EVALUATION OF COMMISSIONING METHODS ON BUILDING AUTOMATION SYSTEM OF DEDICATED OUTDOOR AIR SYSTEM

A Thesis in
Architectural Engineering

by

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ABSTRACT

Building Automation Systems (BAS) are widely used in large commercial buildings to assist in the management of the building HVAC system. The purpose is to replace manual operation with automatic operation, improve indoor air comfort, and to reduce energy consumption through improved control strategies. One reason for lack of energy conservation for BAS is that the settings in building automation system are not optimized according to the operation building system condition and load requirements.

To address this issue, studies focused on commissioning for BAS, which can be called building re-tuning, have been developed by PNNL to provide optimized solutions for building operators. However, the building re-tuning solutions having been promoted are mainly for the Variable Air Volume system, problems may persist when the BAS for a different type of system needs to be commissioned, for example a Dedicated Outdoor Air System (DOAS). The air handling process for DOAS is very different from the process for a VAV system, despite the fact that DOAS is also widely implemented in commercial buildings.

In order to address these issue, this project focuses on the evaluation of effectiveness of the common VAV BAS commissioning measures to the Dedicated Outdoor Air System. The main research method is modeling with the EnergyPlus program. Baseline models with DOAS and fan coil system have been built in this study, and 6 types of commissioning measures are implemented and compared with the base models. The energy performance for the commissioning measures are simulated in 16 different
locations in the U.S. Finally, the analysis will be based on the comparison between the effectiveness of measures in different climates, between a VAV system and a DOAS, as well as comparison between DOAS unit and parallel cooling system.

This document includes a literature review on commissioning and DOAS, a case study for commissioning a DOAS, and the energy modeling process for this study. The result of modeling and the detailed coding about the commissioning measures are also presented.
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Chapter 1
INTRODUCTION

1.1 Background
In U.S.A., energy consumption in commercial sector is around 18% to total annual energy use, and HVAC system consumes around 33% of that total. Developing more efficient buildings helps ensure a steady supply of affordable power and significantly lowers operating costs for business. Researchers have investigated commissioning results for 224 existing buildings, and they found commissioning is one of the most cost-effective methods to improve energy efficiency in commercial buildings. Study shows that the median energy cost savings through commissioning is around 15% or $0.27/sf per year, and the median payback period is around 0.7 years [6].

Building automation systems are widely used in commercial buildings for building energy management. Many studies and engineering experience indicate commissioning a building automation system can be cost effective. One reason is that it doesn’t require much equipment replacement since frequently the commissioning only requires changing some set points.

PNNL has developed a study to evaluate the energy effectiveness of some common commissioning/ re-tuning methods to large commercial buildings. The study compared the energy performance between a respectively base model with the models that have been implemented individually or combined commissioning/building retuning methods. The models are built based on DOE large office building reference model and are simulated using Energyplus. Energy performance is evaluated based on the energy
savings calculated in terms of annual percentage energy savings compare to baseline. And HVAC system’s energy saving is broken into sub-components of heating, cooling, fans and pumps. The re-tuning measures that are investigated in PNNL’s study include: [1]

A1. Shortened HVAC schedules
A2. Static pressure reset
A3. Supply-air-temperature reset
A4. Supply-air temperature reset
A5. Changing (but keeping constant) the supply-air set point
A6. Reduce/lower VAV damper minimum air flow rate
A7. Wider thermostat temperature range
W1. Minimum outdoor-air fraction set to “0” during unoccupied hours
W2. Chilled-water differential pressure (DP) reset
W3. Chilled-water temperature reset
W4. Hot-water DP reset
W6. Hot-water temperature reset
W6. Condenser water temperature reset
W7. Plant shut down when there is no load

Those methods do not take much effort and expense since its just need to change some set point in BASs, but in the mean time they can bring improvement to energy performance of HAVC system, and also to indoor air quality.
The result of PNNL’s study shows that those re-tuning methods, which only require some changes to control simulation with little capital investment, have the potential to save a relatively large fraction of HVAC energy consumption. And after compare the energy saving between measures implemented to different HVAC sub-system, they found that measures from air-side can bring largest savings.

However, the HVAC system in their model is traditional VAV system, there might be some difference when implementing those measures to a different kind of system, for example DOAS, which has a different air handling process.

DOAS is now widely used in commercial building. It can provide the space with dedicated outdoor air, thus the indoor air quality can be largely improved compare to traditional VAV system. Also, while the traditional VAV system uses the whole supply air to handle both latent and sensible load, DOAS could reduce the energy consumption by separating the latent load handling process and sensible load handling process. Normally there would be a parallel cooling and heating system for space sensible heating and cooling, for example chilled beam system, fan coil unit system. Because the air handling process of DOAS is different with traditional VAV system, the commissioning to DOAS would also be different.

Thus there’s a need to evaluate the energy effectiveness of common commissioning/building retuning measures for DOAS. And better solutions for commissioning a DOAS should be developed.
1.2 Methodology
The Main method for this study is energy modeling through Energyplus, to find out if there's any difference in energy saving from DOAS and VAV system. Energyplus models are developed for DOAS is to research about the energy effectiveness of the energy efficiency measures studied by PNNL. Baseline models for DOAS with Fan Coil cooling system are developed. Research is developed by studying the effect after implementing common commissioning measures to baseline models.
And a case study is also conducted in an existed office building with DOAS implemented, in order to identify the gap between modeling and actual implementation. Building 661, an office building in Philadelphia, is investigated in this project. Data from the BAS of building 661 are analyzed.

1.3 Objectives
The objective for this project is to identify the difference between commissioning/ building retuning for VAV system and DOAS, so as to provide assistance in commissioning for DOAS.
Chapter 2

LITERATURE REVIEW

This chapter includes literature review about building retuning, building automation system, commissioning, and dedicated outdoor air system (DOAS). Chapter 2.1 gives brief introduction about building retuning, and chapter 2.2 and chapter 2.3 further introduces the commissioning with BAS.

2.1 Building Retuning
Developed by PNNL, building retuning is a systematic process to identify and correct building operational problems that lead to energy waste [1]. It can be considered as a scaled down RCx which requires little capital investment. By taking advantage of building automation system, building retuning can be a very cost-effective way to conserve building HVAC energy. Common building retuning measures include for example, shorten the HVAC schedules, optimizing supply air temperature, adjust the supply fan static pressure set points. The main strategy is to reset the set-points and control algorithms, which have led to unnecessary energy consumption or even malfunctions of HVAC system.

2.2 Building Automation System
Building automation system (BAS) or building management system is a system that can automatically control the building heating, cooling, ventilation and air conditioning (HVAC) system, and other system for example lighting system and hot water system. It can be considered to encompass both hardware and software. The hardware normally
includes sensors, actuators, controllers and wiring, and the software mainly includes control algorithms, user interface, and other packaged functionality in modern BAS [3]. The BAS have been widely used over years because of it can provide convenience for the building operators and managers to manage the whole building system so as to reduce the energy consumption and improve indoor comfort. Modern BAS always can operate the building systems on a very high level [3], documenting and managing the energy performance of multi subsystems for example heating and cooling, fans, pumps, lighting, and equipment. Fig 1 shows the user interface of the BAS of a medium size office building in Philadelphia. Building managers can read and trend data through it, and also can operate the whole building system easily.

Figure 1 Building Automation System of Building 661
2.3 Commissioning

2.3.1 Definition and Purpose

It is defined in ASHRAE Guideline that “The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria”. Commissioning is a process starting from the design phase and continually be implemented till the operating phase. The aim is to bridge the gap between design, construction, operation and the expectation of the building owners. There are different types of commissioning, initial commissioning, retro-commissioning, re-commissioning, and ongoing-commissioning. Table 1 describe the commissioning process types from IEA’s study [3].

![Diagram of Commissioning Process Types]

Table 1 IEA’S description for commissioning process types [3]

2.3.2 Commissioning Plan

Commissioning plan is one of the significant tools to help commissioning follow a well-organized process. As is defined in the ASHRAE Guideline, commissioning plan is “A document that outlines the organization, schedule, allocation of resources, and documentation requirements of the Commissioning Process” [3]. Three types of
commissioning plan tools were used within the Annex which are, Standard Models of Commissioning Plans (SMCxP), Check lists, Matrix for Quality Control (MQC), of which three SMCxP includes the typical steps and defines a customized Cx process, and MQC is a quality-control oriented tool and have been developed in excel application. For example, MQC_IP is developed by Japanese team, which describes typical matrix and includes detailed links directed to required documents, technical tool information, and directly tool itself to run a program. Figure 1 shows the interface of MQC Matrix [13].

![Figure 1 MQC Matrix Interface](image1)

**2.4 Commissioning with BAS**

Building control systems are widely used to manage building systems. The trend is that more subsystems are coming under the control of BAS, and BAS is becoming more modular. Those modularized components of system could be tested and commissioned at the factory before arriving the building and installation, thus the on-site commissioning for BAS would be mainly about: [3]

- Malfunctions caused by the installation process for example wiring connection;
- Point of sensors in control logic;
- Commissioning the energy system with the assistant from building automation system itself, for testing and correcting operation.

This study mainly focuses on the third aspect, the commissioning to building energy performance with the help of building management system.

### 2.4.1 Testing with BAS

Function Performance Testing (FPT) is a significant step before any commissioning process. Malfunction in HVAC system may be due to Design fault, selection or sizing mistakes, Manufacturing fault or initial deterioration, installation fault, wrong tuning, control failure and Abnormal conditions of use. The functional performance testing is devoted to the detection of such possible malfunction and to its diagnosis. Table 2 is a list of common faults in AHU surveyed by Yoshida et al (1996) and classified into five groups by Peng Xu et al [9], based on a classification presented in Haves et al (1996).

Testing of building system can be performed taking advantages of BAS and can be categorized to passive testing and active testing [3]. Passive testing is to use BAS to read and trend data from sensors of the system without disturbing the original operation of the system. The selection of the data point is a significant step in testing process. Fig 3 shows the chilled water temperature difference calculated from data output from BAS. Active testing means to manually change some settings in BAS to evaluate the system performance so as to get more information about the operation and function performance. Passive testing is performed in this study to the BAS of an office building in Philadelphia and the result analysis can be found in Chapter 3.

<table>
<thead>
<tr>
<th>Group I Fault</th>
<th>Supply/Return Fan</th>
<th>Heating/Cooling Coil &amp; Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage of outside air damper</td>
<td>Range error in variable-frequency drive</td>
<td>Control valve leakage</td>
</tr>
<tr>
<td>Incorrect minimum position of outdoor air damper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group II Fault</th>
<th>Supply/Return Fan</th>
<th>Heating/Cooling Coil &amp; Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside or exhaust dampers stuck closed or partially closed</td>
<td>Complete failure, e.g., seized, broken belt, power tripped</td>
<td>Valve or actuator stuck open or partially open</td>
</tr>
<tr>
<td>Leakage of return air damper</td>
<td>Wrong type of fan</td>
<td>Coil, valve, or pipe blocked</td>
</tr>
<tr>
<td>Return air damper stuck open or partially open</td>
<td>Incorrect rotation direction or wrong fan installed</td>
<td>Filter partially clogged</td>
</tr>
<tr>
<td></td>
<td>Undersized fan</td>
<td>Fouled coil</td>
</tr>
<tr>
<td></td>
<td>Stuck at intermediate speed</td>
<td>Incorrect function of DP sensors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group III Fault</th>
<th>Supply/Return Fan</th>
<th>Heating/Cooling Coil &amp; Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damper(s) or actuator(s) stuck</td>
<td>Complete failure, e.g., seized, broken belt, power tripped</td>
<td>Valve or actuator stuck</td>
</tr>
<tr>
<td>Actuators fail to respond to changing control signal</td>
<td>VFD or inlet guide vanes fail to respond to changing control signal</td>
<td>Actuator fails to respond to changing control signal</td>
</tr>
<tr>
<td>Sensor offset/failure</td>
<td>Sensor offset/failure</td>
<td>Sensor offset/failure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group IV Fault</th>
<th>Supply/Return Fan</th>
<th>Heating/Cooling Coil &amp; Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hysteresis in actuator(s) or damper linkage(s)</td>
<td>Hysteresis in VFD or inlet guide vanes</td>
<td>Hysteresis in actuator or valve linkage</td>
</tr>
<tr>
<td>Damper and actuator mismatch</td>
<td>Variable speed drive malfunction</td>
<td>Improper installation of actuator and valve</td>
</tr>
<tr>
<td>Excessive nonlinearity</td>
<td></td>
<td>Poor valve authority</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group V Fault</th>
<th>Supply/Return Fan</th>
<th>Heating/Cooling Coil &amp; Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor loop tuning</td>
<td>Poor loop tuning</td>
<td>Poor loop tuning</td>
</tr>
<tr>
<td>Software error</td>
<td>Software error</td>
<td>Software error</td>
</tr>
<tr>
<td>Incorrect control signal</td>
<td>Incorrect control signal</td>
<td>Incorrect control signal</td>
</tr>
</tbody>
</table>

**Figure 3 Chilled water temperature difference**

#### 2.4.2 Tools and Methods

Model based methods and rule based methods are two of the common methods in commissioning with BAS. Model based methods can be used to assist in analysis when
predicting the performance of building system under certain action. Current domain simulation tools include DesignBuilder, Energyplus, eQuest, Autodesk Revit, Autodesk CAD etc., and can be interoperable when using together for modeling [4]. Energyplus is used in this thesis study to simulate the energy performance changes of large commercial building with DOAS system, and the details of the modeling and analysis can be found in Chapter 4. Rule based methods means to build certain logic according to physical engineering rules among, for example, temperature, heat transfer, and energy consumption [3].

Automatic commissioning tools can be built and applied in BAS commissioning process, but the available tools are few and the technology is still under developed. Example tools and their testing can be found in Annex 40 project [3].

One of the important aspect of commissioning to BAS is to identify the control logic behind the system operation, so as to track down the problem located and to correct and improve the system performance. A Japanese team (Shioya et al., 2004) have developed a tool, Control Logic Tracer (CLT), to help users and building managers to identify the control logic with operational data input [3].

2.5 Dedicated Outdoor Air System
Dedicate Outdoor Air System (DOAS) is a type of HVAC system that separate the sensible and latent load handling process by two parallel systems: a dedicated outdoor air system for ventilation and dehumidification, and a parallel system for example chilled beam system and fan coil systems to handle sensible heating load. This type of HVAC system is developed because of the potential problems that cause by traditional
VAV system. For traditional VAV system, the ventilation is only an incidental part of the whole air conditioning process when handling the interior air to provide heating and cooling. This inadequate ventilation would lead to uncomfortable indoor air quality, even causing sick building syndrome.

Large commercial building always has complex zone types serving the needs for multiple function and occupancy schedule. It was found by Mumma that there’s difficulty in ensuring both proper temperature and proper ventilation in all spaces with VAV systems, providing less air to meet temperature settings but more to provide needed ventilation. Studies have proved that, to meet ASHRAE ventilation standard, VAV consumes 20-70% outdoor air more than DOAS, and to control both sensible and latent load, VAV invariably lead to high relative humidity. What’s more, Mumma provides comparative cost estimates for conditioning a 186000sf office building in Philadelphia with conventional VAV system and DOAS with parallel radiant systems. The result is that, for installation, the cost of VAV system is 1.4 times compare to DOAS, and for operation, VAV systems would cost 1.29 times to the DOAS with parallel cooling [11]. And DOAS can be a very reliable and simple method to meet ASHRAE standard 62-1991 [12].

2.5.1 Air handling process
Outdoor air is supplied via supply fan to the DOAS units to be dehumidified through cooling coil or desiccant dehumidification. Study shows that dehumidification by cooling coil is good for situation when dew-point temperature of supply air is required to be above 40F, and active desiccant dehumidification can be good for situation when dew
point temperature of supply air is below 40F. The reheat coil is installed in the AHU to serve the need when required supply air dew point temperature is lower than the desired supply air dry-bulb temperature. The conditioned air is supplied to the space to remove moisture generated by infiltration, occupants, and evaporation of indoor fluid etc. [12].

2.6 Energy Modeling
Building system is complicated because of its various components that may influence the heat balance of building, for example occupancy, construction, HVAC system, also outside weather. Thus it would require detailed and comprehensive simulation when performing analysis work [3]. When analyzing the energy performance of a building, four aspects should be taken into consideration, the construction, HVAC system, occupancy and outside environment condition.

Carnegie Mellon university have done conducted a study summarizing the complete process of a whole-building energy performance model development under specific conditions and constraints [4]. The study includes building a model for a building with EnergyPlus version 6.0 program. The process of model development mainly includes the categorization the model input data, specification the available information sources for modeling input data, and the development of the framework of modeling process. They separate the data into category components for example building geometry, occupancy, building envelop, thermos zones and HVAC systems etc. ASHRAE standard and DOE reference models are two main sources to be referred to in the modeling process [10].
Computer modeling are also widely used in both research and commissioning practice. It can be a link between the design, operation and commissioning, to help with the function performance testing and result analysis and predict when implementing commissioning methods [4].

2.6.1 DOE Reference building---Large Office
Standard building energy models for most common types of commercial buildings have been developed by the U.S. Department of Energy (DOE) Building Technologies program to serve in the research of building energy. And the Energyplus input files describing those building in details are available online. 16 building types are modeled throughout 16 locations in the U.S.

<table>
<thead>
<tr>
<th>Program</th>
<th>Form</th>
<th>Fabric</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Number of floors</td>
<td>Exterior walls</td>
<td>Lighting</td>
</tr>
<tr>
<td>Total floor area</td>
<td>Aspect ratio</td>
<td>Roof</td>
<td>HVAC system types</td>
</tr>
<tr>
<td>Plug and process loads</td>
<td>Window fraction</td>
<td>Floors</td>
<td>Water heating equipment</td>
</tr>
<tr>
<td>Ventilation requirements</td>
<td>Window locations</td>
<td>Windows</td>
<td>Refrigeration</td>
</tr>
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<td>Occupancy</td>
<td>Shading</td>
<td>Interior partitions</td>
<td>Component efficiency</td>
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<tr>
<td>Space environmental conditions</td>
<td>Floor height</td>
<td>Internal mass</td>
<td>Control settings</td>
</tr>
<tr>
<td>Service hot water demand</td>
<td>Orientation</td>
<td>Infiltration</td>
<td></td>
</tr>
<tr>
<td>Operating schedules</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Categories in DOE Reference Model [5]

The building types include office building, school building, stand-alone retail building, strip mall building, supermarket, service restaurant, hotel, hospital, outpatient healthcare, warehouse and apartment building. The 16 locations include, Miami, Houston, and Atlanta etc. Those locations can represent a significant portion of existing building locations and are included into all climate zones in the U.S. Table 3 shows the
main categories described in the reference building models [5] and Table 4 gives a simple description about the climate for those reference cities.

<table>
<thead>
<tr>
<th>Representative City</th>
<th>DOE Climate Zone</th>
<th>Dew Point (°F)</th>
<th>June-September Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Code</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>Miami, FL</td>
<td>1A</td>
<td>Very Hot, Humid</td>
<td>72</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>2A</td>
<td>Hot, Humid</td>
<td>70</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>2B</td>
<td>Hot, Dry</td>
<td>52</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>3A</td>
<td>Warm, Humid</td>
<td>65</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>3B-CA</td>
<td>Warm, Dry, California</td>
<td>58</td>
</tr>
<tr>
<td>Las Vegas, NV</td>
<td>3B -other</td>
<td>Warm, Dry</td>
<td>38</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>3C</td>
<td>Warm, Marine</td>
<td>51</td>
</tr>
<tr>
<td>Baltimore, MD</td>
<td>4A</td>
<td>Mixed, Humid</td>
<td>62</td>
</tr>
<tr>
<td>Albuquerque, NM</td>
<td>4B</td>
<td>Mixed, Dry</td>
<td>47</td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>4C</td>
<td>Mixed, Marine</td>
<td>50</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>5A</td>
<td>Cool, Humid</td>
<td>58</td>
</tr>
<tr>
<td>Boulder, CO</td>
<td>5B</td>
<td>Cool, Dry</td>
<td>44</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>6A</td>
<td>Cold, Humid</td>
<td>57</td>
</tr>
<tr>
<td>Helena, MT</td>
<td>6B</td>
<td>Cold, Dry</td>
<td>42</td>
</tr>
<tr>
<td>Duluth, MN</td>
<td>7</td>
<td>Very Cold</td>
<td>51</td>
</tr>
<tr>
<td>Fairbanks, AK</td>
<td>8</td>
<td>Subarctic</td>
<td>42</td>
</tr>
</tbody>
</table>

Table 4 Climate of 16 reference Cities [5]
Chapter 3
CASE STUDY

3.1 Introduction
A case study is conducted in a medium sized office building which is located at Philadelphia. The building is newly renovated with DOAS and chilled beam cooling system. Detailed research is conducted to the building’s HVAC system, BAS, and building commissioning history.

The process of this case study mainly follow the PNNL’s large commercial building re-tuning training instruction. Differences between commissioning methods to VAV system and DOAS are identified, also gaps between energy modeling and practical implementation are recognized.

3.2 Building Information

3.2.1 Basic Information
The building in this study is Building 661 located at Navy Yard Philadelphia, which is a medium sized office building. The building has a floor area of 38,000 GSF, and was designed as a living laboratory for building science researchers to test the real world application of a number of energy conservation measures. The building was built in 1942 and was formerly a Navy recreation center which has a tight building envelope, and the renovation was finished in 2014. The building has three areas with distinct
occupancy pattern and HVAC system type.

Figure 4 System Distribution [14]

<table>
<thead>
<tr>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC System</td>
<td>Energy Recovery</td>
<td>Heat recovery RTUs</td>
</tr>
<tr>
<td></td>
<td>DOAS &amp; Chilled</td>
<td>VFV multi-split system</td>
</tr>
<tr>
<td></td>
<td>Beam</td>
<td></td>
</tr>
<tr>
<td>Cooling Plant</td>
<td>Air source Heat</td>
<td>Air source Heat Pump</td>
</tr>
<tr>
<td></td>
<td>Pump</td>
<td></td>
</tr>
<tr>
<td>Heating Plant</td>
<td>Supplemental</td>
<td>Supplemental condensing boiler</td>
</tr>
<tr>
<td></td>
<td>condensing boiler</td>
<td>No supplemental heating</td>
</tr>
</tbody>
</table>

Table 5 Description of HVAC system [14]

3.2.2 HVAC system

Figure 4 shows the intersection building with description of HVAC systems. DOAS with chilled beam cooling and fin tube heating are implemented to the area 1, main working space and atrium. Area 2, which is mainly conference room space, is covered with roof.
top unit system. And area 3, where individual office located, is implemented with VFV multi-split system. More detailed information for systems of three areas is shown in Table 5.

3.2.3 Dedicated Outdoor Air system (DOAS)
Figure 5 gives a brief introduction about air handling process of the DOAS air handling unit. Besides the regular components as dehumidification cooling coil, pre-heating and re-heating coil, fans and dampers, there’s a heat recovery wheel and desiccant dehumidification wheel implemented in the AHU. The outdoor air would firstly get the recovered heat from the exhausted air and then mix with the return air under certain outdoor air fraction. Dehumidification is mainly done through the cooling coil with reheat coil to control the supply air temperature within certain set point range. The supply and return fans in AHU are both variable frequency drive although constant volume of air is supplied to the system all year round for minimum ventilation. Sensors are placed at certain point sending data to the controller and connecting actuators to control the valves and dampers’ position and fan speed etc.

Thus in this case study, potential difference of the commissioning process and methods can be detected starting from the identification of the difference between characteristics of the DOAS and VAV systems. General and specific Building Retuning Process flow for Large Commercial building with Building Automation System are developed, with data needed, competency required addressed, in order to fill the gaps
existing in building retuning implementation.

3.3 Building Automation System

3.3.1 Data points

The building management system of building 661 takes control over the HVAC system of the building and is provided with user interface to assist in monitoring over bellow data points:

- Air Temperature: space air temperature, supply/ exhaust/ return air temperature;
- Water Temperature: chilled water supply/ return temperature, cooling/ heating coil entering and leaving temperature, hot water supply/ return temperature;
- Pressure: supply air pressure, energy recovery wheel entering air pressure, etc.;
- Air volume: supply/return/exhaust air volume of DOAS unit and fan power boxes;
- Water volume: chilled water supply/ return water volume rate, hot water volume rate, etc.;
- CO₂ concentration;
- Humidity: supply/ return air humidity ratio, space air humidity ratio;
- Fan speed;
- Valve and dampers’ position;
- Status of equipment: on/off for chiller, compressor, fans, pumps;
- Energy consumption: energy consumption of fans, chillers, daily gas consumption, etc.;

3.3.2 Control and Operation Status
Control document from the design company of building 661 have been researched to learn about the system operation strategy at design stage. Schedule, ventilation, fan operation, are mainly studied in this chapter.

Malfunctions may exist in the BAS causing by fault in installation of the BAS, wiring, or improper working status of equipment such as sensors and actuators. Thus before the investigation to BAS, a report from a project at CBEI, regarding the sensors functioning, have been researched to know whether the components in BAS are working properly. The report shows that following sensors are not working properly in Building 661: [8]

a. Relative humidity sensors of working room #131 and #139

b. Temperature sensor of Exhausting Fan-3 for ICON lab

3.3.2.1 Schedules
From the control document at design stage, the HVAC system of building 661 operate with following schedule.

- Occupied Mode: From 7am to 6pm
- Unoccupied Mode (night setback): 6pm to 12am; 12am to 7am

The BAS of building 661 have been investigated to learn about the HVAC operation status. The operation schedule can be identified based on the status of fans, pumps, or
supply air volume. Figure 6 shows the supply air volume with the occupancy schedule setting in BAS.

![Figure 6 HVAC system schedule and occupancy schedule](image)

3.3.2.2 Temperature
The DOAS system is designed to maintain a dew point temperature within the chilled beam areas of 57 degrees Fahrenheit at all times. The supply air temp shall vary between 62 degrees Fahrenheit for cooling, and 85 degrees Fahrenheit upon a call for heating. Below is the thermostat set points at design stage:

- **Occupied Mode**:
  - dew-point: 57 F;
  - cooling set point: 75 F (adjustable);
  - heating set point: 70 F (adjustable).

- **Unoccupied Mode (night setback)**:
  - dew-point: 60 F;
  - cooling set point: 85 F (adjustable);
heating set point: 60 F (adjustable).

- Holiday Mode (extended leave):
  dew-point: 60 F;
  cooling set point: 85 F (adjustable);
  heating set point: 50 F (adjustable).

3.3.2.3 Minimum ventilation
To maintain the indoor air quality, DOAS supply minimum outside air to space for ventilation. When in occupied mode, the controller measures the space CO2 levels and modulate the outside air dampers closed to 1500 CFM outdoor air minimum and the return air damper open on dropping CO2 concentrations, to maintain a CO2 set point of 700 ppm within the space. The controller measures the outside airflow in CFM. The detailed ventilation status can be found in Chapter 5.

3.3.2.4 Supply Fan Operation
The supply fan VFD is operated at a constant speed as set by the contractor upon a call for heating or cooling in the occupied and holiday modes. When the controller is in the occupied mode, the supply fan will operate continuously. And if the supply fan fails to provide status for 30 seconds (adjustable) the fan will be turned off, the outside air damper and all cooling / heating will be disabled, and an alarm will be annunciated.

3.3.2.5 Static Pressure Reset
The fan in DOAS units of Building 661 is variable frequency drive but is set to a constant speed providing minimum air volume all year round. Figure 7 shows that the supply air volume never changes whatever the outside air temperature and relative humidity.
3.3.2.6 Thermostat Set Point

The split system in building system is also under control by BAS. Figure 8 shows the thermostat setting for a small conference room which for the most of time is not occupied. It was complained by the resident of the building that this zone temperature is too low. Thus a low Supply air temperature in cooling season would not only lead to energy waste but also not good for indoor comfort.
3.3.2.7 Chilled-water Temperature
The chilled water temperature difference is calculated from the data of chilled water supply and return temperature output from BAS. It is shown by Figure 9 that the temperature difference is around 8F.

![Chilled Water Delta T in June](image)

**Figure 9 Chilled Water Difference Temperature**

3.4 Conclusion
1. Malfunctions are widely existed in large commercial buildings not only the ones having been used for many years but also newly constructed, like building 661, and can be easily re-tuned taking advantages of BAS.

2. Gaps exist between PNNL’s building retuning training material and the implementation of commissioning to Dedicated Outdoor Air System.

3. The accessibility of data point needed in building automation system is crucial to the commissioning process.
4. The gaps of energy modeling and practical implementation are discussed in chapter 5, after comparison of modeling results and system operation of building 661.
4.1 Introduction
Energy savings for different individual RcX/retuning measures are estimated in this study through simulation, with Energyplus programming. In order to compare the difference if implementing same measures to VAV system and DOAS, the same measures targeted in PNNL’s energy saving modeling project are studied [1]. And this study only focuses on the air-side measures mentioned in PNNL’s report which shows most significant portion of energy saving for VAV system.

For energy simulation, baseline models with common practice inefficiencies are firstly developed refer to an existed DOAS EnergyPlus model [6] and PNNL’s baseline model [1]. And to evaluate the energy performance improvement, individual measures are then implemented to baseline models refereeing to EnergyPlus Engineering Reference [7]. Those models are referred as “Cx models” in this paper. The individual measures include:

1. Shorten HVAC schedules
2. Static Pressure Reset
3. Supply-Air Temperature Reset
4. Supply-air Temperature Constant Set Point
5. Wider Thermostat Range
6. Minimum Outdoor Air Reset
4.2 Baseline model
Baseline models are developed by fitting DOASs into DOE reference large office building models. Figure 10 gives a simple description of the building. There are three floors and a basement underground.

![Figure 10 Description of the building](image)

Four DOAS with fan coil systems are implemented separately into three floors and the basement. The occupancy of the building can be found in chapter 4.2.1, and 4.2.2 gives a simple description of the HVAC system.

4.2.1 Occupancy and Load
The building is occupied mainly from 8 am to 5 pm during weekdays and some period on Saturdays. Table 6 shows the occupancy rate of typical office space [5]. For the models in this study, the occupancy density for floor above the ground are 200sf/ person, and the occupancy density for basement is 400sf/ person. Table 7 shows the occupancy schedule of the building, which is described by fraction of total number of residents before specific hour of time.

<table>
<thead>
<tr>
<th>Space Type</th>
<th>Occupancy per Space</th>
<th>Occupancy</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>–</td>
<td>200</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Table 6 Occupancy rate of office space
The heating and cooling load on design day can be found in Figure 11. The results are calculated from the data generated from baseline model simulated in Chicago.

<table>
<thead>
<tr>
<th>By Time of</th>
<th>6:00 AM</th>
<th>7:00 AM</th>
<th>8:00 AM</th>
<th>12:00 AM</th>
<th>13:00 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Fraction</td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.95</td>
<td>0.5</td>
</tr>
<tr>
<td>By Time of</td>
<td>17:00 AM</td>
<td>18:00 PM</td>
<td>20:00 PM</td>
<td>22:00 PM</td>
<td>24:00 PM</td>
</tr>
<tr>
<td>Occupancy Fraction</td>
<td>0.95</td>
<td>0.7</td>
<td>0.4</td>
<td>0.1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 7 Occupancy Schedule of Weekdays in Model

![Design Heating/Cooling Load-Chicago](image)

Figure 11 Design Load

4.2.2 HVAC system
As is described previously, the HVAC system simulated in this study is DOAS with fan coil system. There’s one DOAS unit on each of the floor. And each floor is divided into five zones, four perimeter zones and one core zone. Fan coil units are installed in all zones. And the DOAS units are ducted to the inlet of the fan coil units. Figure 12 shows the description of the DOAS in each floor.

As is shown in the figure, the DOAS unit in each floor are implemented with hot and cold water coils, standard variable air volume (VAV) fan, heat recovery unit and an economizer which is controlled based on enthalpy. The fan coil units would mix the
outdoor air and return air and then supply the mixed air to the zone. Hot and cold water coils and constant air volume (CAV) fans are implemented in fan coil units.

An electric compression chiller and a single-speed cooling tower are modeled to build a simple central cooling plant, and a simple central heating plant contains a hot water boiler. All of the equipment is auto sized [6].

![HVAC system on each floor](image)

**Figure 12 HVAC system on each floor**

### 4.3 Model with Individual Methods - Cx models

Individual measures are implemented to the baseline models, to develop “Cx models”.

The individual measures include:

1. Shorten HVAC schedules
2. Static Pressure Reset
3. Supply-Air Temperature Reset
4. Supply-air Temperature Constant Set Point

5. Wider Thermostat Range

6. Minimum Outdoor Air Reset

Those 6 methods have been studied in the PNNL’s study for retuning a VAV system, this study pick the same measures so as to compare the result generated from VAV system and DOAS.

4.3.1 A1-Shortened HVAC schedules
It is prompted by PNNL’s study that the HVAC system can be set to nighttime setback mode 2~4 hours earlier on both weekdays and weekends when building is not fully occupied. The baseline model has a HVAC schedule 6 a.m. to 22 p.m. on weekdays and 6 a.m. to 18 p.m. on Saturdays. These schedules have been shortened by 1 hour in A1a model and 2 hours in A1b model.

In Energyplus programming, the schedules of fans, pumps, thermostats, chiller, cooling tower etc. have been shortened 1-2 hours. Detailed settings can be found in Appendix A.

4.3.2 A2 - Static Pressure Reset
The mechanism of this measure is that, when supply same amount of air, the fan energy would increase with a higher static pressure set point. Resetting the static pressure set point means to automatically adjust it according to the measured static pressure value, which is associated with supply air volume.

This measure requires that the supply fan system is operational. Thus it might be not applicable for some DOAS, for example when supply fan in terminal unit is constant
speed, or the parallel system is radiant cooling/ heating system. The supply fans in FCUs in the models are constant speed, and this study means to evaluate the conditions when the fans in terminal units are not operational. Thus the measure is only applied to the VFD in supply fans in DOAS units, while in PNNL’s study, this measure was implemented to the VFDs in terminal VAV boxes [1].

In Energyplus programming, detailed fan models with inputs of static pressure reset based on supply air volume were implemented to the supply fan of DOAS central AHU. The relationship between static pressure set point and the supply air volume is described by certain curves in fan models. For base model, the curve with constant output of static pressure set point is applied, and for models with A2 measure, the curve with linearly changing output of static pressure set point is implemented.

The curves are based on the SPR Model, which gives simple description of pressure resetting procedure based on supply-air flow (Federspiel 2004, 2005) [7]. The method includes measurement of the static pressure and the air volume rate of supply air at multiple point within supply fan air volume range, while the damper position in DOAS units in changing to satisfy the setting of thermostat. The model describe the leaner relationship as follow: [7]

\[
\frac{(P_{sm} - P_{sm,\text{min}})}{(P_{sm,\text{max}} - P_{sm,\text{min}})} = \frac{(Q_{fan} - Q_{fan,\text{min}})}{(Q_{fan,\text{max}} - Q_{fan,\text{min}})}
\]

Thus,

\[P_{sm} = C_1 + C_2 \times Q_{fan}\]
Where the $P_{sm}$ is the static pressure, $P_{sm,min}$ is the minimum static pressure when damper is fully open, $P_{sm,max}$ is the maximum static pressure, $Q_{fan}$, $Q_{fan,min}$, and $Q_{fan,max}$ are the volume rate, minimum air volume rate and maximum air volume rate of supply air. The model shows a linear relationship between static pressure and fan air volume. For base model, the $C_1$ equals to the maximum static pressure and $C_2$ equals to zero, so as to define a constant static pressure setting. For A2 model, same maximum static pressure can be reached when the air volume of fan reaches its maximum.

4.3.3 A3 - Supply-Air Temperature Reset

In shoulder season, when the load for heating and cooling are not high, lower supply air temperature set point at the outlet of central air handling unit might generate higher reheat energy in terminal units. Thus adjusting supply air temperature set point according to outdoor air temperature can be applied to VAV system to save more energy. While for DOAS the humidity of the supply air should be considered because the DOAS is responsible for space latent load. However, in Energyplus, it is hard to model the control strategy of adjusting supply air humidity based on outdoor air condition, thus this study only focus on the sensible load part.

As for simulation, the SA Temperature in EnergyPlus varies linearly between two temperatures, the supply air temperature at outdoor low temperature (SATOL) and the supply air temperature at outdoor high temperature (SATOH). The rule is to apply SATOL when outdoor air temperature is below certain temperature point, which is 0 C, and apply SATOH when outdoor air temperature is above the temperature point set as 32C.
When the outdoor air is between 0 to 32°C, the supply air temperature would be calculated linearly between SATOH and SATOL.

The baseline model has a constant cooling supply air temperature of 12.8°C, and constant heating supply air temperature of 12.2°C. The A3 model adjusts this temperature between 12.8°C and 16.7°C based on the outdoor air temperature.

**4.3.4 A4 - Supply-air Temperature Constant Set Point**
The supply air temperature set point sometimes may be too low. This measure means to evaluate the influence on HVAC energy saving when changing constant supply air set point. The baseline model set the supply air temperature at 55°F, and this set point has been changed to 53°F and 58°F in A4 model. The setting of thermostat keeps the same.

Just as is mentioned previously, DOAS should be able to handle the latent load of the space. While since the dehumidification effect is hard to be simulated in Energypuls, this study only focus on the sensible part of the comparison between VAV and DOAS.

**4.3.5 A5 - Wider Thermostat Range**
In winter, the temperature of core zone might be higher than the perimeter zone because of the interior heat gain. The main mechanism of this measure is that there’s heat transfer between core zone and perimeter zone, so that there’s no need to heat or cool the zone too high or too low. Compare to the baseline model, A6 model increases the set point of thermostat by 2 degrees in cooling season and decrease it by 2 degrees in heating season.
4.3.6 A6 - Minimum Outdoor Air Reset
This measure means to close the outside air damper during unoccupied hours. In baseline model, the minimum outdoor air fraction set point is enforced during HVAC start up time in the morning, although the space is not occupied. And in A6 model, this minimum outdoor air fraction set point is only enforced during occupied hours.
It is defined by ASHRAE Standard 62.1 about minimum ventilation that, breathing zone outdoor air flow can be calculated from two parts, the minimum outdoor air flow per person and per floor area.

\[ V_{bz} = R_p P_z + R_a A_z \]

Where \( V_{bz} \) is outdoor air flow rate, \( R_p \) is outdoor airflow required per person, \( P_z \) is zone population, \( R_a \) is outdoor air flow rate required per zone floor area, and \( A_z \) is zone floor area.

DOAS is designed to provide dedicated outdoor air to space to improve the indoor air quality, and the minimum ventilation are required by both occupancy and zone area.
Thus whether this measure is legal for DOAS need to be further studied. This study only focus on the energy saving effect comparison between VAV and DOAS.
In baseline model, the minimum outdoor air fraction is enforced during morning start up time. In A6 model, the minimum outdoor air fraction schedule is modified based on the actual occupied schedule.
Detailed setting for all the measures can be found in Appendix A-E
Chapter 5
RESULT AND ANALYSIS

5.1 Introduction
This chapter describes the result of Energyplus simulation, case study, and the analysis. Those three parts are presented for all 6 measures mentioned in previous chapter, and the analysis is based on results of modeling and actual monitoring. 6 measures’ results and analysis can be found from chapter 5.2 to 5.7

5.1.1 Calculation process
The modeling result are firstly generated from Energyplus, then the percentage of onsite HVAC energy saving are calculated by following equations:

\[ \text{Energy Saving} = \frac{Q_B - Q_{Cx}}{Q_B} \times 100\% \]

\[ Q = E_{fan} + E_{pump} + E_{clg} + E_{htg} \]

Where the \( Q_B \) is total onsite HVAC energy of baseline model and \( Q_{Cx} \) is total onsite HVAC energy of the model after RCx/re-tuning measures implemented. The total onsite HVAC energy is calculated by sum up the fan power, pump energy, electricity consumption of cooling and gas consumption of heating.

5.1.2 Case Study
This chapter present the monitoring result about the operation of building 661. The six measures studied in this thesis are focused. The purpose is to identify whether there might be any gap between modeling and actual implementation.
5.2 A1-Shortened HVAC schedules
Measure #A1a and measure #A1b means to shut off the HVAC systems 1 hour and 2
hours earlier on both weekdays and Saturdays, and keep the HVAC system off on
Sundays and holidays. The operation schedule of base model is from 6 am to 22 pm in
weekdays from 6 am to 18 pm on Saturdays.

5.2.1 A1-Modeling results
Around 6% of energy can be found when shorten the HVAC schedules by 1 hour and
around 12% of energy saving can be found when shorten the HVAC schedule by 2 hours.
Figure 14 shows the result of the energy saving of subsystems by shorten 1 hour on
HVAC schedules. Figure N shows the total onsite HVAC saving after shorten the schedule
by 2 hours, and the result from PNNL’s study on VAV system are also presented in Figure
15.
For measure #A1, larger heating energy savings can be found in colder climate where the heating season is longer for example Fairbanks, and larger cooling energy can be found in warm and hot climate, for example Los Angeles and Houston. The result is similar to the result for VAV system with shorten schedules.

![Shortened HVAC schedules by 2 hours](image)

**Figure 15** Shortened HVAC schedules by 2 hours - DOAS

![Shortened HVAC schedules by 2 hours – VAV [1]](image)
The total energy saving effect is caused by the combination effect of savings by reduced working hours and the increasing consumption during night setback mode when system trying to keep the indoor temperature within proper range.

![Indoor Air Temperature - Shortened HVAC schedules](image)

*Figure 16 Indoor Air Temperature - Shortened HVAC schedules*

The space temperature of core zone on cooling and heating design day in Chicago, to serve as an example, is examined. Figure 16 shows that after the measures implemented, the space temperature is still in good range during occupied hours.

**5.2.1 A1-Case Study Result**

The status of supply fan in DOAS unit and secondary chilled water pump are monitored to identify the operation schedule of HVAC system in building 661. Figure N shows that the HVAC system of building 661 runs from 5 am to 7 pm daily, although the building only occupied from 9 am to 5 pm. Thus there’s energy saving opportunity for this measure. Checking the operation schedule and adjust it is necessary.
5.3 A2-Static Pressure Reset

This measure means to reset duct static pressure when the dampers are opened in smaller range. According to DOE reference modeling for fan, fan power in watt is:

\[ P_{sf} = \frac{f_{pl} \cdot m_{design} \cdot \Delta P_{fan,tot}}{(\eta_{fan} \cdot \rho_{air})} \]

Figure 18 Fan performance curve—“Manufacture’s Data from Loren Cook Company” [7]
Where $f_{pl}$ is part load factor related with flow, $m_{design}$ is the reference design air flow rate, and $\Delta P_{fan,tot}$ is the supply fan pressure rise, which must be sufficient to overcome the pressure drop of AHU. Figure 18 shows the relationship between fan power and the air flow with a constant pressure rise in duct. The pressure drop of AHU is depending on the duct static pressure, leakage of equipment and duct, and the pressure drop through the whole duct work including dampers, coils, and filters etc., which would increase to the amount as the square of the air flow [7].

The pressure rise can be expressed as:

$$\Delta P_{fan,tot} = A_{fpr}Q_{fan}^2 + B_{fpr}Q_{fan} + C_{fpr}Q_{fan}\sqrt{P_{sm} - P_o} + D_{fpr}(P_{sm} - P_o)$$

Where $\Delta P_{fan,tot}$ is the fan total pressure rise, $Q_{fan}$ is the air flow at design condition, $P_{sm}$ is the static pressure set point of duct, $P_o$ is the space static pressure outside the duct. $A_{fpr}, B_{fpr}, C_{fpr},$ and $D_{fpr}$ are constant coefficient [7]. The function shows that the total fan pressure rise would increase with a higher static pressure set point, also the fan power would increase although the same amount is supplied to the space. Thus the fan power could be reduced if the duct static pressure set point can be reset based on the duct pressure drop, which is related with the changing damper position when supplied different air volume to the space. As is described before in Chapter 4 measure A2, duct static pressure is reset by input a linear function curve describing the static pressure based on changing air volume.
5.3.1 A2-Modeling Result
Lower than 0.3% of energy saving can be found after static pressure reset are implemented to supply fans in DOAS AHUs and higher energy saving can be found in warmer climate. However, compare to the effect after static pressure reset to VAV system, which can be found in Figure 19 and Figure 20, the energy saving from DOAS with fan coil systems is low. The reason is that for DOAS, the measure is implemented to fans in DOAS units which only supply small fraction of air to the space for ventilation, which only consume small part of energy. And for VAV system, the measures are

Figure 19 Static Pressure Reset – VAV [1]

Figure 20 Static Pressure Reset - DOAS
implemented to VAV boxes in each zone, which are responsible for supplying total amount of supply air to the space. Thus the energy saving can be higher. And there’s a secondary effect that heating energy increase and cooling energy decrease, because the heat rejection from fan to the airstream become less after resetting the pressure.

Figure 21 Indoor Air Temperature - Static Pressure Reset

Figure 21 shows that after implementation, the space temperature of core zone on cooling and heating design day in Chicago, is still in good range during occupied hours.

5.3.2 A2-Case Study Result
The DOAS in building 661 is designed to only provide small fraction of air for minimum ventilation. Although the supply fan in DOAS unit has variable speed drive, the supply fan rarely modulated and is set to 70% of full speed almost all year round.

The set point of static pressure is not available on BAS. The monitored value can be found in inch of water, which shows that it is changing with the volume of supply air.
5.4 A3-Supply-Air Temperature Reset

The mechanism for this measure is to automatically adjust the supply air temperature based on the outdoor air temperature, so as to reduce the heating and cooling energy in terminal units.

5.4.1 A3-Modeling Result

Larger saving can be found in warmer climate where there’s a longer shoulder season, which is the same for both DOAS and VAV system, while in coldest climate, DOAS shows a different energy saving pattern than VAV. For VAV system, both the energy saving in
coldest and hottest climate are a lot lower than warmer climate. Figure 23 and 24 describes the energy saving for DOAS and VAV system.

![Supply-Air Temperature Reset](image)

**Figure 23 Supply Air Temperature Reset - DOAS**

What’s more, around 7% to 20% of total HVAC energy saving can be found for DOAS, as is shown in Figure 23, which is lower than energy saving generated from VAV system,

![Supply Air Temperature Reset](image)

**Figure 24 Supply Air Temperature Reset – VAV [1]**

which can be up to 45%, shown in Figure 24. The reason is that, compare to VAV system,
the amount of air, from DOAS, with adjusted temperature is only a small fraction of total air supplied to space.

In this study, the outdoor low and high temperature point, which is used to decide the supply air temperature, are the same in whatever climates and locations, but it might be better to be set specifically based on the certain climate and location.

Figure 25 shows that after implementation, the space temperature of core zone on cooling and heating design day in Chicago, is still in good range during occupied hours.

![Figure 25 Indoor Air Temperature - Static Pressure Reset](image-url)

**Figure 25 Indoor Air Temperature - Static Pressure Reset**

**5.4.2 A3-Case Study Result**

As is showed in figure N, there’s a minimum and maximum discharge air temperature on building 661’s BAS user interface. And the discharge air temperature and humidity, the outdoor air temperature and humidity are shown in Figure 26 and Figure 27. Because the data of some period of time was not available, thus the rules of supply air
temperature modulation haven’t been identified. The control logic of the supply air
temperature need to be further investigated when implementing this measure.

5.5 A4-Supply-air Temperature Constant Set Point
The baseline model has a constant supply air temperature of 55F, it has been changed
to 53F and 58F for comparison.
5.5.1 A4-Modeling Result

Figure N shows the comparison result between setting supply air temperature as 53 F and 58 F, and the baseline of temperature 55F.

![Supply-air Temperature Constant Set Point](image-url)

Figure 28 Supply Air Temperature Set Point of 53F and 58F

Figure 29 and 30 shows the result after changing the supply air temperature to 58 F for DOAS and VAV system. Up to 2.5% of energy saving can be found for DOAS, which is much lower than result from VAV system, up to 21%. The main reason is the same with A3 measure, that the amount of air with adjusted temperature is only small fraction of total air supplied to the space.
Figure 29 Increase SAT Constant Set Point - DOAS

In order to evaluate the indoor comfort after changing the supply air temperature, the indoor air temperature of a core zone of one day in both heating and cooling season are shown with the occupancy schedule. Figure 31 shows that after changing the supply air temperature, there’s no big changes in indoor air temperature.

Figure 30 Increase SAT Constant Set Point – VAV [1]
5.5.2 A4-Case Study Result
The A3 and A4 measure are both about the supply air temperature. Thus the description of monitoring result can be found in 5.4.2 A3-Case Study Result.

5.6 A5-Wider Thermostat Range

5.6.1 A5-Modeling Result
The saving pattern based on climate of DOAS shows different than VAV system, which can be shown in figure 32 and 33. The reason need to be figured out in further study. And since the dehumidification effect is ignored in this study, space humidity should be monitored when implementing this measure to actual building to insure indoor air comfort. For DOAS, Large energy saving can be reached after wider the thermostat range especially in cooler climate. The reason is that more heating energy are consumed during heating season, lower the set point for seating can reduce the load on heating
coil which can be supplemented by internal heat gain of heat transfer from core zones to the perimeter zones.

Also, temperature of one of the core zone on design day, in Chicago, have been shown in Figure 34. It shows that after implementing this measure, the space temperature
might be not proper. However, the actual performance need to be further monitored in actual building.

![Space Temperature after Wider Thermostat Range](image)

**Figure 34 Indoor Air Temperature - Wider Thermostat Range**

### 5.6.2 A5-Case Study Result

Figure 35 shows the thermostat set point of space temperature of building 661. There are current heating and cooling set point of 72 F and 68 F, and the unoccupied and occupied thermostat set points. The control logic of the thermostat set point should be figured out when implementing this measure.
5.7 A6-Minimum Outdoor Air Reset

The minimum outside air is set to zero during un occupied period.
5.7.1 A6-Modeling Result

It can be found in Figure 36 that, except for Boulder, higher heating saving can be found in colder climate and higher cooling saving can be found in Hotter climate, which is the same as the result of VAV system. However, the minimum outdoor air fraction of VAV model in PNNL’s study is unknown. Thus the result is not comparable between VAV system and DOAS for this measure.

**Figure 38 Minimum Outdoor Air Reset – VAV [1]**

**Figure 37 Indoor Air Temperature - Minimum Outdoor Air Reset**
5.7.2 A6-Case Study Result
As is mentioned previously, the DOAS unit only supply small fraction of outdoor air to the space for minimum ventilation. And Figure N shows that the constant fraction of air is enforced daily starting from 5 am, although the space is occupied starting from 9 am. The CO$_2$ concentration is also shown. However, the Figure shows that the CO$_2$ sensor doesn’t work properly.

![Figure 39 Outdoor Air Volume - Building 661](image)
Chapter 6

CONCLUSIONS

This study means to compare the effectiveness of the building retuning measures, promoted by PNNL, between VAV system and DOAS. The same measures studied in PNNL’s research have been targeted and the similar research method have been used, which is Energyplus simulation.

Simple DOAS with fan coil unit systems are fitted into DOE large office building, and common practice inefficiencies have been implemented to build the baseline model. 6 air side RCx/ retuning measures have been applied to the baseline models. Both the baseline model and the model with measures are simulated in 16 U.S. location. Finally the energy savings in percentage are calculated from the simulation result for analysis.

In order to investigate whether those measures have the chance to be implemented to an actual building, a case study have been developed in an office building in Philadelphia, which is the building 661. Because of some limitation, the measures haven't been implemented to the BAS but the data accessibility, and the re-tuning opportunities have been investigated.

6.1 Conclusion

1. The DOAS units is only responsible for ventilation and latent load in the building, which the energy consumption is relatively lower than the energy consumed by the parallel system. Less energy saving can be found associated with fan modulating
2. For DOAS with parallel Fan Coil system, since it’s also air system, most of the commissioning measures that is promoted for VAV systems’ air side can also be properly implemented, although only small energy savings can be generated by DOAS unit.

3. Commissioning measures to the DOAS energy system with the assistance from BAS shall be further researched separately since the difference between two types of system is existed. More effort should be made on the parallel cooling/ heating system since larger fraction of energy is consumed by them.

4. The type of parallel system implemented with DOAS are variable such as chilled beam system, low temperature radiant system, and fan coil system. The commissioning measures to the air side of the system related with sensible load would be inapplicable for DOAS with radiant parallel system.

5. Time, money and effort is required in the commissioning process but the energy saving can be promising.

6.2 Limitation
1. For modeling, the DOAS with fan coil units system may not be the typical DOAS. For example, there’s only one type of occupancy schedule for all zones, while in real world commercial office building would have multiple occupancy schedule and the function for the different zones shall be various.

2. There are some difference in the modeling of the measures because the PNNL’s model is not available.

3. There are some other HVAC system in PNNL’s model, such as solar heating system, while the HVAC system in this study is only DOAS with fan coil system.
4. The accuracy of the models need to be validated.

6.3 Future Work
1. The combined energy saving effect can be estimated after implementing the measures in combination. Also the water side measures can be evaluated in future study.

2. More typical model for large office building with DOAS shall be developed.

3. The gaps between simulation and actual implementation should be further identified.

4. Other system type, for example DOAS with chilled beam system, shall be studied.
Appendix A EnergyPlus input for shorten HVAC schedule

Schedule:Compact,
HVACOperationSchd,       !- Name
On/Off,                  !- Schedule Type Limits Name
Through: 12/31,          !- Field 1
For: Weekdays,           !- Field 2
Until: 06:00,            !- Field 3
0.0,                     !- Field 4
Until: 22:00,            !- Field 5
1.0,                     !- Field 6
Until: 24:00,            !- Field 7
0.0,                     !- Field 8
For: Saturday,           !- Field 9
Until: 06:00,            !- Field 10
0.0,                     !- Field 11
Until: 18:00,            !- Field 12
1.0,                     !- Field 13
Until: 24:00,            !- Field 14
0.0,                     !- Field 15
For: SummerDesignDay,    !- Field 16
Until: 06:00,            !- Field 17
0.0,                     !- Field 18
Until: 22:00,            !- Field 19
1,                       !- Field 20
Until: 24:00,            !- Field 21
0,                       !- Field 22
For: WinterDesignDay,    !- Field 23
Until: 06:00,            !- Field 24
0,                       !- Field 25
Until: 22:00,            !- Field 26
1,                       !- Field 27
Until: 24:00,            !- Field 28
0,                       !- Field 29
For: Sunday Holidays AllOtherDays,  !- Field 30
Until: 07:00,            !- Field 31
0,                       !- Field 32
Until: 18:00,            !- Field 33
0,                       !- Field 34
Until: 24:00,            !- Field 35
0;                       !- Field 36
Schedule:Compact,
FanAvailSched,   !- Name
Fraction,        !- Schedule Type Limits Name
Through: 12/31,  !- Field 1
For: WeekDays CustomDay1 CustomDay2,  !- Field 2
Until: 6:00,     !- Field 3
0,              !- Field 4
Until: 22:00,    !- Field 5
1,              !- Field 6
Until: 24:00,    !- Field 7
0,              !- Field 8
For: Saturday,   !- Field 9
Until: 06:00,    !- Field 10
0,              !- Field 11
Until: 18:00,    !- Field 12
1,              !- Field 13
Until: 24:00,    !- Field 14
0,              !- Field 15
For: SummerDesignDay,  !- Field 16
Until: 06:00,    !- Field 17
0,              !- Field 18
Until: 22:00,    !- Field 19
1,              !- Field 20
Until: 24:00,    !- Field 21
0,              !- Field 22
For: WinterDesignDay,  !- Field 23
Until: 06:00,    !- Field 24
0,              !- Field 25
Until: 22:00,    !- Field 26
1,              !- Field 27
Until: 24:00,    !- Field 28
0,              !- Field 29
For: Sunday Holidays AllOtherDays,  !- Field 30
Until: 07:00,    !- Field 31
0,              !- Field 32
Until: 18:00,    !- Field 33
0,              !- Field 34
Until: 24:00,    !- Field 35
0;              !- Field 36
Schedule:Compact,
PumpOperationSchd,   !- Name
On/Off,        !- Schedule Type Limits Name
Through: 12/31,   !- Field 1
For: Weekdays,   !- Field 2
Until: 06:00,    !- Field 3
0,              !- Field 4
Until: 22:00,    !- Field 5
1,              !- Field 6
Until: 24:00,    !- Field 7
0,              !- Field 8
For: Saturday,   !- Field 9
Until: 06:00,    !- Field 10
0,              !- Field 11
Until: 18:00,    !- Field 12
1,              !- Field 13
Until: 24:00,    !- Field 14
0,              !- Field 15
For: SummerDesignDay,  !- Field 16
Until: 06:00,    !- Field 17
0,              !- Field 18
Until: 22:00,    !- Field 19
1,              !- Field 20
Until: 24:00,    !- Field 21
0,              !- Field 22
For: WinterDesignDay,  !- Field 23
Until: 06:00,    !- Field 24
0,              !- Field 25
Until: 22:00,    !- Field 26
1,              !- Field 27
Until: 24:00,    !- Field 28
0,              !- Field 29
For: Sunday Holidays AllOtherDays,  !- Field 30
Until: 07:00,    !- Field 31
0,              !- Field 32
Until: 18:00,    !- Field 33
0,              !- Field 34
Until: 24:00,    !- Field 35
0;              !- Field 36
Schedule:Compact,
HVACOperationSchd_Short1, !- Name
On/Off, !- Schedule Type Limits Name
Through: 12/31, !- Field 1
For: Weekdays, !- Field 2
Until: 6:00, !- Field 3
0.0, !- Field 4
Until: 21:00, !- Field 5
1.0, !- Field 6
Until: 24:00, !- Field 7
0.0, !- Field 8
For: Saturday, !- Field 9
Until: 06:00, !- Field 10
0.0, !- Field 11
Until: 17:00, !- Field 12
1.0, !- Field 13
Until: 24:00, !- Field 14
0.0, !- Field 15
For: SummerDesignDay, !- Field 16
Until: 06:00, !- Field 17
0.0, !- Field 18
Until: 22:00, !- Field 19
1, !- Field 20
Until: 24:00, !- Field 21
0, !- Field 22
For: WinterDesignDay, !- Field 23
Until: 06:00, !- Field 24
0, !- Field 25
Until: 22:00, !- Field 26
1, !- Field 27
Until: 24:00, !- Field 28
0, !- Field 29
For: Sunday Holidays AllOtherDays, !- Field 30
Until: 07:00, !- Field 31
0, !- Field 32
Until: 18:00, !- Field 33
0, !- Field 34
Until: 24:00, !- Field 35
0; !- Field 36
Schedule:Compact,
FanAvailSched_Short1,  !- Name
Fraction,                !- Schedule Type Limits Name
Through: 12/31,          !- Field 1
For: WeekDays CustomDay1 CustomDay2,  !- Field 2
  Until: 6:00,           !- Field 3
  0,                    !- Field 4
  Until: 21:00,         !- Field 5
  1,                    !- Field 6
  Until: 24:00,         !- Field 7
  0,                    !- Field 8
  For: Saturday,         !- Field 9
  Until: 06:00,          !- Field 10
  0,                    !- Field 11
  Until: 17:00,          !- Field 12
  1,                    !- Field 13
  Until: 24:00,          !- Field 14
  0,                    !- Field 15
  For: SummerDesignDay,  !- Field 16
  Until: 06:00,          !- Field 17
  0,                    !- Field 18
  Until: 22:00,          !- Field 19
  1,                    !- Field 20
  Until: 24:00,          !- Field 21
  0,                    !- Field 22
  For: WinterDesignDay,  !- Field 23
  Until: 06:00,          !- Field 24
  0,                    !- Field 25
  Until: 22:00,          !- Field 26
  1,                    !- Field 27
  Until: 24:00,          !- Field 28
  0,                    !- Field 29
  For: Sunday Holidays AllOtherDays,  !- Field 30
  Until: 07:00,          !- Field 31
  0,                    !- Field 32
  Until: 18:00,          !- Field 33
  0,                    !- Field 34
  Until: 24:00,          !- Field 35
  0;                    !- Field 36
Schedule: Compact,
PumpOperationSchd_Short1, !- Name
On/Off, !- Schedule Type Limits Name
Through: 12/31, !- Field 1
For: WeekDays CustomDay1 CustomDay2, !- Field 2
Until: 6:00, !- Field 3
0, !- Field 4
Until: 21:00, !- Field 5
1, !- Field 6
Until: 24:00, !- Field 7
0, !- Field 8
For: Saturday, !- Field 9
Until: 06:00, !- Field 10
0, !- Field 11
Until: 17:00, !- Field 12
1, !- Field 13
Until: 24:00, !- Field 14
0, !- Field 15
For: SummerDesignDay, !- Field 16
Until: 06:00, !- Field 17
0, !- Field 18
Until: 22:00, !- Field 19
1, !- Field 20
Until: 24:00, !- Field 21
0, !- Field 22
For: WinterDesignDay, !- Field 23
Until: 06:00, !- Field 24
0, !- Field 25
Until: 22:00, !- Field 26
1, !- Field 27
Until: 24:00, !- Field 28
0, !- Field 29
For: Sunday Holidays AllOtherDays, !- Field 30
Until: 07:00, !- Field 31
0, !- Field 32
Until: 18:00, !- Field 33
0, !- Field 34
Until: 24:00, !- Field 35
0; !- Field 36
Schedule: Compact,

Htg-SetP-Sch, ! Name
Temperature, ! Schedule Type Limits Name
Through: 12/31, ! Field 1
For: WeekDays CustomDay1 CustomDay2, ! Field 2
Until: 6:00, ! Field 3
13, ! Field 4
Until: 7:00, ! Field 5
18, ! Field 6
Until: 22:00, ! Field 7
23, ! Field 8
Until: 24:00, ! Field 9
13, ! Field 10
For: WinterDesignDay, ! Field 11
Until: 24:00, ! Field 12
23, ! Field 13
For: SummerDesignDay, ! Field 14
Until: 24:00, ! Field 15
13, ! Field 16
For: Saturday, ! Field 17
Until: 06:00, ! Field 18
13, ! Field 19
Until: 18:00, ! Field 20
23, ! Field 21
Until: 24:00, ! Field 22
13, ! Field 23
For: Sunday Holidays AllOtherDays, ! Field 24
Until: 07:00, ! Field 25
13, ! Field 26
Until: 18:00, ! Field 27
13, ! Field 28
Until: 24:00, ! Field 29
13; ! Field 30
Schedule:Compact,

   Clg-SetP-Sch,   !- Name
Temperature,   !- Schedule Type Limits Name
Through: 12/31,   !- Field 1
For: WeekDays CustomDay1 CustomDay2,   !- Field 2
Until: 6:00,   !- Field 3
32,   !- Field 4
Until: 22:00,   !- Field 5
24,   !- Field 6
Until: 24:00,   !- Field 7
32,   !- Field 8
For: WinterDesignDay,   !- Field 9
Until: 24:00,   !- Field 10
32,   !- Field 11
For: SummerDesignDay,   !- Field 12
Until: 24:00,   !- Field 13
24,   !- Field 14
For: Saturday,   !- Field 15
Until: 06:00,   !- Field 16
32,   !- Field 17
Until: 18:00,   !- Field 18
24,   !- Field 19
Until: 24:00,   !- Field 20
32,   !- Field 21
For: Sunday Holidays AllOtherDays,   !- Field 22
Until: 07:00,   !- Field 23
32,   !- Field 24
Until: 18:00,   !- Field 25
32,   !- Field 26
Until: 24:00,   !- Field 27
32;   !- Field 28
Schedule:Compact,
   Htg-SetP-Sch_short1,       !- Name
Temperature,            !- Schedule Type Limits Name
Through: 12/31,          !- Field 1
For: WeekDays CustomDay1 CustomDay2,  !- Field 2
Until: 6:00,             !- Field 3
13,                     !- Field 4
Until: 7:00,             !- Field 5
18,                     !- Field 6
Until: 21:00,            !- Field 7
23,                     !- Field 8
Until: 24:00,            !- Field 9
13,                     !- Field 10
For: WinterDesignDay,    !- Field 11
Until: 24:00,            !- Field 12
23,                     !- Field 13
For: SummerDesignDay,    !- Field 14
Until: 24:00,            !- Field 15
13,                     !- Field 16
For: Saturday,           !- Field 17
Until: 06:00,            !- Field 18
13,                     !- Field 19
Until: 17:00,            !- Field 20
23,                     !- Field 21
Until: 24:00,            !- Field 22
13,                     !- Field 23
For: Sunday Holidays AllOtherDays,  !- Field 24
Until: 07:00,            !- Field 25
13,                     !- Field 26
Until: 18:00,            !- Field 27
13,                     !- Field 28
Until: 24:00,            !- Field 29
13;                      !- Field 30
Schedule:Compact,
  Clg-SetP-Sch,  !- Name
Temperature,    !- Schedule Type Limits Name
Through: 12/31,  !- Field 1
For: WeekDays CustomDay1 CustomDay2,  !- Field 2
  Until: 6:00,     !- Field 3
    32,          !- Field 4
  Until: 21:00,   !- Field 5
    24,          !- Field 6
  Until: 24:00,   !- Field 7
    32,          !- Field 8
For: WinterDesignDay,  !- Field 9
  Until: 24:00,   !- Field 10
    32,          !- Field 11
For: SummerDesignDay,  !- Field 12
  Until: 24:00,   !- Field 13
    24,          !- Field 14
For: Saturday,        !- Field 15
  Until: 06:00,   !- Field 16
    32,          !- Field 17
  Until: 17:00,   !- Field 18
    24,          !- Field 19
  Until: 24:00,   !- Field 20
    32,          !- Field 21
For: Sunday Holidays AllOtherDays,  !- Field 22
  Until: 07:00,   !- Field 23
    32,          !- Field 24
  Until: 18:00,   !- Field 25
    32,          !- Field 26
  Until: 24:00,   !- Field 27
    32;          !- Field 28
Appendix B EnergyPlus input for Static pressure reset

!- =========== ALL OBJECTS IN CLASS: FAN:COMPONENTMODEL ===========

Fan:ComponentModel,
  DOAS_1 Supply Fan,     !- Name
  DOAS_1 Heating Coil Outlet,  !- Air Inlet Node Name
  DOAS_1 Supply Fan Outlet,  !- Air Outlet Node Name
  HVACOperationSched,     !- Availability Schedule Name
  autosize,            !- Maximum Flow Rate {m3/s}
  0,                   !- Minimum Flow Rate {m3/s}
  1,                   !- Fan Sizing Factor
  0.3048,              !- Fan Wheel Diameter {m}
  0.0873288576,       !- Fan Outlet Area {m2}
  1,                   !- Maximum Fan Static Efficiency
  9.76,                !- Euler Number at Maximum Fan Static Efficiency
  0.260331812,        !- Maximum Dimensionless Fan Airflow
  autosize,            !- Motor Fan Pulley Ratio
  autosize,            !- Belt Maximum Torque {N-m}
  1,                   !- Belt Sizing Factor
  0.167,               !- Belt Fractional Torque Transition
  2000,                !- Motor Maximum Speed {rev/min}
  autosize,            !- Maximum Motor Output Power {W}
  1,                   !- Motor Sizing Factor
  1,                   !- Motor In Airstream Fraction
  Power,               !- VFD Efficiency Type
  autosize,            !- Maximum VFD Output Power {W}
  1,                   !- VFD Sizing Factor
  VSD Example,         !- Fan Pressure Rise Curve Name
  DiagnosticSPR,       !- Duct Static Pressure Reset Curve Name
  FanEff120CPLANormal, !- Normalized Fan Static Efficiency Curve Name-Non-Stall Region
  FanEff120CPLAStall,  !- Normalized Fan Static Efficiency Curve Name-Stall Region
  FanDimFlowNormal,    !- Normalized Dimensionless Airflow Curve Name-Non-Stall Region
  FanDimFlowStall,     !- Normalized Dimensionless Airflow Curve Name-Stall Region
  BeltMaxEffMedium,    !- Maximum Belt Efficiency Curve Name
  BeltPartLoadRegion1, !- Normalized Belt Efficiency Curve Name - Region 1
  BeltPartLoadRegion2, !- Normalized Belt Efficiency Curve Name - Region 2
  BeltPartLoadRegion3, !- Normalized Belt Efficiency Curve Name - Region 3
  MotorMaxEffAvg,      !- Maximum Motor Efficiency Curve Name
MotorPartLoad, !- Normalized Motor Efficiency Curve Name
VFDPartLoad,    !- VFD Efficiency Curve Name
General;        !- End-Use Subcategory
Fan:ComponentModel,

DOAS_1 Supply Fan, !- Name
DOAS_1 Heating Coil Outlet, !- Air Inlet Node Name
DOAS_1 Supply Fan Outlet, !- Air Outlet Node Name
HVACOperationSched, !- Availability Schedule Name
autosize, !- Maximum Flow Rate \{m^3/s\}
0,
!- Minimum Flow Rate \{m^3/s\}
1,
!- Fan Sizing Factor
0.3048,
!- Fan Wheel Diameter \{m\}
0.0873288576,
!- Fan Outlet Area \{m^2\}
1,
!- Maximum Fan Static Efficiency
9.76,
!- Euler Number at Maximum Fan Static Efficiency
0.260331812,
!- Maximum Dimensionless Fan Airflow
autosize,
!- Motor Fan Pulley Ratio
autosize,
!- Belt Maximum Torque \{N\cdot m\}
1,
!- Belt Sizing Factor
0.167,
!- Belt Fractional Torque Transition
2000,
!- Motor Maximum Speed \{rev/min\}
autosize,
!- Maximum Motor Output Power \{W\}
1,
!- Motor Sizing Factor
1,
!- Motor In Airstream Fraction
Power,
!- VFD Efficiency Type
autosize,
!- Maximum VFD Output Power \{W\}
1,
!- VFD Sizing Factor
VSD Example,
!- Fan Pressure Rise Curve Name
DiagnosticSPR2, !- Duct Static Pressure Reset Curve Name
FanEff120CPLANormal, !- Normalized Fan Static Efficiency Curve Name-Non-Stall Region
FanEff120CPLAStall, !- Normalized Fan Static Efficiency Curve Name-Stall Region
FanDimFlowNormal, !- Normalized Dimensionless Airflow Curve Name-Non-Stall Region
FanDimFlowStall, !- Normalized Dimensionless Airflow Curve Name-Stall Region
BeltMaxEffMedium, !- Maximum Belt Efficiency Curve Name
BeltPartLoadRegion1, !- Normalized Belt Efficiency Curve Name - Region 1
BeltPartLoadRegion2, !- Normalized Belt Efficiency Curve Name - Region 2
BeltPartLoadRegion3, !- Normalized Belt Efficiency Curve Name - Region 3
MotorMaxEffAvg, !- Maximum Motor Efficiency Curve Name
MotorPartLoad, !- Normalized Motor Efficiency Curve Name
VFDPartLoad, !- VFD Efficiency Curve Name
General; !- End-Use Subcategory
!- ============ ALL OBJECTS IN CLASS: CURVE:LINEAR ===========

Curve:Linear,
   DiagnosticSPR,        !- Name
   248.84,              !- Coefficient1 Constant
   0,                   !- Coefficient2 x
   0,                   !- Minimum Value of x
   100,                 !- Maximum Value of x
   62.5,                !- Minimum Curve Output
   248.84,              !- Maximum Curve Output
   Dimensionless,       !- Input Unit Type for X
   Dimensionless;       !- Output Unit Type

Curve:Linear,
   DiagnosticSPR2,      !- Name
   62.5,                !- Coefficient1 Constant
   1.8634,              !- Coefficient2 x
   0,                   !- Minimum Value of x
   100,                 !- Maximum Value of x
   62.5,                !- Minimum Curve Output
   248.84,              !- Maximum Curve Output
   Dimensionless,       !- Input Unit Type for X
   Dimensionless;       !- Output Unit Type
Appendix C Supply-Air Temperature Reset based on Outdoor-Air Temperature

!- =========== ALL OBJECTS IN CLASS: SETPOINTMANAGER:OUTDOORAIRRESET ======

SetpointManager:OutdoorAirReset,
   DOAS_1 Cooling Supply Air Temp Manager, !- Name
   Temperature, !- Control Variable
   16.7, !- Setpoint at Outdoor Low Temperature {C}
   0, !- Outdoor Low Temperature {C}
   12.8, !- Setpoint at Outdoor High Temperature {C}
   32, !- Outdoor High Temperature {C}
   DOAS_1 Supply Fan Outlet;!- Setpoint Node or NodeList Name
Appendix D Wider Thermostat Range

Schedule:Compact,

Htg-SetP-Sch,     !- Name
Temperature,      !- Schedule Type Limits Name
Through: 12/31,   !- Field 1
For: WeekDays CustomDay1 CustomDay2,  !- Field 2
Until: 6:00,      !- Field 3
13,              !- Field 4
Until: 7:00,      !- Field 5
18,              !- Field 6
Until: 22:00,     !- Field 7
21,              !- Field 8
Until: 24:00,     !- Field 9
13,              !- Field 10
For: WinterDesignDay,  !- Field 11
Until: 24:00,     !- Field 12
23,              !- Field 13
For: SummerDesignDay,  !- Field 14
Until: 24:00,     !- Field 15
13,              !- Field 16
For: Saturday,    !- Field 17
Until: 06:00,     !- Field 18
13,              !- Field 19
Until: 18:00,     !- Field 20
21,              !- Field 21
Until: 24:00,     !- Field 22
13,              !- Field 23
For: Sunday Holidays AllOtherDays,  !- Field 24
Until: 07:00,     !- Field 25
13,              !- Field 26
Until: 18:00,     !- Field 27
13,              !- Field 28
Until: 24:00,     !- Field 29
13;              !- Field 30
Schedule:Compact,
  Clg-SetP-Sch, !- Name
Temperature, !- Schedule Type Limits Name
Through: 12/31, !- Field 1
For: WeekDays CustomDay1 CustomDay2, !- Field 2
  Until: 6:00, !- Field 3
  32, !- Field 4
  Until: 22:00, !- Field 5
  26, !- Field 6
  Until: 24:00, !- Field 7
  32, !- Field 8
For: WinterDesignDay, !- Field 9
  Until: 24:00, !- Field 10
  32, !- Field 11
For: SummerDesignDay, !- Field 12
  Until: 24:00, !- Field 13
  24, !- Field 14
For: Saturday, !- Field 15
  Until: 06:00, !- Field 16
  32, !- Field 17
  Until: 18:00, !- Field 18
  26, !- Field 19
  Until: 24:00, !- Field 20
  32, !- Field 21
For: Sunday Holidays AllOtherDays, !- Field 22
  Until: 07:00, !- Field 23
  32, !- Field 24
  Until: 18:00, !- Field 25
  32, !- Field 26
  Until: 24:00, !- Field 27
  32; !- Field 28
Appendix E Minimum Outdoor Air Reset

!- ========= ALL OBJECTS IN CLASS: FAN:VARIABLEVOLUME ==========
Schedule: Compact,
    MinOASch,        !- Name
    Fraction,       !- Schedule Type Limits Name
    Through: 12/31,  !- Field 1
    For: SummerDesignDay,  !- Field 2
    Until: 06:00,    !- Field 3
    0.0,            !- Field 4
    Until: 22:00,    !- Field 5
    1.0,            !- Field 6
    Until: 24:00,    !- Field 7
    0.05,           !- Field 8
    For: Weekdays,   !- Field 9
    Until: 06:00,    !- Field 10
    0.0,            !- Field 11
    Until: 07:00,    !- Field 12
    0.1,            !- Field 13
    Until: 08:00,    !- Field 14
    0.2,            !- Field 15
    Until: 12:00,    !- Field 16
    1,              !- Field 17
    Until: 13:00,    !- Field 18
    0.5,            !- Field 19
    Until: 18:00,    !- Field 20
    1,              !- Field 21
    Until: 20:00,    !- Field 22
    0.7,            !- Field 23
    Until: 22:00,    !- Field 24
    0.4,            !- Field 25
    Until: 24:00,    !- Field 26
    0,              !- Field 27
    For: Saturday,   !- Field 28
    Until: 08:00,    !- Field 29
    0,              !- Field 30
    Until: 17:00,    !- Field 31
    .5,             !- Field 32
    Until: 24:00,    !- Field 33
    0,              !- Field 34
    For: AllOtherDays,  !- Field 35
    Until: 24:00,    !- Field 36
    0;              !- Field 37
Schedule:Compact,
MinOASch_Base,   ! Name
Fraction,        ! Schedule Type Limits Name
Through: 12/31,  ! Field 1
For: SummerDesignDay,  ! Field 2
Until: 06:00,    ! Field 3
0.0,            ! Field 4
Until: 22:00,    ! Field 5
1.0,            ! Field 6
Until: 24:00,    ! Field 7
0.05,           ! Field 8
For: Weekdays,   ! Field 9
Until: 06:00,    ! Field 10
0.0,            ! Field 11
Until: 22:00,    ! Field 12
1,              ! Field 13
Until: 24:00,    ! Field 14
0,              ! Field 15
For: Saturday,   ! Field 16
Until: 06:00,    ! Field 17
0,              ! Field 18
Until: 17:00,    ! Field 19
1,              ! Field 20
Until: 24:00,    ! Field 21
0,              ! Field 22
For: AllOtherDays,  ! Field 23
Until: 24:00,    ! Field 24
0;               ! Field 25
Schedule:Compact,
BLDG_OCC_SCH, !- Name
Fraction, !- Schedule Type Limits Name
Through: 12/31, !- Field 1
For: SummerDesignDay, !- Field 2
Until: 06:00, !- Field 3
0.0, !- Field 4
Until: 22:00, !- Field 5
1.0, !- Field 6
Until: 24:00, !- Field 7
0.05, !- Field 8
For: Weekdays, !- Field 9
Until: 06:00, !- Field 10
0.0, !- Field 11
Until: 07:00, !- Field 12
0.1, !- Field 13
Until: 08:00, !- Field 14
0.2, !- Field 15
Until: 12:00, !- Field 16
0.95, !- Field 17
Until: 13:00, !- Field 18
0.5, !- Field 19
Until: 17:00, !- Field 20
0.95, !- Field 21
Until: 18:00, !- Field 22
0.7, !- Field 23
Until: 20:00, !- Field 24
0.4, !- Field 25
Until: 22:00, !- Field 26
0.1, !- Field 27
Until: 24:00, !- Field 28
0.05, !- Field 29
For: Saturday, !- Field 30
Until: 06:00, !- Field 31
0.0, !- Field 32
Until: 08:00, !- Field 33
0.1, !- Field 34
Until: 14:00, !- Field 35
0.5, !- Field 36
Until: 17:00, !- Field 37
0.1, !- Field 38
Until: 24:00, !- Field 39
0.0, !- Field 40
For: AllOtherDays, !- Field 41
Until: 24:00,  
0.0;
REFERENCES


