Energy simulation model for commercial buildings Beridarebanan 4, 11 and 77, with ice thermal storage.

By

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District cooling companies enforce a large penalty based on peak demands, which current cooling methods do not address properly. Building developers are exploring alternatives methods to reduce the said peak demands. The use of Ice Thermal Storage is an nontraditional method within the Scandinavian countries, but has shown to be a method to peak shave as well as load shifting in other regions of the worlds.

The goal of the thesis was to "investigate the potential of ice thermal storage for cooling demand and peak shaving for Beridarebanan 4, 11, 77". The energy simulation was accomplished using the building performance simulator software IES VE. As inputs to the simulation, building data from the renovation project and corresponding weather data were used. The resulting simulation model was validated against renovated data with differences of 3.3% and 41.9% for the heating and cooling loads, respectively. The large discrepancy within cooling was determined to be weighted heavily by cooling strategy implemented within the building. When similar cooling strategies were implemented results were consistent with one another. This validation was investigated on a building, zone, and room level to look for consistency. The resulting simulated heating and cooling demands from IES VE were input into a then created ice thermal storage controller within MS Excel.

In all, with the stable electrical and district cooling prices, a payback of 12 years was calculated for a 4.5 MWh, 6 hour storage ITS system. Results also show that for a 6 hour storage capacity, the controller exceeded the 1 000 kW price tier 4 hours out of the entire year, making it an ideal storage size. Current Swedish Electrical Market incentivize peak shaving rather than energy saving, accounting for nearly 80% of the yearly savings. The margin for earning more for the energy savings has negative consequences for potentially exceeding the 1 000 kW cooling threshold.
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1.1 Background

According to the International Energy Agency (IEA) nearly a third of all of the world’s energy consumption as well as CO$_2$ lies within the building sector, and by 2060 infrastructure in the building sector will double, accounting for more than 230 billion m$^2$ [1]. With efforts of becoming more energy conscientious, countries are targeting the building sector for more reliable and sustainable construction materials, control strategies, heating and cooling alternatives. Sweden in particular, is a front runner for district systems, being fourth in sales for district heating with nearly 183 Petajoules [22]. Traditionally outside of Scandinavia, supplying heating and cooling is accomplished by each building having its own boiler and cooling source, however in a district system, this demand is met through a central unit. The district heating and cooling infrastructure consists of several kilometers of insulated pipes, fed by the central production unit and distributed to the end user.

Market share for general heating in Sweden has evolved drastically in the last 50 years, with trends going toward district heating and heat pumps. On the other hand heating sources such as electric heating are on the decline, while fuel oil is almost all but extinct. Current shares of heating sources in Sweden are 55% district heating, 22% heat pump, while the remainder is split evenly between firewood/natural gas and electric heating [28]. The first district heating system was introduced in Karlstad in 1948. Within the City of Stockholm, nearly 60% of the buildings are connected to the district system [12].

District Cooling on the other hand is fairly new concept in Sweden, being first introduced in Västerås in 1992. The relatively slow introduction of district cooling compared to heating was in part to the ban of CFC’s in the late 20$^{th}$ century. The district cooling network was approximated in
2014 of delivering 3.6 PJ, while infrastructure for it has been increasing steadily 8 percent since 2000 [28]. In Stockholm, there are two plants (Värtaverket and Hammarbyverket) supplying cooling to Vasastan, Östermalm, Kungsholmen and parts of Sodermalm and Hammarbyhöjden [12].

The project properties in question (Beridarebanan 4, 11 and 77) is a complex consisting of four buildings that were constructed in the late 1950’s and are now being renovated in late 2019 by the property owner, Vasakronan. The buildings are situated between the streets Sveavägen and Sergelgatan, a block away from Sergel Torg. The complex consists of 23 stories, 4 of which are below ground. The first level below ground is mainly for retail, restaurant kitchens, and gyms, while the remaining three floors are warehouse, storage, parking and maintenance rooms. Above ground, the first three floors are a large mixture of space types, between gym, retail, office, restaurants, etc. The remaining above ground floors are only with the high-rises, consisting of office spaces. The spaces being renovated are the low-rise and below ground areas. In terms of energy, the renovation considerations being analyzed are ground source heat pumps (GSHP), as well as ice thermal storage (ITS). The buildings current energy demands are supplied with district heating and cooling, however the original systems put in place in the 1950’s were gas boilers and chillers.

For the purposes of both the ongoing project as well as the thesis, the building are divided into three sections, where House 1 is Sveavagen 13, House 2 is Sveavagen 11, and House 3 and 4 are Sveavagen 9. The house numbers can be summarized as the towers, where House 3 and 4, are the same section, but have two towers, as shown in Figure 1.1, below. The nomenclature of the buildings will continue as this for the remainder of the report. All information regarding the existing buildings were provided by SEC Projekt AB and Damag AB. SEC Projekt AB was in charge of the energy needs of the building for both ventilation and plumbing, while Damag AB was project management. These two, along with others provided all information not publicly available.

![Figure 1.1: House Number Nomenclature](image)
1.2 Objectives and Research Questions

Ice thermal storage (ITS) has been a relatively mature technology for the purpose of cooling, for many years prior to mechanical refrigeration, using the ice available naturally [31]. Yet, only fairly recently has the technology been implemented on a commercial level in countries such as United States and China. Typically ITS is not of immediate interest to Nordic countries such as Sweden due to lack of cooling demands on a yearly basis, however in the application of large commercial shopping malls, cooling is often needed year round.

The thesis proposed by the company Damag AB is an open-ended research topic of the buildings energy evaluation, giving no specific constraints. Ultimately the requirement from Damag AB is to model the energy needs of the buildings, and if ice thermal storage is a viable option. The objective of this thesis for KTH aims to "Investigate the potential of ice thermal storage for cooling demand and peak shaving for Beridarebanan 4, 11 and 77". To accomplish this objective the following sub-objectives are broken down to:

- Create an accurate energy model using building performance simulations (BPS) of the properties in question for heating and cooling loads of the building.
- Create a techno-economic analysis of an ice thermal storage system that meets the energy needs of the building, including payback periods and return on investment.
- Study the ice thermal storage from an energy perspective.

1.3 Purpose

Simulations in general are necessary to better predict and assess the behavior of the system of interest. For the purpose of this project, the building energy simulation is of interest to show the buildings demands. The results show Vasakronan (the end user) the scale in which to size equipment for all the demands. These demands can vary based on the system inputs, for example the type of glass used, insulations, control tragedies for ventilation, as well as many more aspects. This flexibility allows the designers to test various scenarios, in an attempt to optimize the design in an attempt to appease all the stakeholders. The simulation acts as a means of checks and balances through the design phase, allowing the iteration of these inputs. Since this simulation is based on the proposed renovations, the results will be compared to the existing demands. The baseline results of building will be analyzed with and without the ITS system to compare performances and payback periods.

Despite being in a Nordic climate, Beridarebanan 4, 11 and 77, requires year-round cooling due to being a large commercial building, making ITS a technology of interest. In the Swedish district cooling network, the suppliers often set pricing schemes to have an annual flat rate based off a peak threshold (kr/år) with a power price (kr/kW). The way the scheme is laid out is that the
user becomes penalized for large peaks by paying for the flat rate (kr/år). A traditional district cooling system has to match the demand spikes which often correlate to peak energy prices. The purposes of the ITS within the report are to implement peak shaving. Typical applications of ITS also include load shifting, to produce ice while electricity is cheap and discharge while expensive. This technology ultimately reduces the users energy utility bill, despite not reducing the consumption. ITS is also advantageous to stabilize the demand of the grid, by shifting the load from the peak hours to off hours.

### 1.4 Limitations

In many cases of research, limitations are a common theme which occur. Being that the project was for a developing firm, several groups were working in parallel. Limitations experienced during the course of the project were, for example, the project architectures working in floor plans and layouts for the buildings in parallel. In order to create a proper simulation, the building geometry and layout has to be considered. After several iterations of the floor plan geometry from the architect, a preliminary design was selected to continue. The layout of the buildings have been altered in comparison to the one created for the simulation. This ultimately has no impact on the research contents of the paper, however did take a large amount of time in the process.

Other limitations include time/computational power as well as becoming familiar with the software packages SketchUp and IESVE, which are explained in detail in Section ??.

Much of the time consuming work was in the monotonous creation of the buildings geometry within the software SketchUp. Due to the size of the project, simulations within IESVE often take several hours just to simulate a few weeks. In order to simulate the entire year, the building was divided into the three separate housing sections (House 1, 2, 3&4) as explained in the background section on the report. The time lag of the simulations created a slow process flow, where a single alternations could take upwards of a few days of simulation time.

When comparing measured data with the simulation, one has to realize that the two buildings being compared are not the same. The measured data represents real-time behavior, while the simulation represents the building with renovations. To best compare and validate the simulations are to model the building as is, however this information is not readily available and to collect it would require an extraordinary amount of time that would go out of scope for this thesis.

### 1.5 Motivation

The motivation of the project is to check viability of ITS to large commercial buildings in Nordic countries, as well as to accelerate the introduction of ITS. The technology itself, is simplistic in its design integrating seamlessly to existing infrastructure and more often being very affordable, with low upfront costs. Examples of this technology can be observed in the EnWave Chicago district.
cooling network. Dating back to the mid 1990's this project has been long enough established showing its viability in the Chicago market[9].

### 1.6 Outline

The structure of the remaining report is separated into four main sections which are theory, methodology, results and discussion/conclusion. Each section is further organized into subsection going into more detail. As the titles of the section imply, the theory covers the contents of the technologies, methodology of tackling the problem statement, results of the project, conclusion and some discussion points.

The project can be separated into three main sections, creating the building geometry, calculating the buildings heating and cooling demands, and lastly the performance of the Ice thermal storage ITS. The demands are handled in the software IESVE (Integrated Environmental Solutions Virtual Environment), while the ITS analysis is handled separately being post processed in MS Excel.
2.1 Building Performance Simulation

Building performance simulation (BPS) is the use of computational simulations based on mathematical models to simulate the behaviour of a building and its performance from an energy perspective. For this, it inputs information of the building itself (e.g. materials, occupation), as well as boundary conditions (e.g. average ambient temperatures, ground conditions). Depending on its complexity, this can aim to give an approximate model that is comparable to a real world building [14]. A building simulation can be used as a tool to test the possible outcome of different design proposals in order to develop a desired solution depending on the stakeholders. These outcomes range from low budget, energy efficient, innovation control strategies..etc. For this, first a baseline model is created and then compared against models which have different solutions implemented [23]. In the present, BPS is widely used as a tool for Building Information Modeling (BIM). BIM is defined as the use of a shared digital representation of a built object (including buildings, bridges, roads, process plants, etc.) to facilitate design, construction and operation processes to form a reliable basis for decisions [15]. Real buildings (or future buildings) are represented as digital building models with all its components, which can be structures, furniture, ventilation systems, piping, etc. BIM allows that all the working disciplines work together and simultaneously, allowing the information to be shared in real time for its whole life cycle[27].

The first approach to this technology took in the early 1970s, but it wasn't until the 1990s that productivity on this field started to flourish, after following a hype cycle. At the moment this discipline on continuous development. The technology is starting to be used in more projects and stages within them [14], but still their ability to support building design is limited. Within the years, a great number of BPS have been developed. A study in 2008 reviewed 20 of the most used BPS in terms of their capabilities. Because the BPS have grown very diversely, the study
recommends being able to rely on not only one BPS but to know a few in order to get the best of every BPS depending on the necessities. It also raises the recurring question of how trustful are simulators in reality [10]. A simulator can have various sources of errors, both internal and external of the software. Internal errors include: errors within the mathematical solutions of the models, bugs, and differences between the equipment of the real building versus the simplified model of the processes in the simulations. External errors include: Differences between the micro-climate that affects the building versus the weather input used by the BPS, differences in the physical properties of the building (including HVAC systems), control strategies, occupancy schedules behaviour, equipment effects and also user error into providing the correct inputs [21].

To be able to trust the results of a BPS, results from the simulations need to match real results to a certain margin of error. For this, validations with existing buildings can be done. With time methods of verification have been developed, such as Building Energy Simulation Tests (BESTEST). These group of procedures are made to test and diagnose the simulation capabilities of building energy simulation programs, so that strengths, weaknesses and gaps can be identified. The method combines empirical validation, analytical verification and comparative analysis and was developed together by the International Energy Agency (IEA) and the National Energy Energy Laboratory (NREL) [21]. The method was later adopted with some refinements by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in accordance with procedures of the American National Standards Institute (ANSI), making the Standard method of BESTEST ASHRAE Standard 140 [21] [3]. Depending on which parameter wants to be analyzed, different test cases of BESTESTs are used.

An investigation in 2002 applied the BESTEST diagnostic method on different BPS: CA-SIS, CLIM2000, ENERGYPLUS, PROMETHEUS, TRNSYS-TUD and DOE-2.1E. It compared model results against test results from analytical solutions. The test found bugs and algorithm errors in the BPS, being helpful to spot and identify them, proving to be a cost effective way of testing BPS software that needs to validate its design [20].

A research presented in 2012 did an empirical validation to review the results of three different Building Performance Simulators: Autodesk Ecotect, Green building Studio and IES VE. For this, two buildings were simulated in all three softwares and the results were compared against measured data. All three softwares used the same geometry files for their simulations, minimizing the potential errors that can come with external inputs. The energy gains for the different rooms in each building were taken from ASHRAE Standard 90.1. The results were divided into three categories: heating, cooling and overall energy use and were compared by monthly and yearly consumption. In summary, the results showed that the simulators were able to predict model accurately the energy consumption only in a limited number of cases. A typical BPS is considered accurate is its percent difference is less or equal to 15% of the measured data [18]. The incapability to input correct schedules for occupancy, electrical lighting use and equipment use was considered to be the most likely source of error for all simulations [23].
Ultimately this study was trying to model the usage of the actual building. By only inputting the ASHRAE loads into the scheduling does not reflect how the building is actually being used. Something to note is between the three BPS's, similar behavior were shown making the measured data seem like the outlier.

2.2 Trimble SketchUp

Sketchup is a 3D modeling program developed by Trimble Inc. The program has a variety of applications such as architecture, interior design, civil and mechanical engineering, as well as film and video game design. For the purpose of this project, Sketchup was used to create the building geometry that will later be simulated. In most other 3D computer aided design (CAD) programs, several properties are imbedded within the geometry, whereas in Sketchup only a few are. This makes Sketchup extremely powerful and stable for large assemblies, whereas within another architecture package, the model would be considerably larger.

2.3 Integrated Environmental Solutions (IES)

The software IES is a building performance simulator (BPS), and meets the international standards of ASHRAE 140, BESTTEST, CISBE TM33, as well as EU EN13791: July 2000. The objective of BPS packages are to accurately predict the performance of a building based on the input values entered into the program. These inputs can be varied to study the effects they have on the model. Examples of the parameters can be different types of insulation, windows, how adding shading can effect the solar gain within the building. The premise of the program is to take all the considerations, and provide a summary of the performance of the building for a period of time. IES, in short, is a transient solver with which given all the inputs, solves the heating balances of each zone for each hour.

A large thing to keep in mind is that IES uses .TMY, .EPW, and .FWT file formats for its weather simulation data. These data sets are representative of 'typical' weather conditions, meaning it is a weighted average of the previous 30 years. The effects of this are explained in the methodology section below.

2.4 Ice Thermal Storage (Literature Review)

Ice Thermal Storage (ITS) is a cooling method that uses ice as the storage medium for the purpose of cooling. The method aims to shift peak hour cooling loads to non-peak hours, by producing and storing ice at non-peak hours and using it at peak hours [29]. This can lead not only to reduce peak consumption, but also to reduce the capital cost of equipment by reducing the maximum capacity required for the necessary equipment. ITS has a large advantage of a storage means, due to the storage medium being water/ice keeping costs lower, than other
alternatives to phase change materials (PCM). Moreover, this system aims to reduce the primary energy consumption. One factor is the increased efficiency of base load plants at night due to the lower ambient temperature, thus lowering the condensing temperature of the cycle and moreover, increasing the cycle’s COP. The second, the decreased transmission losses at night due to the less power transmitted at night hours[25]. The third factor is the fact that when the ITS is used, the air conditioner compressor will run at a constant load, decreasing the transient losses[8]. Being a thermal energy storage system, ITS uses the concept of PCM’s to store latent energy (approximately 92kWh per cubic meter of water), without a large temperature swing. Depending on the installation of the cooling systems, the chillers can both charge the storage tanks as well as supply cooling to the building simultaneously [6]. This type of flexibility allows the combination of chiller and storage to have various operation modes which are explained in detail in the methodology section of the report.

There are two main types of ice-on-coil ITS, external and internal melt. In both systems, ice is formed on submerged pipes through which a refrigerant is circulating. The variation of the two comes in the discharge phase, where external melt systems run water over the ice build, melting it externally, whereas internal melt systems run a warm coolant through a pipe, melting the ice internally. Advantages of the external melt systems are that they require less piping and are generally used for smaller applications making them often simpler, however the melt rate can vary drastically. For large structures such as commercial buildings, internal melt systems are more often selected due to the controlled closed loop cooling system [11].

Ice thermal storage has been in constant investigation for improving its performance and economic feasibility. The research on it started in early 1990’s in China [17] and has been in development since. There, the use of Ice Thermal Storage for cooling purposes has developed at an increased rate, with this technology increasing from 2 systems in 1993 to 716 systems in 2015 [17], putting ITS as an alternative within cooling especially in places with high mean temperatures. Since its development, various cases have been studied and registered, specially in countries which have hot and humid climates. The investigations have evaluated the reliability of ITS to shave peak consumption and its effectiveness to reduce overall consumption through analytical and numerical case studies. There are several published investigations where the feasibility of the ITS has been researched, both theoretically and practically. A number of them are presented within the remainder of the section.

One of these examples is in Thailand, where as of 2001, commercial buildings spent between 40% and 60% of their electricity costs only in cooling of their facilities. A research in 2001 developed a computer model to predict the performance of an air conditioning system with and without an ITS. This study compared energy consumption and electricity costs in commercial buildings that use air conditioning, using time-related tariffs to calculate the electricity costs, as that is the case for commercial buildings in Thailand. The results of the investigation detected a reduction in 5% in the overall energy consumption when the ITS was constantly used at fully
Also, the simulation showed an overall reduction of 55% in the electricity costs, which were highly related to the Time-related tariffs applied within the country[8].

A research publication of 2006 shows the evaluation of using ITS for a clinic building in Kuwait, a country where the share of fossil fuel was steadily increasing partially due to high peak loads compared to installed capacity, being 78.8% in 2002 [25]. The high peak loads are partially a consequence of the high use of AC systems for cooling during the summer, supported by highly subsidized electricity prices. The use of ITS was studied as a viable option for the country to reduce peak consumption and to reduce cooling equipment size, costs related to it and space usage. Moreover, the idea of delivering low chilled water temperature (as low as 1°C) can lead to a reduction in piping and air distribution. The evaluation was done by using a software for studying the effect of a chiller capable of providing cooling and charging the ITS with different operation strategies, leading to an increase in the size of the equipment, contrary to the initial thoughts. As conclusions, the chiller with ITS had to a slight increase of the overall energy consumption compared to the conventional AC without ITS, and it eliminated the peak load.

In 2015, a study evaluated a multi-purpose building in Taipei. The study concluded that annual savings of 37% were achieved, mainly because of time-dependent electricity tariff schemes, as ITS was successful in reducing energy cost by shifting the consumption from on-peak to off-peak periods[30]. In 2016, an evaluation on the feasibility of ITS for commercial buildings in Brazil concluded that ITS can shift peak demand successfully and generate savings but the economical feasibility will not only depend on climate but also on the present electricity tariff and if it considers a peak price on it [5].
3.1 Introduction

The working methodology is divided into three phases. First a prestudy phase is done, where the information about the buildings Beridarebanan 4, 11 and 77 is gathered and an introduction to the software packages Trimble Sketchup and IES VE is done. The modeling phase consists in the actual model creation in both software packages, including the troubleshooting and constant update in both of them. The last phase consists in: the validation of the simulation model, an analysis of the results, improvement propositions and analysis, and the techno-economic evaluation of the implementation of an ice thermal storage unit.

3.2 Prestudy

The prestudy delves into the more technical side of the report as well as some inputs. Being the study of an existing property, the building owner (Vasakronan) provided measured heating and cooling data for 2016. The building plans and layout were provided by SEC Projekt AB and Damag AB, both being companies involved in the renovation project.

3.2.1 Building Renovation Information

As mentioned in the background, the properties Beridarebanan 4, 11 and 77 were constructed in the late 1950’s. Below ground, there are four levels. The first level below ground is a combination of gym, retail, and restaurant spaces. The second and third are in large parking and storage spaces as well as housing large server rooms for cell phone providers. The last floor below ground houses large storage tanks, that were used for oil prior to the properties integration to the district
heating system in the early 1990's. These tanks despite being no longer used, are of interest for the attempt of re-purposing them for the ice thermal storage. An example of a floor plan given by the architect is shown below on figure 3.1.

The ground floor consists of mainly retail space, restaurants and large foyers to accommodate heavy foot traffic. The first floor above ground is a mixture of continuous of the of retail/restaurants from the ground floor as well as gym space. The second floor above ground is the start of the towers, and the end of the atrium's that of are located in the houses. The second floor also hosts a large terrace area, located at the negative space of the towers and atrium's. The remaining floors above are the towers themselves, consisting mostly of office space and corridors. The windows on the first three floors wrap the entire perimeter of the north, west, south, and east facades. On the towers, only the north and south sides have windows, while the east and west are structural concrete walls.

Since the first construction in the 1950's the properties has been renovated a few times since, most recently House 3 receiving new facades in the late 1990's. The renovations being considered for 2019 include complete overhauls such as new facades for the lower levels, drilling for boreholes, laying new roofing on the entire terrace, as well as VVS controls, equipment, etc...Vasakronan alongside this reports effort, intend to drill boreholes, and have received permits to do so in at least House 1.
3.2. PRESTUDY

3.2.2 Building Energy Implementations

In the previous section 3.2.1, the buildings background and structural aspects were discussed. This section focuses on the energy implementations and proposed control strategies. Currently the buildings heating and cooling demand is solely met through the district system. The base cooling demand is met by using chillers, while the rejected condenser heat is used to meet the heating demand. Any shortage or overage is met or rejected by district heating, respectively.

The proposed energy system continues to utilize the district system, however with the implementation of geothermal energy with ground source heat pumps (GSHP), ice thermal storage and dry cooling towers. Similar to the current strategy, the proposed system meets the cooling demand by district cooling using chillers. The condenser heat is utilized to meet any heating demanded, with excess being rejected to the boreholes dry coolers and kitchen canopy heat recovery systems. Any additional heating demand is met by either geothermal or district heating depending on the availability of the geothermal. In the case where the cooling demand exceeds the heating demand, the operational mode of the geothermal systems will change to free cooling. In the situations where the ground is fully charged, the ice thermal storage is used for to peak shave the cooling demand.

Modeling of the geothermal systems was tasked to E.ON (energy provider company). The resultant of the study (reference the study) shows the geothermal system can provide constant 750 kW cooling demand. This demand is used within the ITS controller as a logic gate, as to when activate and deactivate.

On a control level, the buildings proposed strategy will include night purge. Traditionally, air handling units are seldom used during the night due to the lack of activity. This strategy uses outdoor air to cool the building, effectively acting as if the windows where open. Depending the outdoor temperature, the ventilation will turn on and the supply air temperature could vary (also called reset temperature). Supply air flows and temperatures vary based on the room types and are shown in the Appendix A under the room templates (tables A.3 and A.4). Another implementation within the variable air volume (VAV) is the varying supply air temperature (SAT). Depending on the outdoor temperature the SAT can vary, utilizing the outdoor air in the similar sense of the night purge. An important note is that both control strategies are not implemented within the current building.

3.2.3 Energy Utility

As mentioned prior, the property currently operates using the district heating and cooling system. The energy provider for heating and cooling is Stockholm Exergi while Ellevio provides electricity. All energy pricing used for this report are those given by the providers. Example of the cooling pricing schemes presented by Exergi is down below in Figure 3.2. The end user pays a flat fee kr/år based on the installed peak capacity, as well as a price rate for kr/kW for the energy used.
CHAPTER 3. METHOD, DESIGN AND IMPLEMENTATION

PRIS INFORMATION
Priserna gäller för år 2018 och redovisas enkätvis under momen. Stockholm Exergi har rätt att ändra priser och prisskillnader en gång per kalenderår och enligt villkor i allmänna avtalavillkor.

<table>
<thead>
<tr>
<th>ÅRETFAKT</th>
<th>FAST DEL</th>
<th>EFFEKTPRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50 kW</td>
<td>3 000 kr/år</td>
<td>900 kr/kW, år</td>
</tr>
<tr>
<td>51-100 kW</td>
<td>8 000 kr/år</td>
<td>800 kr/kW, år</td>
</tr>
<tr>
<td>101-250 kW</td>
<td>30 500 kr/år</td>
<td>575 kr/kW, år</td>
</tr>
<tr>
<td>251-500 kW</td>
<td>61 750 kr/år</td>
<td>450 kr/kW, år</td>
</tr>
<tr>
<td>501-1 000 kW</td>
<td>111 750 kr/år</td>
<td>350 kr/kW, år</td>
</tr>
<tr>
<td>över 1 000 kW</td>
<td>161 705 kr/år</td>
<td>300 kr/kW, år</td>
</tr>
</tbody>
</table>

ENERGIPRIS
- Jun-aug: 450 kr/MWh
- Apr-maj, sep-okt: 180 kr/MWh
- Jan-mar, nov-dec: 0 kr/MWh
- Jan-mar, nov-dec: -150 kr/MWh

* Förutsätter att energiviktad medeltemperaturen på 10,5°C eller lägre tillkommer en avgift om 90 kr/MWh, °C

3.3 Implementation

With the information gathered on the Prestudy, the process of creating a proper model for the buildings Beridarebanan 4, 11 and 77 starts. In short, Sketchup is used to create the geometry of the building, despite IES having its own geometry creator. Sketchup in general has a more user friendly and stable platform to creating geometry over IES. The iterative process starts of creating the geometry begins with the drawing of every floor from the floor plans in Sketchup. To overcome its poor geometry creator, IES created a plug-in within Sketchup to export Sketchup geometry seamlessly to IES. The export includes things such as doors, windows, and voids. Within IES, the energy parameters are assigned, such as weather data and location, construction materials, user behavior, lighting, etc...

3.3.1 Geometry Model

For the Geometric model, the software Trimble Sketchup 2017 was used. Floor plans were given by the architecture company Wester +Elsner in the form of 2D .dwg files. Each .dwg was imported...
3.3. IMPLEMENTATION

into Sketchup, and was extruded to create 3D geometry. Depending on the type of studying being done, there are options between thin or thick wall geometry. Thin wall geometry, treats the wall as 2D object but is later is given thickness in the building simulation softwares. Thick walled geometry predefines the walls thickness within Sketchup itself. Typical in energy simulations is to use thin walled geometry, allowing more flexibility within the building simulator. Therefore, this work uses thin walled geometry in its simulations.

To simplify the model, the following considerations were applied:

- Large rooms are split into smaller areas to increase the resolution of the IES Energy Model. The boundaries of each zone are assigned as holes (no resistance applies in between zones of the same room).

- All floors are normalized to the same height. Due to the inherent nature of the sloping terrain, floors between the three houses are not the same. To avoid unwarranted complexity in IES, House 1 is used as reference for each floor height for all buildings.

- The layout of each tower is based off the $9^{th}$ floor of the associated tower. Ultimately the renovation being done are on the commercial and retail spaces, however the towers needed to be taken into account for the purposes of the energy model.

Figure 3.3: Final Geometric Model Within Sketchup
3.3.2 IES VE Energy Model

The software Integrated Environmental Solutions - Virtual Environment version (IESVE) 2017.0.0.3 was used to create an energy model based on the geometry model. The geometry model was exported to IES VE using an official plug-in that allows the identification of zones created in the geometry model and its proper exportation. Due to the large scale of the simulation, the model was separated into three models, House 1, House 2, and House 3 & 4. To model the adjacent building when separating the houses, an additional material was created with a very low overall heat transfer coefficient (also called U-value). This material was called “adjacent building” within the simulation file and was made to simulate the expected thermal equilibrium between buildings.

3.3.2.1 Construction Materials

The U values used in each part of the construction within the energy model are presented in Table 3.1. The information about the properties of the different materials is gathered from information given during several meetings with SEC Projekt AB. On appendix A, table A.1, the complete information on the construction materials used in IES is presented.

<table>
<thead>
<tr>
<th>Building Envelope</th>
<th>U value (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Walls</td>
<td>0.81</td>
</tr>
<tr>
<td>Internal Walls</td>
<td>1.79</td>
</tr>
<tr>
<td>External Floors</td>
<td>0.22</td>
</tr>
<tr>
<td>Internal Floors</td>
<td>1.12</td>
</tr>
<tr>
<td>Roof</td>
<td>0.71</td>
</tr>
</tbody>
</table>

3.3.2.2 Zone Templates

To create an energy model specifically for different types of buildings, IES assigns different parameters to the different rooms depending on its purpose. For this, templates which contain useful information for the model are applied to each type of room. This includes heating and cooling set points, supply air flow and temperature, ventilation strategy, occupation schedule information, lighting and equipment gain, each of which is independent for each template. Every template also accounts for its own ventilation control strategy. Constant Air Volume and Variable Air Volume systems are used. Appendix A Tables A.3 and A.4 present the different zone templates with their main parameters. As an example on how zone templates work, The zone template for Retail spaces is explained. The retail spaces are configured to have an operational temperature between 21.5 and 24.5 °C, meaning that getting outside this temperature range will trigger the cooling and heating system for this zone. The supply air system has a capacity of of 3.5 L/(s*m²). During the day (from 7 to 18 hours), its flow is controlled with a minimum of 20% and
increased depending on the ambient temperature and the CO₂ concentration. The temperature is variable (called reset) depending on the return air temperature, in a way to maintain the ambient temperature controlled on occupied hours. During night it switches to night purge, where the flow is controlled by the ambient temperature (0 if the ambient temperature is below 21°C and 67% of its maximum capacity if it is over 23 °C). The supply temperature equals the outdoor temperature until a minimum of 12 °C and shutting the flow if the outdoor temperature goes out of the range of 5 and 19°C.

The energy model accounts for approximately 3350 zones, organized in 10 different zone templates. Table 3.2 shows the amount of rooms per zone type and the total area of each type.

<table>
<thead>
<tr>
<th>Zone type</th>
<th>Number of rooms</th>
<th>Total Floor Area (m²)</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>102</td>
<td>3239</td>
<td>3.9%</td>
</tr>
<tr>
<td>Retail</td>
<td>267</td>
<td>9149</td>
<td>11.0%</td>
</tr>
<tr>
<td>Kitchen</td>
<td>20</td>
<td>620</td>
<td>0.7%</td>
</tr>
<tr>
<td>Restaurant</td>
<td>105</td>
<td>2956</td>
<td>3.6%</td>
</tr>
<tr>
<td>Gym</td>
<td>59</td>
<td>2066</td>
<td>2.5%</td>
</tr>
<tr>
<td>Storage, Corridors &amp; Misc.</td>
<td>1331</td>
<td>21902</td>
<td>26.4%</td>
</tr>
<tr>
<td>Garage</td>
<td>133</td>
<td>8048</td>
<td>9.7%</td>
</tr>
<tr>
<td>Highrise Office</td>
<td>1270</td>
<td>34028</td>
<td>41.1%</td>
</tr>
<tr>
<td>Server Room</td>
<td>3</td>
<td>229</td>
<td>0.3%</td>
</tr>
<tr>
<td>Event Room/Atrium</td>
<td>42</td>
<td>631</td>
<td>0.8%</td>
</tr>
<tr>
<td>Totals</td>
<td>3342</td>
<td>82 868</td>
<td>100%</td>
</tr>
</tbody>
</table>

As seen in Table 3.2, the largest types in the building are Highrise Office (41.1%) and Storage, Corridors & Misc. (26.4%). This is expected, as the skyscrapers has 16 floors which won’t be renovated, keeping them as offices and without changes in the HVAC system, thus having its one Zone configuration from the lowrise part. The Storage, Corridors & Misc. Zone template also includes all the types that did not fit in the rest, i.e. stairs, shafts, elevators and elevator lobbies. The types that use the smallest floor area share are the Server rooms and the Restaurant Kitchens. These two zones have large internal gains compared to the other zones, which make their simulation necessary for reliable results.

Heat recovery rates of 78% and 50% were assigned to the low-rise and high-rise respectively, to mimic the current air handling units (AHU). The low-rise buildings have received upgrades during the years of renovation, while the ones on the high-rise remain original. Included infiltration rates through facades were also set to three times larger for the high-rise compared to the low-rise to mimic the renovation discrepancies as well as the high wind exposure seen by the towers.
3.4 Post Processing, Evaluation and ITS design

After the simulation, certain considerations that could not be included in the model were added in a post-simulation calculation step, using MS Excel. This steps are in order to mimic shortcomings of IES and include:

- For the consumption of Domestic Hot Water (DHW), it was added as a constant energy consumption of 33.5 kW. It was calculated considering:
  - Consumption of 3 kWh/(m²*year) for the office spaces.
  - Consumption of 25 kWh/(m²*year) for the restaurant kitchens.
  - Consumption of Domestic Hot Water was considered to be of 2 kWh/(m²*year) for the remaining zone types.

- A cooling energy consumption of 150kW base load was added to match the measured base load. This is a blanket baseload to cover, refrigeration needs such as, refrigerators for restaurant kitchen, vending machines for soft drinks, additional high voltage transformers, switchgear rooms, etc.. The reasoning for this is to limit the amount of room templates in the model, to keep the computational time down, seeing that time restraints are already a large limitation within the project.

With the above considerations placed, the information was organized, analyzed and discussed. Then, the remainder steps were carried, which are: the validation of the model against real data, the realization of different scenarios and the design and proposal of an Ice Thermal Storage System. The following subsections present the aforementioned steps.

3.4.1 Model Validation

A model validation is necessary to confirm that the simulation can get reliable results for future simulations. In order to validate the energy building model, a comparison of results with 2016 measured energy consumption data was proposed, as this was the latest year in which measured data was available. The model was then adapted and simulated to 2016 weather data. Using the open source software provided by EnergyPlus, the IES weather file was converted into a comma separated value (.CSV) format where it could be altered within Excel to include the 2016 weather data. Once altered, the .CSV is then converted back to its original .EPW file extension.

A typical weather file consists of several parameters that ultimately effect the performance of the buildings in question. The now 2016 weather file consists of the updated dry bulb as well as dew point temperatures, as to that was the only data set provided in hourly. Remaining considerations such as wind speed, solar irradiance, and cloud coverage were not available, therefore remained the same as the original weather file. The weather data was taken from the Swedish Meteorological and Hydrological Institute (SMHI) [26].
3.4.2 Scenarios

After the model has been validated and a baseline has been done, two different proposals for implementation were made, each with a simulation and Life-Cycle Cost analysis (LCCA) to check the feasibility of implementation. The two scenarios are:

- **Scenario 1:** Extra insulation in the terrace roof. Another talking point for Vasakronan in the renovations is to insulate the terrace roof on +2tr. The proposal is to change the current roofing approximately $0.7 \text{ W/m}^2\text{°K}$ U-value to a value of $0.2 \text{ W/m}^2\text{°K}$.

- **Scenario 2:** Widen temperature heating and cooling set points by 1°C to every zone type. Vasakronan, the building owner, would like to know how the set points effect the heating loads, cooling loads and the possible side effects regarding thermal comfort inside those zones. For this, the Predicted Percentage Dissatisfied Index (PPD) of the is analyzed which predicts the share of people that wouldn't be at a thermal comfort at a specific area and it is normally used to measure the thermal comfort inside a thermal environment.

For the LCCA, a cost of 0,80 kr/kWh for district heating and cooling was used as well as 0,67 kr/kWh for electricity. The prices are according with the information of the providers, described in subsection 3.2.3. Inflation was set at 2% in accordance to Vasakronan’s requirements. Aside from the explained, all economic parameters were given by Vasakronan in the form of a their LCC templates.

3.4.3 Ice Thermal Storage (ITS)

The ideology of the ITS is to reduce the peak cooling demands. From the measured 2016 data given from Vasakronan, the peak cooling demands is approximately 2 400 kW, while the pricing threshold from Stockholm Exergi was 1 000 kW, as shown below in Figure 3.2. In order to fall into the 500-1 000 kW range the ITS needs to pick up the remaining 1 400 kW of peak capacity. Something to keep in mind is that 2016 was an above average summer in terms of the normal temperature conditions. In addition, a study was done to see the effects of the boreholes by E.ON AB, resulting in a near 750 kW cooling capacity. This 750 kW cooling capacity implemented in the ITS controller as a constant and regularly available resource. This parameter limits the amount of hours that the ITS is operational. SEC Projekt AB was in contact with an American ITS provider named Baltimore Air Company. Quotes given by Baltimore Air Company were given in terms of storage capacity 170 964€ for 3,9 MWh and 213 294€ for 4,9 MWh. These prices included all equipment and transport of the entire system, however excluded installation costs.

Typical modes of operation according the manufacturer (Baltimore Aircoil Company) for ITS systems are listed below.

1. **Mode 0: System Off** - Neither the chiller or ITS are in current use. This mode is not explained by manufacturers however is needed to complete the logic schemes stability,
almost as a fail safe. This mode should never be triggered since this assumes that the demand at that current time step is zero. This should never be true is there is always a baseload to be met.

2. Mode 1: Ice Build Only - The refrigerant within the chillers is looped through the storage tanks creating ice build on the coils. This operation mode assumes there is no base cooling load, only ice build, meaning the chillers are only serving charging of the ITS.

3. Mode 2: Ice Build with Cooling - Some of the refrigerant from the chiller is used to ice build while the remainder is diverted to meet the cooling demand. This operation mode occurs when there is a cooling which does not exceed the installed power (750 kW) of the ITS.

4. Mode 3: Cooling (Ice Only) - This operation mode occurs when the cooling demand is less the rated power of the ITS. This operation implies that the chiller is off, and the cooling demand is met only by the ITS.

5. Mode 4: Cooling (Chiller Only) - The chillers supplies all the cooling demand and maintains the temperatures. This operation mode may occur while having charge within the ITS. Depending on the priority of the scheme in place, chillers serve all the cooling demand, despite means of using other technologies.

6. Mode 5: Cooling (Both ITS and Chiller) - In this operation mode the chiller may precool the refrigerant prior to entering the ITS where it cooled the remainder of the way to the design temperature. This may occur when the cooling demand exceeds the ITS power rating.

This list of operation modes above, goes under the assumptions that the system prioritizes using the ice, which is common in an electrical spot market. In Sweden however, electrical prices are fairly stable based on the pricing scheme provided in Section 3.2.3. As explained above there are typically five operation modes in the ITS design which include, ice building, ice building and cooling, cooling with ice only, cooling with chiller only, and cooling with both chiller and ice. Depending on how the ITS is implemented the operational modes vary in how and when they are used. To tie together the building loads to the ITS, a controller was created within Excel to simulate how and when these operational modes will be triggered. Due to Sweden’s electricity market and heating pricing schemes, the controller was prioritized when the remaining cooling demand (after considerations from the boreholes) exceeds 1 000 kW. This is in response to the next price point tier explained in Figure 3.2. The controller was created for the purposes of simulating this prioritization scheme, as well as to get the appropriate sizing of the ITS.

The controller has four major logics gates which are current storage level, demand level, priority hour, and the comparison between the cooling demand and ITS power as shown below, in Figure 3.4. The controller begins at the start of every hour assessing the ITS’s current level, and then assuring that the demand is greater than zero. Once it classifies the demand, the controller
moves to see if the current time step is a priority hour. Lastly depending the three previous gates, the process flow goes to assess whether the current cooling demand is greater than the ITS's power.

Vasakronan’s main objective for the ITS is to avoid that new payment tier from the utility company, however the logic scheme also includes the use of priority hours. What this addition does is set another level of control, allowing the user to use the controller for example in an electric spot market, by setting the priority hour parameter to a price point. Being that the current electricity price scheme of Sweden sets a flat rate rather than a dynamic rate, this project states the electrical price as a flat rate as well, thus bypassing the priority hour logic gate of the controller.

![Ice Thermal Storage Controller Logic Scheme with Priority Hours](image)

Figure 3.4: Ice Thermal Storage Controller Logic Scheme with Priority Hours

Ultimately the flexibility of the controller is for the optimization of the ITS, not only to study a predefined scenario. The controller allows for the user to vary several parameters such as the power rating of the system, storage size (hrs), charge rate (hr/hr), and coefficient of performance (COP) of the chillers. As a general simplification, the chiller exhaust will operate to -6°C while in heat pump mode at a COP of 3.6, and in summer is run as a cooler at 10°C at a COP of 5.1.
4.1 Introduction

In this chapter the simulation results are presented for the different models studied. First, a baseline model is presented and discussed doing a comparison against actual consumption of heating and cooling data. Then, two models, each with different design proposals are presented and discussed against the baseline model, making a comparison using a LCC analysis. Lastly, the results for the ITS controller are presented.

4.2 Model Validation

As explain in section 3.4.1, the simulated model had to be validated against real data. To do so, the simulation was compared to the measured consumption of the building for the year 2016 provided by Vasakronan. As explained in Section 1.4 the renovated plans given by the architecture firm Wester + Elsner differ from the current layout. These renovations include retrofitting new windows as well as a general overhaul of the layouts of the low-rises. Each comparison made during the validation of the model is in terms of the subsequent section it is in. Example being, if concluding the statement "the schedule is validated" within section 4.2.1 then the statement applies to that section and that section alone.

Due to the size of the building simulation, as explained prior, the model was divided into the separate files, House 1, House 2, and House 3&4. This format is also how Vasakronan provided the measured data, with the only exception being for cooling for House 2, and 3&4 being combined in this instance. As a general overview, Table 4.1 below shows the comparisons of heating and cooling energy in terms of megawatt hours measured for the entire year. For the 2016 year heating
CHAPTER 4. RESULTS

and cooling between the two models differ by 3.3% and 41.9% respectively. The discrepancies and discussions are further investigated in the following sections.

<table>
<thead>
<tr>
<th>Total Sums</th>
<th>2016 Measured</th>
<th>2016 Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating (MWh)</td>
<td>Cooling (MWh)</td>
</tr>
<tr>
<td>House 1</td>
<td>1888.3</td>
<td>898.8</td>
</tr>
<tr>
<td>House 2</td>
<td>2156.9</td>
<td>3040.6</td>
</tr>
<tr>
<td>House 3&amp;4</td>
<td>2878.4</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>6923.5</td>
<td>3939.4</td>
</tr>
</tbody>
</table>

Table 4.1: Comparison of Heating and Cooling of the Simulation and Measured Data 2016

4.2.1 Heating Validation

In validating the heating loads, the measured data was compared to the simulated. Peak occurs when the outdoor temperature is -15°C at 7am, directly prior to the workday beginning and is 3950kW for the measured and 3764kW for the simulated. Figure 4.1, below shows a week long comparison of the two data sets.

The figure shows the two data sets matching for when the ventilation is turned on in the beginning of the day, however for the measured data, the ventilation continues to provide heating, while the simulated heating drops off quickly. The measured data maintains around the peak value for a few hours, while the simulated data only peaks for an hour then levels downs. On the
first few days of the week the two data sets match in behavior but differ in scale, however on the other day there are other days where the measured data doesn’t follow the trend of the simulated data and remains higher. This type of behavior can be attributed to the differences on actual versus simulated internal gains from people, lighting as well as heating and cooling setpoints.

During the weekends heating for the simulation exceeds that of the measured data, both in peak and steady state, showing that the activity levels for the simulation anticipating more commerce. Logic would assume that with more people, there would be less of a heating demand, because of a larger internal gain, however this is outmatched by the intended increased of the retail space. This matches the proposed intention of the renovations, confirming the scheduling for the weekends.

During the weekdays, off peak work hours, the building comparison shows that the simulated data heats more at night compared to the measured data, giving the indications of differences in control strategies. This was confirmed by IES maintaining room temperatures above the heating set point despite ambient temperatures at -10°C. Temperatures within the rooms hovered at 22.5°C during the day and 21.5°C while the heating set point was 20°C.

4.2.2 Cooling Validation

Figure 4.2 shows the cooling comparison of both the simulated and measured peak data for 2016. For both Monday and Tuesday, weather conditions were approximately 27°C with 50% relative humidity at 8AM, causing the large peak. Peak cooling for the measured data was 2362 kW and 1923 kW for the simulated, with approximate base loads of 380 kW and 200 kW, respectively.
Due to the nature of the project, several theories had to be explored in order to validate the cooling demand. With all of these in mind, the largest single factor explored was the control strategy. The building developers throughout the project have only divulged limited information regarding the spaces being renovated while remaining largely anonymous with the constructions and strategies of the high rise portion.

The associated peaks of the simulated cooling data follow the load curves of the measured data, with slightly lower peaks. This base load, varies in the measured data from approximately 200 kW in the winter to closer to 400 kW in the summer. In the simulated data set, the only objects requiring base loads were the large server rooms which are operated by telecommunications companies and were set to approximately 200 kW.

Despite the relative peaks being close to one another, the total summation of the energy used between the measured and simulated data showed a 42% difference, as seen in Table 4.1. A large contribution for this discrepancy is in the non-summer months, as shown in Figure 4.3.

![Figure 4.3: Comparison of Measured vs Simulated Peak Cooling Data](image)

Figure 4.3 shows that in the spring months the simulated data remains close to base load, with a very subtle bump in midday. This small shift during the midday illustrates the threshold of the weather to trigger the need for cooling. The measured data however demonstrates that the need for cooling on the order of 300 kW more than the base load during the middays. It is not until the cooling demand exceeds 600 kW that the simulation data rises above the baseload. Something to note as well is that each time the simulated data rises above baseload, the baseload of the measured data rises. As a point of reference, the ambient temperature on May 2nd which
causes the rise of the simulated data from the baseload was 17 °C. For the measured data this occurs as early as February, when temperatures are still hovering around freezing.

Several aspects of the renovations for this project were targeting on lowering the cooling demand side of things. These renovations include complete overhaul of the facades for the ground floor as well as 1tr, new glass for the atrium’s located on 2tr. Another consideration is the use of night purging of the building as well as the SAT of each rooms.

The proposed control strategy had chill beams in the atrium, and the office areas, both low and high rise, with no separate trigger temperature other than the cooling set points. This strategy prioritizes cooling with the air supply until reaching the cooling set point, when the chill beams are activated. This means in the spring and fall months, the building is largely cooled by the ambient air temperatures (free cooled), lowering the cooling demand. This is a justification as to why in Figure 4.3 the simulated cooling demand is triggered when ambient temperatures are above a threshold.

Because of the uncertainty of the buildings current control strategy, alternative strategies were created to model the behavior shown in the measured data. One alternative was to remove night purge, being that the current building doesn’t utilize it. Upon studying the results the cooling demands increased only approximately 5% with the large majority of the increase in the summer time and little in the spring/fall months. This is in large due to the fact that the night purge was activated when the ambient temperature was between 12°C to 19°C (between 20:00 – 7:00). Another alternative that was explored was the use of fan coil units in several zone types, and having the fan coils prioritize the cooling, and having the air supply maintain CO₂ and supplement cooling as needed. To due so, the cooling set was lowered to trigger the fan coil units, while the original cooling set point was inserting into the scheduling of the air supply. The resulting cooling demands of the changes stated above are seen in Figure 4.4.

Figure 4.4 shows that even in the cooler months of March, the cooling demand increased dramatically, matching the measured data in both the peaks, as well as the longevity of the cooling season. Due to time limitations this study was only conducted on House 1. Despite the validation of the cooling by the fan coil control strategy the remainder the report deals with the control strategy proposed by Vasakronan. This comparison was only conducted to better conclude the current control strategy of the building, and to not propose one. This validation however did allow for the confidence to proceed with the baseline scenario.
4.3 Baseline Model

Having validated the model, the results of the baseline after the future renovations are presented in this section. Results will be analyzed from a building perspective as well as from a room level perspective. As a reminder the results showed in this section use the IES weather file, not the 2016 weather file which was used in the analysis of the model validation in Section 4.2. Another point to make is the following results uses Vasakronan’s proposed control strategy, not the fan coil strategy explored in Section 4.2.2

4.3.1 Heating and Cooling Demand

<table>
<thead>
<tr>
<th>Total Sums</th>
<th>Baseline Heating (MWh)</th>
<th>Cooling (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td>2252.0</td>
<td>584.1</td>
</tr>
<tr>
<td>House 2</td>
<td>1922.1</td>
<td>567.0</td>
</tr>
<tr>
<td>House 3&amp;4</td>
<td>3517.6</td>
<td>995.1</td>
</tr>
<tr>
<td>Totals</td>
<td>7691.7</td>
<td>2146.0</td>
</tr>
</tbody>
</table>

Figure 4.5: Heating and Cooling Annual Energy Consumption
From the simulation, the annual heating and cooling consumption's are 7692 MWh and 2146 MWh respectively considering all buildings. From this it can be concluded that all houses consume a similar amount of energy (considering houses 3 and 4 together) and are relatively balanced, with a standout of house 1 that consumes 29.2% of the annual heating load and 27.2% of the annual cooling load. Figure 4.6 below, shows the year-long heating and cooling loads for the project. The maximum heat demand is 3199 kW the 29th of December between 7:00 and 8:00, with other two heat demands of 3189 kW the 20th of December and of 3182 the 1st of February at the same hours.

![Figure 4.6: Heating and Cooling Demand Baseline Beridarebanan 77, 4 and 11](image)

The outdoor temperatures from the weather file at those moments are of -2.3°C, -8.2°C and -15.7°C respectively. The day of most heating demand is the 22th of December with a total need of 57,13 MWh. Despite the average temperature of the day being -4.4°C, the average wind speed is the second highest of the year. The general shape of the building provides large surface area, exposed to higher winds. The surrounding structure, are no more than five to six stories tall, providing minimal wind break to the towers.

The data within Figure 4.6 the heating demand has an outlier around hour 3 650, registering nearly 1 500 kW despite being June 6th. Studying the hour further reveals that ambient temperature is approximately 10°C, relatively normal, however the wind speeds were gusting at 30 m/s. This shows the relevance that the wind speed has on the heating (and potentially cooling) consumption, especially on the towers, which demand in average 59% of the total heating demand that day.

The maximum cooling demand is 1836 kW, on June 24th occurring when the outdoor temper-
ature is 27.0°C, both being the hottest temperature of the year, but also being the fourth day in a row of temperature above 25°C. Minimums are the domestic how water for heating during some time spans in the summer, while cooling has minimum base load of approximately 200 kW.

From the energy (heating and cooling combined) consumption, the highrise require between 32% and 80% respectively. This large fluctuation is large in due to scheduling, ambient conditions and space types. For example, during the weekend the highrises are unoccupied being that they are largely offices. Because the highrise building won’t be renovated, improvements made for energy reduction won’t affect that part of the building, meaning that the highrise won’t reduce its energy consumption.

4.3.2 Room level analysis

To show the simulation results in a more detailed view, an analysis is performed on a specific room of the building. For this analysis, an office in floor 1 of House 1 has been chosen, as it has occupants during day time, solar gain, ventilation control lighting and equipment gains, making it accountable for a quantifiable energy analysis. The office also is placed towards one facade, so it is objective of heat losses through windows and solar radiation during the day. The day chosen is June 24th, the warmest day of the year according to the weather data. Figure 4.7 below, presents the energy balance for the analysed office mentioned above. The temperature stays between 22.2°C and 24.5°C during the whole day; which is between the set points established for an office space (21.5 to 24.5). People, lighting and equipment gains have considerable effect during the office hours, as they are related to the building occupation happening. This can be seen as the three gains increase at the same time occupation increases as input in the zone template configuration for office spaces, starting from 7.30 am.

![Figure 4.7: Energy analysis of an office space on June 24th, Floor 7, House 1](image-url)
4.3. BASELINE MODEL

Being the warmest day of the year, the energy consumption is only in the form of cooling loads for the office space and no heating load is measured. The cooling effects include air sensible cooling, cooling units (chilled beams), as well as external conduction gains when the space is cooling itself by delivering energy to the neighbouring spaces. Figure 4.8 presents the cooling demands of this space.

Figure 4.8: Cooling energy demand for an office space in floor 1 of House 1

Figure 4.9 shows that the energy consumption in the form of cooling. Until approximately 8 am, the space conditioning sensible loads and the air system sensible load go with the same path, meaning that the air supply is meeting the cooling requirements just by delivering air. After that, an imbalance between both is produced, at the same time where the cooling plant sensible
load starts, meaning that the cooling load is not possible to be met by only the air supply and chilled beams are necessary to cool the space. During night time, the chilled beams decrease their power until the load is met only by the use of air, which is outdoor air at night by the use of the night purge strategy. During the day, the conditioning by air supply accounts for 64% of the cooling load, while the chilled beams supply the remaining 36%. This shows the large impact the ventilation strategy has on the energy consumption of the space. During the day, air is supplied at constant 19°C and is conditioned by room temperature and CO$_2$ levels, which need to be at low levels to keep the office at a comfortable breathing level.

Figure 4.9 shows the airflow and the CO$_2$ levels of the studied room. During the first hours of the day, the airflow maintains almost steady flow and later increases in response of the expected occupation as discussed in the previous paragraphs. This keeps the levels of CO$_2$ below 600 ppm as a result, which are levels below 1000 ppm, the limit where poor air is normally set [24]. After normal office hours, number of people is decreased to a base and airflow strategy is switched. Being the warmest day, the airflow stops as it is only activated when the outdoor air is below 19 °C in order to utilize the outdoor air to cool the building, as configured in the zone templates configuration. Because of that, the levels of CO$_2$ rise to a peak on almost 660ppm, also safe. Once the outdoor air reaches 19 °C at around 21:30, the airflow starts running again, therefore cooling the building.
4.4 Scenario 1 - Extra Insulation in Terrace Roof

For this scenario, the roof in question is the terrace roof which is located on +2tr. This roof is the footprint of the entire building minus the highrise towers and atriums, making it approximately 3 230 m$^2$. The current construction of the roof consists of concrete, gravel and asphalt, equating to a U-Value of 0,71 W/m$^2$K. The new recommended construction for the roof is a combination of concrete, lightweight concrete, and cellular foam insulation resulting in a U-Value of 0,25 W/m$^2$K.

4.4.1 Heating and Cooling Demand

The annual heating consumption on this scenario is 7429 MWh, being a 3.4% below the annual heating consumption of the baseline scenario. This is not strongly seen at any point of the year, but only as a overall reduction to the heating demand throughout the year. The cooling demand does not suffer any noticeable change compared to the baseline scenario. The renovated roof represents 6% of the above ground surface area, but only 3.4% reduction in heating. As explained in 4.3.1, due to the geometry of the building, the towers account for the majority of the heating demand as well as 60% of the surface area. This explains the relatively low effect of the different U-value roofing materials, since the demand from the towers is so inflated.

4.4.2 LCC Analysis

The results for the Life-cycle Cost Analysis for Scenario 1 are presented in table 4.2.

<table>
<thead>
<tr>
<th>Table 4.2: Scenario 1 Life Cycle Analysis Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific Investment</strong></td>
</tr>
<tr>
<td><strong>Terrace Area</strong></td>
</tr>
<tr>
<td><strong>Total Investment</strong></td>
</tr>
<tr>
<td><strong>Energy savings</strong></td>
</tr>
<tr>
<td><strong>Annual Savings</strong></td>
</tr>
<tr>
<td><strong>Payback Period</strong></td>
</tr>
</tbody>
</table>

The results of the economic study lead to a payback period of 16 year, which could be discussed if it is feasible or not depending on the building owners’ objectives. The specific cost of 1000 kr/m$^2$ only takes into account the cost of extra insulation that is being studied to be used for the terrace roof, and not taking into account all the related costs of the renovations. This has not been taken into account because the renovations will be made anyway, so the costs related to renovations are taken as sunk costs. If these costs would be taken into account, the specific investment would rise up to 3500 kr/m$^2$, as discussed in the presentation meeting [19]. This would lead to a payback period of more than 50 years.
4.5 **Scenario 2 - Widen Temperature Setpoints by 1 °C**

As explained in section 3.4.2, this scenario considers to widen temperature heating and cooling set points by 1°C. For example a room template of 21°C - 24°C becomes 20°C - 25°C. Other factors being considered in the results are relative PPD as well as CO\textsuperscript{2} concentrations within the building. The widening of the set point will intrinsically effect how the controls of the building will operate within IES. The ranges of the baseline room heating and cooling set points can be found in Appendix A.

4.5.1 **Heating and Cooling Demand**

Figure 4.10 shows the energy demands for the building complex on the simulation year for the new set points. As expected the general shape of the demand throughout the year remains similar to that of the baseline scenario.

![Figure 4.10: Heating and Cooling Demand of Scenario 2 for Beridarebanan 77, 4 and 11](image)

The annual heating consumption on scenario 2 is 6463 MWh, 16.0% below the annual heating consumption of the baseline scenario. As occurred in the baseline, the reduction is seen within the whole year and not in any point in particular and keeping the same tendencies in the graph. The cooling annual consumption is 2964 Mwh, 3.8 % below the baseline cooling demand. The differences in reduction of heating and cooling demands indicate the difference in consumption between heating and cooling. Heating is generally used more during the year and has a stable more predictable demands throughout the year than cooling. Cooling is more spastic according to the weather and solar gain of that particular day. Also the discrepancy in reduction between
heating and cooling shows where in the temperature range IES balances toward. Being that the heating by share was effected more so, IES typically toggles on the lower end of the range.

### 4.5.2 Analysis

Being that the only change made for this scenario is the heating and cooling setpoints, the investment made for it is assumed as negotiable. Having new setpoints also permits to save a total energy of 1310 MWh, which turns into annual savings of 10,4 Mkr. With this numbers, it can be said that from an economical point of view this scenario is feasible. Despite this, other factors should be considered and are used to provide further discussion. One factor that should be analysed is the Predicted Percentage of Dissatisfied (PPD). Having high values of PPD can also result in a lower productivity in an office space [24].

![Figure 4.11: PPD Comparison, Baseline vs. S2, House 1: Room 0012](image)

Figure 4.11 presents the PPD for an office area located in floor 1 for the simulated year on scenario 2 and the baseline scenario. Comparing both, scenario 2 shows an annual average of 6.4% and peak of 20.6% (achieved on July 26th of the simulated year), while the baseline shows an annual average of 7.4% and a peak of 19.0 (achieved on July 30th). ASHRAE Standard 55, sets the acceptance range in a 80% of occupant acceptability [4]. On the other hand, the Swedish Work Environment Authority (Arbetsmiljöverket), based on the standard ISO7730:2006 [16], states that PPD should be under 10% for a good work environment [2]. The baseline scenario exceeds the 10% limit by 734 hours during the year and maintains a PPD under 20% during the whole study year. Scenario two goes over 10% of PPD on 775 hours and over 20% on 6 hours. Following the Swedish regulation, both scenarios exceed the limit, mainly during the summer
season. It can be concluded that the cooling capacity should be improved in order to be able to
keep a comfortable environment during high outdoor temperatures. Also, the cooling set point
could be further decreased to provide a more comfort ambient temperature.

4.6 Ice Thermal Storage

As a quick summary of previous discussions in 3.4.3 there are five operation modes within the
ITS controller. Figure 4.12 below, is the hour summation of the modes being triggered throughout
the year long run, according to the ITS controller developed.

<table>
<thead>
<tr>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
<th>Mode 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Build</td>
<td>Ice Build and Cooling</td>
<td>Cooling - Ice Only</td>
<td>Cooling - Chiller Only</td>
<td>Cooling Both</td>
</tr>
<tr>
<td>0</td>
<td>186</td>
<td>0</td>
<td>8480</td>
<td>94</td>
</tr>
</tbody>
</table>

Figure 4.12: Summation of Modes Being Triggered

As expected from the cooling base load present, Mode 1 where only ice build is present should
never be triggered. Mode 3, where the building is only cooled by the ITS is never triggered
because of the peak shaving strategy explained in Section 3.4.3, as well as since the 1 000 kW
threshold exceeds the ITS's cooling power. Mode 5, where both district and ITS cooling are in
operation for 94 hours of the year, where the cooling demand exceeds 1000 kW. Mode 2, where ice
is being built while district cooling is on, operates for 186 hours of the year. Mode 4, where only
the chiller serves the cooling load is in operation 8480 hours of the year. In total the ITS produces
52.3 MWh of cooling capacity throughout the year saving approximately 26 730 kr in cooling cost,
however spending 17 280 kr in electricity to charge the system, ultimately saving 9 450 kr in
energy. The storage levels at any given point in the year are shown in Figure 4.13, below.

Figure 4.13: ITS Storage Levels Throughout the Year Based on Cooling Demand
4.6. ICE THERMAL STORAGE

Being that the cooling system is primarily run by a chiller, excess heat is dumped into the boreholes to the limit of 1 000 kW cooling demand. Everything exceeding 1 000 kW must be met by the ITS. Figure 4.13 shows that when this threshold is exceeded, the ITS system comes online depleting the stored energy. The system studied was a 4.5 MWh with 6 hours of storage, equating to 750 kW of continuous cooling capacity. As shown in the figure above, there are a few hours in which the storage is depleted. This would result in a 4 hour period where the district cooling would either exceed 1 000 kW or the building operator chooses let the building exceed the cooling set point for that period. Ultimately the ITS must power 750 kW of cooling, so the only alternative to not deplete the storage is to increase the capacity. At approximately 9 hours or 6.8 MWh the ITS is never depleted. To increase the storage by 50% to operate for 4 hours, the remainder of the report assumes the investor would choose the initial 4.5 MWh option. Figure 4.16 below, are the price savings based on the prices set by the energy companies.

<table>
<thead>
<tr>
<th>Peak Cooling (kW)</th>
<th>Flat Rate Tier (kr)</th>
<th>Peak Price (kr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1 835</td>
<td>161 705</td>
</tr>
<tr>
<td>With ITS</td>
<td>1 000</td>
<td>111 750</td>
</tr>
<tr>
<td>Difference</td>
<td>-49 955</td>
<td>-200 644</td>
</tr>
</tbody>
</table>

Figure 4.14: ITS Pricing Breakdown

According to the pricing scheme mentioned in Figure 3.2, the ITS would save approximately 50 000 kr within the category of "Fast Del", while assuming we the peak cooling demand of 1 835 kW would save approximately 200 000 kr within the "Effektpris" peak purchasing. Calculated previously the savings in terms of energy was 9 450 kr.

Due to the low usage of the ITS, the payback period was calculated using the same heating and cooling costs for both the baseline and ITS scenarios. Being the same demand, ultimately the heating and cooling costs would be the same, so both variables were removed for simplification. Using Vasakronan’s economic figures of 8% discount rate and 2% growth rate it is expected to be a 12 year payback period, for an initial investment of 2 250 000 kr, and 250 000 kr in savings. This is represented by the intersection of the two curves within Figure 4.15, below. The results show where the initial investment remains constant, and the savings slowly depreciating each year. The area between the curves to the left of the intersection, is the payback of the investment. Everything to the right of the intersection is the money profited.
Due to the limited operation using the peak-shaving methods, alternative scenarios were explored. Since the electrical prices in Sweden are stable, a method of discharging whenever charge was available was implemented within the ITS controller. Since district cooling is at no cost from November until March, the ITS controller does not operate then due to the economic incentives. Being that the cost of district cooling varies through the months, alternatives were done for both April through October, and June - August. The results of which are shown below in Figure 4.16. These savings are shown based on the charge rate (hr/hr) of the ITS. The quoted ITS system was rated at 0.5 hr/hr.

Figure 4.16: ITS Saving - Non Peak Shaving
Figure 4.16 shows that depending on the price scheme operated within one could expect about a 75% increase in the energy saving at nearly every charge rate. At the quoted charge rate of 0.5 hr/hr the savings are approximately 60 000 kr and 35 000 kr for June - August and April - October, respectively. Being the alternative method discharges whenever it has charge, this would not allow the system to stay under the 1000 kW peak cooling demand, meaning the loss of the flat rate tier fee as well as peak price savings. Ultimately this would mean nearly 190 000 kr/year additional to have, making it a nonviable option in economic terms. No subsequent LLC analysis was performed for this scenario.
5.1 Conclusion

An energy model that can predict the activity for the buildings Beridarebanan 4, 11 and 77 was created. This model was validated against real consumption data with differences of 3.3% for heating loads and 41.9% for cooling loads. As explored in the validation section, the main contributor for the cooling discrepancy was the control strategy itself, which was not accounted within the simulation. The differences between data from the actual and simulated data also come from the fact that the simulated building considers the future renovations, strategies, schedules and gains that are not currently present, adding a uncertainty.

From the generated demands from the building simulation, a subsequent ITS controller was created to model the activity of the ITS system during a peak-shaving strategy. The payback period of a 4.5 MWh, 750 kW cooling power, ice thermal storage system is 12 years, despite only operating for 94 hours of the year. Based on the findings from the alternative ITS controller scenarios, the 12 year payback period has the ability to be shortened given higher resolution control strategy.

Ultimately the current pricing scheme of the district cooling as well as stable electrical prices give little to no incentives toward load shifting which the focus of study within the literature review. The savings instead were generated in large to the peak price and tier point within the cooling scheme, and not the cost of energy. Considering that district cooling is at no cost between Nov-Mar there is no incentive to use ITS during those months. Due to the stable electrical price the Swedish energy market in terms of ITS, penalizes large peaks rather than energy consumption, eliminating incentive for load shifting. This incentivizes ITS installation highly to eliminate the uncertainty of peaks.
5.2 Considerations and Future Works

The global energy market is a constantly fluctuating entity. Predictions of how the market will be in the future are never certain. Sweden has a large base load generation potential with large production met by hydro power (40.3%) and nuclear reactors (39.3%) [13], keeping the price for electricity stable. Hydro production capacity has been stable for the last 50 years, while stability for nuclear has been for the past 35 years [7]. Sweden has recognized that their hydro power potential is limited, and with potential phase out of nuclear power, electrical prices may not be as stable with the increasing demand. Something to consider would be a non-stable electrical price and how that would affect the results. In this work, ITS is been economically attractive due to its peak shaving effect (so the reduced expenses for peak power), but in other works ITS has been an economically attractive option in electricity price schemes that are dynamic [8].

This project building is not a perfect representation of all commercial buildings in Scandinavia, and further refinement of this representation should be developed. The criteria for each building development project differs from stakeholder to stakeholder. Standards for building optimization are in place by Sweden Green Building Council, however those criteria might differ from the stakeholders.

Due to the early stages of the project, much of the information provided by Vasakronan and SEC Projekt were preliminary. This included the use of the fixed chiller COP's within the calculation of the ITS controller. Realistically a model could be created to find the inlet/outlet of the hot and cold sides of the chiller based on the plant schematics, however this level of detail would far surpass the time allotted for this project. A future work to give better resolution would be to calculate the temperatures needed from the chiller based on the building's energy demands.

Within the results of the ITS an alternative scenario to peak-shaving was run due to the initial low usage of the system. The alternative scenario ran the control to use storage if it has it, with no regard to peaks. This was the case since it is difficult to predict weather conditions. A consideration to take, is that a controller could be built to have some weather prediction factors based on Power v Demand curves generated by the building simulation software. This controller can find the optimal between using all storage, but predicting the demand can store prior to the peak heating demands. Results of the peak-shaving controller benefited approximately 10 000 kr in savings where the alternate scenario had an energy savings of 60 000 kr in the June-August period. Given that the payback in Section 4.6 was 12 years, and the energy savings was only 10 000 out of 250 000 of annual savings. If said new controller could increase the energy savings, the payback period could be sooner than 12 years.

Peak-shaving is a concept that is globally accepted as beneficial for stabilizing the electrical grid. Another consideration for ITS payback period is that the peak above 1000 kW cooling demand was 1835 kW for the building studied. The peak price account for 80% of annual savings. If the peak was to rise the potential annual savings subsequently would increase as well. Depending on the pricing of the larger ITS system to support the larger peak, would be of
interest for future study.

From the investigations read within the literature review, ITS could be considered an interesting option but its feasibility is very linked to the electricity and energy tariff scheme from the country where the ITS is being placed. In many instances within the review, incentives for ITS were to avoid high electrical prices created within an electrical spot market and create load shifts as well as paying in non-peak hours. In the case for Sweden, the stable electrical market creates the incentive to avoid the peak price penalty and tier points. Despite the incentives being different, the outcome for both are similar since the make the consumer aware of how, when and why the energy is being used. Something to consider for future work, is the use of controller with the electrical market of the other Scandinavian countries.
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doi: https://doi.org/10.1063/1.4913646.

A review on cool thermal storage technologies and operating strategies.  
# Appendix A - Model Information

Table A.1: Construction Materials

<table>
<thead>
<tr>
<th>Building Envelope</th>
<th>Material(s), Outside to inside</th>
<th>Overall U Value, W/m²*K</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Walls</td>
<td>Steel, 12.5 mm Cork Insulation from Oak Tree, 50 mm Cast Concrete (medium), 75 mm Gypsum Plasterboard, 12.5 mm</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Plasterboard, 12.5 mm Cavity, 50 mm Plasterboard, 12.5 mm</td>
<td>1.79</td>
</tr>
<tr>
<td>External Floor</td>
<td>Insulation, 98.2 mm Reinforced Concrete, 100 mm Cavity, 50 mm Chipboard Flooring, 20 mm</td>
<td>0.22</td>
</tr>
<tr>
<td>Internal Floor</td>
<td>Synthetic Carpet, 12.5 mm Cast Concrete (Dense), 200 mm Cavity, 500 mm Acoustic Tile, 12.5 mm</td>
<td>0.22</td>
</tr>
<tr>
<td>Roof</td>
<td>Slate Tiles, 60 mm Tile Bedding, 200 mm Asphalt, 20 mm Cast Concrete (Dense), 50 mm Asbestos Cement Decking, 36mm Cast Concrete (Lightweight), 235 mm Cast Concrete (Dense), 200 mm</td>
<td>0.71</td>
</tr>
<tr>
<td>Terrace Roof</td>
<td>cell8</td>
<td>cell9</td>
</tr>
<tr>
<td>External Glazing</td>
<td>Clear Float, 6 mm Cavity, 12 mm Clear Float, 6 mm</td>
<td>1.20; g-value: 0.44</td>
</tr>
<tr>
<td>Internal Glazing</td>
<td>Glass</td>
<td>3.84; g-value: 0.87</td>
</tr>
</tbody>
</table>
Table A.2: Glazing Materials

<table>
<thead>
<tr>
<th>Glass Model</th>
<th>Material(s), Outside to inside</th>
<th>Parameters</th>
<th>Comment</th>
</tr>
</thead>
</table>
| COOL-LITE Xtreme; Double Glazed | Clear Float, 6 mm  
Cavity, 15 mm  
Clear Float, 4 mm | U: 1.34 W/m² * K g: 0.33 | First Floor - Hötorget  
First Floor - Sergelgatan (w. Ext. Shading) |
|                        | Clear Float, 6 mm  
Cavity, 15 mm  
Clear Float, 4 mm | U: 0.74 W/m² g: 0.30 | First Floor - Sveavägen                                 |
| ECLAZ, Double Glazed   | Clear Float, 4 mm  
Cavity, 18 mm  
Clear Float, 4 mm | U: 1.23 W/m² * K g: 0.61 | Bottom Floor - Sveavägen  
Master Samuelsgatan |
| ECLAZ, Triple Glazed   | Clear Float, 4 mm  
Cavity, 18 mm  
Clear Float, 8 mm  
Cavity, 18 mm  
Clear Float, 4 mm | U: 0.75 W/m² g: 0.60 | Bottom Floor - Hötorget  
Bottom Floor - Sergelgatan (w. Ext. Shading) |
| Atrium Glass, Vertical | Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm | U: 0.73 W/m² g: 0.26 | All Houses                                               |
| Atrium Glass, Horizontal - New | Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm | U: 0.85 W/m² g: 0.20 | House 1 Terrace Roof                                    |
| Atrium Glass, Horizontal - Old | Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm  
Cavity, 12 mm  
Clear Float, 6 mm | U: 3.84 W/m² g: 0.87 | Houses 2,3,4 Terrace Roof                              |
<table>
<thead>
<tr>
<th>Template</th>
<th>Operational Room Temp</th>
<th>Supply Air Temp</th>
<th>Airflow L/(s·m²)</th>
<th>Running Time Ventilation</th>
<th>Control Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Offices</strong></td>
<td>21.5-24.5 °C</td>
<td>Nightpurge @ min 12 °C Constant T @ 19°C</td>
<td>2.0</td>
<td>Nightpurge: If Outdoor 5°C&lt;T&lt;19°C, then Amb. T: 21-23°C = 0%-67%, If not, 0% Day (7-18): 20% min, Temp 23.5; 2 °C band control CO2 925, 150 ppm band control Weekend Off</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Restaurants</strong></td>
<td>21.5-24.5 °C</td>
<td>Nightpurge @ min 12 °C Reset: 16°C&lt;T&lt;20°C</td>
<td>4.0</td>
<td>09-23; 50% min, Temp 21.5 controlled, 100% max</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Restaurant Kitchens</strong></td>
<td>21.5-24.5 °C</td>
<td>Nightpurge @ min 12 °C Reset: 15°C&lt;T&lt;20°C</td>
<td>45</td>
<td>09-23, 50% min, Temp 21.5 controlled, 100% max</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Retail</strong></td>
<td>21.5-24.5 °C</td>
<td>Nightpurge @ min 12 °C Reset: 15°C&lt;T&lt;20°C</td>
<td>3.5</td>
<td>Nightpurge: If Outdoor 5°C&lt;T&lt;19°C, then Amb. T: 21-23°C = 0%-67%, If not, 0% Day (7-18): 20% min, Temp 23.5; 2 °C band control CO2 925, 150 ppm band control Weekend Off</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Warehouse/Corridors</strong></td>
<td>15-28 °C</td>
<td>19 °C</td>
<td>0.35</td>
<td>7-18 Weekdays</td>
<td>CAV</td>
</tr>
<tr>
<td><strong>Gyms</strong></td>
<td>21.5-24.5 °C</td>
<td>Nightpurge @ min 12 °C Reset: 13°C&lt;T&lt;20°C</td>
<td>5.0</td>
<td>7-18; 20%-100% Controlled by Room T. and CO2; Night Purge as office</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Garage</strong></td>
<td>19-28 °C</td>
<td>Nightpurge @ min 12 °C Reset: 15°C&lt;T&lt;20°C</td>
<td>1.0</td>
<td>70% 7-19; 20% Rest of Time</td>
<td>VAV, No Control</td>
</tr>
<tr>
<td><strong>Skyscraper Offices</strong></td>
<td>21.5-24.5 °C</td>
<td>19 °C</td>
<td>1.5</td>
<td>Nightpurge: If Outdoor 5°C&lt;T&lt;19°C, then Amb. T: 21-23°C = 0%-67%, If not, 0% Day (7-18): 80% min, Temp 23.5; 2 °C band control CO2 925, 150 ppm band control Weekend Off</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
<tr>
<td><strong>Server Rooms</strong></td>
<td>21-24 °C</td>
<td>19 °C</td>
<td>0.35</td>
<td>7-18 Weekdays</td>
<td>CAV</td>
</tr>
<tr>
<td><strong>Atriums</strong></td>
<td>21.5-25.5 °C</td>
<td>Nightpurge @ min 12 °C</td>
<td>2.0</td>
<td>Nightpurge: If Outdoor 5°C&lt;T&lt;19°C, then Amb. T: 21-23°C = 0%-67%, If not, 0% Day (7-18): 80% min, Temp 23.5; 2 °C band control CO2 925, 150 ppm band control Weekend Off</td>
<td>VAV, Temp+ CO2 Control</td>
</tr>
</tbody>
</table>
**Table A.4: Zone Template Information Pt.2**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>39 m² (0.7 diversity factor)</td>
<td>90 W sensible, 60 W latent</td>
<td>70% Weekdays 7-18, 1 hour shoulders, 10% rest of time</td>
<td>7 W/m²</td>
<td>Same as occupation</td>
<td>12 W/m² (0.5 diversity factor)</td>
<td>Same as occupation</td>
</tr>
<tr>
<td>Restaurant</td>
<td>33 m²</td>
<td>100 W sensible, 60 W latent</td>
<td>70% 11-15 &amp; 17-21, 15% off hours</td>
<td>7 W/m²</td>
<td>07-23 every day</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Restaurant Kitchens</td>
<td>3/20 m²</td>
<td>100 W sensible, 60 W latent</td>
<td>100% 07-23</td>
<td>10 W/m²</td>
<td>07-23 every day</td>
<td>25 W/m² sensible and latent</td>
<td>70% 07-23</td>
</tr>
<tr>
<td>Retail spaces</td>
<td>3/5 m²</td>
<td>100 W sensible, 60 W latent</td>
<td>Weekdays: 50% 08-19, 1 hour shoulders - 20% Weekend: 50% 08-19</td>
<td>3.5 W/m²</td>
<td>08-19 Weekdays 10-18 Weekends</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Warehouses/Corridors</td>
<td>1/50 m²</td>
<td>100 W sensible, 60 W latent</td>
<td>100% Weekdays 7-18, 10% other times</td>
<td>7 W/m²</td>
<td>100% Weekdays 7-18</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Gym</td>
<td>3/20 m²</td>
<td>115 W sensible, 120 W latent</td>
<td>70% Weekdays 7-18, 1 hour shoulders, 10% rest of time</td>
<td>7 W/m²</td>
<td>100% Weekdays 7-18</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Garage</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Skyscraper Offices</td>
<td>3/9 m² (0.6 diversity factor)</td>
<td>90 W sensible, 60 W latent</td>
<td>70% Weekdays 7-18, 1 hour shoulders, 10% rest of time</td>
<td>7 W/m²</td>
<td>Same as occupation</td>
<td>12 W/m² (0.5 diversity factor)</td>
<td>Same as occupation</td>
</tr>
<tr>
<td>Server</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
<td>25000 W</td>
<td>On continuously</td>
</tr>
<tr>
<td>Event/Atrium</td>
<td>3/9 m² (0.25 diversity factor)</td>
<td>90 W sensible, 50 W latent</td>
<td>70% Weekdays 7-18, 1 hour shoulders, 10% rest of time</td>
<td>7 W/m²</td>
<td>Same as occupation</td>
<td>12 W/m² (0.5 diversity factor)</td>
<td>Same as occupation</td>
</tr>
</tbody>
</table>