that the reheat component is turned on for Scenario 1 and Scenario 4. Comparing Scenario 1 and Scenario 4, it is apparent that there are some savings in certain areas. As an example, the reheat components for 03_Open_Laboratory area needs to be on continuously but achieving the desired temperature range only 66% of the time as shown in Table 2. Comparing it with Scenario 4 where the reheat components need to be turn on only 34% of the time but achieving a far better desired temperature range 84% of the time as shown in Table 6. All in all, it amounted to 70% savings in terms of reheat energy for 03_Open_Laboratory area.

Table 10: 8 ACH and 5 ACH Reheat Perecentage Hours On Tabulation

Location	8 ACH with Reheat - % hours ON	5 ACH Reheat - % hours ON
L11_01_Blood Processing Room	100	50.9
L11_01_Dark Room	100	98.3
L11_01_Entry Vestibule	100	100
L11_01_Freezer	58.1	82.9
L11_01_Fume Hood	100	100
L11_01_Linear Equipment	100	88.2
L11_01_Mass Spec Lab Large	7.5	0
L11_01_Mass Spec Lab Small	0	0
L11_01_Open Laboratory	98.5	43.7
L11_01_Tissue Culture	100	100
L11_01_Virus Room	100	100
L11_02_Blood Processing Room	100	58.8
L11_02_Entry Vestibule	100	100
L11_02_Freezer	18.4	0
L11_02_Fume Hood	100	100
L11_02_Linear Equipment	100	100
L11_02_Mass Spec Lab Small	93.7	100
L11_02_Open Laboratory	100	33.8
L11_02_Tissue Culture	100	88.9
L11_02_Virus Room	100	100
L11_03_Entry Vestibule	100	100
L11_03_Freezer	64	0
L11_03_Open Laboratory	100	33.1
L11_04_Entry Vestibule	100	100
L11_04_Open Laboratory	99.3	57.2
L11_05_Open Laboratory	99.9	46.6
L11_06_Open Laboratory	100	53.3
L11_07_Open Laboratory	98.2	48.5
L11_08_Open Laboratory	100	39.1
L11_09_Open Laboratory	100	34
L11_10_Open Laboratory	99.7	20.4
L11_11_Open Laboratory	98.9	41.5
L11_12_Open Laboratory	100	49
L11_13_Open Laboratory	100	40.7

5.6 Minimise Dehumidification and Reheat Energy

As part of the energy optimisation simulation exercise, methods to reduce reliance on the reheat coils have been reviewed. A passive wrap around heat pipe coil provides the best approach of introducing reheat downstream of the cooling without the need for an external power source.

A heat pipe is a device that efficiently transfers heat from a hot area to a cooler area using a phase change process. It consists of a sealed metal tube containing a small amount of working fluid, usually a liquid with a low boiling point like water or ammonia.

Heat pipes can improve energy efficiency by recovering waste heat from exhaust air and transferring it to pre-cool or pre-heat incoming fresh air. This reduces the load on cooling and heating equipment, leading to a lower energy consumption.

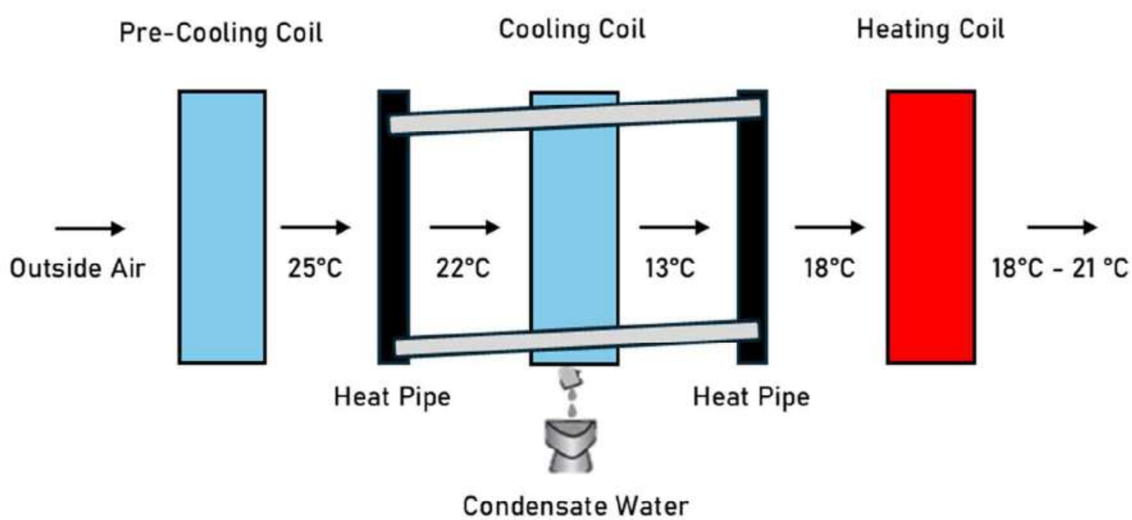

Figure 37: Heat Pipe Schematic Diagram

Figure 37 shows the assumption made for the heat pipes scenario. In theory the heat pipes are ideal for this type of scenario. However, in practice, they may not perform as well due to the need to install them within the AHU, where space constraints in the existing AHU room could pose a challenge.

Furthermore, due to the location of the heat pipes where it is located centrally in the AHU, it becomes difficult to maintain the space conditions in individual laboratory closely resulting in all the laboratory areas overheating as shown in Table 11.

Table 11: Temperature and RH Tabulation for 5 ACH with Reheat and Heat Pipes

Location	Temperature (°C) - % hours in range			RH (%) - % hours in range		
	<= 23	>23 to <=25	> 25	<= 55	>55 to <=65	> 65
L11_01_Blood Processing Room	0	27.7	72.3	100	0	0
L11_01_Dark Room	0	79.2	20.8	100	0	0
L11_01_Entry Vestibule	0	100	0	100	0	0
L11_01_Freezer	0	77.7	22.3	100	0	0
L11_01_Fume Hood	0	100	0	100	0	0
L11_01_Linear Equipment	0	75.6	24.4	99.2	0.8	0
L11_01_Mass Spec Lab Large	0	0	100	100	0	0
L11_01_Mass Spec Lab Small	0	0	100	100	0	0
L11_01_Open Laboratory	0	15.4	84.6	100	0	0
L11_01_Tissue Culture	0	64.2	35.8	100	0	0
L11_01_Virus Room	0	100	0	100	0	0
L11_02_Blood Processing Room	0	30.5	69.5	100	0	0
L11_02_Entry Vestibule	0	100	0	100	0	0
L11_02_Freezer	0	69.9	30.1	100	0	0
L11_02_Fume Hood	0	100	0	100	0	0
L11_02_Linear Equipment	0	100	0	100	0	0
L11_02_Mass Spec Lab Small	0	100	0	99.9	0.1	0
L11_02_Open Laboratory	0	13.1	86.9	100	0	0
L11_02_Tissue Culture	0	29.3	70.7	100	0	0
L11_02_Virus Room	0	100	0	100	0	0
L11_03_Entry Vestibule	0	100	0	100	0	0
L11_03_Freezer	0	78	22	99.9	0.1	0
L11_03_Open Laboratory	0	11.8	88.2	100	0	0
L11_04_Entry Vestibule	0	100	0	100	0	0
L11_04_Open Laboratory	0	15.6	84.4	100	0	0
L11_05_Open Laboratory	0	14.7	85.3	100	0	0
L11_06_Open Laboratory	0	16.9	83.1	100	0	0
L11_07_Open Laboratory	0	30	70	100	0	0
L11_08_Open Laboratory	0	17.5	82.5	100	0	0
L11_09_Open Laboratory	0	12.2	87.8	100	0	0
L11_10_Open Laboratory	0	7.2	92.8	100	0	0
L11_11_Open Laboratory	0	10.2	89.8	100	0	0
L11_12_Open Laboratory	0	15.5	84.5	100	0	0
L11_13_Open Laboratory	0	12.5	87.5	100	0	0

6 Conclusion

Of the scenarios simulated, Scenario 4 presents the most desirable outcome for indoor temperature and humidity.

Based on this, three key conclusions can be made:

1. **A lower, constant volume ACH is feasible** but not at the initially proposed 4 ACH. A further optimised airflow rate places the weighted average ACH that maintains space temperature set point and humidity at peak load conditions at 4.17 ACH. During the detailed design process, the lower minimum of each of the space can be assessed to set the lowest possible ACH permitted by the code but still satisfy the cooling load. In addition to this, a Facility Air Quality Monitoring system shall monitor the labs and exhaust air streams and increase the ACH when air quality events occur.
2. **Reheat coils are necessary for humidity control.** In the scenarios that have been simulated, the cases without reheat coils all observed zones experiencing high humidity. Any consideration of system retrofit of should consider this.
3. **Reheat coils are necessary for temperature control.** While SS 641 allows for lower ACH for labs, this is limited to a fixed rate of 4 ACH during occupied hours. As such, the reheat coil system in this case would be necessary to modulate supply air temperature in response to dynamic loads within the space.

With the introduction of the heat pipe, the results yielded spaces overheating due to the higher supply air temperature that the reheat coils encounter on the inlet. Because the reheat coil system cannot be eliminated as shown in the results of Scenario 4, a heat pipe would not be recommended in conjunction with the existing HRU infrastructure.

With the implementation of the Aircuity system, the energy savings associated to reducing the lab exhaust from 8 ACH to an average of 4.17 ACH is as follows:

Table 12: Facility Monitoring System Energy Savings

	Baseline (8 ACH)	Proposed (4.17 ACH)	Percentage Reduction
L11 Lab ACMV Single Pass System Annual Energy Consumption (kWh)	1,182,189	654,466	44.6%

The savings above include chilled water, fan power, and reheat system energy savings.

It is recommended that the following activities are carried out before any retrofit work is undertaken at the facility:

1. Re-balancing of all airside systems to design airflows
2. Re-commissioning of all HRUs and reheat coil system
3. Re-balancing of chilled water distribution system.

7 Costing

This section outlines the estimated costs associated with the project.

7.1 Scope of Costing

The objective of the exercise is to get an understanding of the Rough Order of Magnitude (ROM) costs associated to the **Facility Air Quality Monitoring System (System 1)** and the **Demand Controlled Exhaust System (System 2).** As the two systems can be installed and operate independently of one another, the costing has been separated between System 1 and System 2.

ROM costing has been provided by Aircuity along with system schematics outlining a high level scope of the project. During the costing exercise, it was found that the installation of System 1 for the entirety of Level 11 was cost prohibitive, so the scope was reduced to represent installation of the North Core only.

Facility Air Monitoring System (System 1) Scope

- Complete and operational Aircuity system
- Replacement of re-heat valves for Phoenix Controls
- Electrical contractor installation of all Aircuity equipment, structured cable, and components
- Mechanical contractor installation of re-heat valves (assumes 1 for 1 replacement, no piping, unions and drains)
- System startup and commissioning
- Airflow reset and integration with the BMS for laboratory demand control ventilation
- Testing and balancing for all the VAVs / terminals units impacted by the project
- Engineering
- Project Management
- Web-based analytics and performance platform.
- Assurance Service – beginning with startup and ending 12 months after project completion

Demand Controlled Exhaust System (System 2) Scope

- Install the Aircuity IAQ platform to measure TVOCs in the EF riser or plenum for 16 Lab Exhaust Fans (listed below)
- Develop and implement new EF sequence.
- Enable dynamic EF control – modulating EF speed and discharge velocity based on Aircuity TVOC readings.
- Integrate into existing BMS
- Commission system

7.2 Costing Summary

Below is a breakdown of the ROM costing associated to System 1 and System 2:

Facility Air Monitoring System (System 1) Scope

- Budgetary Project Cost $459,000 (SGD)
- Annual Energy Savings $76,734
- Simple Payback 5.6 Years

Demand Controlled Exhaust System (System 2) Scope

- Budgetary Project Cost $299,747 (SGD)
- Annual Energy Savings $245,509
- Simple Payback 1.3 Years

A breakdown of the budgetary proposals, scope, and exclusions may be found in Appendix E – Aircuity Budgetary Pricing.

8 Appendices

8.1 Appendix A – Lighting Power Budget (LPB)

S/N	Zone Name	Area (m2)	Light Fitting Type	Power Consumption per fitting including Driver/Ballast Loss (W)	No. of Fittings	Total Power Consumption based on fitting type (W) (C x E)	Current Lighting Power Budget (W/m2)	Improved LPB (40% reduction from Current)
		(A)	(B)	(C)	(E)	(F)	(F/A)	(W/m2)
1	L11_01_Open Laboratory	82.1	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	30	1350	16.64	9.98
			16W LED Down Light	16	1	16		
2	L11_02_Open Laboratory	61.3	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	20	900	16.51	9.91
			16W LED Down Light	16	7	112		
3	L11_03_Open Laboratory	82.8	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	25	1125	15.52	9.31
			16W LED Down Light	16	10	160		
4	L11_04_Open Laboratory	68.2	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	20	900	15.31	9.18
			16W LED Down Light	16	9	144		
5	L11_05_Open Laboratory	53.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	20	900	18.65	11.19
			16W LED Down Light	16	6	96		
6	L11_06_Open Laboratory	62.3	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	19	855	14.75	8.85
			16W LED Down Light	16	4	64		
7	L11_07_Open Laboratory	9.1	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	2	90	16.92	10.15

			16W LED Down Light	16	4	64		
8	L11_08_Open Laboratory	31.3	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	7	315	11.60	6.96
			16W LED Down Light	16	3	48		
9	L11_09_Open Laboratory	55.6	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	20	900	17.91	10.75
			16W LED Down Light	16	6	96		
10	L11_10_Open Laboratory	68.2	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	20	900	15.31	9.18
			16W LED Down Light	16	9	144		
11	L11_11_Open Laboratory	82.1	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	30	1350	16.64	9.98
			16W LED Down Light	16	1	16		
12	L11_12_Open Laboratory	61.3	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	20	900	16.51	9.91
			16W LED Down Light	16	7	112		
13	L11_13_Open Laboratory	82.7	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	25	1125	15.54	9.32
			16W LED Down Light	16	10	160		
14	L11_01_Fume Hood	16.8	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	3	135	8.04	4.82
15	L11_02_Fume Hood	16.8	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	3	135	8.04	4.82
16	L11_01_Cold Room	18.6	N.A.					
17	L11_02_Cold Room	18.6	N.A.					
18	L11_01_Freezer	31.3	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	6	270	8.63	5.18

19	L11_02_Freezer	38.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	9	405	10.55	6.33
20	L11_03_Freezer	31.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	6	270	8.60	5.16
21	L11_01_Bacterial/Yeast (Blood Processing Room)	9.8	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	18.37	11.02
22	L11_02_Bacterial/Yeast (Blood Processing Room)	9.7	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	18.56	11.13
23	L11_01_Tissue Culture	49.7	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	20	900	18.11	10.87
24	L11_02_Tissue Culture	49.8	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	20	900	18.07	10.84
25	L11_01_Virus Room	16.5	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	3	135	8.18	4.91
26	L11_02_Virus Room	16.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	3	135	8.23	4.94
27	L11_01_FACS (Mass Spec Lab Small)	15.7	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	6	270	17.20	10.32
28	L11_02_FACS (Mass Spec Lab Small)	15.7	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	6	270	17.20	10.32
29	L1_01_Entry Vestibule	7.6	16W LED Down Light	16	2	32	4.21	2.53
30	L1_02_Entry Vestibule	4.9	16W LED Down Light	16	2	32	6.53	3.92
31	L1_03_Entry Vestibule	8.8	16W LED Down Light	16	2	32	3.64	2.18
32	L1_04_Entry Vestibule	7.6	16W LED Down Light	16	2	32	4.21	2.53
33	L11_01_AHU Room	19.6			2	0	0.00	5.00
34	L11_02_AHU Room	20			2	0	0.00	5.00

35	L11_01_Staircase	25.7	1x54W T5 Ceiling &Ground Recessed Rectangular Linear Luminaire?	54	2	108	4.20	2.52
36	L11_02_Staircase	27.8	1x54W T5 Ceiling &Ground Recessed Rectangular Linear Luminaire?	54	2	108	3.88	2.33
37	L11_03_Staircase	24.6	1x54W T5 Ceiling &Ground Recessed Rectangular Linear Luminaire?	54	2	108	4.39	2.63
38	L11_01_Smoke Stop Lobby	7.2		52	1	52	7.22	4.33
39	L11_02_Smoke Stop Lobby	7.4	2A - 2x26W PLC Recessed Fluorescent Downlight	52	1	52	7.03	4.22
#	L11_01_Corridor Office	31	2A - 2x26W PLC Recessed Fluorescent Downlight	52	5	260	31.48	18.89
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	10	520		
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	7	196		
#	L11_02_Corridor Office	50.9	2A - 2x26W PLC Recessed Fluorescent Downlight	52	10	520	27.98	16.79
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	12	624		
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	10	280		
42	L11_01_Corridor	28.4	2A - 2x26W PLC Recessed Fluorescent Downlight	52	9	468	16.48	9.89

#	L11_02_Corridor	27.7	2A - 2x26W PLC Recessed Fluorescent Downlight	52	8	416	24.84	14.90
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	6	168		
#	L11_03_Corridor	30.7	2A - 2x26W PLC Recessed Fluorescent Downlight	52	6	312	16.55	9.93
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	7	196		
45	L11_04_Corridor	18.6	2A - 2x26W PLC Recessed Fluorescent Downlight	52	5	260	13.98	8.39
#	L11_01_Mass Spec Lab Large	49.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	15	675	19.98	11.99
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	6	312		
#	L11_01_Linear Equipment Area	37.5	16W LED Down Light	16	9	144	3.84	2.30
#	L11_02_Linear Equipment Area	41.1	16W LED Down Light	16	9	144	3.50	2.10
49	L11_01_Store	14	D2 - 2x26W PLC Recessed Fluorescent Downlight	52	3	156	11.14	6.69
#	L11_02_Store	17.1	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.61	9.96
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		

51	L11_01_Fire Fighting Lobby	29	F7A - 1x28W T5 Recessed Trimless Luminaire	28	16	448	15.45	9.27
52	L11_01_Wire Centre	12	W1 - 2x28W T5 Weatherproo f Wall-mounted Fluorescent	56	2	112	9.33	5.60
53	L11_01_MEP Riser	11.3	2x28W T5 Wall mounted fluorescent fitting	56	2	112	9.91	5.95
54	L11_02_MEP Riser	7.5	2x28W T5 Wall mounted fluorescent fitting	56	2	112	14.93	8.96
55	L11_01_Offic e	18.8	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	15.11	9.06
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
56	L11_02_Offic e	17	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.71	10.02
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
57	L11_03_Offic e	17.4	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.32	9.79
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
58	L11_04_Offic e	14.3	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	3	135	16.71	10.03
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
59	L11_05_Offic e	11.4	F5 (LED)-2x22.5W LED Ceiling	45	2	90	17.02	10.21

			Recess Mounted					
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
60	L11_06_Office	14.2	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	20.00	12.00
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
61	L11_07_Office	17.1	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.61	9.96
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
62	L11_08_Office	17.7	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.05	9.63
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
63	L11_09_Office	16.6	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	17.11	10.27
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
64	L11_10_Office	17.1	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.61	9.96
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
65	L11_11_Office	16.8	F5 (LED)-2x22.5W LED Ceiling Recess Mounted	45	4	180	16.90	10.14

			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	2	104		
66	L11_01_Lobby/Lounge	50.9	F4A - 1x28W T5 Recessed Trimless Luminaire	28	9	252	9.35	5.61
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	8	224		
67	L11_02_Lobby/Lounge	74.7	F4A - 1x28W T5 Recessed Trimless Luminaire	28	9	252	11.73	7.04
			F7A - 1x28W T5 Recessed Trimless Luminaire	28	13	364		
			2A - 2x26W PLC Recessed Fluorescent Downlight	52	5	260		
68	L11_01_Meeting Room	45.4	F5 (LED)- 2x22.5W LED Ceiling Recess Mounted	45	12	540	25.64	15.38
			2A - 2x26W PLC Recessed Fluorescent Downlight	52	12	624		
69	L11_01_Service Lift Lobby	35.5	2A - 2x26W PLC Recessed Fluorescent Downlight	52	10	520	14.65	8.79
70	L11_01_Toilet	53.6	D1- 2x18W PLC Recessed Compact Fluorescent Downlight	36	16	576	11.72	7.03
			D2 - 2x26W PLC Recessed Fluorescent Downlight	52	1	52		
71	L11_01_Dark Room	8.9	D2 - 2x26W PLC Recessed Fluorescent Downlight	52	1	52	5.84	3.51

8.2 Appendix B – Lab Equipment Asset List

Description	Equipment Type	Watts per unit	Reference sourced from	Section/ Room Desc
Lenovo ThinkPad P15v G3	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02L
HIGH CONTENT CELL ANALYSIS SYSTEM	Analyzer	44	ASHRAE Fundamentals Handbook - Table 7 Electrochemical analyzer	11TH NORTH HCS ROOM
THERMO SCIENTIFIC SORVALL ST4R PLUS, 240V BENCHTOP	Centrifuge	350	50158527-g-Sorvall X Pro-ST Plus-en.pdf (thermofisher.com)	11TH NORTH HCS ROOM
STERI-CYCLE INCUBATOR HEPA FILTERED CO2 T/C 230V	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH HCS ROOM
SORVALL LEGEND MICRO 21R MICROCENTRIFUGE	Microcentrifuge	300	Sorvall Legend Micro 21R - Thermo Scientific Sorvall Legend Micro Series Instruction Manual [Page 17] | ManualsLib	11TH NORTH HIGH CONTENT SCREENING (HCS) ROOM
COUNTLESS III INSTRUMENT (AMQAX2000)	Automated cell counter	0	(Low Impact)	11TH NORTH HIGH CONTENT SCREENING (HCS) ROOM
Integra VIAFILL Dispenser	Reagent dispenser	0	(Low Impact)	MD6, 11N, HCS Room
OLYMPUS INVERTED MICROSCOPE: CKX53		0	(Low Impact)	MD6, 11TH NORTH HIGH CONTENT SCREENING (HCS) ROOM
13 inch MacBook Pro - Space Grey with an upgrade	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, Level 11N, Bioinformatics area
GELMAN BIOESSENTIAL CLASS II TYPE A2 BIOLOGICAL	Fumehood	0	(Low Impact)	MD6, LEVEL 11TH NORTH HCS ROOM
MACBOOK PRO 13# RETINA DISPLAY 3.0GZ	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 NORTH BENCH 11
CHEF MAPPER XA CHILLER SYSTEM		0	(Low Impact)	11TH 11-01N BENCH 11

CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH TISSUE CULTURE ROOM
DELL POWEREDGE R430 SERVER	CPU	450	Dell R430 Tech Specs | PowerEdge R430 | SaveMyServer	11TH SOUTH PC ROOM
DELL STORAGE MD1400 12 HDS RACKMOUNT		0	(Low Impact)	11TH SOUTH PC ROOM
DELL LATITUDE E5450	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
MACBOOK PRO 13INCH RETINA DISPLAY 2.7OGZ (MF840)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
MACBOOK PRO 13INCH RETINA DISPLAY 2.7OGZ (MF840)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
MACBOOK PRO 13 (MPXW2)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
MACBOOK PRO 13 INCH	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
LENOVO THINKPAD X230T	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11-02J
LENOVO THINKPAD X260	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11-02J
Notebook ThinkPad X1 Carbon G11 21HNCT01	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11-02J
FUJITSU LIFEBOOK S936 (NON-TOUCH DISPLAY TOUCH AS	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH
THERMO FORMA WATER JACKETED CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH SOUTH - TISSUE CULTURE ROOM
THERMO FORMA WATER JACKETED CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH SOUTH - TISSUE CULTURE ROOM
SANYO MEDICAL FREEZER -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH SOUTH BENCH 1
SANYO BIOMEDICAL FREEZER MODEL: MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH SOUTH BENCH 1
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 1A

T100 THERMAL CYCLER	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	11TH SOUTH BENCH 22B
ENVISION MULTILABEL READER		0	(Low Impact)	11TH SOUTH BENCH 22B
ENVISION MULTILABEL READER		0	(Low Impact)	11TH SOUTH BENCH 22B
BODIPY TMR FP D555 SINGLE MIRROR		0	(Low Impact)	11TH SOUTH BENCH 22B
REFRIGERATED CENTRIFUDGE 5424R	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH BENCH 23A
EPPENDORF CENTRIFUGE 5424R	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH BENCH 24A
SANYO MDF U5312 BIOMEDICAL FREEZER -20	Freezer (-20)	205	Performance - Phcbi MDF-U5312 Operating Instructions Manual [Page 30] | ManualsLib	11TH SOUTH BENCH 2B
PHILIPP KIRSCH REFRIGERATOR (SPECIAL-468) 4DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 3A
PHILIPP KIRSCH REFRIGERATOR (SPECIAL-468) 4 DEGREE	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 6A
UPRIGHT ULTRA LOW TEMPERATURE FREEZER			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
UPRIGHT ULTRA LOW TEMPERATURE FREEZER			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
THERMO SCIENTIFIC(FORMA) STERI-CYCLE CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH SOUTH TISSUE CULTURE ROOM
CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH SOUTH TISSUE CULTURE ROOM
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH,

				Bench 22B
13 inch MACBOOK PRO (MPXW2)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH, Bench 22B
TOSHIBA TECRO Z40 (SSD)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH, Bench 23B
HP EliteBook x360 1040 G8	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	L11-02
Supermicro SuperWorkstation 5039A-i	CPU	155	5039A-i | SuperWorkstation | Products | Super Micro Computer, Inc.	MD6 Level 11 – Bioinformatics Core Facility
Supermicro SuperWorkstation	CPU	155	5039A-i | SuperWorkstation | Products | Super Micro Computer, Inc.	MD6 Level 11 – Bioinformatics Core Facility
IMAC 21.5	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02H
MacBook Air 13.6 MDN/10C GPU, M2 CHIP WITH 8C CPU	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
LENOVO THINKPAD T470S	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 South Bench 25A
LENOVO THINKPAD T470S	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
TOSHIBA PORTEGE Z30	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
V520636SG - DELL VOSTRO 3360	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 North Bench 6A
LeicaBiosystems AXL 230-240V/50-60 Hz	Autostainer	0	(Low Impact)	11 South Histology room
FUJITSU LIFEBOOK U938	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11S Bench 21A
THERMO FORMA STERI-CYCLE CO2 INCUBATOR MODEL: 371	CO2 Incubator	451		11TH NORTH - TISSUE CULTURE ROOM
GFL SHAKER	Orbital Shaker	16	ASHRAE Fundamentals Handbook - Table 7 Orbital Shaker	11TH NORTH - BENCH 2
MYCYCLER WITH GRADIENT UPGRADE	Thermal Cycler	200	Appendix A Specifications - BIO RAD MyCycler Instruction Manual [Page 41] | ManualsLib	11TH NORTH - BENCH 5
THERMO SCIENTIFIC (FORMA) ULTRALOW TEMP FREEZER			(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH - FREEZER ROOM

THERMO FORMA STERI-CYCLE CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
SANYO MEDICAL FREEZER (MDF U537) -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 1
SANYO BIOMEDICAL FREEZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 1
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH BENCH 1
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH BENCH 1
LAB REFRIGERATOR 460 LITRES 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH BENCH 13B
FLOOR STANDING REFRIGERATED CENTRIFUGE	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH NORTH BENCH 13B
SANYO BIOMEDICAL FREEZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 2
SANYO MDF U5312 BIOMEDICAL FREEZER -20	Freezer (-20)	205	Performance - Phcbi MDF-U5312 Operating Instructions Manual [Page 30] | ManualsLib	11TH NORTH BENCH 2
AUTOMATED CELL COUNTER		0	(Low Impact)	11TH NORTH BENCH 2
LENOVO THINKPAD X13	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH NORTH BENCH 3
UPGRADE OF OLYMPUS BX43		0	(Low Impact)	11TH NORTH BENCH 5

HIGH SPEED REFRIGERATED MICROCENTRIFUGE (MX305)	Microcentrifuge	300	Sorvall Legend Micro 21R - Thermo Scientific Sorvall Legend Micro Series Instruction Manual [Page 17] | ManualsLib	11TH NORTH BENCH 5A
LAB REFRIGERATOR MODEL:SPEZIAL -468 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH BENCH 6A
MEDICAL FRIDGE UPRIGHT 4 DEGREES	Refrigerator	59.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH BENCH 6A
SANYO BIOMEDICAL FREEZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 6A
THE BELLY DANCER SHAKER LABORATORY	Orbital Shaker	16	ASHRAE Fundamentals Handbook - Table 7 Orbital Shaker	11TH NORTH COLD ROOM
UPRIGHT ULTRA LOW FREEZER (-80 DEGREES)	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
-85 FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
Advanced Cell Diagnostics hybez hybridization	Hybridization system	155	Biotechne ACD HybEZ II User Manual (Page 18 of 30) | ManualsLib	11TH SOUTH BENCH 20B
-80 UPRIGHT FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
FUJITSU LIFEBOOK S937	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 North, bench no 10
HP EliteBook 640G9	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6 11 North Bench 2
Lenovo Thinkpad X13 Gen 2, 13.3" Intel Core i7-118	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, 11 North, Bench 1
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, 11 North, Bench 1A
FUJITSU LIFEBOOK U938	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, 11 North, Bench 1A
FUJITSU LIFEBOOK S937	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, 11 North, Bench 1B
Lenovo Thinkpad X13 Gen 2, 13.3" Intel Core i7-118	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6, 11 North, Bench 1B
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02G (With

				Wang Ling Zhi)
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02G (With Wang Ling Zhi)
LENOVO THINKPAD X1 EXTREME	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02G (With Wang Ling Zhi)
MACBOOK PRO 15 2.7GHz	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6 Level 11
LENOVO THINKPAD X1 EXTREME	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
COUNTLESS 3 AUTOMATED CELL COUNTER		0	(Low Impact)	
EPPENDORF CENTRIFUDGE 5424R	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge I Marshall Scientific	11S Bench 17A
AGILENT 2100 BIOANALYZER DESKTOP SYSTEM	Bioanalyzer system	60	https://hpst.cz/sites/default/files/download/2020/11/5991-3323en-low.pdf	11TH SOUTH - BLOOD PROCESSING ROOM
BIORUPTOR (SONICATION SYSTEM)			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
COVARIS			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
14-inch MacBook Pro - Space Black M3 Pro 18GB 512G	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11
14-inch MacBook Pro - Space Black M3 Pro 18GB 512G	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11
ASUS TP470E NOTEBOOK (90NB0S01TP4)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South Bench 18A
ACER SWIFT 5	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11, outside 11-02J
Acer Travelmate P614 Business Laptop	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11, outside 11-02J
14-inch MacBook Pro - Space Grey	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6 LEVEL 11 BIOINFO ROOM
Lenovo ThinkStation P340 Workstation	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6 level 11 South
PRECISION 5820 TOWER	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02H
LINUX DESKTOP	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02M

MACBOOK GOLD	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02M
Lemur Pro (lemp12) + Launch (launch_2) Keyboard	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02M
Dell Latitude 5330-Touch notebook	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 north bench 10
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 North bench 9B
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH LINEAR EQUIPMENT AREA
MEDICAL FRIDGE UPRIGHT 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH OPP BENCH 10
Dell Latitude 5330-Touch notebook	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	CSI Level 11
GelDoc Go Gel Imaging System with Image Lab			(Freezer Room power consumption – taken from VRF schematic)	11 North Freezer Room
Infors Incubator Shaker Minitron			(Freezer Room power consumption – taken from VRF schematic)	11 North Freezer room
Infors Incubator Shaker Minitron			(Freezer Room power consumption – taken from VRF schematic)	11 North Freezer room
(ND/NanoDropOne-W) NanoDrop™ One (NDOne)			(Freezer Room power consumption – taken from VRF schematic)	11 North Freezer room
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 South
ASUS ExpertBook B5 B5402CVA (Non-touch)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 South
Water Purification System, HALIOS ID		0	(Low Impact)	11 South
PHCbi (Formerly Panasonic) - 150°C Ultra-Low	Freezer	220	MDF-C2156VAN | Cryogenic Ultra Low Freezer | PHCbi (phchd.com)	11 South
Lenovo ThinkPad L14	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11 South Bench 25B
ChemiDoc™ Imaging System			(Freezer Room power consumption – taken from VRF schematic)	11 South freezer room
Infors Incubator Shaker Minitron			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room
Infors Incubator Shaker Minitron			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room

(ND/NanoDropOne-W) NanoDrop™ One (NDOne			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room
ULT -80 degC Laboratory Freezer (Large; > 700Litre			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room
ULT -80 degC Laboratory Freezer (Large; > 700Litre			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room
Differential pressure monitor		0	(Low Impact)	11-01G
LAB REFRIGERATOR	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11N TCR
Biobase fumehood	Fumehood	0	(Low Impact)	11S Histology room
GELMAN BioGUARD CLASS II TYPE A2 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11S Tissue Culture Room
GELMAN BioGUARD CLASS II TYPE A2 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11S Tissue Culture Room
CUSTOM WORKSTATION PC	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11S, Bench 18B.
7900HT SDS 384-well block upgrade Kit (4331406)	PCR System	95	Specification Sheet: ProFlex PCR System (thermofisher.com)	11TH NIRTH - BENCH 13
ABI PRISM 7900HT FAST REAL-TIME PCR SYSTEM	PCR System	95	Specification Sheet: ProFlex PCR System (thermofisher.com)	11TH NORTH - BENCH 13
UV-VIS SPECTROPHOTOMETER	Spectrophotometer	121	ASHRAE Fundamentals Handbook - Spectrophotometer	11TH NORTH - BENCH 13B
FUME CUPBOARD		0	(Low Impact)	11TH NORTH - CHEMICAL ROOM
FUME CUPBOARD		0	(Low Impact)	11TH NORTH - CHEMICAL ROOM
GELMAN CLASS 100 SERIES LAMINAR FLOW CABINETS			(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH - FREEZER ROOM
HOSHIZAKI FM-251 AFE ICE FLAKE MACHINE	ICE FLAKE MACHINE	1325	Dimensions/Specifications; [A] - Hoshizaki FM-251AFE Service Manual [Page 7] | ManualsLib	11TH NORTH -

				FREEZER ROOM
CLASS100 HORIZONTAL LAMINAR FLOW CABINET W SUPPORT			(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH - FREEZER ROOM
CRYOGENIC SYSTEM			(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH - FREEZER ROOM
GELMAN BENCHTOP CLASS II TYPE A2 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
THERMO SCIENTIFIC (SORVALL) REFRIGERATED TABLE TOP	Centrifuge	350	Sorvall ST 8 Compact Centrifuge Series Brochure (thermofisher.com)	11TH NORTH - TISSUE CULTURE ROOM
FORMA STERI-CYCLE CO2 INCUBATOR T/C CO2 SENSER	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
FORMA STERI-CYCLE CO2 INCUBATOR T/C CO2 SENSER	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
GELMAN BENCHTOP CLASS II TYPE A/B3 BIOLOGICAL	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
OLYMPUS INVERTED LABORATORY MICROSCOPE		0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
BSL2 TYPE A/B3 BIOLOGICAL SAFETY CABINET	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
BENCHTOP CLASS II TYPE A/B3 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
LOW SPEED CENTRIFUGE	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH NORTH -

				TISSUE CULTURE ROOM
GELMAN BIOLOGICAL SAFETY CABINET 3FT BH90	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
F03-371-THERMO MODEL 371 CO2 INCUBATOR	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH NORTH - TISSUE CULTURE ROOM
CLASS II BIOLOGICAL SAFETLY CABINENT 3 FOOT	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
BENCHTOP CLASS II TYPE A/B3 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
BENCHTOP CLASS II TYPE A/B3 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
OLYMPUX CKX53 CELL CULTURE MICROSCOPE		0	(Low Impact)	11TH NORTH - TISSUE CULTURE ROOM
HIGH SPEED REFRIGERATED MICROCENTRIFUGE MX-305	Microcentrifuge	300	Sorvall Legend Micro 21R - Thermo Scientific Sorvall Legend Micro Series Instruction Manual [Page 17] | ManualsLib	11TH NORTH BENCH 10B
SANYO BIOMEDICAL FREEZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 13
SANYO BIOMEDICAL FREEZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 13B
TECAN INFINITE M200 MICROPLATE READER (INCL SW+PC)		0	(Low Impact)	11TH NORTH BENCH 13B
C1000 Touch Cycler with 96-deep well reaction	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	11TH NORTH BENCH 13B
C1000 Touch Cycler with 96-deep well reaction	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	11TH NORTH BENCH 13B
CFX96 Optical Reaction Module	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	11TH NORTH

				BENCH 13B
CHEMIDOC MP IMAGING SYSTEM	Imager	200	GE Healthcare - ImageQuant LAS 500 Community, Manuals and Specifications | LabWrench	11TH NORTH BENCH 13B
CYTOCENTRIFUG E	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH NORTH BENCH 2B
ULTRA LOW FREEZER -80	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
INVERTED MICROSCOPE FORBRIGHT PHASE & FLUORESCENCE			(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
-80 FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
ULTRA-LOW TEMPERATURE FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
ULTRA-LOW TEMPERATURE FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
STRATEGENE STRATALINKER		0	(Low Impact)	11TH NORTH IN FRONT OF TCR
KIRSCH SPECZIAL 468 LAB REFRIGERATOR	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH OPP BENCH 1
SANYO BIOMEDICAL FREEZER MODEL U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH OPP BENCH 10
CENTRIFUGE 5415R NO ROTOR REFRIG UK PLUG	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH - BENCH 13A
NANODROP FULL SPECTRUM UV-VIS SPECTROPHOTO METER	Spectrophoto meter	121	ASHRAE Fundamentals Handbook - Table 7 Spectrophotometer	11TH SOUTH - BENCH 17A
AUTOSTAINER	Autostainer	0	https://www.leicabiosystems.com/sites/default/files/media_product-download/2022-02/Leica_ST5010_IFU_3v1M_en.pdf	11TH SOUTH - BENCH 18B
IMAGEQUANT LAS 500	Imager	200	GE Healthcare - ImageQuant LAS 500 Community, Manuals and Specifications | LabWrench	11TH SOUTH - BENCH 19A

ESCO PCR VERTICAL LAMINAR FLOW CABINETS 2FT	Fumehood	0	9010022_PCR Cabinet_SCR & PCR_Combined Brochure_A4_vD_032824.pdf (escolifesciences.com)	11TH SOUTH - BLOOD PROCESSING ROOM
BIOLOGICAL SAFETY CABINET	Fumehood	0	Biosafety Cabinet(BSC-04 II A2)_Suzhou Antai Airtech Co., Ltd (airtechsat.com)	11TH SOUTH - BLOOD PROCESSING ROOM
ANALYTICAL BALANCE AT 460 DR		0	(Low Impact)	11TH SOUTH - CHEMICAL ROOM
FUME CUPBOARD		0	(Low Impact)	11TH SOUTH - CHEMICAL ROOM
FUME CUPBOARD		0	(Low Impact)	11TH SOUTH - CHEMICAL ROOM
CRYOGENIC SYSTEM		0	(Low Impact)	11TH SOUTH - CRYOSTORAGE ROOM
SANYO BIOMEDICAL FREZER: MODEL MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH SOUTH - FREEZER ROOM
HOSHIZAKI MODULAR FLAKE ICE MAKER	ICE FLAKE MACHINE	1325	Dimensions/Specifications; [A] - Hoshizaki FM-251AFE Service Manual [Page 7] | ManualsLib	11TH SOUTH - FREEZER ROOM
SAKURA TISSUE TEK TEC5 TISSUE EMBEDDING		0		11TH SOUTH - HISTOLGY ROOM
LEICA CM3050S CRYOSTAT	Cyrostat	1800	Leica CM3050 S | Cryostat (leicabiosystems.com)	11TH SOUTH - HISTOLOGY ROOM
CITADEL 2000 TISSUE PROCESSOR	Microwave tissure processor	800	Intended Uses; Technical Specifications; Microwave Unit - Milestone KOS Operator's Manual [Page 7] | ManualsLib	11TH SOUTH - HISTOLOGY ROOM
FULLY MOTORIZED ROTARY MICROTOME	Rotary Microtome	100	HistoCore AUTOCUT - Automated Rotary Microtome | Leica Biosystems	11TH SOUTH - HISTOLOGY ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR MODEL: 371	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH SOUTH - TISSUE CULTURE ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR MODEL: 371	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH SOUTH - TISSUE CULTURE ROOM

THERMO FORMA STERI-CYCLE CO2 INCUBATOR MODEL: 371	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH SOUTH - TISSUE CULTURE ROOM
THERMO FORMA STERI-CYCLE CO2 INCUBATOR MODEL: 371	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH SOUTH - TISSUE CULTURE ROOM
GELMAN BENCHTOP CLASS II BIOLOGICAL SAFETY CABINET	Fumehood	0	(Low Impact)	11TH SOUTH - TISSUE CULTURE ROOM
GELMAN BENCHTOP CLASS II BIOLOGICAL SAFETY CABINET	Fumehood	0	(Low Impact)	11TH SOUTH - TISSUE CULTURE ROOM
THERMO FORMA WATER JACKETED CO2 INCUBATOR	CO2 Incubator	100	Forma Series 3 WJ CO2 Incubators Brochure (thermofisher.com)	11TH SOUTH - TISSUE CULTURE ROOM
THERMO FORMA WATER JACKETED CO2 INCUBATOR	CO2 Incubator	100	Forma Series 3 WJ CO2 Incubators Brochure (thermofisher.com)	11TH SOUTH - TISSUE CULTURE ROOM
BENCHTOP CLASS II TYPE A/B3 BIOLOGICAL SAFETY	Fumehood	0	(Low Impact)	11TH SOUTH - TISSUE CULTURE ROOM
CKX41_INVERTED FLUORESCENCE MICROSCOPE		0	(Low Impact)	11TH SOUTH - TISSUE CULTURE ROOM
CKX31_OLYMPUS INVERTED MICROSCOPE		0	(Low Impact)	11TH SOUTH - TISSUE CULTURE ROOM
RUSKINN INVIVO 2 400 HYPOXIA WORKSTATIONS	Workstation	1830	Service Requirements; Electrical Supply Requirements; Figure 1: Invivo Rear Connections; Table 2: Electrical Service Requirements - Baker InvivO2 400 User Manual [Page 12] | ManualsLib	11TH SOUTH - TISSUE CULTURE ROOM
PANASONIC MEDICAL FREEZER MODEL MDF U537D	Freezer (-20)	225	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH SOUTH BENCH 14A
AUTOMATED HANDHELD CELL COUNTER		0	(Low Impact)	11TH SOUTH BENCH 14A
EPPENDORF CENTRIFUGE 5424R	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH BENCH 14B

PROFLEX 3X32-WELL PCR SYSTEM	PCR System	95	Specification Sheet: ProFlex PCR System (thermofisher.com)	11TH SOUTH BENCH 15
MINIAMP PLUS THERMAL CYCLER	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	11TH SOUTH BENCH 15
FLOOR STANDING REFRIGERATED CENTRIFUGES	Centrifuge	350	Sorvall ST 8 Compact Centrifuge Series Brochure (thermofisher.com)	11TH SOUTH BENCH 15A
CENTRIFUGE 5415R W/O ROTOR	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH BENCH 15A
THERMOMIXER C	ThermoMixer	200	Eppendorf ThermoMixer® C	11TH SOUTH BENCH 15B
EPPENDORF CENTRIFUGE 5424R	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	11TH SOUTH BENCH 16
HIGH SPEED REFRIGERATED MICROCENTRIFUGE (MX305)	Microcentrifuge	300	Sorvall Legend Micro 21R - Thermo Scientific Sorvall Legend Micro Series Instruction Manual [Page 17] | ManualsLib	11TH SOUTH BENCH 17A
PCR MACHINE 96G BIOMETRA TONE	PCR System	55	Technical Specifications - Endress+Hauser Analytik Jena Biometra TOne 96 Operating Manual [Page 13] | ManualsLib	11TH SOUTH BENCH 18
AUTOSTAINER	Autostainer	0	https://www.leicabiosystems.com/sites/default/files/media_product-download/2022-02/Leica_ST5010_IFU_3v1M_en.pdf	11TH SOUTH BENCH 18B
HIGH SPEED REFRIGERATED MICROCENTRIFUGE	Microcentrifuge	300	Sorvall Legend Micro 21R - Thermo Scientific Sorvall Legend Micro Series Instruction Manual [Page 17] | ManualsLib	11TH SOUTH BENCH 21B
KIRSCH SPEZIAL-468 LABORATORY REFRIGERATOR 4 DEGRE	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 23A
-20C UPRIGHT TWIN FREEZER	Freezer (-20)	440	11516_4_PHCBI_MDFDU702VXC_Pdt_Sheet_vf.pdf (markitbiomedical.com)	11TH SOUTH BENCH 23A
FLOOR-STANDING REFRIGERATED CENTRIFUGE	Centrifuge	350	Sorvall ST 8 Compact Centrifuge Series Brochure (thermofisher.com)	11TH SOUTH BENCH 23B
MEDICAL FRIDGE UPRIGHT 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 25B
KIRSCH SPECZIAL 468 LAB REFRIGERATOR 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH SOUTH BENCH 25B
BIOMEDICAL FREEZER -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH SOUTH BENCH 25B

GENOMINI WITH UV FILTER AND GENOSOFT SW		0	(Low Impact)	11TH SOUTH BLOOD PROCESSING ROOM
HIGH-THROUGHPUT PLATFORM FOR QC ANALYSIS OF		0	(Low Impact)	11TH SOUTH BLOOD PROCESSING ROOM
-150C ULTRA-LOW TEMPERATURE FREEZER	Freezer	220	MDF-C2156VAN | Cryogenic Ultra Low Freezer | PHCbi (phchd.com)	11TH SOUTH CRYOGENIC ROOM
-150C ULTRA-LOW TEMPERATURE FREEZER	Freezer	220	MDF-C2156VAN | Cryogenic Ultra Low Freezer | PHCbi (phchd.com)	11TH SOUTH CRYOGENIC ROOM
TEMPERATURE MONITORING SYSTEM			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
ULTRA-LOW TEMPERATURE FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
ULTRA-LOW TEMPERATURE FREEZER	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
GelDoc Go Gel Imaging System with Image Lab Touch			(Freezer Room power consumption – taken from VRF schematic)	11TH SOUTH FREEZER ROOM
Leica semi-motorised rotary microtome	Rotary Microtome	100	HistoCore AUTOCUT - Automated Rotary Microtome | Leica Biosystems	11TH SOUTH HISTOLOGY ROOM
KOS MULTIFUNCTIONAL MICROWAVE TISSUE PROCESSOR	Microwave tissure processor	800	Intended Uses; Technical Specifications; Microwave Unit - Milestone KOS Operator's Manual [Page 7] | ManualsLib	11TH SOUTH MMA
BUNDLE CENTRIFUDGE 5810R	Centrifuge	350	Centrifuge 5810 / 5810 R | Your Workhorse in the Lab (eppendorf.com)	11TH SOUTH OUTSIDE TCR
HYBRID REFRIGERATED CENTRIFUGE	Centrifuge	350	Centrifuge 5810 / 5810 R | Your Workhorse in the Lab (eppendorf.com)	11TH SOUTH TC ROOM
COUNTESS II	Cell counter	0	(Low Impact)	11TH SOUTH TISSUE CULTURE ROOM
AUTOCLAVE	Autoclave	300	(Low Impact)	11TH SOUTH TISSUE CULTURE ROOM
DELL(TM) POWEREDGE R420	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH PC ROOM

INTEL(R) XEON(R) PROCESSOR E5-2450 2.10 GHZ 20 M	CPU	95	Intel Xeon Processor E52450 20M Cache 2.10 GHz 8.00 GTs Intel QPI Product Specifications	11TH SOUTH PC ROOM
SUPERMICRO SYS8047R-THRFT			(Low Impact)	11TH SOUTH PC ROOM
DELL TM POWEREDGE R930 (256GB RAM)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH PC ROOM
DELL TM POWEREDGE R930 (512GB RAM)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11TH SOUTH PC ROOM
SUPERMICRO CSE847E2C-R1K28JBOD			(Low Impact)	11TH SOUTH PC ROOM
DELL LATITUDE E5440	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02G
MACBOOK PRO 15 512GB (MJLT2ZP/A ZORG)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
HP LAPTOP 14S-CF2019TX-8NV81PA	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
SANYO BIOMEDICAL FREEZER (MDF U537) -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11 South Opposite B15B
14-inch MacBook Pro - Space Grey Apple M2 Pro	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11-02K
GZ-1730R, MICROCENTRIFUGE	Microcentrifuge		(Low Impact)	Bench 20A (CSI 11 South)
Miu/MC-24C) MIULAB - MC-24C High-Speed Refrigerate	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	Bench 20A (CSI 11 South)
SIMPLIAMP THERMAL CYCLER	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	Bench 20A (CSI 11 South)
iBlot 3 Western Blot Transfer Device	Transfer Device	0	iBlot 3 Western Blot Transfer System (thermofisher.com)	Bench 20A (CSI 11 South)
QUBIT 4 FLUOROMETER WIFI BOX	Fluorometer	0	(Low Impact)	Level 11 South Bench 20A
15-inch MacBook Air - Space Grey M2 8GB 256GB SSD	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South Bench 20B
15-inch MacBook Air - Space Grey M2 8GB 256GB SSD	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South Bench 21B

Dell Mobile Precision Workstation 3571	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South, Bench 21 A
Benchtop Centrifuge	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	Level 11 South, MD6 Cancer Science Institute
Benchtop Centrifuge (Different SOF)	Centrifuge	350	Eppendorf 5424R Refrigerated Centrifuge | Marshall Scientific	Level 11 South, MD6 Cancer Science Institute
PCR Thermal Cycler	Thermal Cycler	164	System Specifications - Applied Biosystems SimpliAmp Thermal Cycler User Manual [Page 65] | ManualsLib	Level 11 South, MD6 Cancer Science Institute
Cat No : 21.2201 LeicaBiosystems BondIII	Staining System	1200	BOND-III Automated IHC Stainer for Immunostaining (leicabiosystems.com)	11 South Bench 19A
CLS143455 PhenoImager HT 1.1 One-time			(Freezer Room power consumption – taken from VRF schematic)	11 South Freezer room
HIGH-PLEX, SINGLE CELL, MULTI-OMICS SPATIAL		0	(Low Impact)	11-02-02B
HP PROBOOK 440 G6	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11S Bench 19A
CO2 INCUBATORS	CO2 Incubator	100	Section 6 - Specifications - Thermo 3010 Series Operating And Maintenance Manual [Page 26] | ManualsLib	11TH NORTH - TISSUE CULTURE ROOM
MICROSOFT SURFACE PRO 256GB	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
Lenovo ThinkPad T14s G3 i7/16GB/512SSD/ MT/W11H	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
LENOVO THINKPAD T470S	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South Bench 18
LENOVO THINKPAD T470S	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
-40 FREEZER	Freezer	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 10-12
SANYO BIOMEDICAL FREEZER MODEL: MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH BENCH 12B
REAL TIME PCR SYSTEM	PCR System	95	Specification Sheet: ProFlex PCR System (thermofisher.com)	11TH NORTH

				BENCH 12B
ULTRA LOW FREEZER -80	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH FREEZER ROOM
ACER SWIFT 5	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11N Bench 7A
FUJITSU LIFEBOOK S936	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	11N Bench 7B
KIRSCH SPECZIAL 468 LAB REFRIGERATOR	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11N Opposite Bench 3
QUBIT 2.0 FLUOROMETER	Fluorometer	240	Qubit 4 Fluorometer | Thermo Fisher Scientific - SG	11TH NORTH BENCH 7A
LAB REFRIGERATOR MODEL SPEZIAL-468 4 DEGREES	Refrigerator	58.3	Laboratory Refrigerator SPEZIAL-468 - KIRSCH pharmaceutical refrigerators, blood bank refrigerators, blood plasma freezers, laboratory refrigerators, laboratory freezers (kirsch-medical.com)	11TH NORTH OPP BENCH 9
SANYO BIOMEDICAL FREEZER MODEL: MDF U537 -20	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH OPP BENCH 9
SANYO MEDICAL FREEZER -25	Freezer (-20)	205	Performance - Sanyo MDF-U333 Instruction Manual [Page 28] | ManualsLib	11TH NORTH OPP BENCH 9A
Dell Latitude 5340	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-North Bench 7
LENOVO THINKPAD T460S	Laptop	54	ASHRAE Fundamentals Handbook - averaged value	
HP LAPTOP 14S-CF2019TX-8NV81PA	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
ULTRA LOW TEMPERATURE FREEZER -80	Freezer		(Freezer Room power consumption – taken from VRF schematic)	11TH NORTH - FREEZER ROOM
F03-371-THERMO MODEL 371 CO2 INCUBATOR	CO2 Incubator	2760	Thermo Scientific Forma 371 Steri Cycle CO2 Incubator; TC 230 from Cole-Parmer (coleparmer.com)	11TH NORTH - TISSUE CULTURE ROOM
Eppendorf Thermomixer C	ThermoMixer	200	Eppendorf ThermoMixer® C	11S core bench 16
13-inch MacBook Pro - Space Grey(M2)	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South, Bench 16A
13 inch MacBook Pro - Space Grey M2 chip with 8	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	Level 11 South, Bench 16B
14-inch MacBook Pro - Space Grey	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	MD6-11-02M
GYROZEN Microcentrifuge	Microcentrifuge	2000	Technical Specifications - GYROZEN 1730R User Manual [Page 9] | ManualsLib	& A-0001166-

				09-00, #12-01, North Core, Bench 7B
LENOVO THINKPAD T470S	Laptop	53	ASHRAE Fundamentals Handbook - averaged value	
Aftershock Flow	CPU	155	5039A-i I SuperWorkstation I Products I Super Micro Computer, Inc.	11-01H

8.3 Appendix C – ApacheHVAC Input

Temperature and Air Flow Control Input for Scenario 2

1. Component 3 (Pre-cooling Coil Controller with Feedback Sensor)

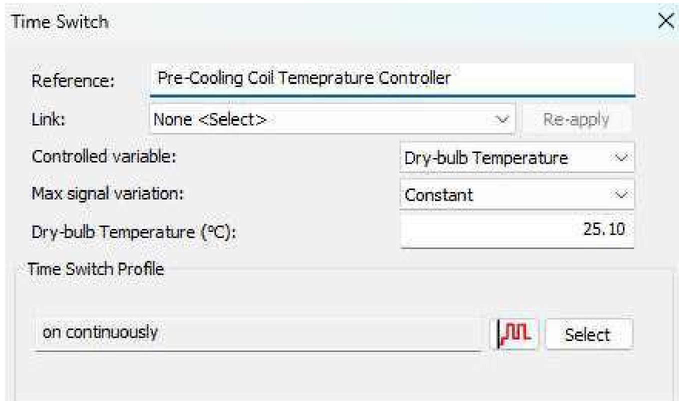

Figure 38: Pre-Cooling Coil Temperature Controller in ApacheHVAC for Scenario 2

2. Component 5 (Supply Air Fan)

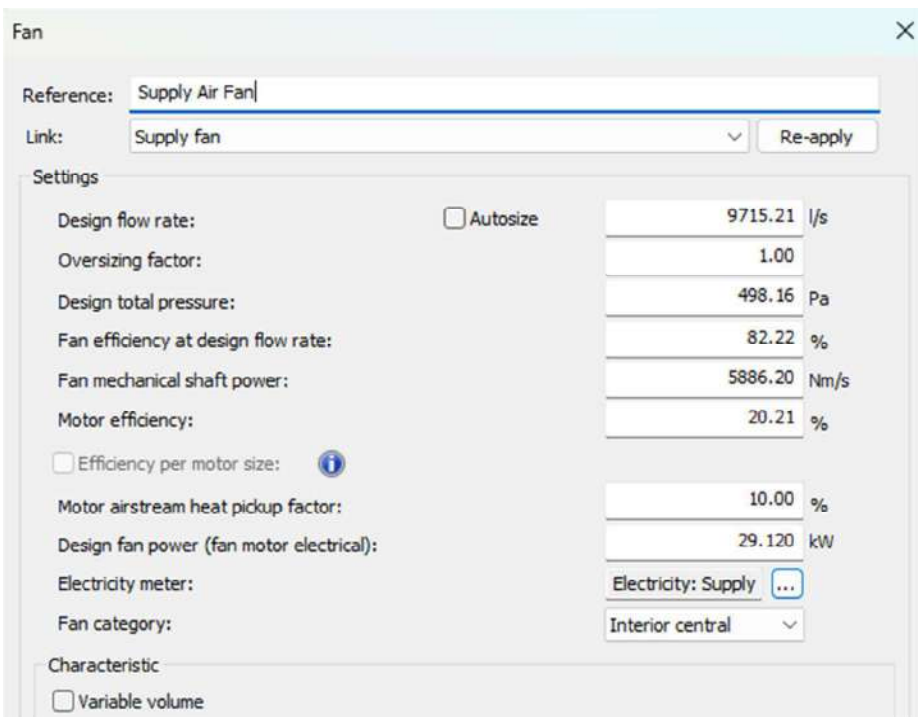

Figure 39: Supply Air Fan Input in ApacheHVAC for Scenario 2

3. Component 6 (Supply Air Fan Occupied Hours Controller)

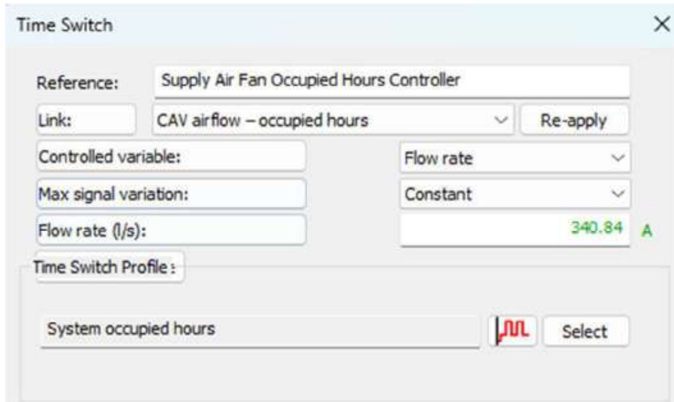

Figure 40: Supply Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 2

4. Component 7 (Supply Air Fan Unoccupied Hours Controller)

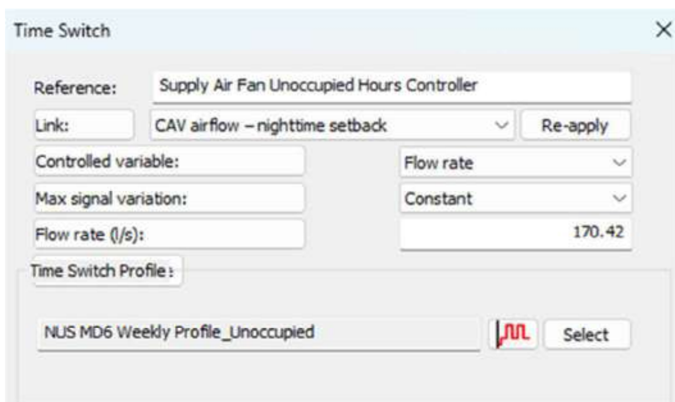

Figure 41: Supply Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 2

5. Component 9 (Reheat Coil Temperature Controller with Feedback Sensor)

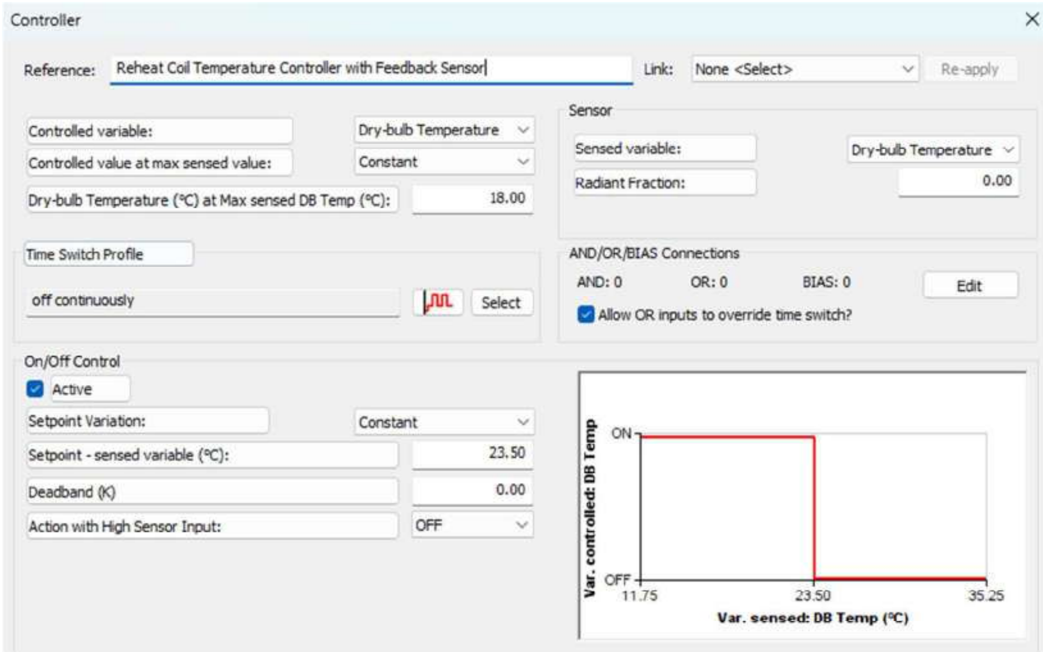

Figure 42: Reheat Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 2

6. Component 10 (Cooling Coil Temperature Controller with Feedback Sensor)

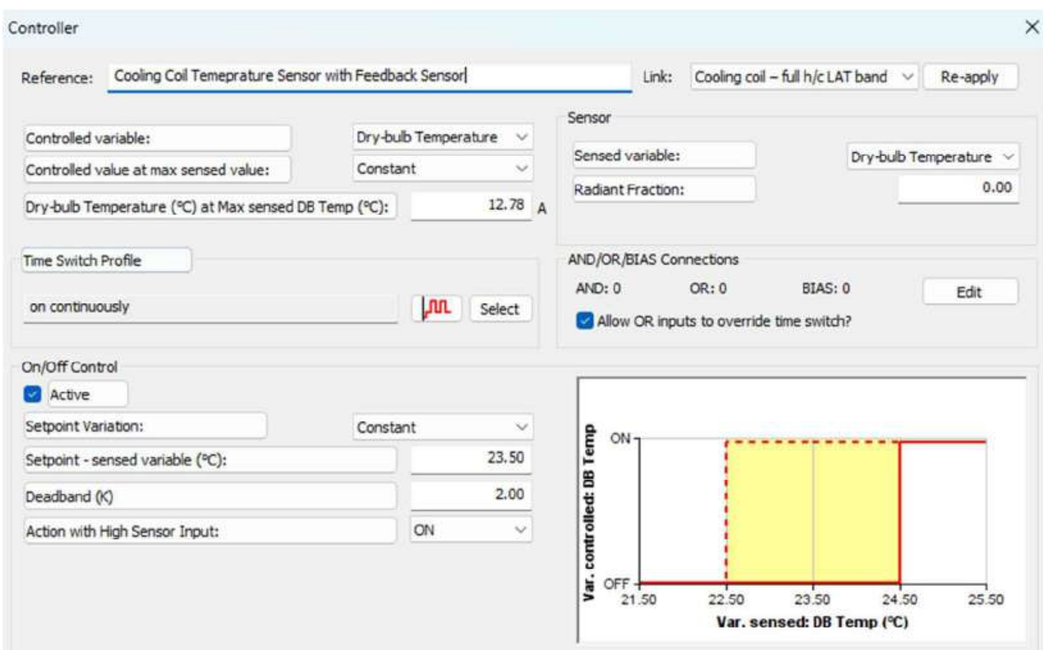

Figure 43: Cooling Coil Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 2

7. Component 11 (Cooling Coil Relative Humidity Controller with Feedback Sensor)

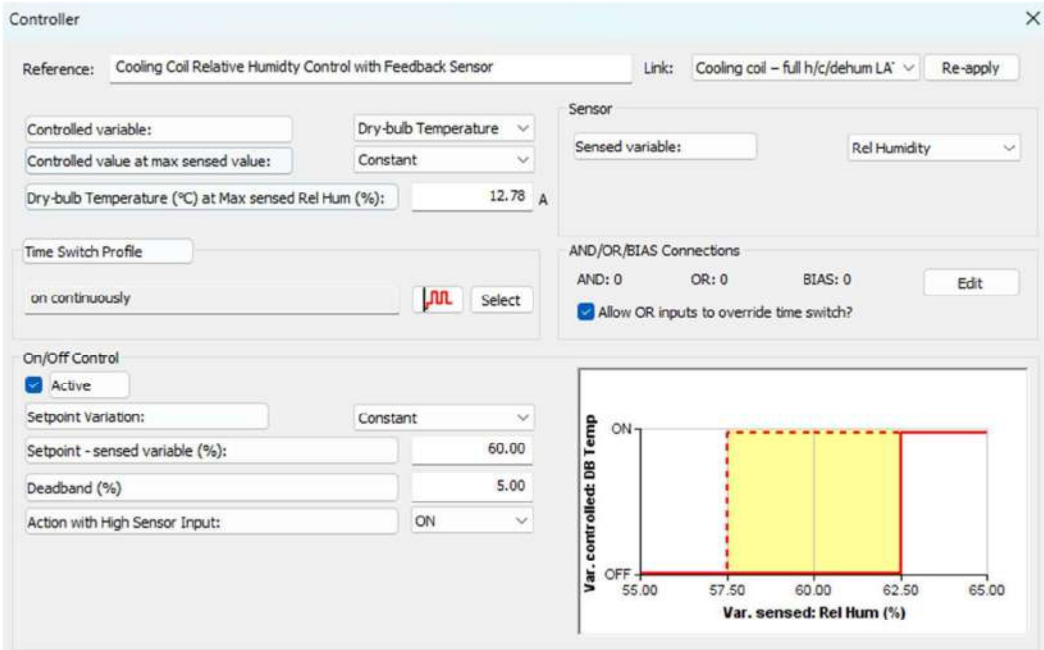

Figure 44: Cooling Coil Relative Humidity Controller with Feedback Sensor in ApacheHVAC for Scenario 2

8. Component 13 (Exhaust Air Fan Controller)

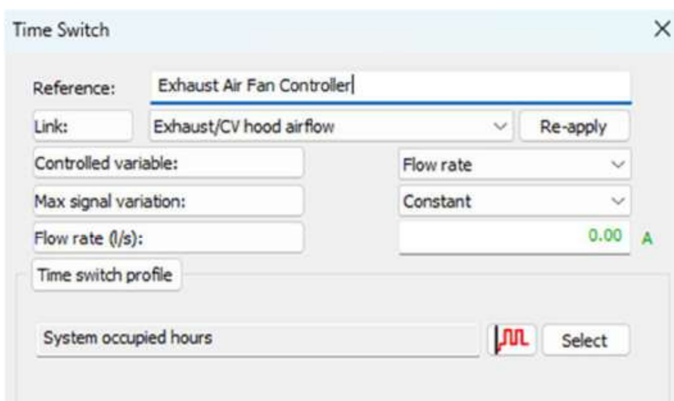

Figure 45: Exhaust Air Fan Controller in ApacheHVAC for Scenario 2

9. Component 14 (Return Air Fan Occupied Hours Controller)

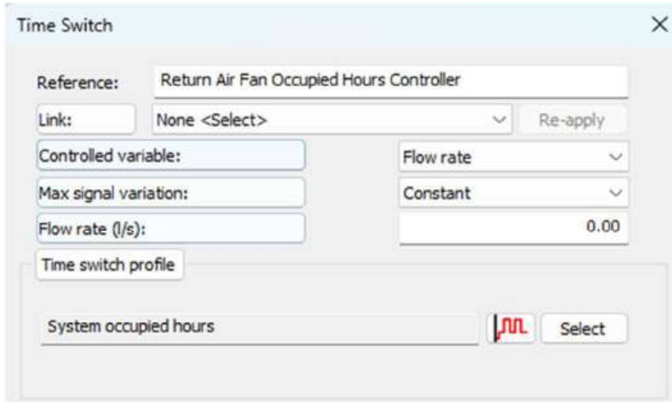

Figure 46: Return Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 2

10. Component 15 (Return Air Unoccupied Hours Controller)

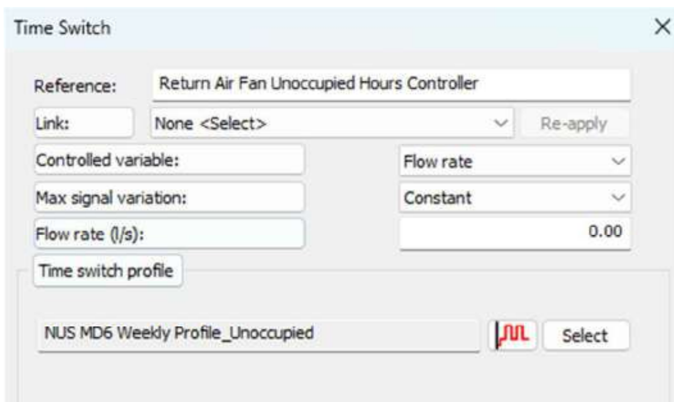

Figure 47: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 2

11. Component 16 (Return Air Fan)

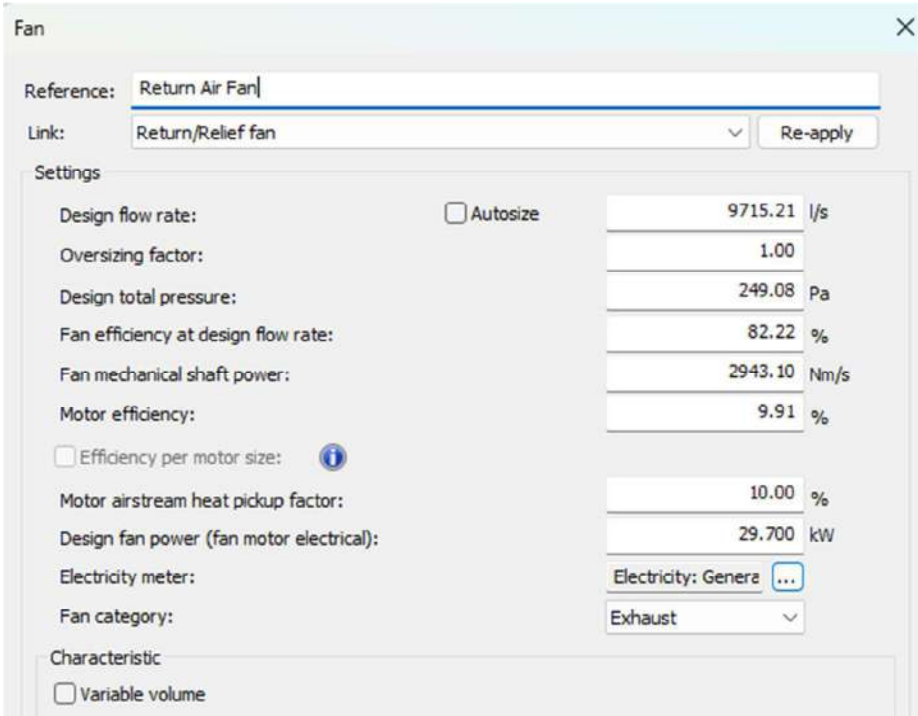

Figure 48: Return Air Fan in ApacheHVAC for Scenario 2

12. Component 17 (Exhaust Air Fan)

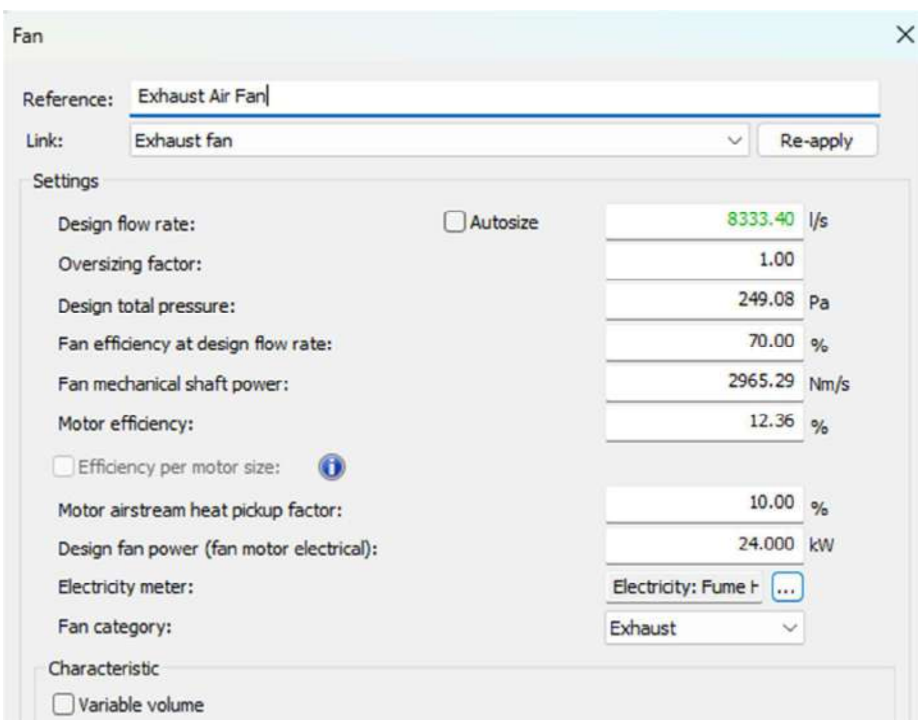

Figure 49: Exhaust Air Fan in ApacheHVAC for Scenario 2

Temperature and Air Flow Control Input for Scenario 3

1. Component 3 (Pre-cooling Coil Controller with Feedback Sensor)

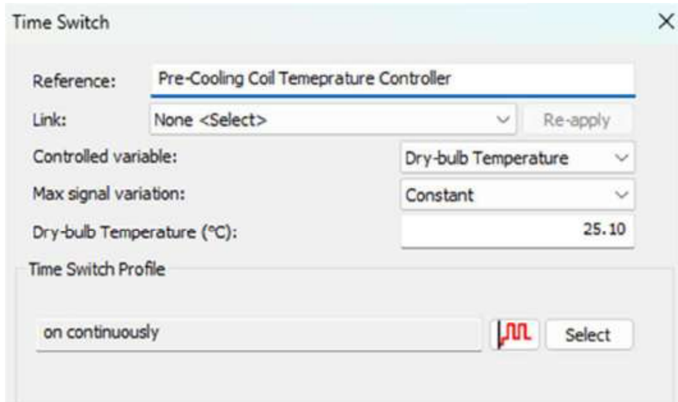

Figure 50: Pre-Cooling Coil Temperature Controller in ApacheHVAC for Scenario 3

2. Component 5 (Supply Air Fan)

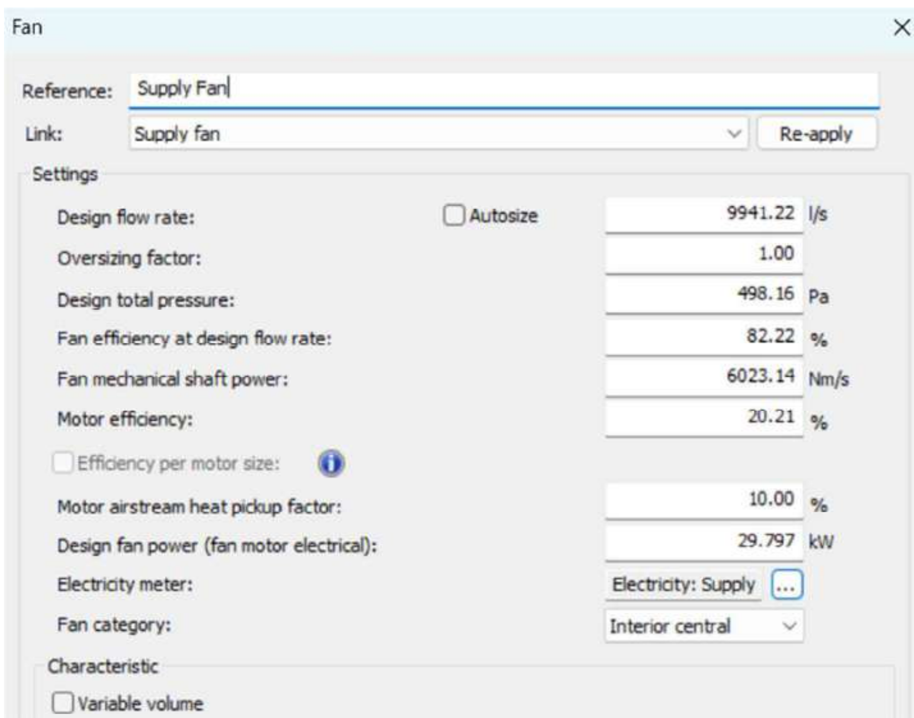

Figure 51: Supply Air Fan Input in ApacheHVAC for Scenario 3

3. Component 6 (Supply Air Fan Occupied Hours Controller)

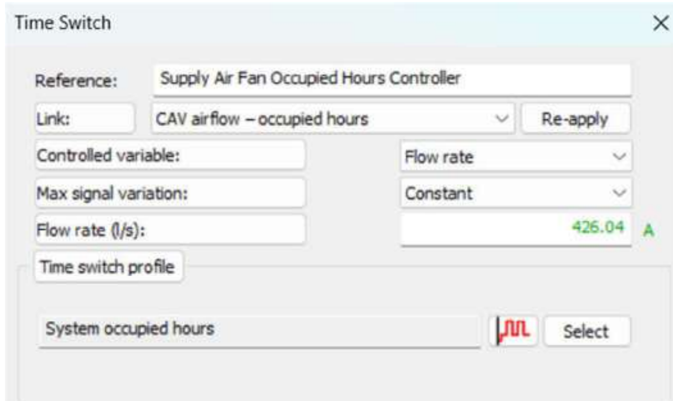

Figure 52: Supply Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 3

4. Component 7 (Supply Air Fan Unoccupied Hours Controller)

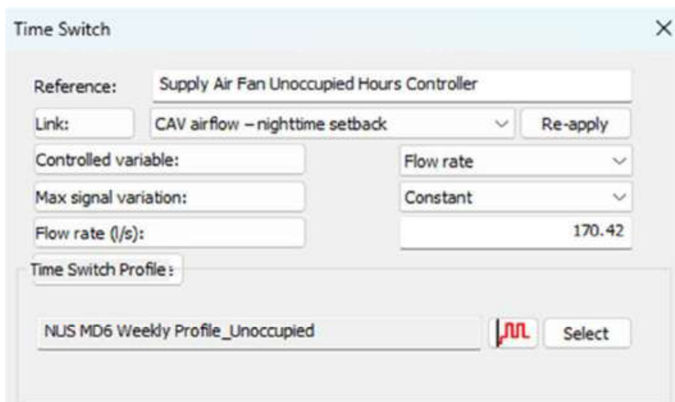

Figure 53: Supply Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 3

5. Component 9 (Reheat Coil Temperature Controller with Feedback Sensor)

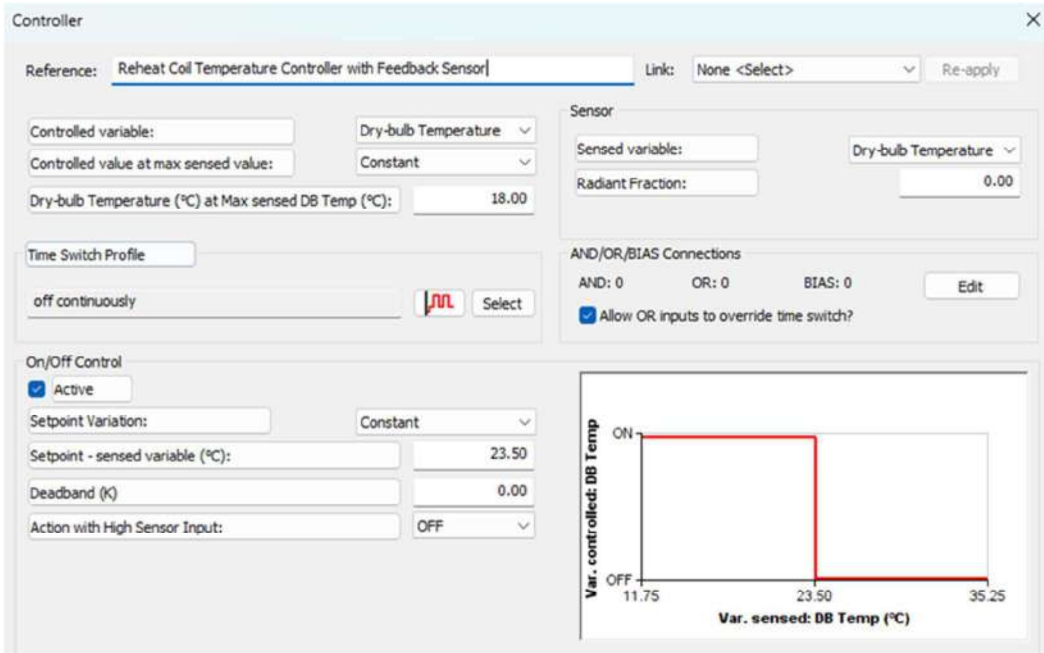

Figure 54: Reheat Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 3

6. Component 10 (Cooling Coil Temperature Controller with Feedback Sensor)

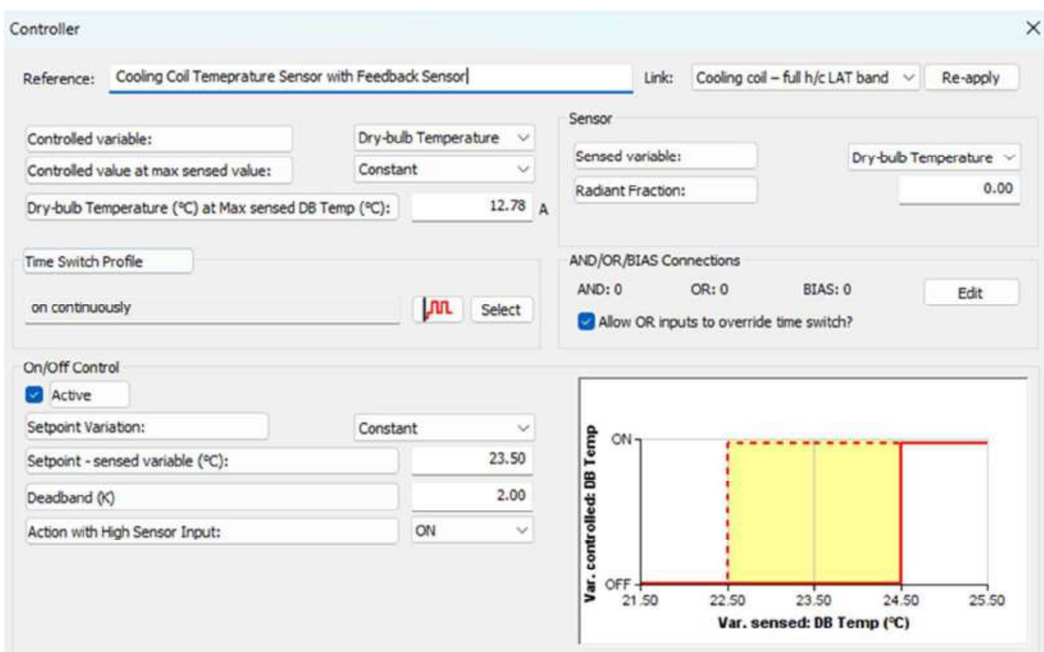

Figure 55: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 3

7. Component 11 (Cooling Coil Relative Humidity Controller with Feedback Sensor)

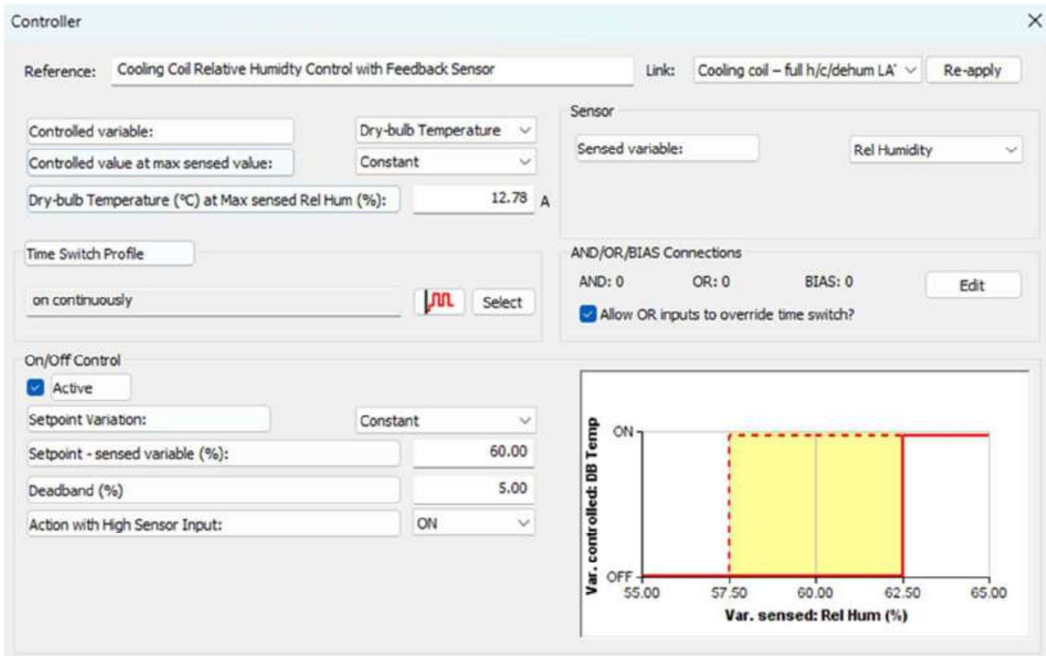

Figure 56: Cooling Coil Relative Humidity Controller with Feedback Sensor in ApacheHVAC for Scenario 3

8. Component 13 (Exhaust Air Fan Controller)

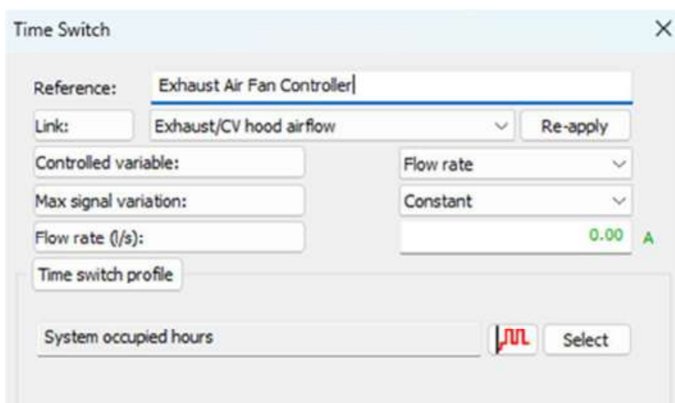

Figure 57: Exhaust Air Fan Controller in ApacheHVAC for Scenario 3

9. Component 14 (Return Air Fan Occupied Hours Controller)

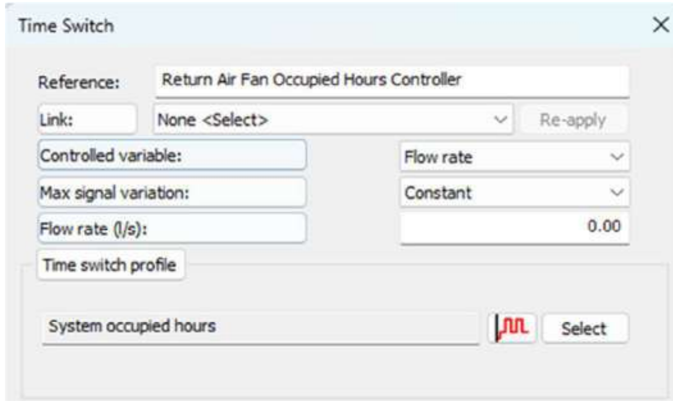

Figure 58: Return Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 3

10. Component 15 (Return Air Unoccupied Hours Controller)

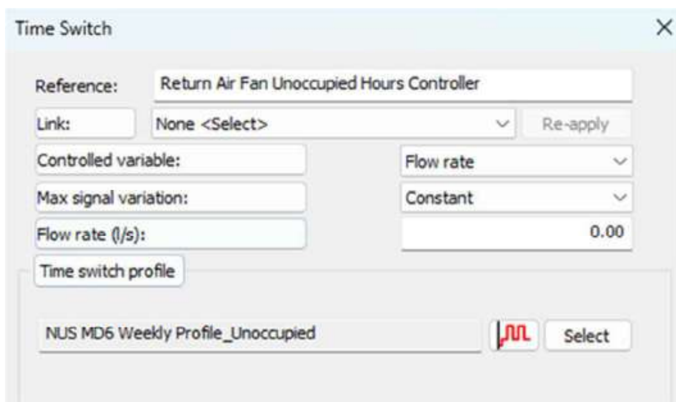

Figure 59: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 3

11. Component 16 (Return Air Fan)

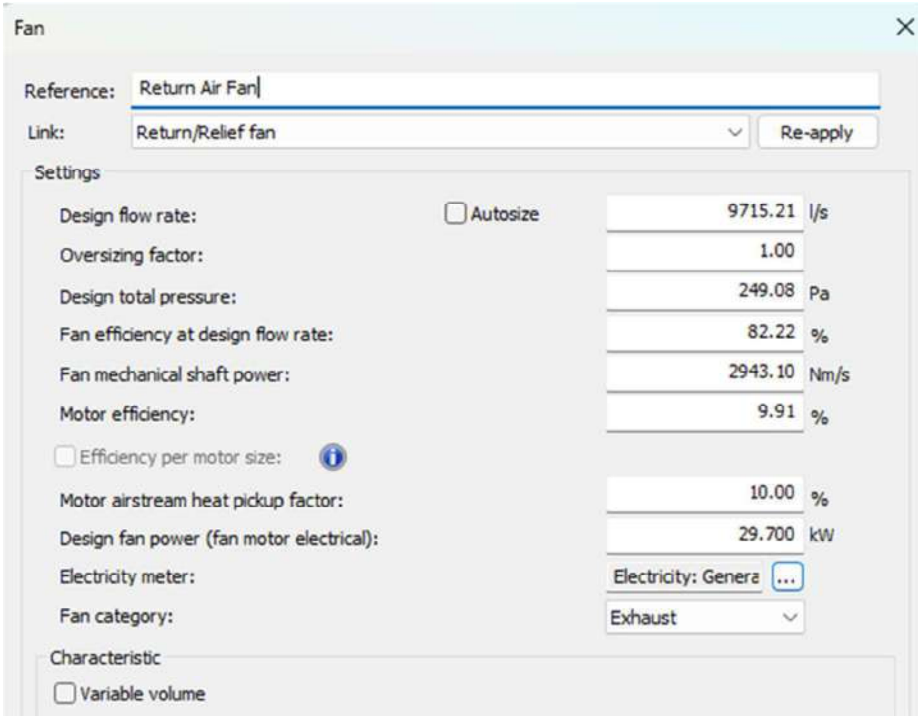

Figure 60: Return Air Fan in ApacheHVAC for Scenario 3

12. Component 17 (Exhaust Air Fan)

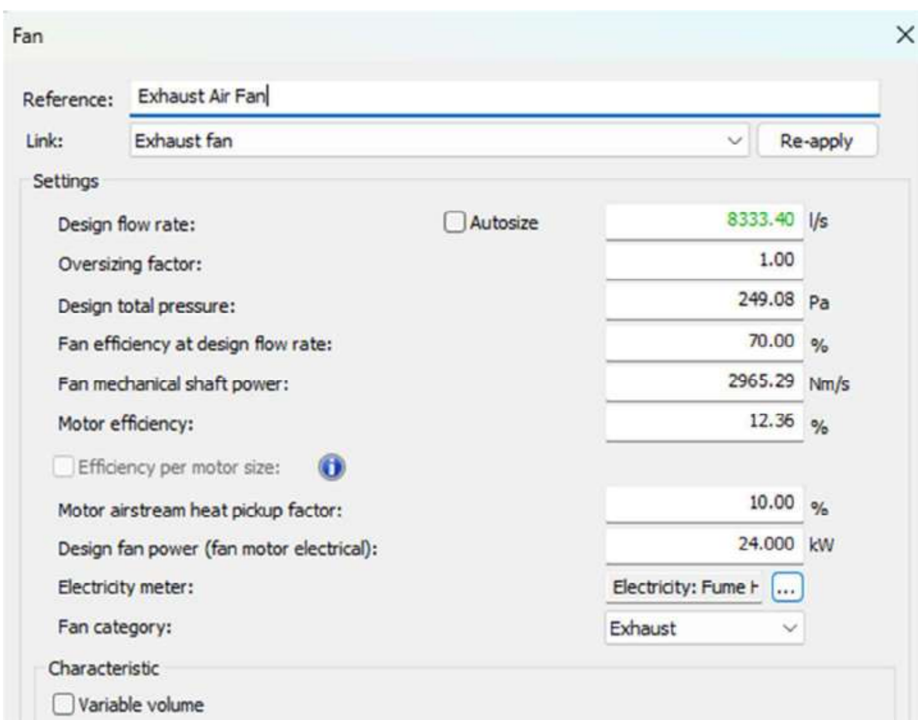

Figure 61: Exhaust Air Fan in ApacheHVAC for Scenario 3

Temperature and Air Flow Control Input for Scenario 4

1. Component 3 (Pre-cooling Coil Controller with Feedback Sensor)

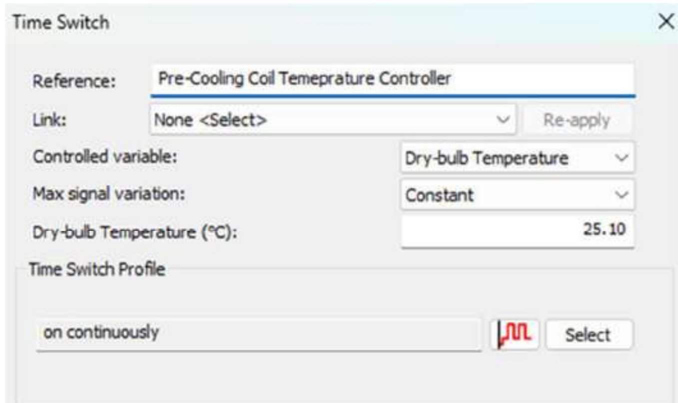

Figure 62: Pre-Cooling Coil Temperature Controller in ApacheHVAC for Scenario 4

2. Component 5 (Supply Air Fan)

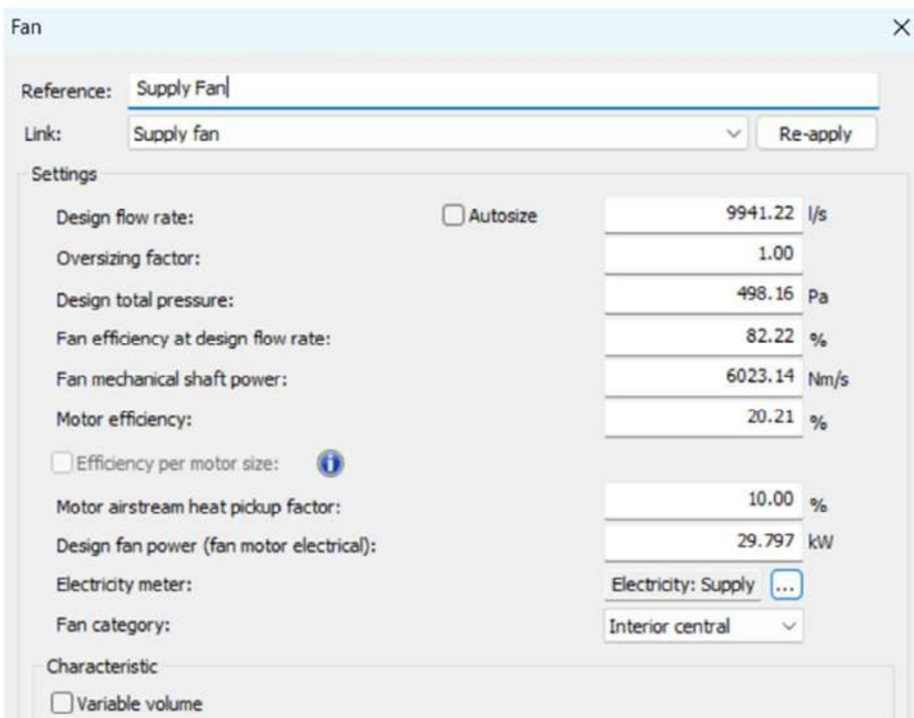

Figure 63: Supply Air Fan Input in ApacheHVAC for Scenario 4

3. Component 6 (Supply Air Fan Occupied Hours Controller)

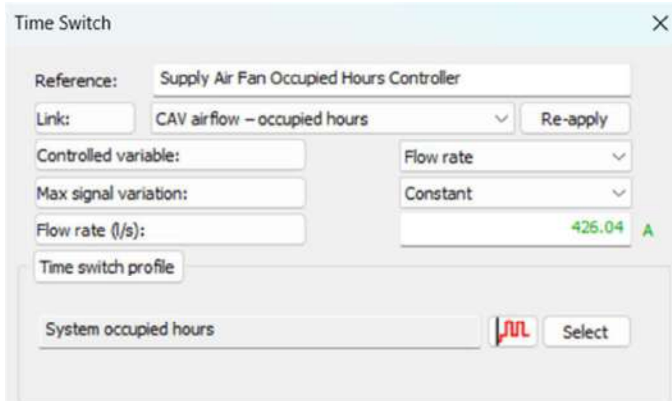

Figure 64: Supply Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 4

4. Component 7 (Supply Air Fan Unoccupied Hours Controller)

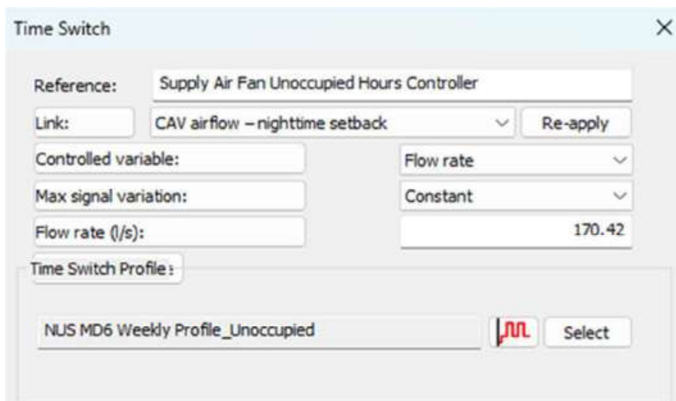

Figure 65: Supply Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 4

5. Component 9 (Reheat Coil Temperature Controller with Feedback Sensor)

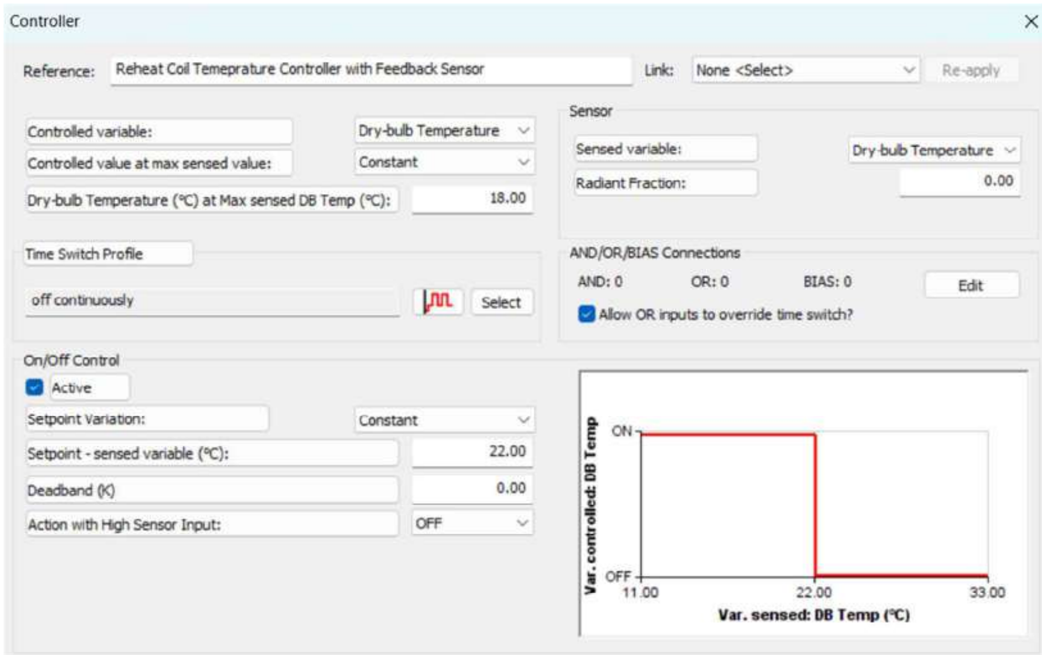

Figure 66: Reheat Temperature Controller with Feedback Sensor in ApacheHVAC for Scenario 4

6. Component 10 (Cooling Coil Temperature Controller with Feedback Sensor)

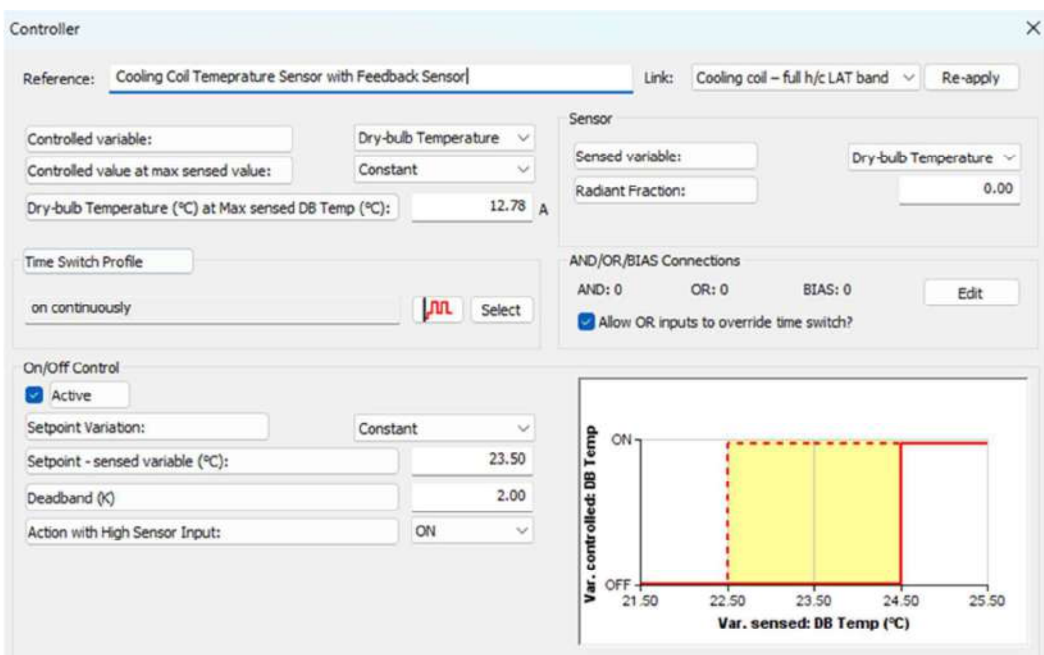

Figure 67: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 4

7. Component 11 (Cooling Coil Relative Humidity Controller with Feedback Sensor)

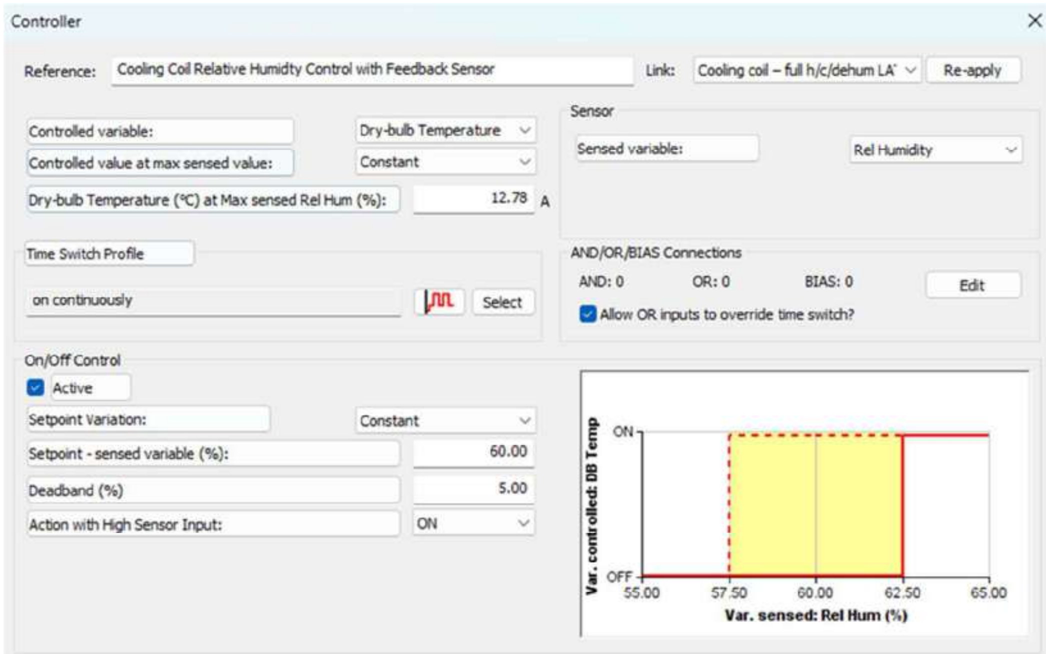

Figure 68: Cooling Coil Relative Humidity Controller with Feedback Sensor in ApacheHVAC for Scenario 4

8. Component 13 (Exhaust Air Fan Controller)

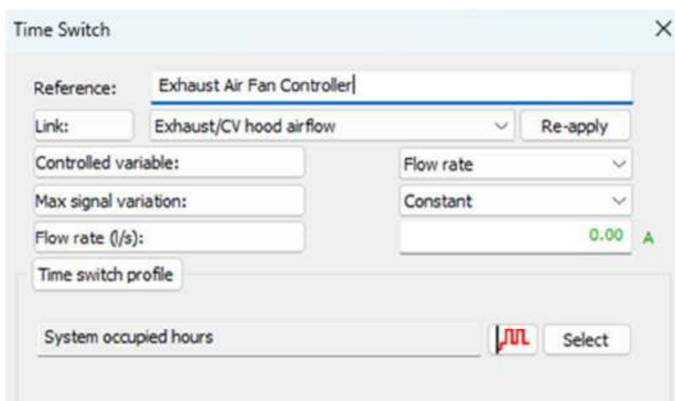

Figure 69: Exhaust Air Fan Controller in ApacheHVAC for Scenario 4

9. Component 14 (Return Air Fan Occupied Hours Controller)

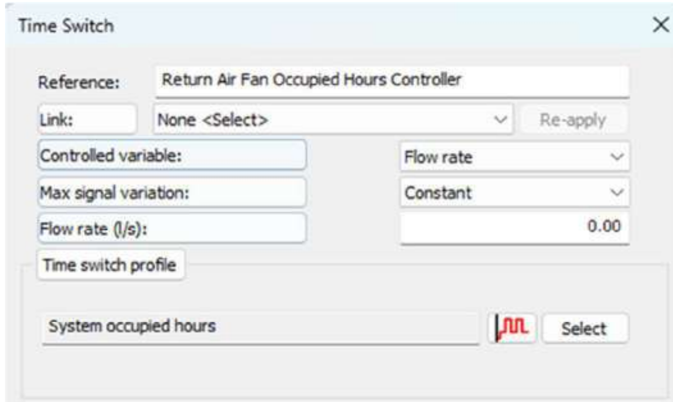

Figure 70: Return Air Fan Occupied Hours Controller in ApacheHVAC for Scenario 4

10. Component 15 (Return Air Unoccupied Hours Controller)

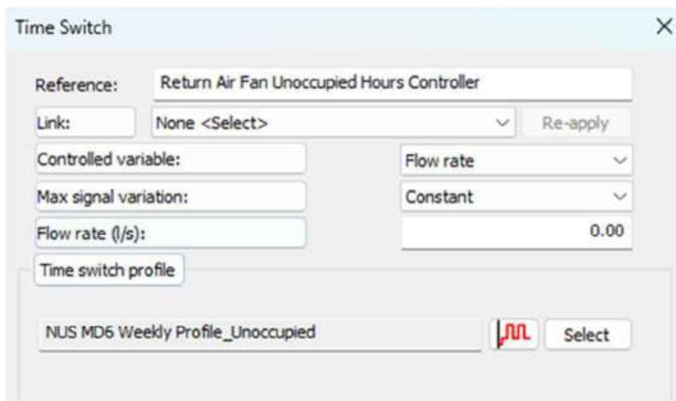

Figure 71: Return Air Fan Unoccupied Hours Controller in ApacheHVAC for Scenario 4

11. Component 16 (Return Air Fan)

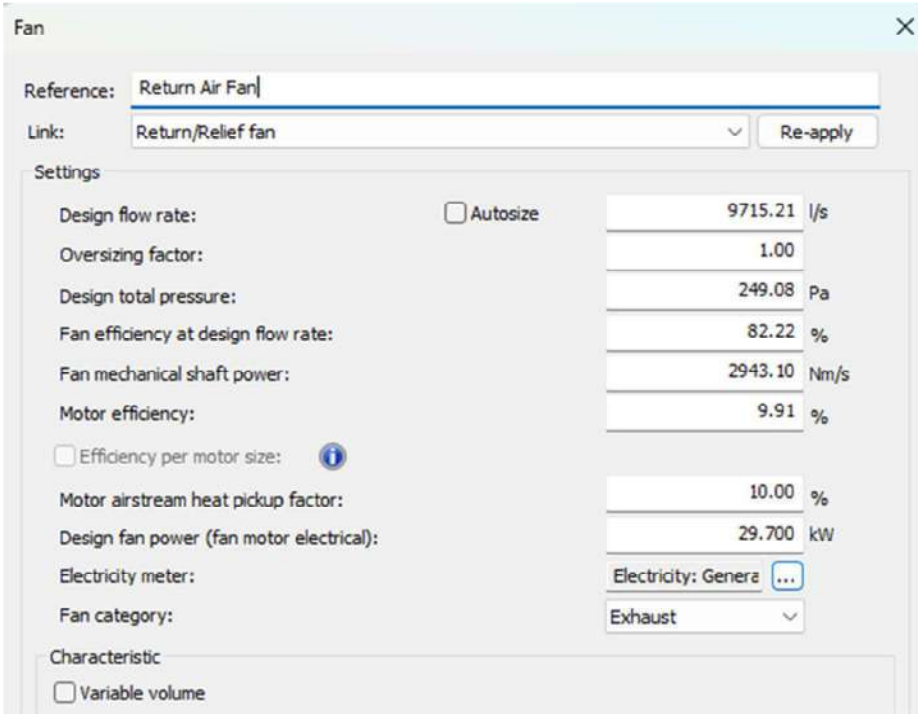

Figure 72: Return Air Fan in ApacheHVAC for Scenario 4

12. Component 17 (Exhaust Air Fan)

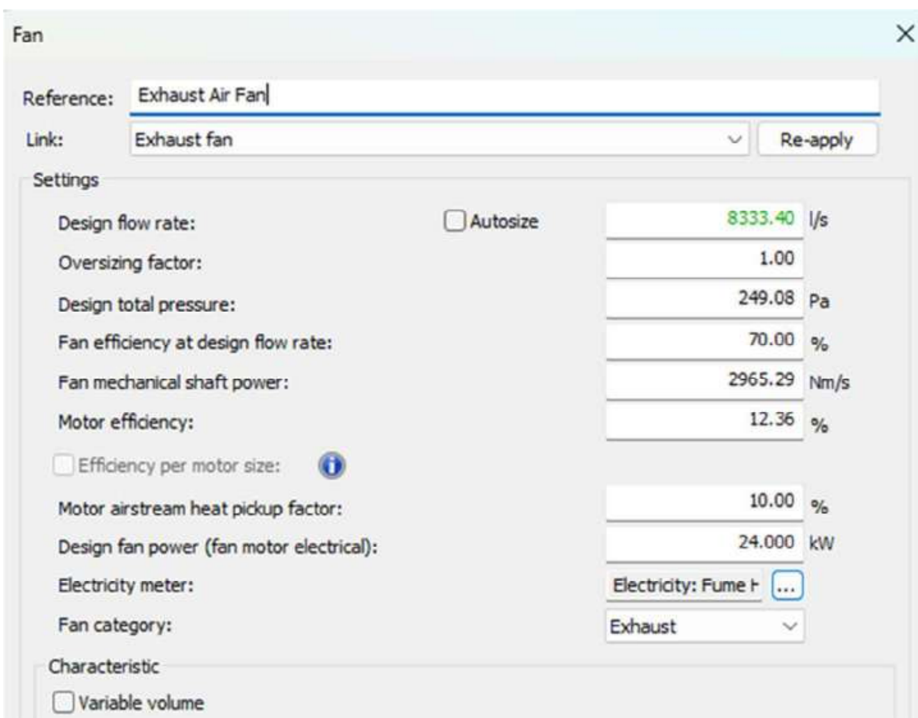

Figure 73: Exhaust Air Fan in ApacheHVAC for Scenario 4

8.4 Appendix D – Zoning Drawings

NUS MD6 - LEVEL 11 ZONING DRAWING

LEGEND

- OTHER BASE BUILDING SYSTEMS
- SINGLE PASS LAB SYSTEM[1]

NOTE 1:
ENERGY MODELLING CONDUCTED ON SINGLE PASS LAB SYSTEM