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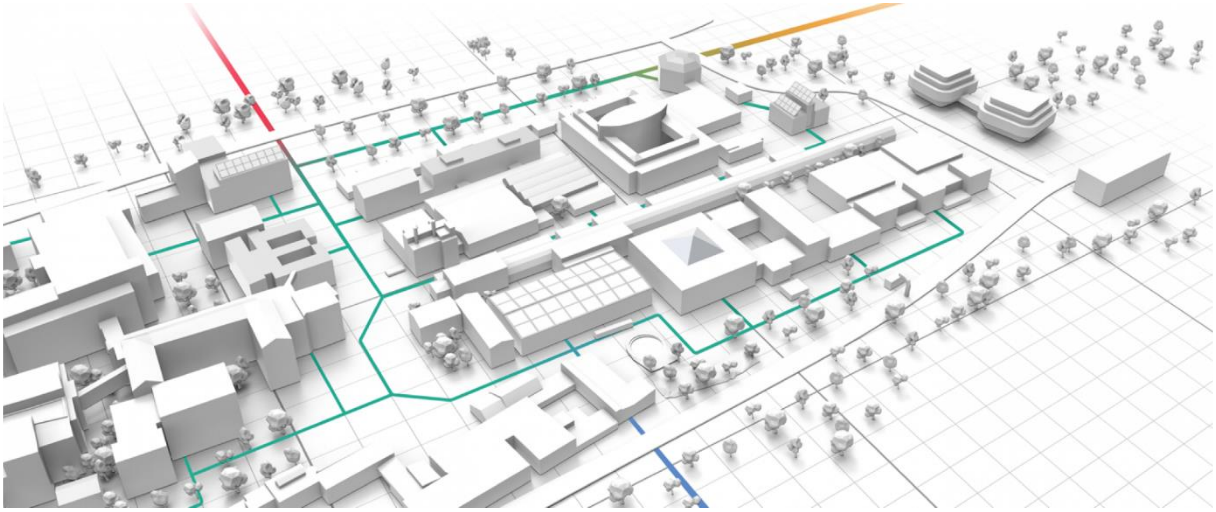
Influencing peak cooling power demand

IN THE FOSSIL FREE ENERGY DISTRICT PROJECT



Master Thesis in the program Sustainable Energy System

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Department of Space, Earth and Environment

Division of Energy Technology

CHALMERS UNIVERSITY OF TECHNOLOGY

Sweden, 2019

MASTER´S THESIS SEEX30

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ABSTRACT

In a country with colder climate such as Sweden, greater needs for cooling only occur during the short summer season, leading to a very noticeable power peak within this period. Such prominent power peak will result in higher investment per kilowatt in the cooling system compare with heating systems. District cooling, as part of the Fossil Free Energy District project emphasis on district level energy systems, allow for easier access to energy data, floor plan and controls. This create a perfect opportunity to combine monitoring thermal comfort of the occupants and controlling the cooling load of buildings. An optimal balance of thermal comfort and supply of cooling can then be determined, effectively reducing peak cooling demand, and thus, reducing both investment cost and environmental impact. To determine this balance, computer-modeling using building simulation software such as IDA ICE can be use along with analysis of current regulation and guidelines on building's thermal climate.

TABLE OF CONTENT

LIST OF ABBRIVIATIONS

FED	Fossil free Energy District
AHU	Air Handling Unit
COP	Coefficient Of Performance
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
CAV	Constant Air Volume
VAV	Variable Air Volume

1 INTRODUCTION

In any workspace environment, maintaining a standard of thermal comfort via cooling or heating is vital to the state of mind and work productivity of the occupants within. As Sweden is a country locate at higher latitude, cooling needs mostly occurs during the warmer period from late May to September, with peak demand usually in July, in contrast to heating need that are present year-round (outdoor temperature got as low as 10°C in July 1st, 2018). This led to most of the cooling equipment acting as peak load device, driving up the cost of investment into cooling when compare with heating.
To save cost and reduce environmental impact, it is necessary to investigate the cooling need and find ways to reduce peak cooling. Campus Johannesberg utilize a district cooling network installed and operate by Akademiska Hus. As a member of the Fossil free energy district project, Akademiska Hus is actively seeking to reduce peak cooling within their facility.

1.1 The FED project

The Fossil-free Energy Districts project, FED, is an effort by the City of Gothenburg to decrease the use of energy and the dependence on fossil fuel. The project includes the city of Gothenburg, Johannesberg Science Park, Göteborg Energi, Business Region Göteborg, Ericsson, Research Institutes of Sweden, Akademiska Hus, Chalmersfastigheter and Chalmers University of Technology. During 2017–2019, the FED testbed situate on Chalmers Campus Johannesberg. FED is co-financed by the European Regional and Development Fund through the Urban Innovative Actions Initiative, an initiative of the European Commission for cities to test new solutions for urban challenges. (Johannesberg Science Park, 2019).

1.2 Purpose

The purpose of this study is to use data provided by Akademiska Hus, computer modelling using IDA ICE, sites visit, to confirm if a reduction in peak cooling is possible in Chalmers campus Johannesberg district cooling network, how much can it be reduced and how will it affect the occupants of the buildings.

1.3 Problem analysis and research questions

Getting an understanding of how the purpose stated above can be archive requires a deeper knowledge of current system. The first research question was formulated as:

RQ1: *Which method of reducing peak cooling suited best at campus Johannesberg?*

As this question is limited to a general understanding of existing systems, the succeeding questions sought to investigate further what problems might occur during the process. To understand what complications may occur the second research question was formulated as:

RQ2: *What kind of problems or setback may happen because of this method?*

The last question aims at determining whether the method should be implemented into the systems or to later use as a base for recommendations for future project.

RQ3: *What benefit does this method provide?*

1.4 Limitations and delimitations

Considering the limited time, this thesis only investigates the district cooling systems at campus Johannesberg, and only one building was modeled in IDA ICE. By modeling more buildings, preferably within different cooling network at different location, more detail understanding of peak cooling is more likely. The result could be different with the additional points of view.

The study is delimited to investigate the cooling network at Chalmers Johannesberg, cooling supply to its buildings and the effect on the occupants. Buildings HVAC involves both heating and cooling, but this study focus on the cooling aspect only, due to time constraints and availability of data.

2 METHOD

The following sections present descriptions regarding how the study was conducted. Figure 1 shows an overview of the methodology used.

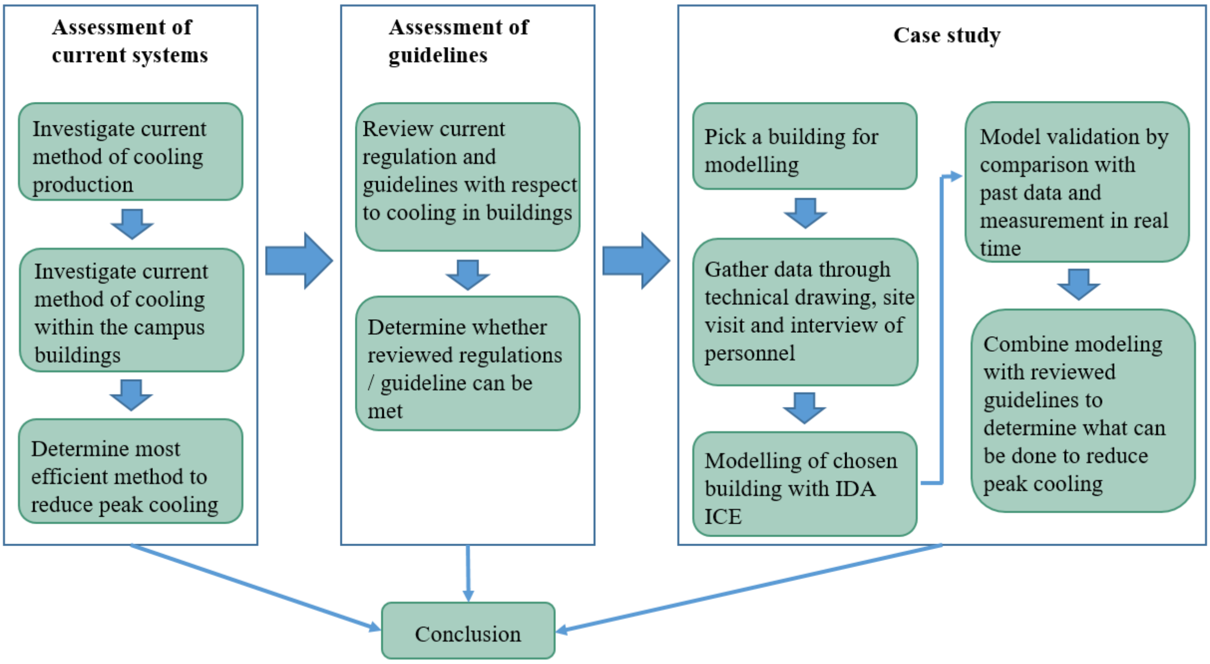

Figure 1. Flow chart describing the study methodology

2.1 Assessment of current system

In order to reduce peak cooling, several methods are available, each focus on different aspect such as cooling production or cooling distribution. Determining which method is most cost effective require an understanding of the cooling systems at campus Johannesberg. This is done via reviewing technical data of the systems provided by Akademiska Hus, as well as interviewing various personnel at Chalmers energy center.

2.2 Assessment of regulations and guidelines

Building's energy performance and thermal comfort directly influence peak cooling. Borverket, the Swedish National Board of Housing, has regulations on these criteria. Other HVAC related association also has guidelines regarding these aspects. All of these regulation and guidelines must be taken into consideration when making change to the cooling systems.

2.3 Case study

A case study at a building in campus Johannesberg is necessary to observe the effects of peak cooling on the comfort of its occupants. The software IDA ICE was used to model the Physics Origo building, the model is then validated with cooling data from 2018 and real time temperature measurement inside the building. Scenario of peak cooling is then implemented into the model.

3 EMPIRICAL FINDINGS

The following chapter describes the finding base on the method presented in chapter 2

3.1 Cooling production at campus Johannesberg

District cooling systems at campus Johannesberg supply chilled water to all buildings managed by Akademiska Hus. The cooling machines are located inside Chalmers energy center (Chalmers Tvärgata 6). Figure 2 is a sketch of the main cooling network, named KB0 by Akademiska Hus.

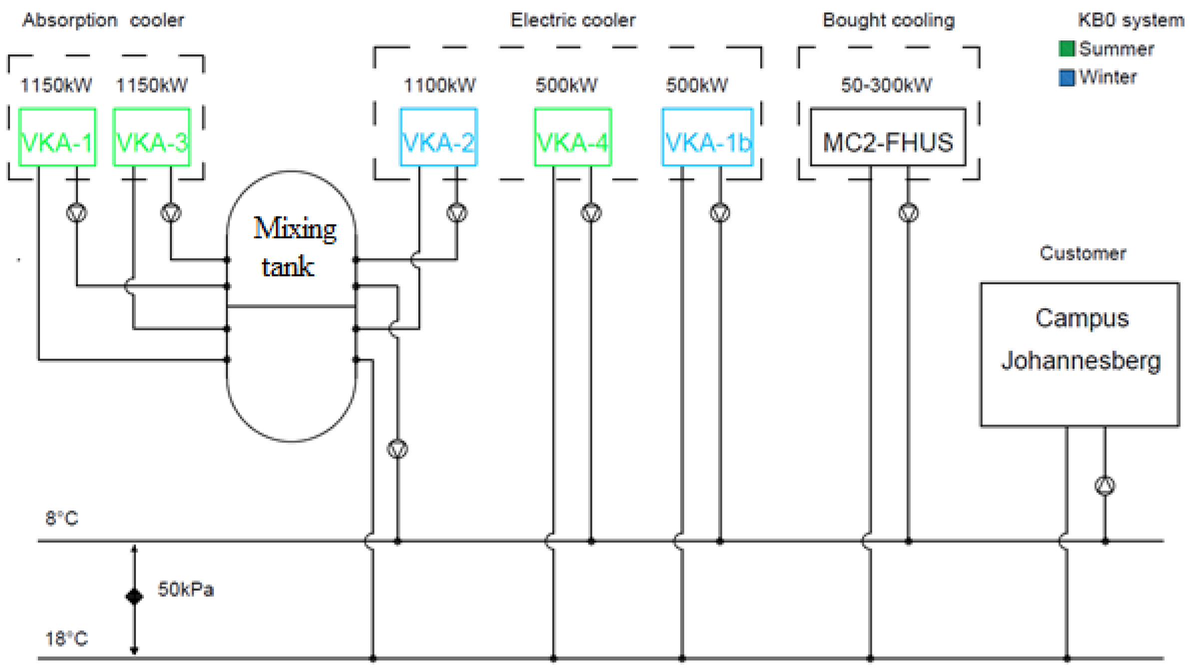

Figure 2. KB0 cooling system

The systems consist of 2 absorption coolers and 3 electric coolers. The 2 absorption coolers (totaling 2300kW) and electric cooler VKA4 (500kW) operate only during summer period (from April 30th to September 30th). Electric cooler VKA2 and VKA1b (1100 kW and 500 kW respectively) would operate during the remainder of the year. There is also possibility of buying extra cooling from Chalmersfastigheter during peak demand (up to 300kW).

3.2 Supply of cooling to campus Johannesberg building

Management of campus Johannesberg's estate is a split responsibility between Akademiska Hus and Chalmersfastigheter, with each company managing roughly half of the buildings in the campus. See appendix A for the detail map of which company manages which building.

The majority of campus buildings managed by Akademiska Hus regulate indoor temperature by controlling their AHU's return air temperature. Figure 3 demonstrates this principle.

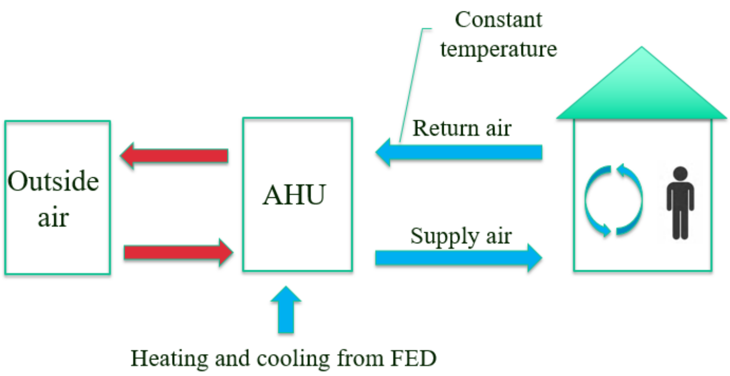

Figure 3. HVAC scheme in buildings managed by Akademiska Hus

Sensors are available to detect return air temperature and the amount of heating and cooling flow into the AHU. PI controls correct the heating and cooling amount to get the desired return air temperature. Return air temperature set points varies from each building and is set by the operators at Chalmers energy center. These return air temperature set points thus directly influence the cooling demand of each building.

3.3 Peak cooling reduction potential

There are opportunities for a scheduling optimization in the KB0 system. Theoretically, every cooling machine has a different coefficient of performance (COP) - output relation. Buy setting up a running schedule base on COP of each machine and current cooling demand, the overall efficiency of the system can be increased. A study done by Xiaoming et.al (2015) on a rather similar cooling network (5 electric cooler and 2 absorption cooler) shows a potential energy saving of 11.4%. Reality poses several difficulties: Akademiska Hus only installed machine VKA2 recently so little operating data is available. A scheduling scheme requires detail past data and is not possible with VKA2. There is also on going negotiation on the price of bought cooling between Akademiska Hus and Chalmersfastigheter and no price was yet set. Thus, at the time of this study, it is not suitable to perform a scheduling optimization. This study will now take the approach of reducing cooling demand, i.e. reducing cooling supply to the buildings.

At Chalmers energy center, AHU's temperature set points is set based on the experience of the operators, what they perceive as comfortable for the tenants. Feedback from the tenants also influence the decisions on these set points, but few studies have been done here on the relationship between temperature set points and occupant's thermal comfort. As one building usually only serve by a few AHUs while these AHUs share the same temperature set point, different rooms in said building will have different operative temperature despite having the same supply air temperature. Room operative temperature depends heavily on room's location, orientation and indoor activities. By monitoring operative temperature of all rooms in one building, it is possible to find an optimal temperature set point that will both satisfy thermal comfort to the occupants, while ensuring low energy demand. This study will therefore benefit from choosing one building in campus Johannesberg as a case study.

4 CASE STUDY

Based on empirical findings, a case study approach is suitable going forward. This chapter will provide details on the process of the case study.

4.1 Selection of study subject

As stated in empirical findings, it is beneficial for this study to use one building in campus Johannesberg as a case study. The ideal building for this should have substantial cooling needs, lots of rooms with different size and function, frequent complains on thermal dissatisfaction and readily available data for modeling.

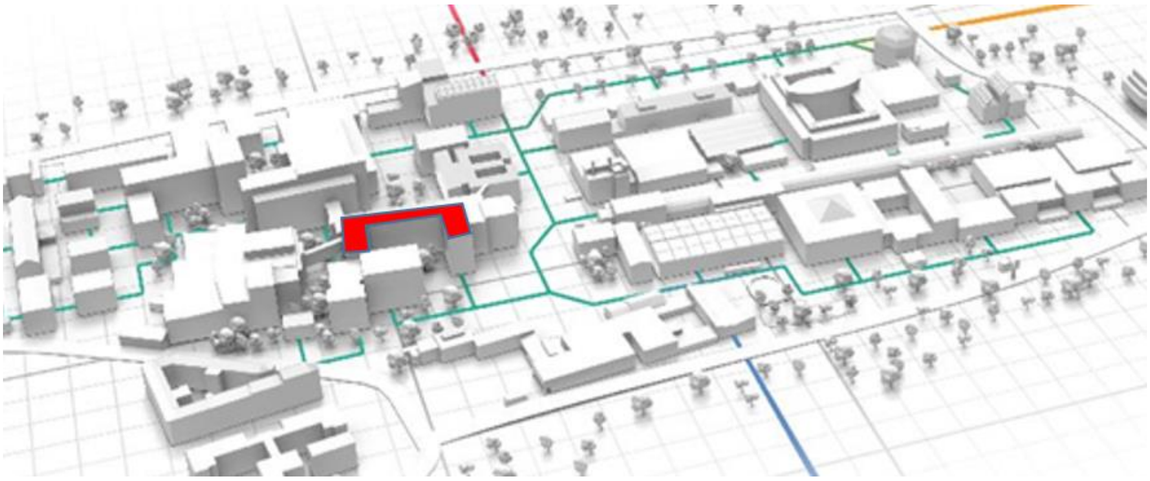

Figure 4. Campus Johannesberg (Physics Origo building in red). Adapted from FED project homepage

The Physics Origo building satisfies all of above criteria. The building was constructed in 1970s and is one of three buildings dedicated to the department of Physics. Located on a hill on the southern side of the campus, it receives a lot of solar radiation while also has high number of occupants. These factors combined drive up the building's cooling demand. There is a variety of rooms with different functions within the building (offices, lecture rooms, auditorium and a café). Akademiska Hus also logged complains regarding thermal comfort of the building in recent time.

4.2 IDA indoor climate and energy

IDA indoor climate and energy (IDA ICE) is a building simulation software developed by EQUA simulation AB. The program provides 3D geometry modeling, flexible input for climate and material data; it also has good visualization tools and efficient quality check. Many studies have shown that IDA ICE simulation results and measured data compare well (Nageler et.al, 2018).

Due to its many merits and good validation, the Physics building will be modeled using IDA ICE. Akademiska Hus has provided data necessary for modeling such as floor plan, HVAC diagram and building materials.

4.3 Fanger thermal comfort model

Developed by P. O. Fanger, the PMV/PPD thermal comfort model is used to calculate the Predicted Mean Vote of a group of people for a combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation (Manuel, 2013). PMV rated thermal sensation on a 7 points scale from -3 (cold) to 3 (hot). Zero is the ideal value, representing thermal neutrality, and recommended limits for PMV is between -0.5 and 0.5. Appendix B gives the formulated expression of PMV.

Thermal sensation of a population is important in determining what conditions are comfortable, yet it is more useful to consider whether people are satisfied. Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD, see appendix B).

For a typical summer situation: Air speed of 0.15 m/s; 50% relative humidity; light clothing level (short and t-shirt) and low metabolic rate (siting, typing), the operative temperature required to get PPD index ≤ 10% is: 24.5°C ≤ PPD ≤ 27.2°C (CBE, 2019). Figure 5 shows the different range of PPD for the aforementioned condition. The darkest green band in the middle is the 5% PPD range, the lighter green band is the 10% PPD range, and the lightest green band is the 15% PPD range. The red dots lie on the 50% relative humidity line shows the minimum/maximum temperature to archive at least 10% PPD.

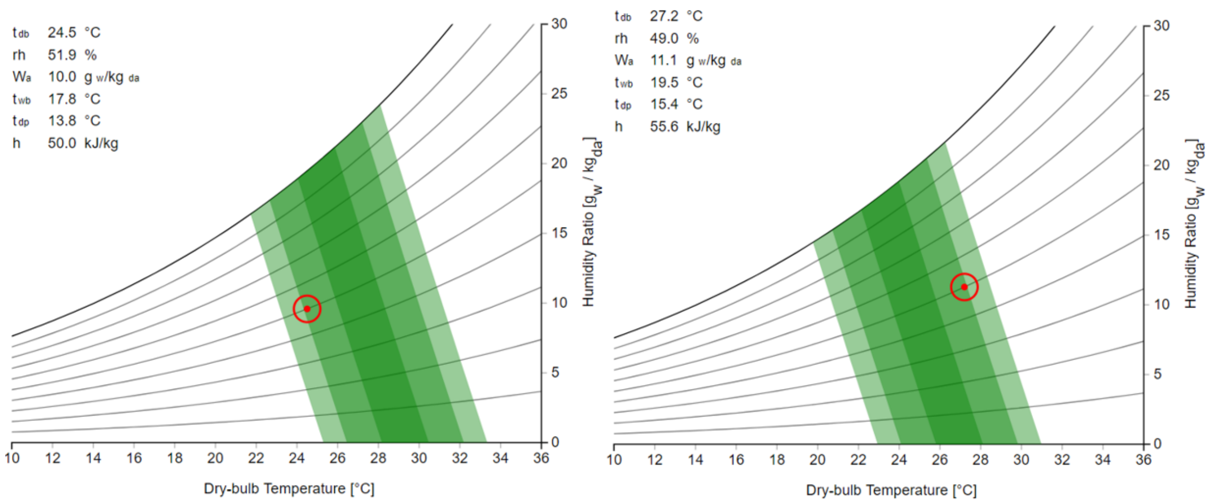

Figure 5. Lower (left) and upper (right) temperature limit to get PPD ≤ 10%. Adapted from CBE thermal comfort tool

Several widely accepted standard, such as ASHRAE-55 and EN-15251, employ Fanger's thermal comfort model.

4.4 Regulations and guidelines on thermal comfort in Sweden

Defining what is the acceptable indoor climate requires extensive studies, which has been done before by various Swedish authorities and associations. The following section describes the regulations and guidelines published, as well as how they will be implemented into the case study.

4.4.1 Swedish national board of housing, building and planning

Borverket – the Swedish national board of housing, building and planning, regulates building related criteria in Sweden. With respect to indoor thermal comfort, Borverket, 2018, section 6:42 listed details for winter design temperature as:

> – the lowest directed operative temperature in the occupied zone is estimated to be 18 ºC in residential and workrooms and 20 ºC in sanitary rooms and healthcare facilities and in rooms for children in preschools and for the elderly in service buildings and similar establishments,
>
> – the difference in directional operative temperature at different points in the occupied zone of the room is calculated at a maximum of 5K,
>
> – the surface temperature of the floor beneath the occupied zone is calculated at a minimum of 16 °C (in sanitary rooms at a minimum of 18°C and in premises utilized by children at a minimum of 20°C) and can be restricted to a maximum of 26 °C.
>
> (Borverket, 2018)

As these regulations put emphasis on thermal comfort during winter, they are less strict in the design of cooling systems. Borverket has no regulation on design temperature in summer. However, operative temperature inside campus buildings need to be above 18 ºC at all time adhering to above regulation.

4.4.2 Swedish Work Environment Authority and Public Health Agency of Sweden

The Swedish Work Environment Authority and Public Health Agency of Sweden (Arbetsmiljöverket och Folkhälsomyndigheten - AFS) listed the following guidelines:

> – If the air temperature in light and sedentary workplace varies from 20–24 ° C in winter and 20–26 ° C in summer, the thermal climate should be investigated more closely.
>
> – The PPD value of a work place should be less than 10%.
>
> (AFS 2009:2, p61-62)

These guidelines give a good base target for indoor climate. They, however, do not account for critical hot days, e.g. there are several days when outdoor temperature went above 30°C in 2018 ("time and date", 2018). During days like these, PPD index can get worse than 10% but only briefly. Further guidelines on how to handle brief critically warm period can be found in the next subsections.

4.4.3 Environmental building

Environmental building (Miljöbyggnad) is an environmental certificate for a building in Sweden, with third parties review environmental performance of Miljöbyggnad building. The system is owned and developed by Sweden's largest organization for sustainable community building, Sweden Green Building Council, which also carries out the certifications. (Miljöbyggnad 3.0, 2015).

Miljöbyggnad indicator 10 (thermal comfort summer) has the following requirement:

	Bronze	Silver	Gold
Office building with comfort cooling	PPD ≤ 15% on a critical warm and sunny day	PPD ≤ 10% on a critical warm and sunny day	Silver + survey or measurement

(Miljöbyggnad 3.0, 2015)

This indicator gives an idea on how to deal with critical day, but has no definition on what said critical day should be. Older version of Miljöbyggnad uses the P27 criteria (Borverket, 2010), where indoor operative temperature should not exceed 27°C for more than 10 working days in July. P27 criteria is a good design threshold for office building, but since the Physics building is for education purpose, July would be during summer break and the building would mostly be empty. The most troubling month for this case study should be in May, when weather is warm and the academic year has not ended.

4.4.4 Swedish HVAC association

The Swedish HVAC association (VVS-tekniska föreningen) published "R1-Guidelines for specification of indoor climate requirements" (Ekberg, 2006) is a collaborated work between the HVAC associations of Nordic countries. This guidebook provides guidelines on indoor thermal comfort in peak warm case, which allow workplace to have high operative temperature of >28°C for less than 80 working hour per year (Ekberg, 2006, p33). This guideline, combine with the one from Miljöbyggnad, should cover the case of education building peak cooling in May.

4.4.5 Development of modelling criteria

Given the conditions: the Physics building is a mix office – education building, it is clear that following guidelines from only one organization is inadequate. Combining guidelines from listed in the above subsections, the design criteria for the IDA ICE model is as follow:

– The lowest operative temperature in the occupied zone 18 °C (Borverket).

– The PPD for normal working condition should be less than 10% (AFS).

– Temperature should not exceed 27°C for more than 10 working days in July (P27).

– Temperature should not exceed 28°C for more than 80 working hour in a whole year (R1).

As for whether or not the design condition of July can satisfy the peak condition in May in the case of education buildings, further study is required.

4.5 Modeling of the Physics building

With the building Physics Origo chosen as subject for case study and modelling criteria set, this study will proceed with collecting data on the building, model it with IDA ICE, and finally validate the model with real data.

4.5.1 Floor plan and building geometry

The Physics Origo (named 07:1 Physik Origo by Akademiska Hus) is an 1821 m^2, 5 stories building located on a hill at the southern side of campus Johannesberg. Due to its geometry and location, the bottom floor is actually called the 4th floor (floor 1 to 3 is part of another building, 07:3 Physik).

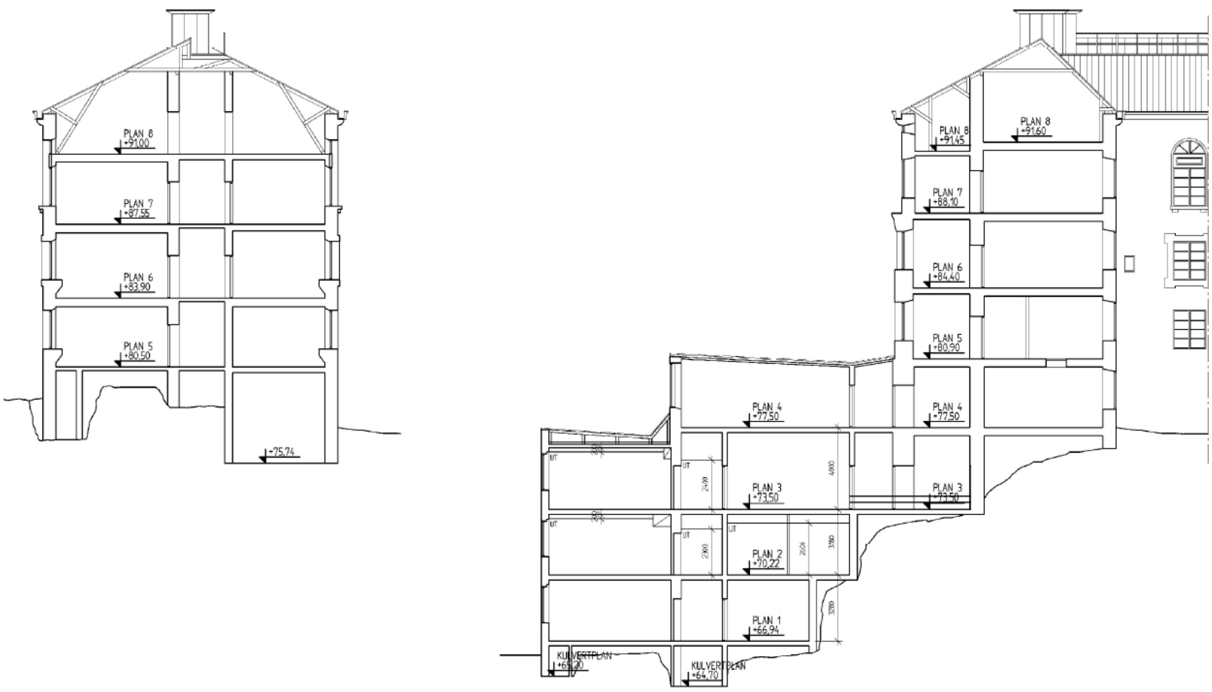

Figure 6. Physics Origo building section view. Floor 1 to 3 is part of another building

The building is U-shape and divided into 2 section: North and South wing. The 2 ends of the wings have offices for various divisions of the department of physics, while the middle side is for educational purpose with lecture rooms, group rooms and a café on 4th floor. Below figures show the floor plan of the 7th floor. The complete floor plans of the whole building can be found in appendix C.

Figure 7. Physics Origo 7th floor North wing

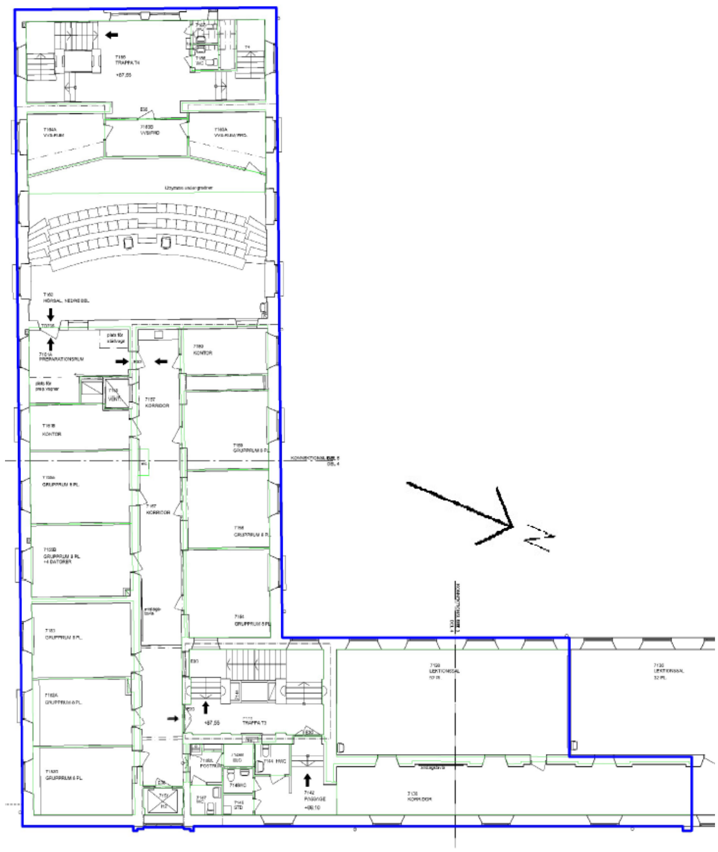

Figure 8. Physics Origo 7th floor South wing

4.5.2 Building HVAC

For ventilation in the Physics Origo building, all of the corridor, office room and stairwells in the building is served by constant air volume (CAV) AHUs, while all of the lecture rooms, group rooms and auditorium is served by variable air volume (VAV) AHUs. This make economic sense, as office rooms have predictable numbers of occupants and indoor activities, thus inexpensive CAV systems can provide a constant amount of airflow into these rooms (Althoff, 2017). Lecture rooms, on the other hand, can have a range of number of people inside, requiring different amount of airflows at different period. More costly VAV systems are installed in rooms like these. A list of rooms, AHU types and airflow rate can be found in appendix D.

Regards district cooling supply to the building, the KB0 systems (see section 3.1) supply cold water to the AHUs inside the building (this AHUs network is named LA01). The network is split into three branches: FB-Sal, Söder, Mitten-del, as in the following figure.

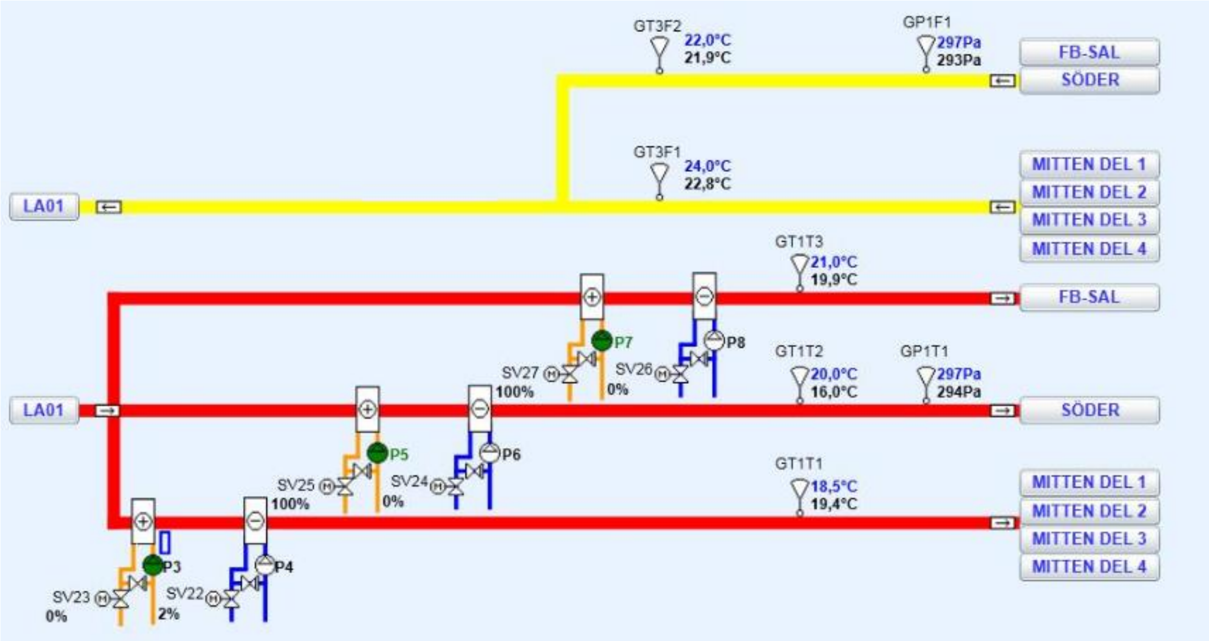

Figure 9. Schematic of cooling supply to Physics Origo building

The branch FB-Sal only supply to the auditorium on the 7th floor, while the Söder branch supply the south wing and the middle part of the building, and Mitten-del supply cooling to the North wing. The Söder branch has the largest maximum cooling capacity: 97kW, follow by FB-Sal (7.3kW) and Mitten-del (5.3 kW). The maximum cooling amount KB0 system will supply to all branches is 97kW, with the Söder branch takes priority. When total cooling demand of all three branches is near 97kW, the FB-Sal and Mitten-del branch will gradually receive less cooling to ensure the Söder branch can reach maximum capacity.

The flow rate of water supply to LA01 heaters and coolers is determined by return air temperature from all three branches. Control valve of the heaters and coolers in LA01 open or close accordingly to maintain a constant return air temperature. The set point currently use for return air temperature in Physics Origo building is 22°C (it is common practice at Akademiska Hus to keep this set point between 20 °C and 23 °C).

Figure 10 show a map of which cooling branch supplying to which part of the building.

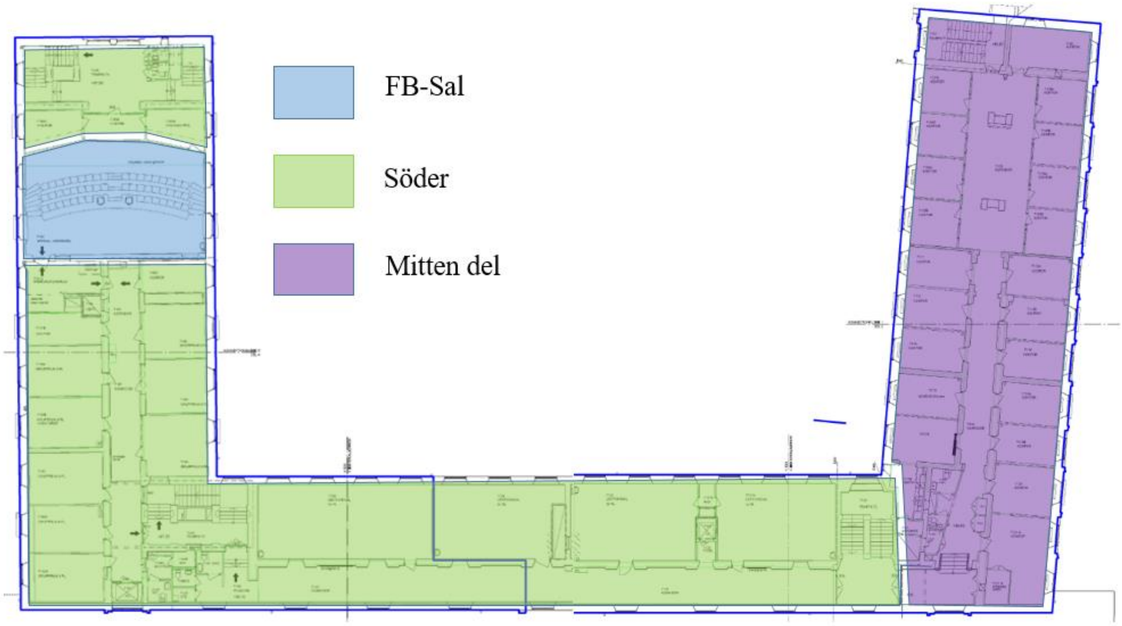

Figure 10. Cooling supply to each zone

4.5.3 Occupancy

Every room in the building was designed for a set number of occupants, and the same number was incorporated into the model. The occupant is set to a 7:00 to 17:00 weekdays working schedule, with one-hour lunch break from 12:00 to 13:00. During summer period (1st June to 1st September), the Lecture room and group room is set to only be occupied 3 hours per day at 50% capacity, and the office room have half the usual number of occupant. The setting for summer period is an effort to simulate the building during summer break, where most of the student will not go to class, and many of the staff will be on vacation.

5 RESULT

With all the needed data ready, a model of the Physics Origo building was made with IDA ICE, using Göteborg weather data of 2013.

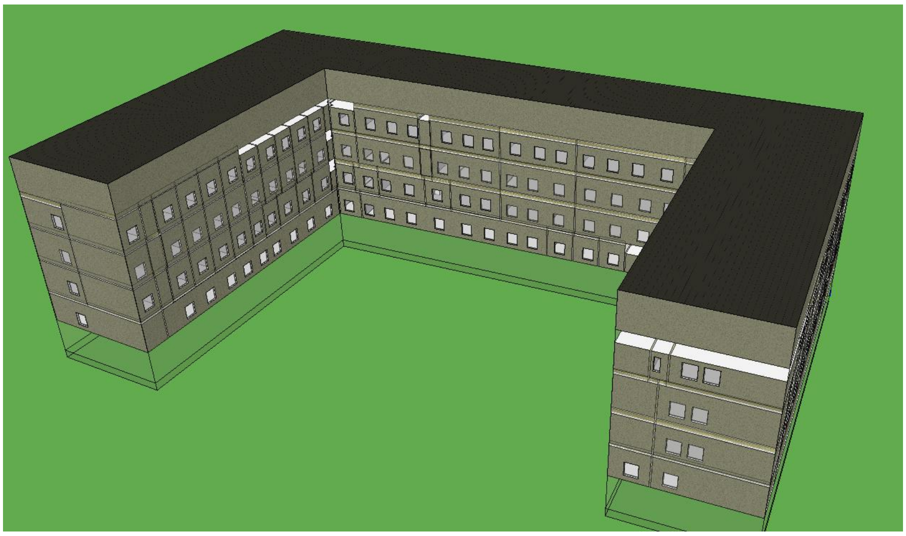

Figure 11. 3D view of the IDA ICE model

5.1 Indoor temperature analysis

Figure 11 shows a visualization of indoor operative temperature for a hot summer day (27ºC outdoor) of the 7th floor (see appendix E for the remaining floors).

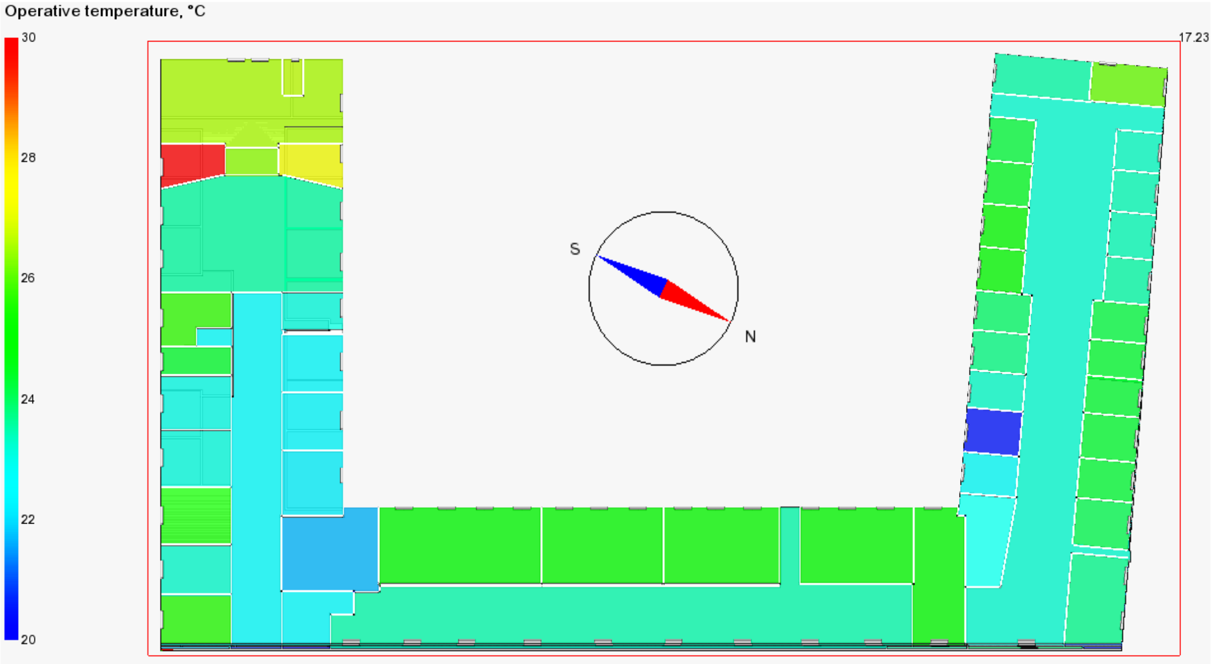

Figure 12. Indoor operative temperature of the 7th floor

The above figure showed that operative temperature is not uniform throughout the building despite all rooms having the same supply air temperature. Warmer rooms are usually those located on the South side (more solar radiation) and the bigger rooms (more people inside). Table 1 shows the min, max and mean operative temperature in all rooms with occupants for each floor, as well as the mean PPD.

Table 1 Thermal comfort of each floor (base case, hot summer day)

Floor	Min temperature (°C)	Max temperature (°C)	Mean temperature (°C)	Mean PPD (%)
4	21	24	22.5	33
5	21	26	23.5	19
6	20.5	26.5	23.5	19
7	20.5	26.5	23.5	19

Chapter 4.3 showed that comfortable operative temperature range (PPD ≤ 10%) is 24.5°C to 27.2°C. It is clear that with current practice, the thermal comfort of the Physics Origo building is poor. Many of the rooms will be too cold, with high mean PPD across all floor. Having cold occupants in a hot summer day is also not energy efficient. A new set point for return air temperature is necessary in order to both improve thermal comfort and energy efficiency.

Choosing a new set point of 25°C, Figure 13 shows the operative temperature of the 7th floor with the new set point.

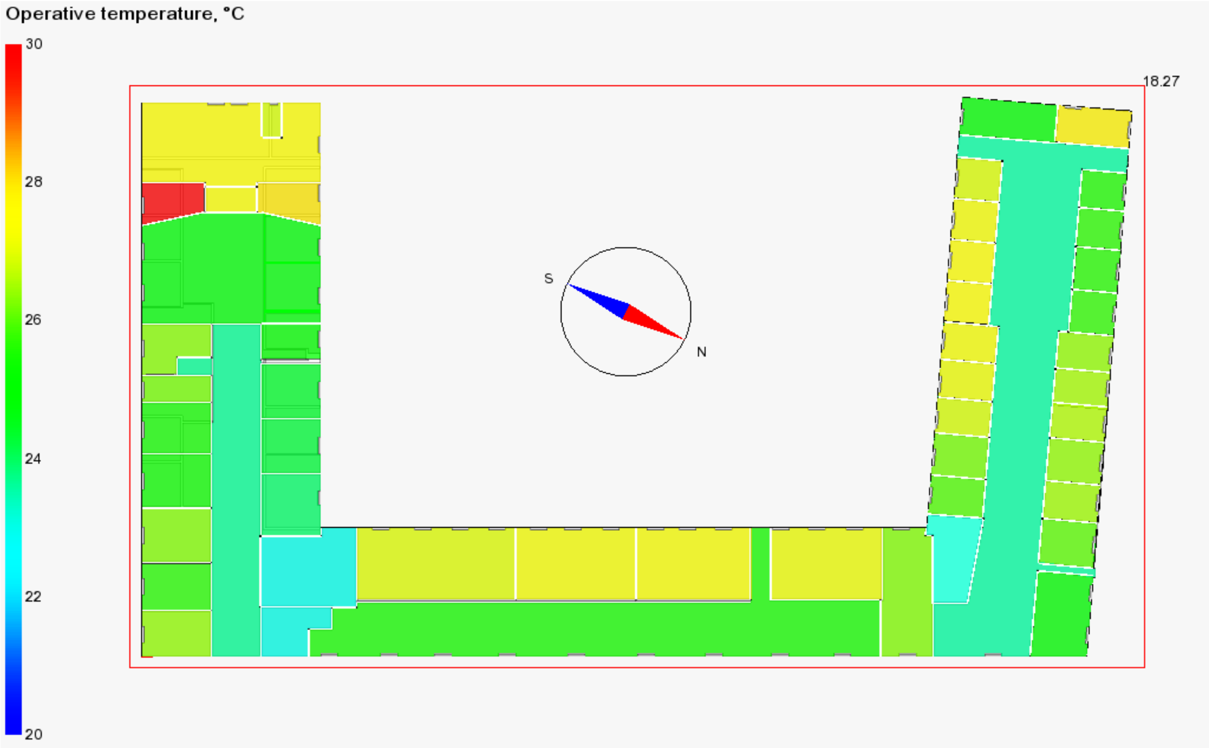

Figure 13. Indoor operative temperature of the 7th floor (25°C set point)

The new set point shows improvements over the base case. Operative temperature is now more reasonable for summer condition across all rooms. Table 2 shows the temperatures and PPD of rooms with permanent occupancy.

Table 2 Thermal comfort of each floor (25^{o}C set point, hot summer day)

Floor	**Min temperature (^{o}C)**	**Max temperature (^{o}C)**	**Mean temperature (^{o}C)**	**Mean PPD (%)**
4	24	27	25.5	5
5	23.5	27.5	25.5	5
6	24	27	25.5	5
7	24	27.5	25.75	5

With the new mean PPD of around 5% and temperature range now closer to comfortable level (section 4.3), thermal comfort in the Physics Origo building is much better with the new set point of 25^{o}C. The new energy performance of the cooling system will be shown in the next section.

5.2 Energy performance

Using 2013 weather data, the IDA ICE result of monthly peak cooling demand for Physics Origo building, with base case as well as 25^{o}C set point, can be found in table 3. Figure 14 also provide a graph for ease of visual.

Table 3 Monthly peak cooling result from IDA ICE

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Peak (base case, kW)	0	0	0	65	75	85	90	97	49	0	0	0
Peak (25^{o}C, kW)	0	0	0	0	4	8	62	85	4	0	0	0

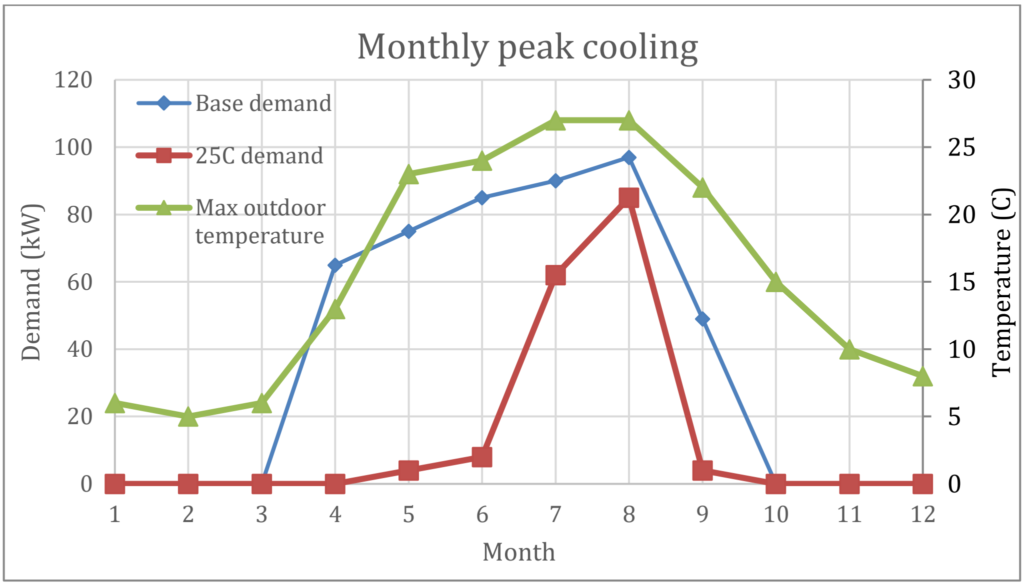

Figure 14. Monthly peak cooling, IDA ICE result

Figure 14 shows a graph comparing peak cooling demand between the original set point and the new 25°C set point, as well as the maximum outdoor temperature for each month. The graph shows a sharp decrease in cooling demand for cooler months (April, May and September). This is because that during those months, operative temperature is commonly between 22°C and 25°C, i.e. between the two set points, thus causing the 22°C set point to have much higher cooling demand compared to 25°C set point. The peaks during hotter months, however, is closer between the two cases, with highest peak goes from 97 kW to 85 kW (12.4% reduction).

The amount of delivered cooling also shows a large difference between the two cases. With the 22°C set point, cooling energy usage for the whole year is 17 MWh, while the 25°C set point resulted in 1.115 MWh (93% reduction) (see appendix F). It is worth noting that the high percentage of reduction is partly due to 2013 being a cool year (operative temperature mostly lies between 2 set points). A hotter year will result in a less amount of saving between the two cases.

5.3 Compliance with guidelines

Section 4.4.3 conclude with a set of criteria to check whether the model complies with various regulation and guidelines from the Swedish authority. In order to check if the new 25°C set point satisfy these criteria, a closer look at the most critical room is necessary.

The most critical room is defined as the room that has highest number of tenants, occupied hour and operative temperature combined. The 48 persons lecture room on the 7th floor thus represented the most critical room.

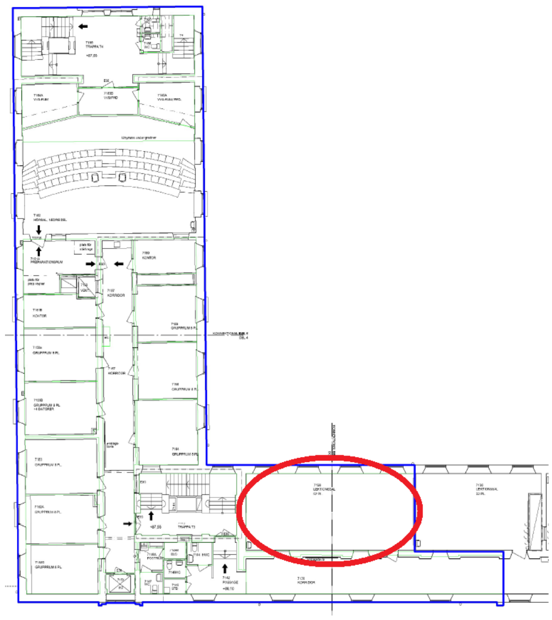

Figure 15. The most critical room, circled in red

Figure 16 shows a temperature duration curve of this room at three different set points: 22^{o}C, 25^{o}C and 26^{o}C for the April-October period (the period when there is a need for cooling).

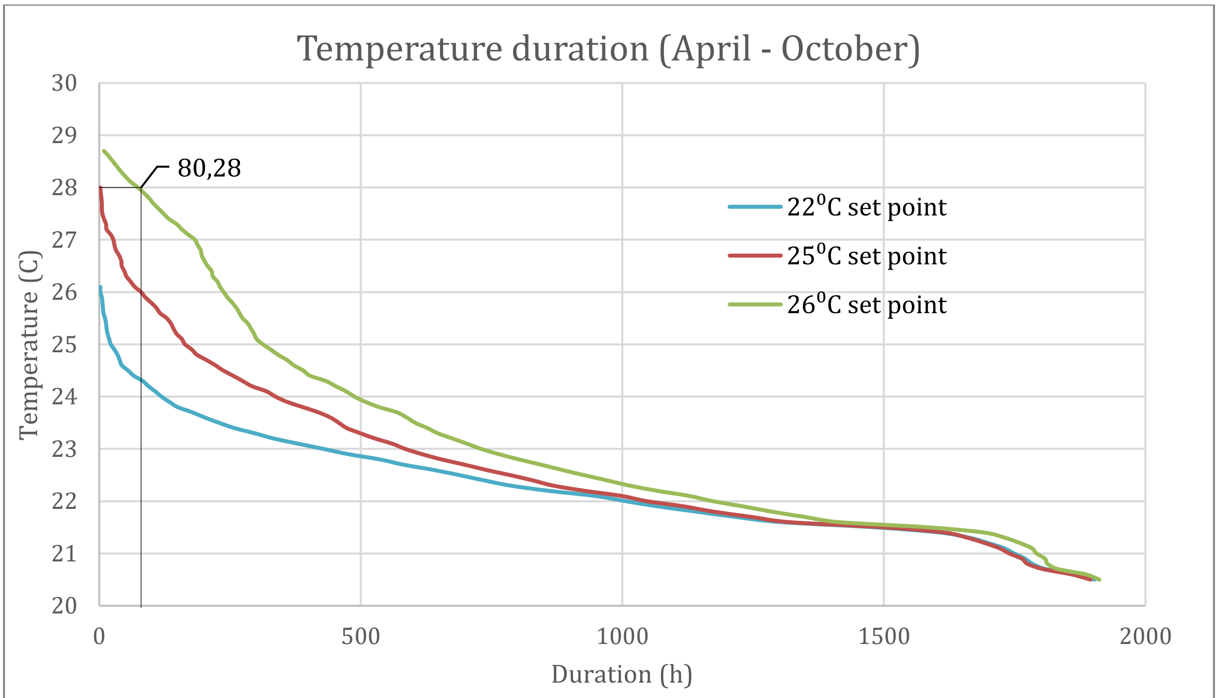

Figure 16. Critical room temperature duration curve

The curves showed that at no point does the operative temperature of this room drops below 20^{o}C, which satisfied Borverket requirement for lowest allowed temperature. The guideline of temperature should not exceed 28^{o}C for more than 80 working hour in a whole year (Swedish

HVAC association) is satisfied for the 22°C and 25°C set point, but not the 26°C set point. This is the reason why the set point of 26°C or higher was not in consideration.

Figure 17 shows a temperature duration curve of this room during July.

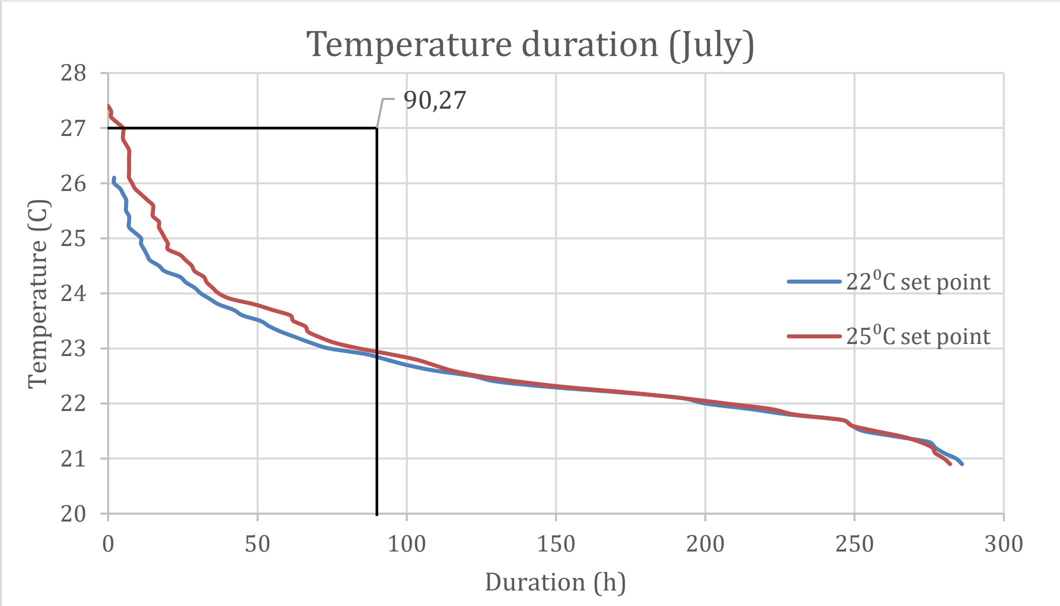

Figure 17. Critical room temperature duration curve (July)

From this curve, it is clear that the guideline: Temperature should not exceed 27°C for more than 10 working days in July (P27) is met.

Overall, the new 25°C set point was able to satisfy most of the criteria set in section 4.4.3. The exception was the mean PPD of this room is 11% instead of the recommended 10%, but 1% difference in PPD should not cause much issue. Furthermore, the clothing level of the occupants inside the room is hard to predict, and will vary from person to person, so this mean PPD value is only relatively accurate.

5.4 Uncertainties and model validation

There are several uncertainties that affect the accuracy of the model. Most of these uncertainties are due to human behavior: it is very hard to predict what the tenants will do inside a building. Table 3 list some common problems and how severe it affect model accuracy. The effect on accuracy was determined by varying the affected parameter in the simulation while keeping other parameters constant.

Table 4 Common issues that affect model accuracy

Problem	Description	Effect on accuracy
Doors and windows	Sometime people would open the door or window while cooling fan is on, letting cooled air escape from one zone to another	High
Number of occupants	The amount of people inside lecture rooms and group rooms is uncertain	Medium
Occupancy schedule	The schedule for group room is not set. Lecture are sometimes canceled	Medium
Switches	People some time forget to turn off lights and cooling fans when they leave the room	Medium
Windows curtain	Curtains greatly influence how much solar radiation a room may receive. How people uses curtain is hard to predict	Low, only affect room with South facing windows

With all of listed above problems it is clear that it is impossible to get a perfectly accurate model. However, rules and restriction can be apply to modeling to account for the uncertainties. The constructed IDA ICE model has implemented some of the rules, as can be seen in table 5.

Table 5 Methods of implementing uncertainties into the model

Problem	Method of implementation
Doors and windows	Some % of leakage was applied to each room
Number of occupants	Lecture rooms and group average 60% their maximum capacity (experience from site visit)
Occupancy schedule	Schedule from Time Edit (Chalmers schedule website) was used
Switches	All fans are simulated to run for an additional 30 minutes after people has left
Windows curtain	All room will use curtain 50% of the time when solar radiation is high

With uncertainties established and remedy implemented, it is necessary to validate the model with real time data. The first method involves comparing the real peak with simulated peak demand. Monthly peak cooling data from 2018, provided by Akademiska Hus, is compared with modeling result from IDA ICE in figure 18. The graph also included a simulation result without accounting for any of the uncertainty factor.

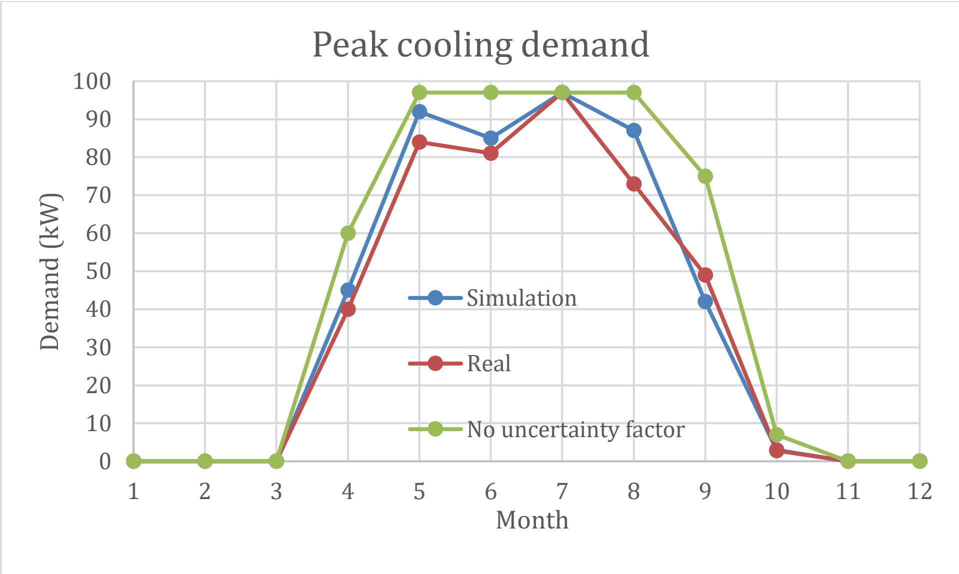

Figure 18. Peak cooling comparison between real data and simulation

The comparison showed that prediction is relatively accurate when the cooling load is medium to low, but the model over predict when cooling load is high (above 40kw). This coincides with the fact that high cooling load means high number of occupants inside the building, which increases the uncertainties factor. As for the simulation case without any uncertainty factor, the demand was much higher and reach the maximum capacity of 97kW during all of the hottest month. The reason for this is without accounting for occupancy schedule and number of occupants, the fans are always simulated to be running at maximum speed during the whole working day, even during summer break where the building is mostly empty.

Another validation step follows. Temperature measurement was done during a one-week period inside the Physics Origo building during May. The measured temperatures then compared with modeling results from IDA ICE (using them same weather profile as the day when measurement happened). The equipment used was a Testo 810 infrared thermometer, which has an accuracy of ± 0.5^{o}C (appendix G). Since energy use directly correlated with temperature difference between indoor and outdoor, this method of validation should present the accuracy of the model. Figure 19 plots the measured temperature versus the temperature predicted by IDA ICE. Details of the measured temperature can be found in appendix H.

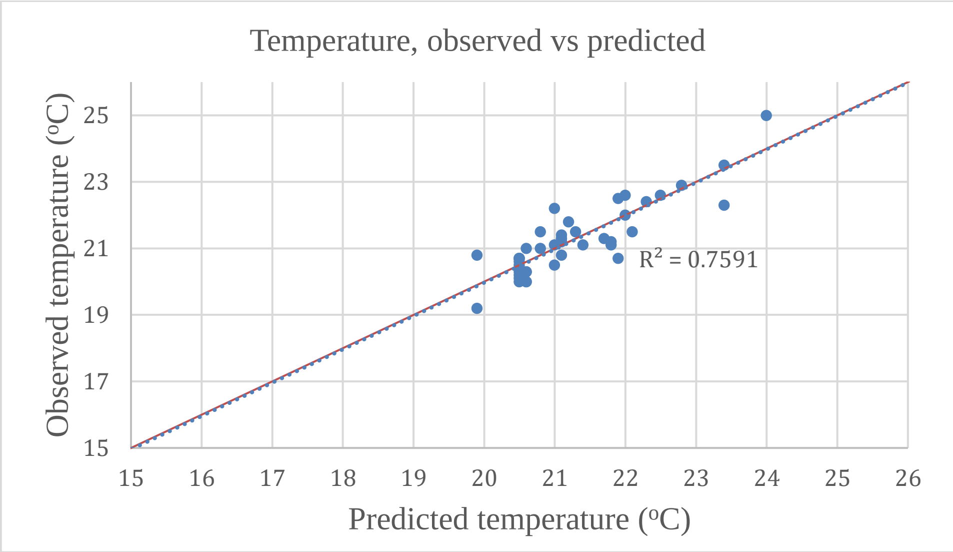

Figure 19. Model validation, predicted vs observed temperature

The graph showed promising result. Plotted points cluster around the perfect prediction line and distributed randomly above and below the line, which suggest there is no systematic error. The fitted line coincides with the perfect prediction line, and the R^2 value of 0.759 is high. Frost (2018), suggested that human act unpredictable, and studies that involve human behavior can with R^2 values as low as 0.5 are still acceptable.

Overall, this study has certain amount of inaccuracies within it. Possible reasons to the inaccuracies were listed, along with appropriate measures to remedy them. Both validation method suggested that the model has good accuracy and the information it provides is reliable.

6 CONCLUSIONS

6.1 The cooling systems of campus Johannesberg

As a stakeholder of the FED project, there are strong motives for Akademiska Hus to seek a way to reduce peak cooling in Chalmers energy center. Since there were difficulties studying the KB0 cooling system from the production side, the issue of peak cooling was approached from the demand side instead. With the abundance of data and little study has been done previously on the thermal comfort of the occupants at campus Johannesberg, there is great potential for a new or revised method that enables greater energy efficiency while also improves the tenant's satisfaction.

This further leads into a matter of defining what a comfortable indoor climate is for the tenants. As Sweden is a country with cooler climate, regulations only exist to ensure thermal comfort during wintertime. As the focus is peak cooling, this study took a closer look at various guidelines for thermal comfort during summer. The result was a combination of design criteria aimed at the comfort of the tenants. A case study at the Physics Origo building follows, with a computer model of the building constructed in IDA ICE. After implementing changes into the model that satisfy the new criteria, it is ascertained that thermal climate of the Physics Origo building can be improved by a large margin, while reducing peak cooling by 12.4%.

Using a computer model as a tool of study means that there will be inherence inaccuracies involve. Computer models, while may be able to simulate physical object, struggle when it deals with human behavior. It is important to identify factors that influence modeling accuracy and implement rules and restriction to account for those factors. Likewise, validating the model with real life data and measurement is also an important step. At the moment, the IDA ICE model of the Physics Origo building validated well with measured data, and the information obtained from this model can be relied on when making change to the cooling systems at Chalmers.

6.2 Future work

In the future, follow-up studies for this thesis could be useful. Investigation on other buildings in campus Johannesberg can show if the design criteria archived from analyzing various regulation and guidelines is applicable to the whole campus. Study on whether or not the guidelines on thermal comfort that are based on the assumption of July being the hottest month can also be applied in case of education building is needed. In the case of buildings with multiple AHUs, it will be interesting to see the effect of different temperature set points for each AHU. Computer model of the whole campus will reveal if optimization for both thermal comfort and energy efficiency is possible with every building, and a graph of energy efficiency versus thermal comfort for each building can then be made.

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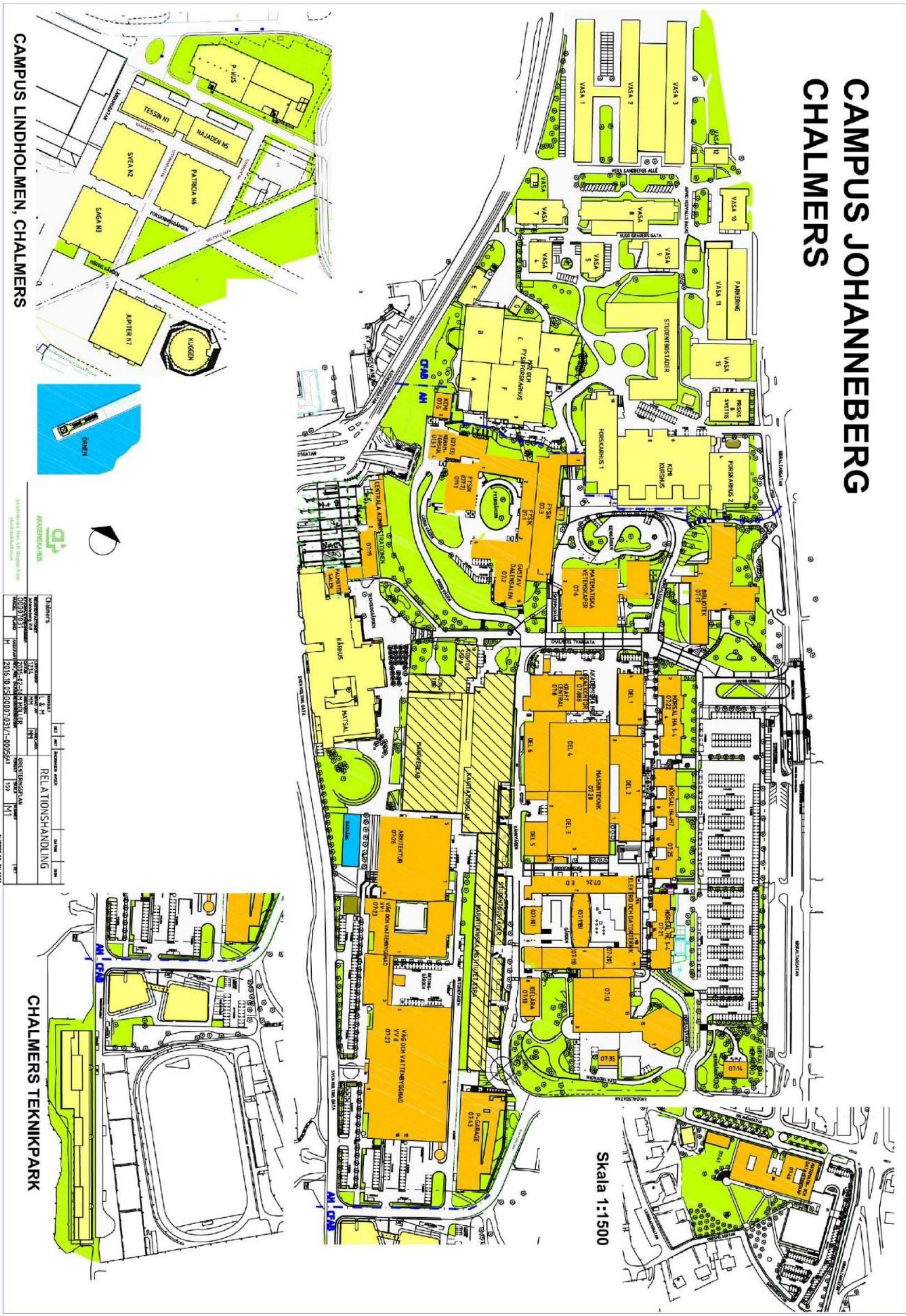
APPENDIX A: Campus Johannesberg properties map



APPENDIX B: Calculation of PMV and PPD

(Manuel, 2013)

$PMV = (0.303e^{-2.100*M} + 0.028)*[(M-W)- H - E_c - C_{res} - E_{res}]$ (1)

Where:

M - Metabolic rate (W/m^2)

W - Effective mechanical power (W/m^2)

H - Sensitive heat losses

E_c - The heat exchange by evaporation on the skin

C_{res} - Heat exchange by convection in breathing

E_{res} - Evaporative heat exchange in breathing

In equation 1, the terms H, E_c, C_{res}, and H_{res}, correspond to the heat exchange between the body and the surrounding environment and are calculated from the following equations:

$H = 3.96*10-8*f_{cl}*[(t_{cl}+273)4 - (t_r+273)4] - f_{cl}*h_c*(t_{cl}-t_a)$ (2)

$E_c = 3.05*10-3*[5733 – 6.99*(M-W)-p_a]-0,42*[(M-W)-58,15]$ (3)

$C_{res} = 0.0014*M*(34-t_a)$ (4)

$E_{res} = 1.7*10-5*M*(5867-p_a)$ (5)

Where:

I_{cl}: Clothing insulation (m^2 K/W)

f_{cl}: Clothing surface area factor

t_a: Air temperature (°C)

t_r: Mean radiant temperature (°C)

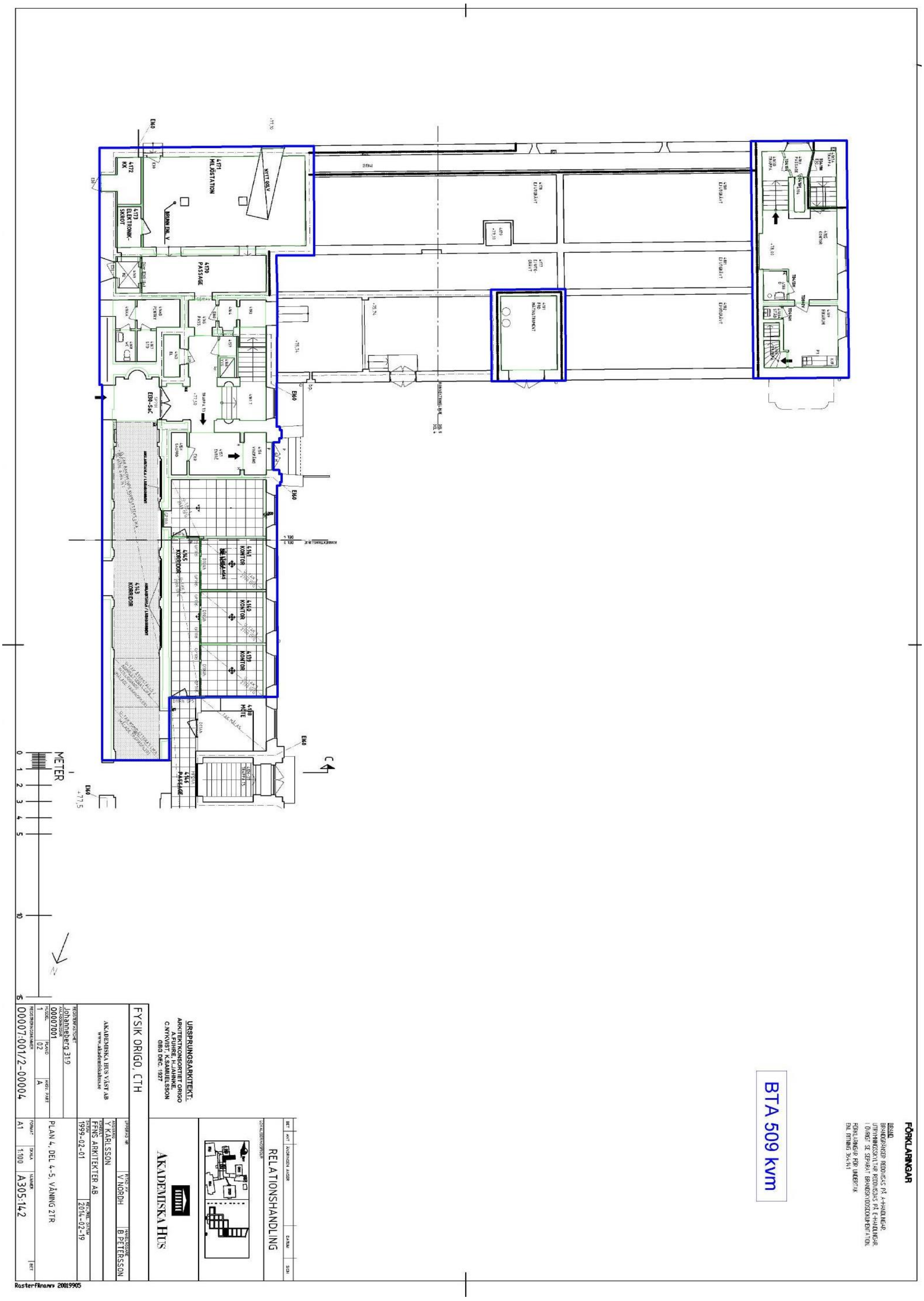
v_{ar}: Relative air velocity, in meters per second (m/s)

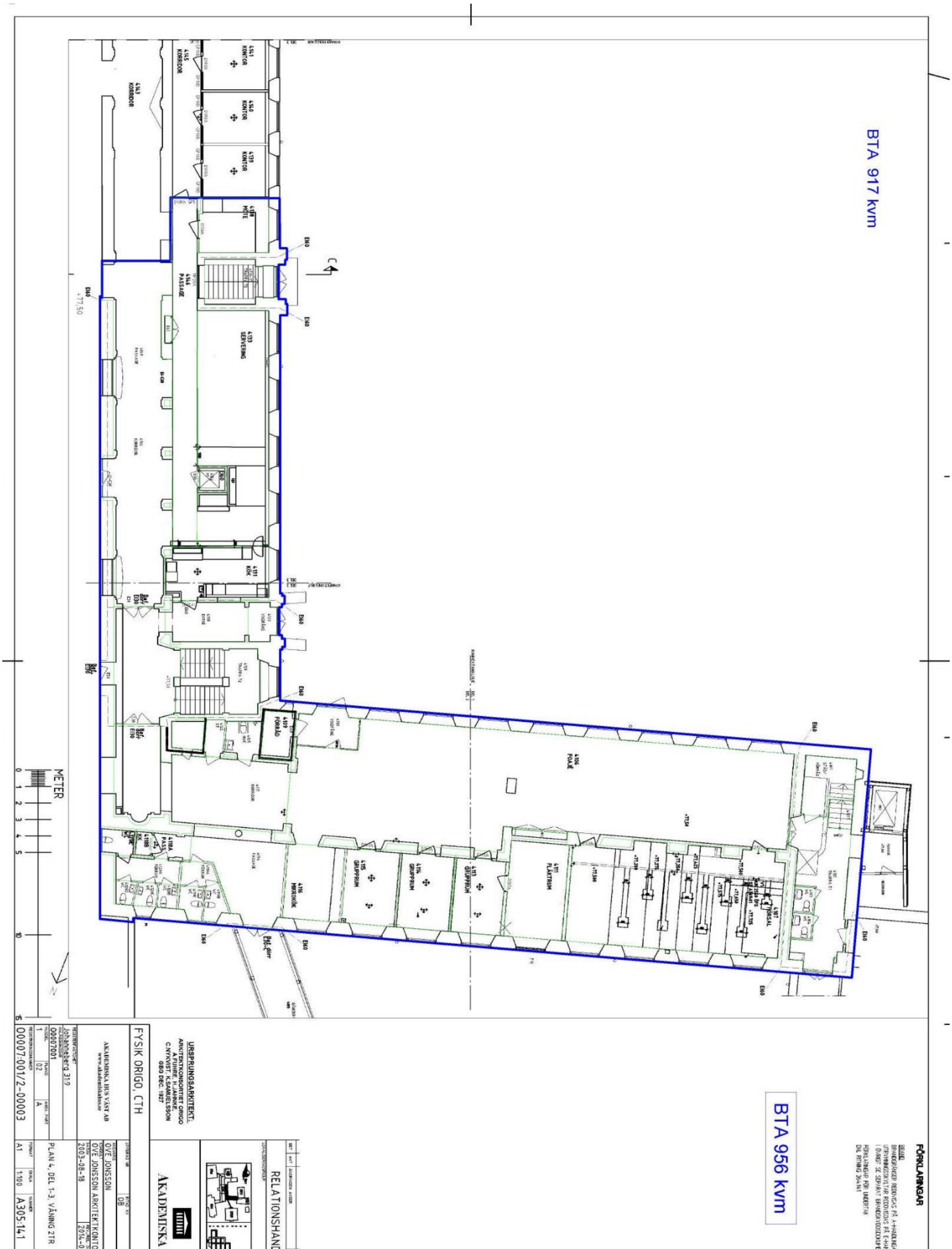
p_a: Water vapor partial pressure (Pa)

t_{cl}: Clothing surface temperature (°C)

$$PPD = 100 - 95e^{-(0.03353PMV^4+0.2179PMV^2)} \quad (9)$$

APPENDIX C: Floor plan of the Physics Origo building

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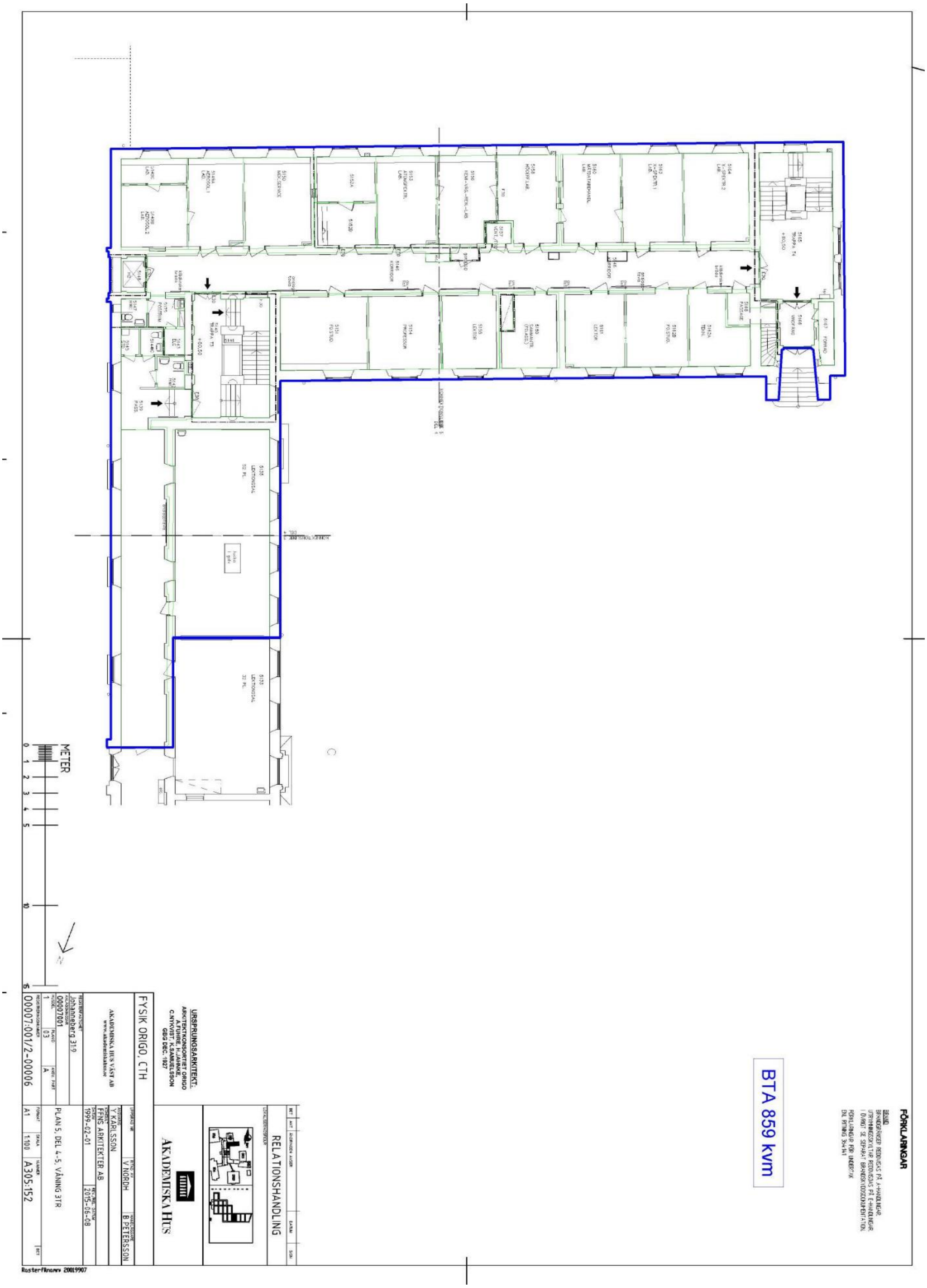
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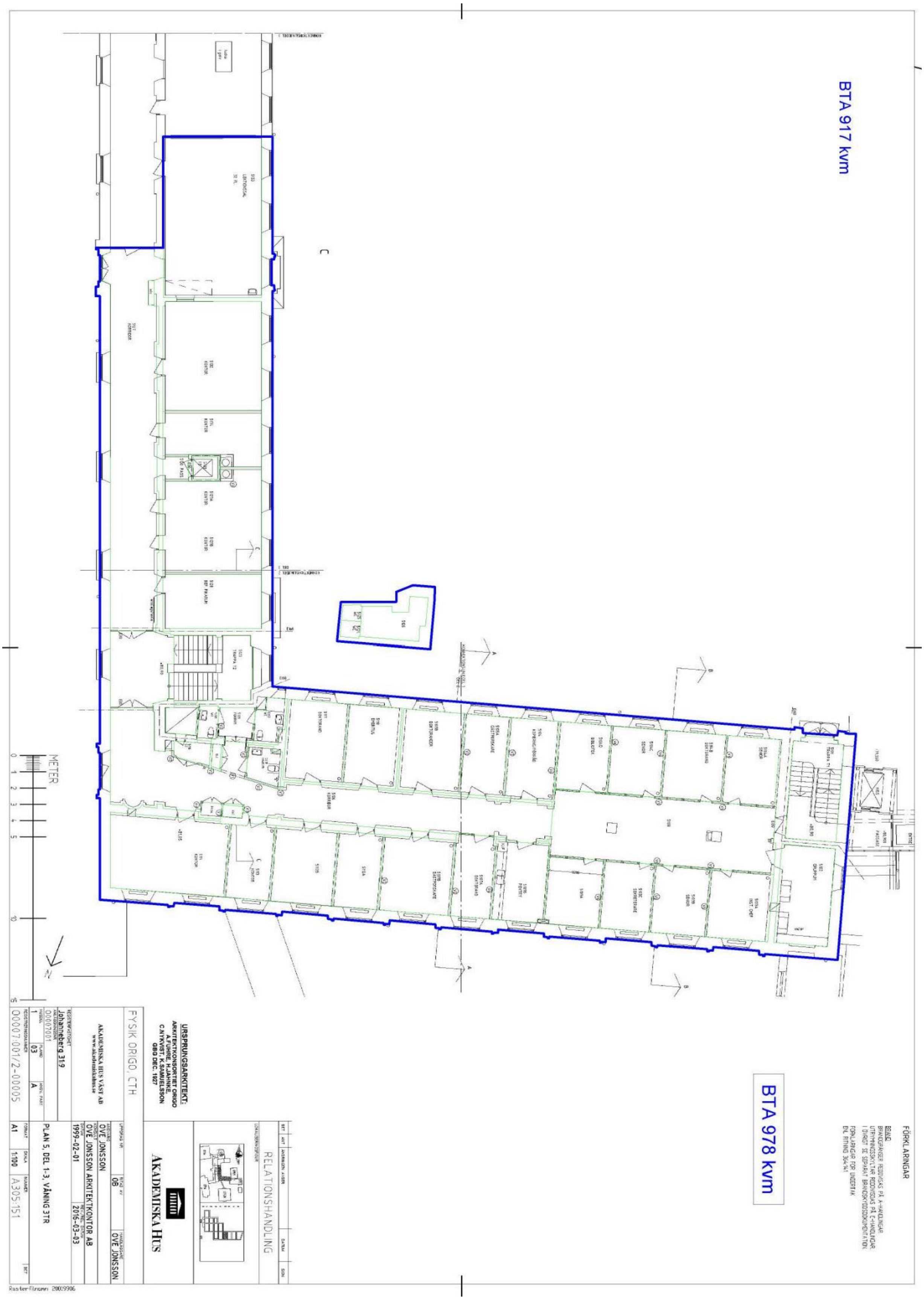
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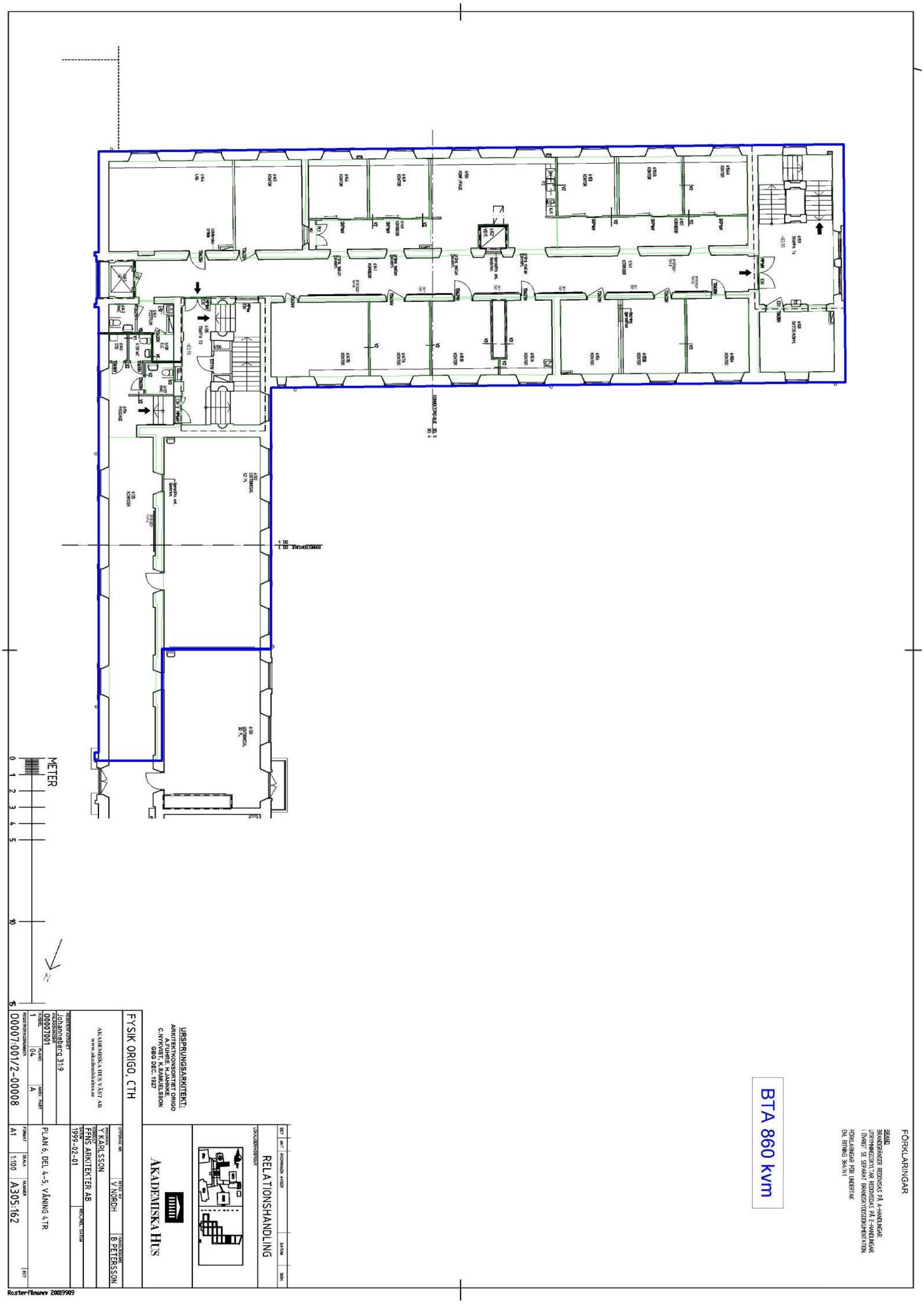
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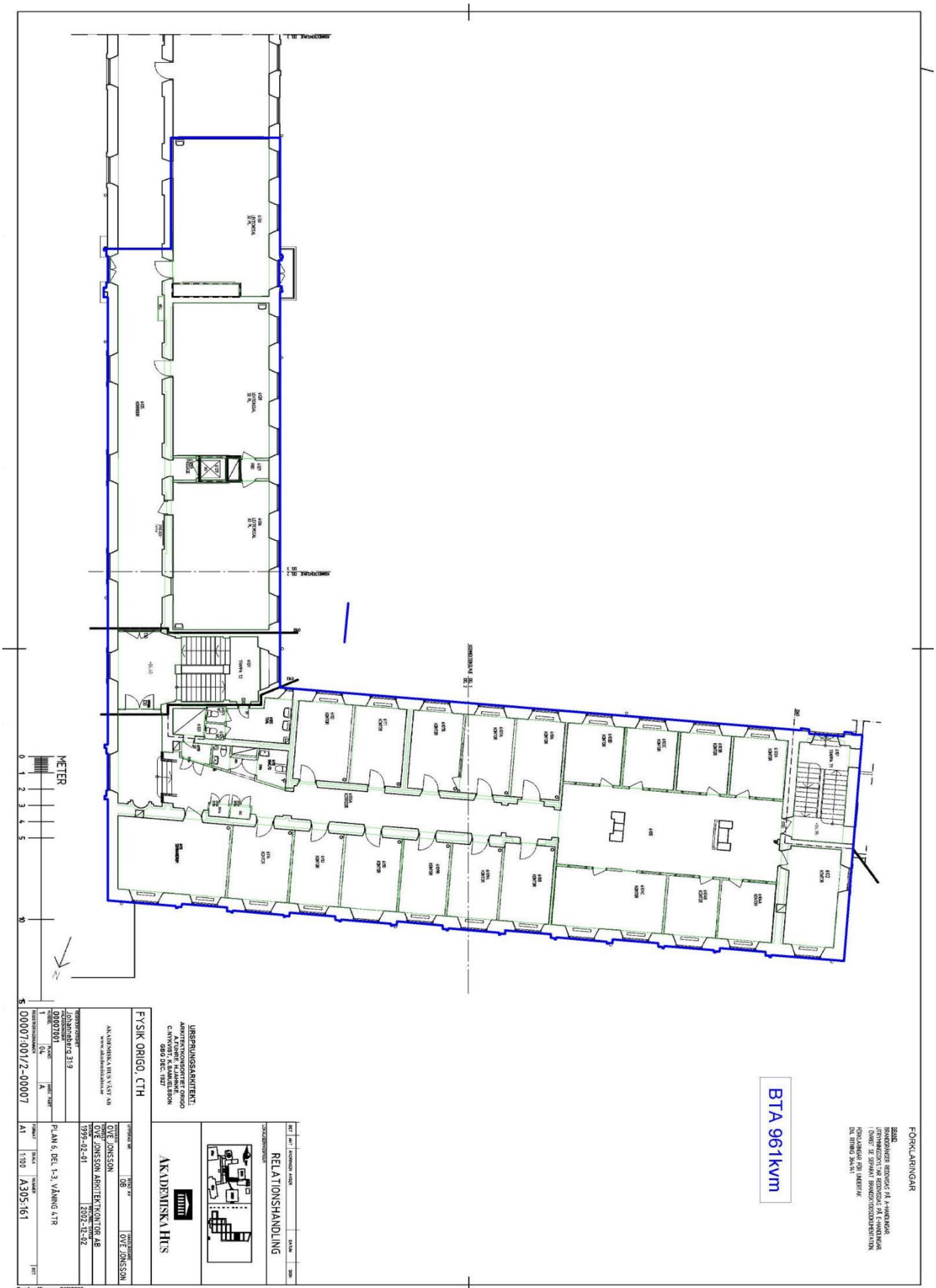
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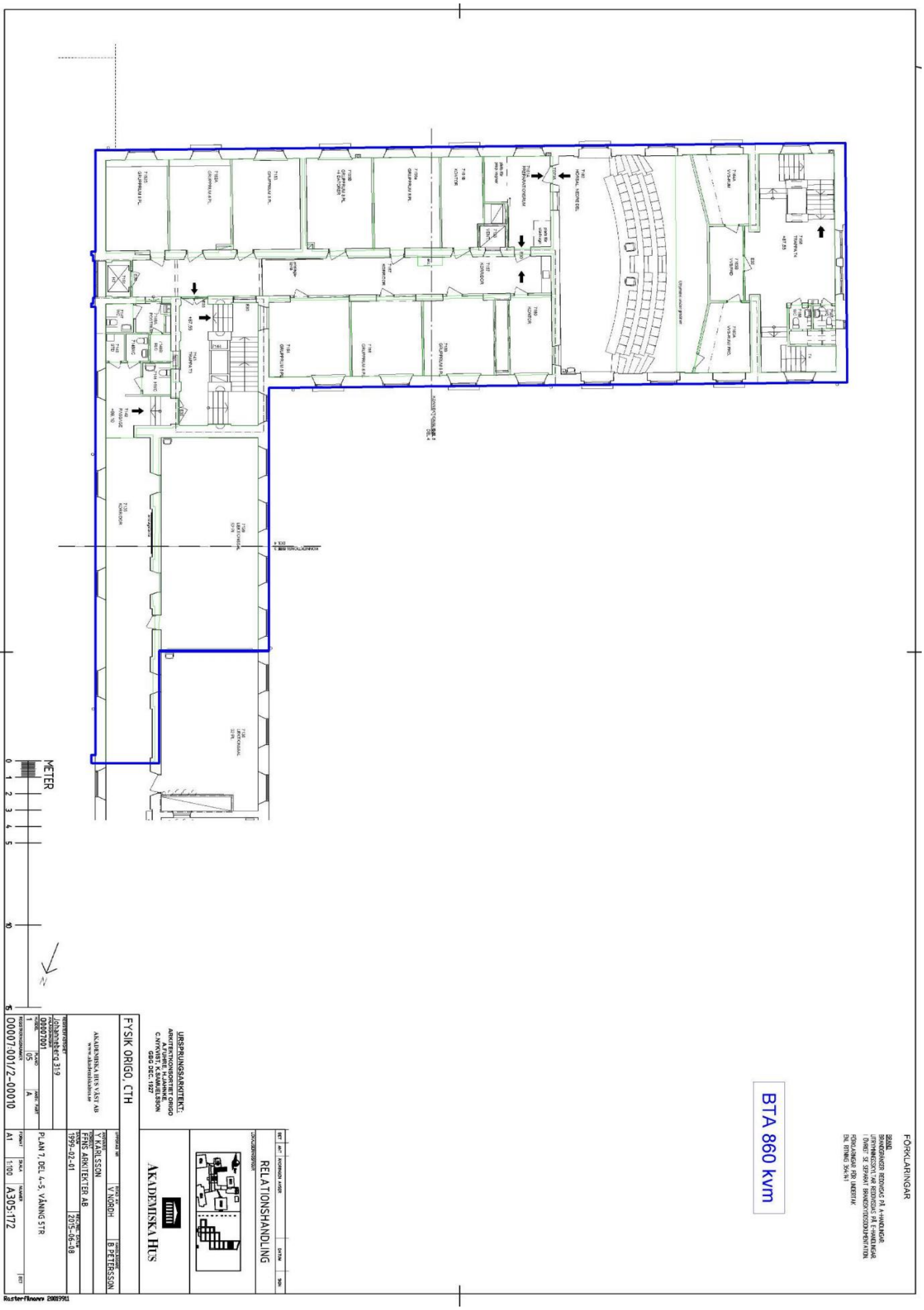

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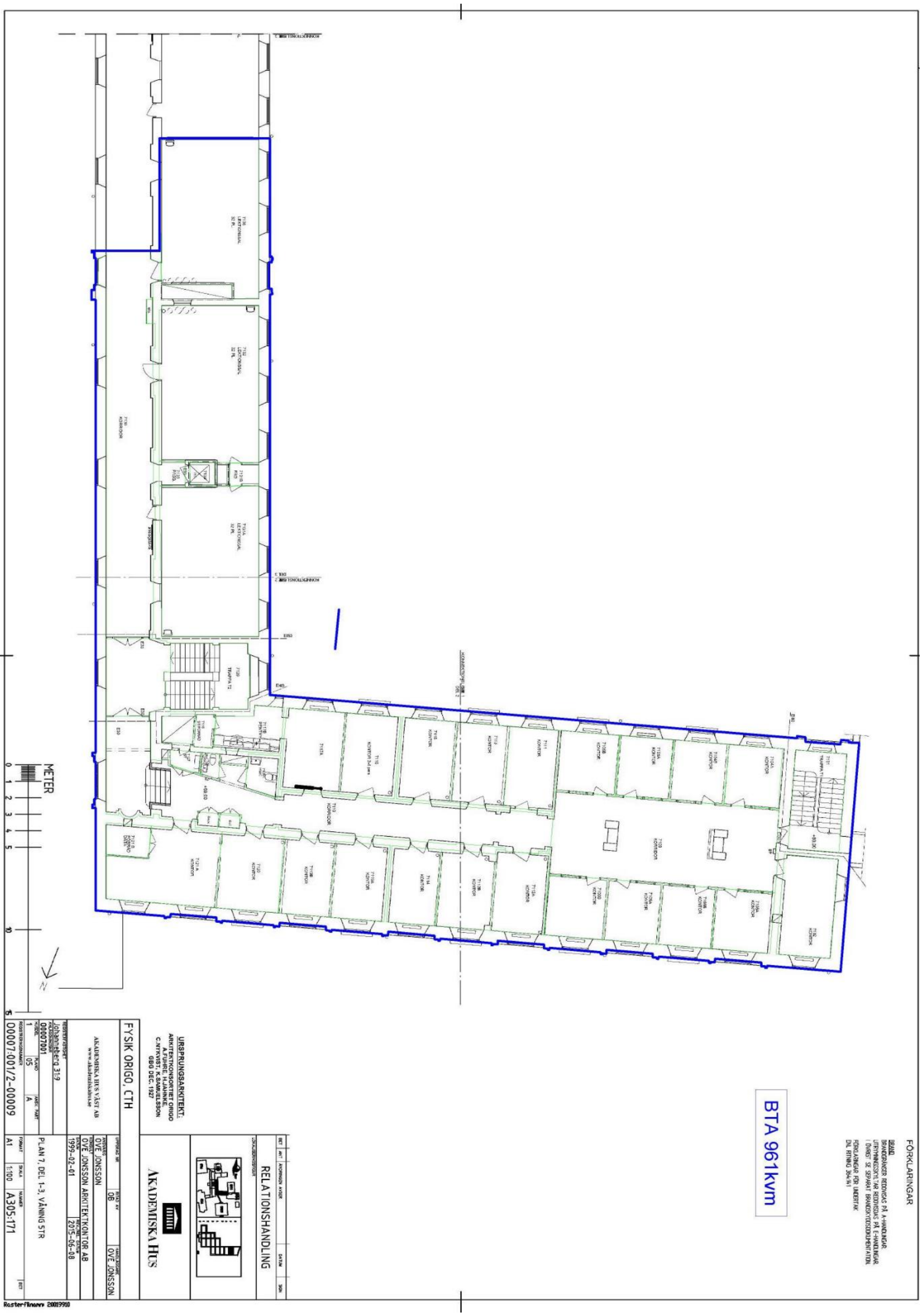
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APPENDIX D: Airflow rates in Physics Origo building

Room	Floor height (m)	Area (m^2)	Supply air (L/s)	Return air (L/s)	Occupant	Light (W)	Equipment (W)	System
4000 unused	4.2	428	n.a.	n.a.	0	0	0	CAV
4101 trappa	4.2	42.23	25	50	0	422.3	0	CAV
4106 korridor	4.2	398.6	25	450	0	3986	0	CAV
4107 hörsal (null)	4.2	80.62	225	225	0	806.2	604.6	CAV
4111 fläkrum(null)	4.2	21	n.a.	n.a.	0	210	157.5	CAV
4113 grupp(null)	4.2	13.33	100	100	0	133.3	99.98	VAV
4114 grupp(null)	4.2	14.31	100.2	100.2	0	143.1	107.3	VAV
4115 grupp(null)	4.2	14.31	100.2	100.2	0	143.1	107.3	VAV
4116 kök	4.2	15.63	31.26	31.26	0	156.3	312.6	CAV
4120 wc	4.2	13.51	100	100	0	135.1	0	CAV
4128 trappa	4.2	47.95	25	50.01	0	479.5	0	CAV
4131 cafe (null)	4.2	112.9	0	0	0	0	0	CAV
4139 kontor	4.2	12.39	60	60	1	123.9	92.93	CAV
4140 kontor	4.2	12.39	60	60	1	123.9	92.93	CAV
4141 kontor	4.2	12.39	60	60	1	123.9	92.93	CAV
4143 korridor	4.2	303.7	20	150	0	3037	0	CAV
4165 trappa	4.2	46.36	25	50.02	0	463.6	0	CAV
4166 wc	4.2	18.27	50	50	0	182.7	0	CAV
4170 passage	4.2	39.97	15	15	0	399.7	0	CAV
4171 miljöstation	4.2	63.25	25	25	0	632.5	316.3	CAV
4185 kontor/trappa	4.2	47.14	75	75	1	471.4	353.6	CAV
4189 fika	4.2	18	34.99	34.99	1	180	135	CAV
4191 mätinstrument	4.2	15.3	30.6	30.6	1	153	114.8	CAV
5101 trappa	8.2	23.99	25	25	0	239.9	0	CAV
5102 grupp	8.2	18	100	100	5	180	135	VAV
5103A chef	8.2	10.8	25	25	1	108	81	CAV
5103B senior	8.2	11.16	25	25	1	111.6	83.7	CAV
5103C sekretare	8.2	12.24	24.48	24.48	1	122.4	91.8	CAV
5104 kopiering	8.2	10.12	34.99	34.99	1	101.2	75.9	CAV
5104A senior	8.2	11.86	35	35	1	118.6	88.95	CAV
5104B dr	8.2	11.7	34.99	34.99	1	117	87.75	CAV
5104C senior	8.2	11.7	34.99	34.99	1	117	87.75	CAV
5104D bibliotek	8.2	11.7	36	34.99	1	117	87.75	CAV
5105A forskare	8.2	11.44	34.99	34.99	1	114.4	85.8	CAV
5105B dr	8.2	15.84	35.01	35.01	1	158.4	118.8	CAV
5106 korridor	8.2	256.4	50	600	0	2564	0	CAV
5107A dr	8.2	11.01	35	35	1	110.1	82.58	CAV
5107B forskare	8.2	17.2	35	35	1	172	129	CAV
5109A	8.2	12.24	34.99	34.99	1	122.4	91.8	CAV
5109B pentry	8.2	13.77	26	26	1	137.7	103.3	CAV
5110 kontor	8.2	13.86	35	35	2	138.6	104	CAV
5111 dr	8.2	15.84	35.01	35.01	1	158.4	118.8	CAV

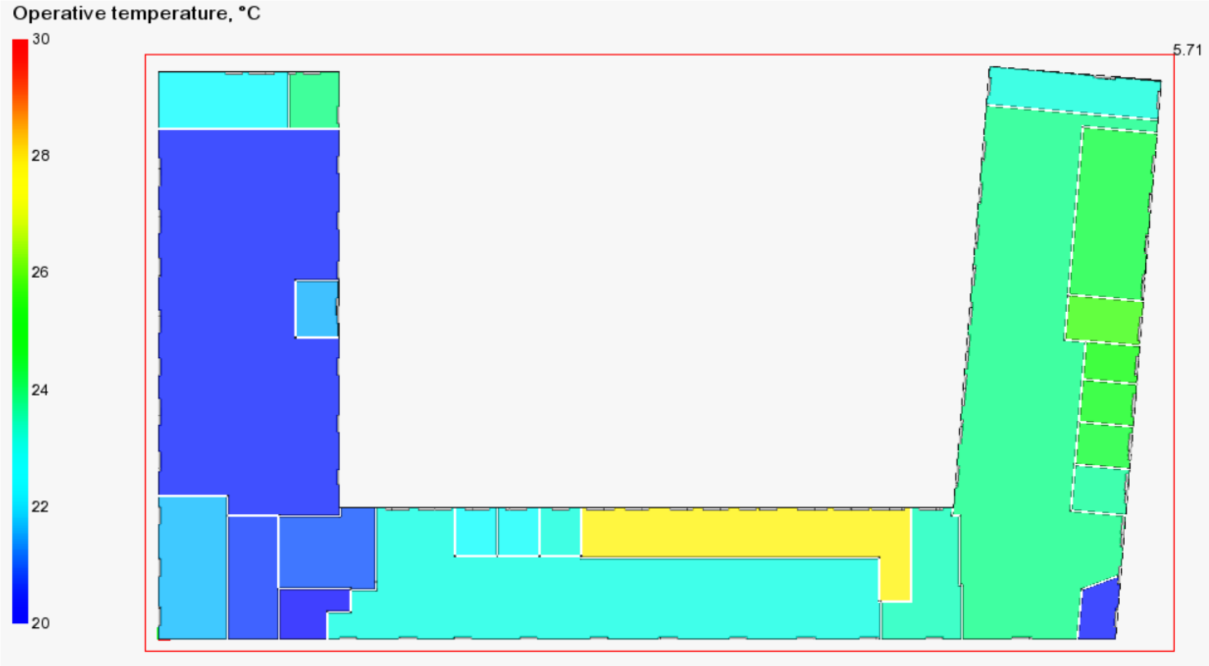
5112A	8.2	12.57	50	50	1	125.7	94.28	CAV
5112B	8.2	17.53	50	50	1	175.3	131.5	CAV
5113 kontor	8.2	12.33	50	50	1	123.3	92.48	CAV
5114 kontor	8.2	30.72	153.6	153.6	2	307.2	230.4	CAV
5117 WC	8.2	24.57	75.01	75.01	0	245.7	0	CAV
5123 trappa	8.2	38.38	25	50.01	0	383.8	0	CAV
5127 korridor	8.2	207.4	275	275	0	2074	0	CAV
5128 fika	8.2	20.24	49.99	49.99	0	202.4	151.8	CAV
5129 kontor	8.2	36.52	50	50	5	365.2	273.9	CAV
5130 kontor	8.2	18.1	69.99	69.99	5	181	135.8	CAV
5132 kontor	8.2	40.12	89.99	89.99	5	401.2	300.9	CAV
5133 lecture 32	8.2	57.23	290	290	25	572.3	429.2	VAV
5133 lecture 52	8.2	76.11	440	440	35	761.1	570.8	VAV
5140 trappa	8.2	46.36	0	25	0	463.6	0	CAV
5146 korridor	8.2	162	0	169.9	0	1620	0	CAV
5147 wc	8.2	18.27	0	50	0	182.7	0	CAV
5149a lab	8.2	20.32	75	75	3	203.2	152.4	CAV
5149b lab	8.2	17.06	240	190	3	170.6	128	CAV
5149C lab	8.2	6.765	15	15	1	67.65	50.74	CAV
5150 Mek service	8.2	25.92	89.99	89.99	0	259.2	194.4	CAV
5151 stud	8.2	26.4	40	0	2	264	198	CAV
5152A	8.2	10.92	25	25	0	109.2	81.9	CAV
5152B	8.2	11.47	25	25	0	114.7	86.03	CAV
5153 lab	8.2	22.38	75	75	3	223.8	167.8	CAV
5154 prof	8.2	22.08	24.99	0	1	220.8	165.6	CAV
5155 lektor	8.2	17.28	25	0	1	172.8	129.6	CAV
5156 lab	8.2	20.83	80.01	80.01	2	208.3	156.2	CAV
5158 lab	8.2	21.42	80	80	2	214.2	160.7	CAV
5159 samman	8.2	15.88	54.99	0	1	158.8	119.1	CAV
5160 lab	8.2	22.38	95	95	3	223.8	167.8	CAV
5161 lektor	8.2	18.1	25	0	1	181	135.8	CAV
5162A Tenik	8.2	18.48	25	25	1	184.8	138.6	CAV
5162B Stud	8.2	18.86	25.01	0	1	188.6	141.5	CAV
5163 lab	8.2	22.38	75	75	3	223.8	167.8	CAV
5164 lab	8.2	24.74	75.01	75.01	3	247.4	185.6	CAV
5165 trappa	8.2	47.14	25	25	0	471.4	0	CAV
5166 passage	8.2	18	25	25	0	180	0	CAV
6101 trappa	12.4	23.99	25	50	0	239.9	0	CAV
6102 kontor	12.4	18	25	20	1	180	135	CAV
6103A kontor	12.4	11.86	25	20	1	118.6	88.95	CAV
6103B kontor	12.4	11.7	25	20	1	117	87.75	CAV
6103C kontor	12.4	11.7	25	20	1	117	87.75	CAV
6103D kontor	12.4	11.7	25	20	1	117	87.75	CAV
6104A kontor	12.4	10.8	25	20	1	108	81	CAV
6104B kontor	12.4	11.16	25	20	1	111.6	83.7	CAV
6104C kontor	12.4	25.02	49.99	49.99	1	250.2	187.7	CAV

6106 kontor	12.4	12.98	34.99	34.99	1	129.8	97.35	CAV
6106A korridor	12.4	262.1	0	450	0	2621	0	CAV
6107A kontor	12.4	13.2	35.01	30	1	132	99	CAV
6107B kontor	12.4	12.54	35	30	1	125.4	94.05	CAV
6108 kontor	12.4	13.2	25	20	1	132	99	CAV
6109A kontor	12.4	13.2	25	20	1	132	99	CAV
6109B kontor	12.4	12.35	24.56	24.56	1	123.5	92.63	CAV
6110 kontor	12.4	14.96	25	1	1	149.6	112.2	CAV
6111 kontor	12.4	14.96	35.01	35.01	3	149.6	112.2	CAV
6112 kontor	12.4	13.64	35	29.99	1	136.4	102.3	CAV
6113 kontor	12.4	13.2	25	20	1	132	99	CAV
6114 kontor	12.4	15.84	25	20.01	1	158.4	118.8	CAV
6115 seminarium	12.4	30.72	153.6	153.6	5	307.2	230.4	CAV
6121 trappa	12.4	42.71	25	25	0	427.1	0	CAV
6122WC	12.4	24.57	50	50	0	245.7	0	CAV
6125 korridor	12.4	216.1	275.1	275.1	0	2161	0	CAV
6126 lecture 32	12.4	53.1	290	290	25	531	398.3	VAV
6128 lecture 32	12.4	55.17	290	290	25	551.7	413.8	VAV
6130 lecture 32	12.4	57.23	290	290	25	572.3	429.2	VAV
6132 lecture 52	12.4	76.11	440	440	35	761.1	570.8	VAV
6135 trappa	12.4	46.36	92.72	92.72	0	463.6	0	CAV
6141 korridor	12.4	224.5	99.99	200	0	2245	0	CAV
6142 wc	12.4	18.27	0	99.99	0	182.7	0	CAV
6144 lab	12.4	42.56	110	110	3	425.6	319.2	CAV
6145 kontor	12.4	25.2	60	60	2	252	189	CAV
6146 kontor	12.4	11.52	60	60	1	115.2	86.4	CAV
6147A kontor	12.4	17.1	25	0	1	171	128.3	CAV
6147B kontor	12.4	27	39.99	0	2	270	202.5	CAV
6149 kontor	12.4	11.52	35	35	1	115.2	86.4	CAV
6150 paus	12.4	52.55	74.99	74.99	1	525.5	394.1	CAV
6151A kontor	12.4	13.45	25	0	1	134.5	100.9	CAV
6151B kontor	12.4	17.5	25.01	0	1	175	131.3	CAV
6153 kontor	12.4	11.68	35	35	1	116.8	87.6	CAV
6154 kontor	12.4	17.1	25	0	1	171	128.3	CAV
6155A kontor	12.4	17.1	25	0	1	171	128.3	CAV
6155B kontor	12.4	17.1	25	0	1	171	128.3	CAV
6156A kontor	12.4	11.68	35	35	1	116.8	87.6	CAV
6156B kontor	12.4	11.68	35	35	1	116.8	87.6	CAV
6158 dator	12.4	18	25	0	1	180	135	CAV
6159 trappa	12.4	47.14	25	50.02	0	471.4	0	CAV
7101 trappa1	16.6	23.99	25	25	0	239.9	0	CAV
7102 kontor	16.6	18	25	25	1	180	135	CAV
7103 korridor	16.6	259.1	0	150	0	2591	0	CAV
7104A kontor	16.6	11.86	35	25	1	118.6	88.95	CAV
7104B kontor	16.6	11.7	36	26	1	117	87.75	CAV
7105A kontor	16.6	11.7	25	15	1	117	87.75	CAV

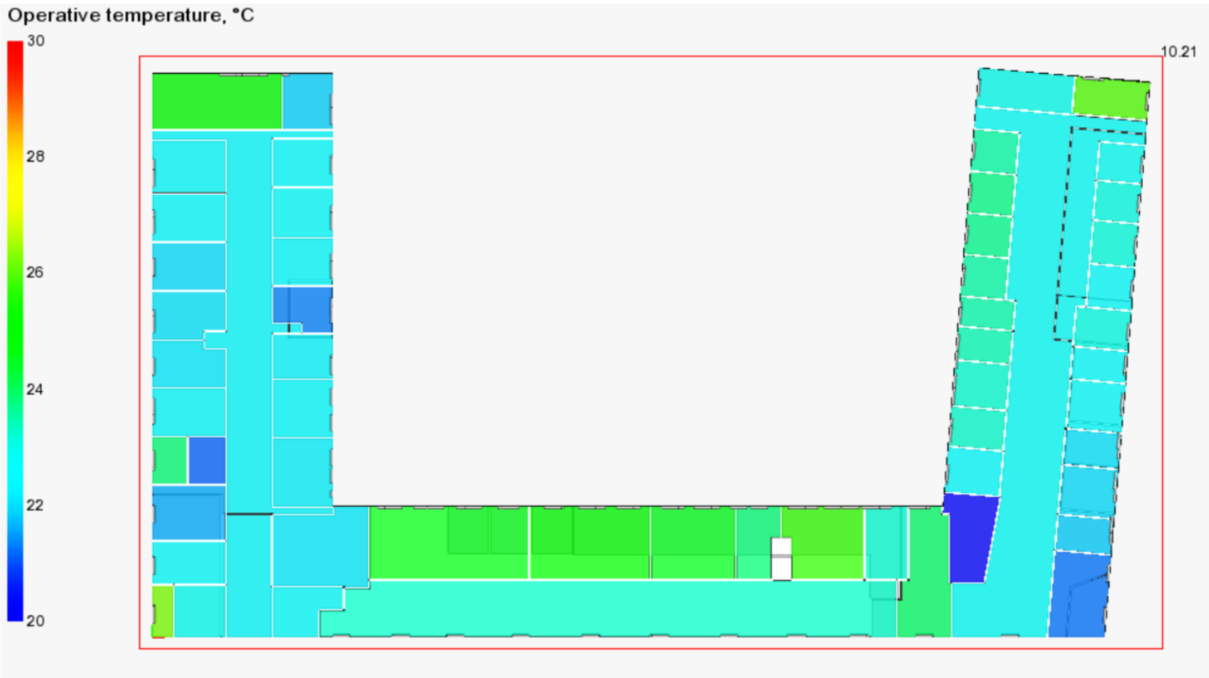
7105B kontor	16.6	11.7	25	15	1	117	87.75	CAV
7108A kontor	16.6	10.8	25	15	1	108	81	CAV
7108B kontor	16.6	11.16	25	15	1	111.6	83.7	CAV
7109A kontor	16.6	12.24	24.99	14.99	1	122.4	91.8	CAV
7109B kontor	16.6	12.24	24.99	14.99	1	122.4	91.8	CAV
7111 kontor	16.6	12.98	50	50	2	129.8	97.35	CAV
7112A kontor	16.6	13.2	25	15	2	132	99	CAV
7112B kontor	16.6	13.2	25	15	2	132	99	CAV
7113 kontor	16.6	13.2	50	50	2	132	99	CAV
7114 kontor	16.6	12.35	25	15.01	2	123.5	92.63	CAV
7115 kontor	16.6	12.54	50	50	2	125.4	94.05	CAV
7116 kontor	16.6	14.96	185.1	110	2	149.6	112.2	CAV
7117A kontor	16.6	13.64	48.44	48.44	2	136.4	102.3	CAV
7119A kontor	16.6	14.96	25	15	2	149.6	112.2	CAV
7119B kontor	16.6	13.2	25	15	2	132	99	CAV
7120 kontor	16.6	15.84	25	15	2	158.4	118.8	CAV
7121 kontor	16.6	30.72	25	15	3	307.2	230.4	CAV
7128 WC	16.6	24.57	0	50	0	245.7	0	CAV
7129 trappa2	16.6	42.71	25	25	0	427.1	0	CAV
7130 korridor	16.6	210.5	274.9	274.9	0	2105	0	CAV
7131A lecture 32	16.6	53.1	290	290	25	531	398.3	VAV
7132 Lecture 32	16.6	55.17	290	290	25	551.7	413.8	VAV
7136 Lecture 32	16.6	57.23	290	290	25	572.3	429.2	VAV
7138 Lecture 52	16.6	76.11	440	440	35	761.1	570.8	VAV
7143 trappa3	16.6	46.36	25	25	0	463.6	0	CAV
7147 wc	16.6	18.27	0	20.01	0	182.7	0	CAV
7152A grupp	16.6	21.28	74.99	74.99	5	212.8	159.6	VAV
7152B grupp	16.6	20.74	75	75	5	207.4	155.6	VAV
7153 grupp	16.6	24.4	74.98	74.98	5	244	183	VAV
7155A grupp	16.6	22.96	74.99	74.99	5	229.6	172.2	VAV
7155B grupp	16.6	24.36	74.98	74.98	5	243.6	182.7	VAV
7156 grupp	16.6	21.12	75	75	5	211.2	158.4	VAV
7157 korridor	16.6	111.1	20	0	0	1111	0	CAV
7159 grupp	16.6	21.12	75	75	5	211.2	158.4	VAV
7160 kontor	16.6	13.68	24.99	24.99	1	136.8	102.6	CAV
7161A preprum	16.6	18.68	0	35.01	0	186.8	140.1	CAV
7161B kontor	16.6	11.76	25	25	1	117.6	88.2	CAV
7162 hörsal	16.6	127.6	1400	1400	80	1276	957	VAV
7163A VVS	16.6	14.56	n.a.	n.a.	0	145.6	109.2	CAV
7163B VVS	16.6	8.799	n.a.	n.a.	0	87.99	65.99	CAV
7164 grupp	16.6	24	75	75	5	240	180	VAV
7164A VVS	16.6	14.56	n.a.	n.a.	0	145.6	109.2	CAV
7165 trappa4	16.6	91.52	25	25	0	915.2	0	CAV
7166/7167 wc	16.6	4.2	0	29.4	0	42	0	CAV
8000 empty	20.8	1828	n.a.	n.a.	0	0	0	CAV
Total		8886	12598	14232	561	65173	22734	CAV

APPENDIX E: Simulated temperature in each room

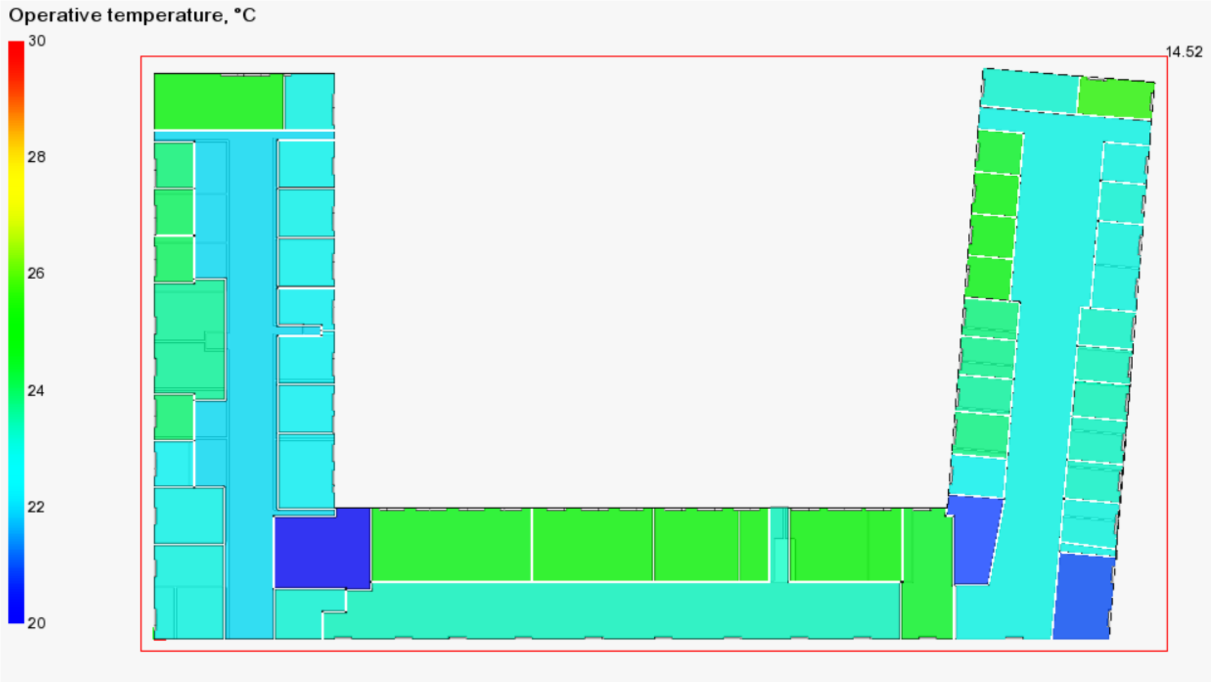
22°C set point, 27 °C outdoor temperature



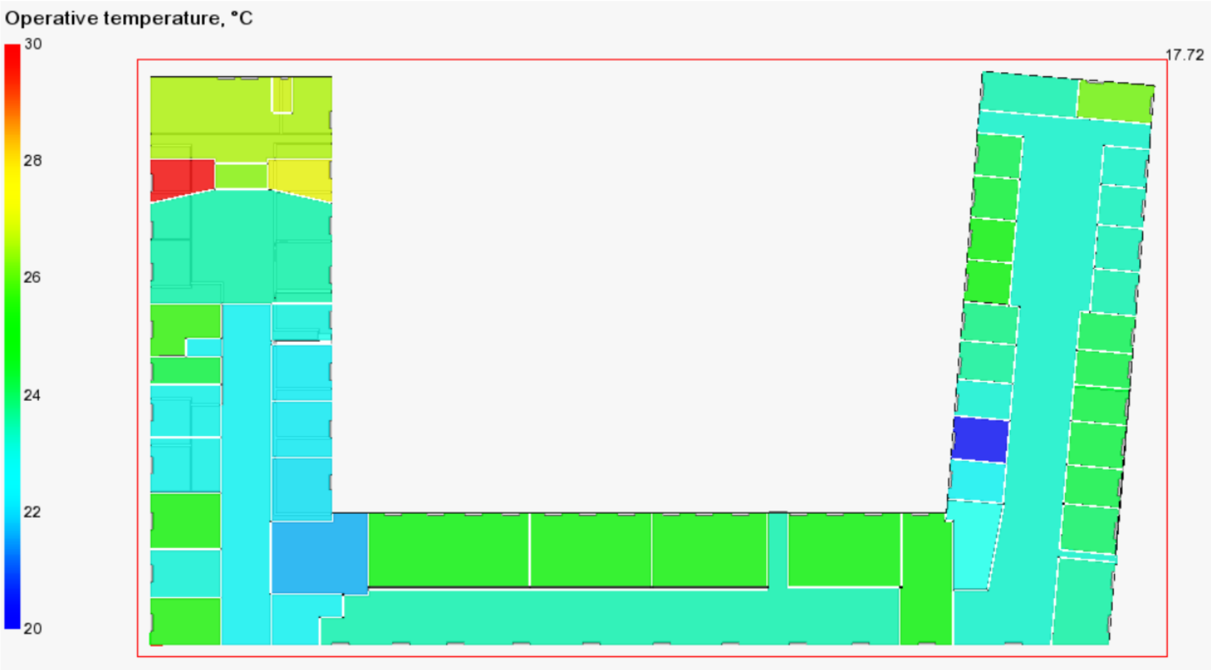
4th floor (22°C set point)



5th floor (22°C set point)

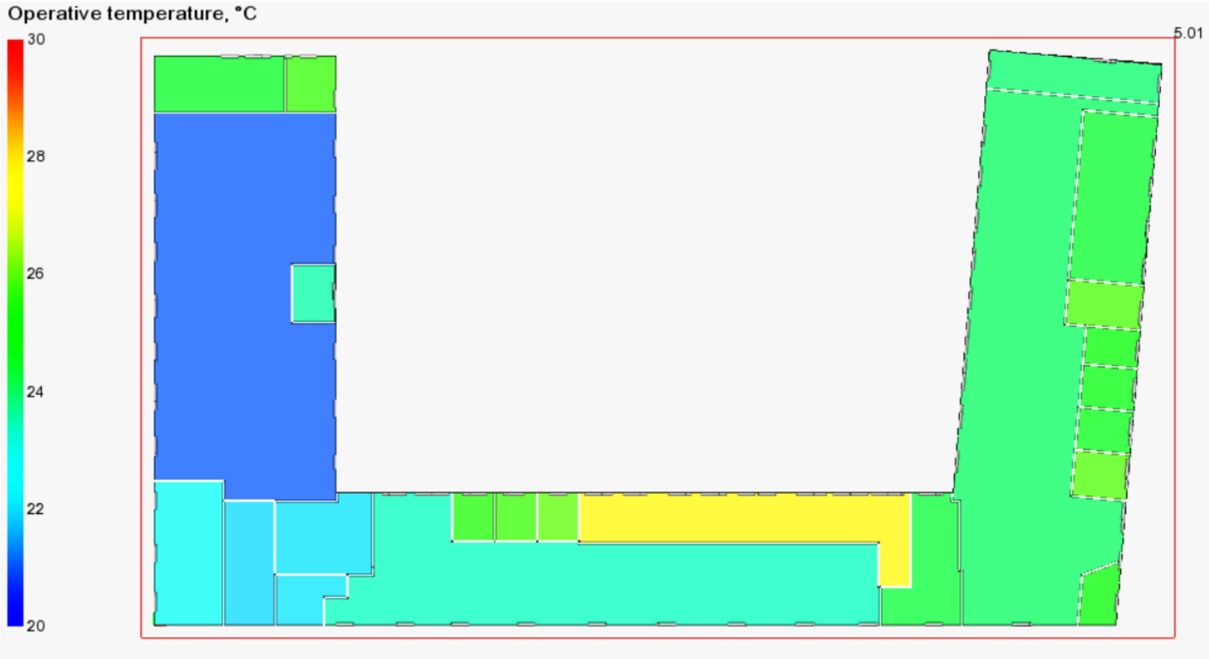


6^{th} floor (22^{o}C set point)

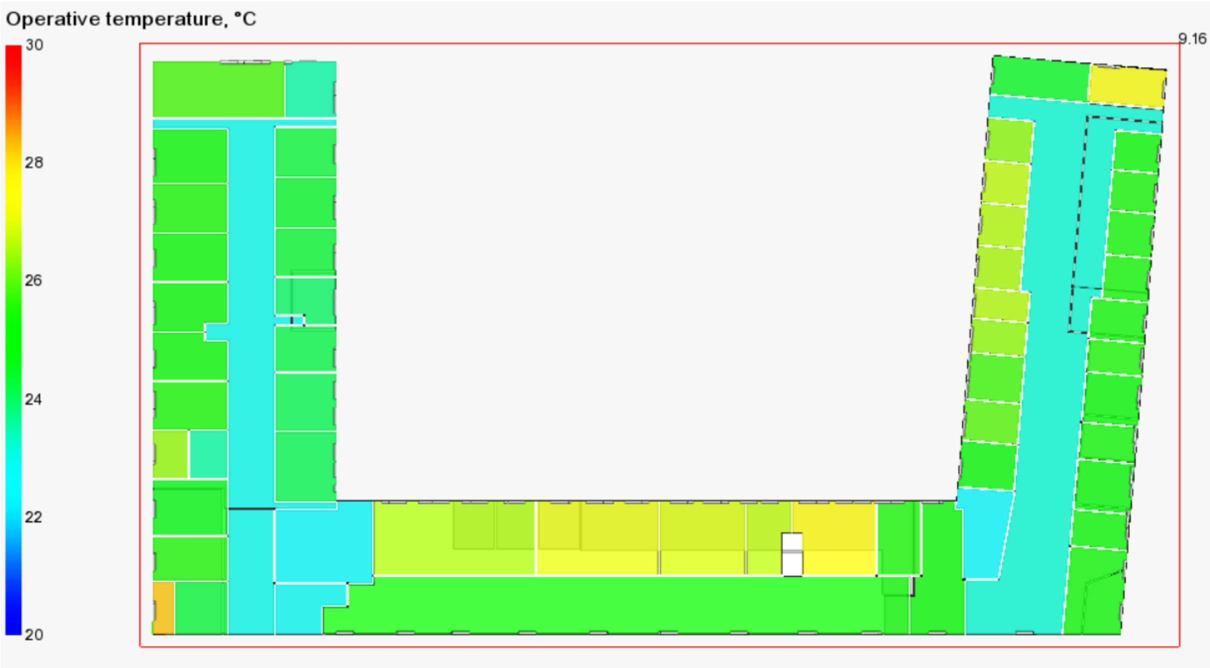


7^{th} floor (22^{o}C set point)

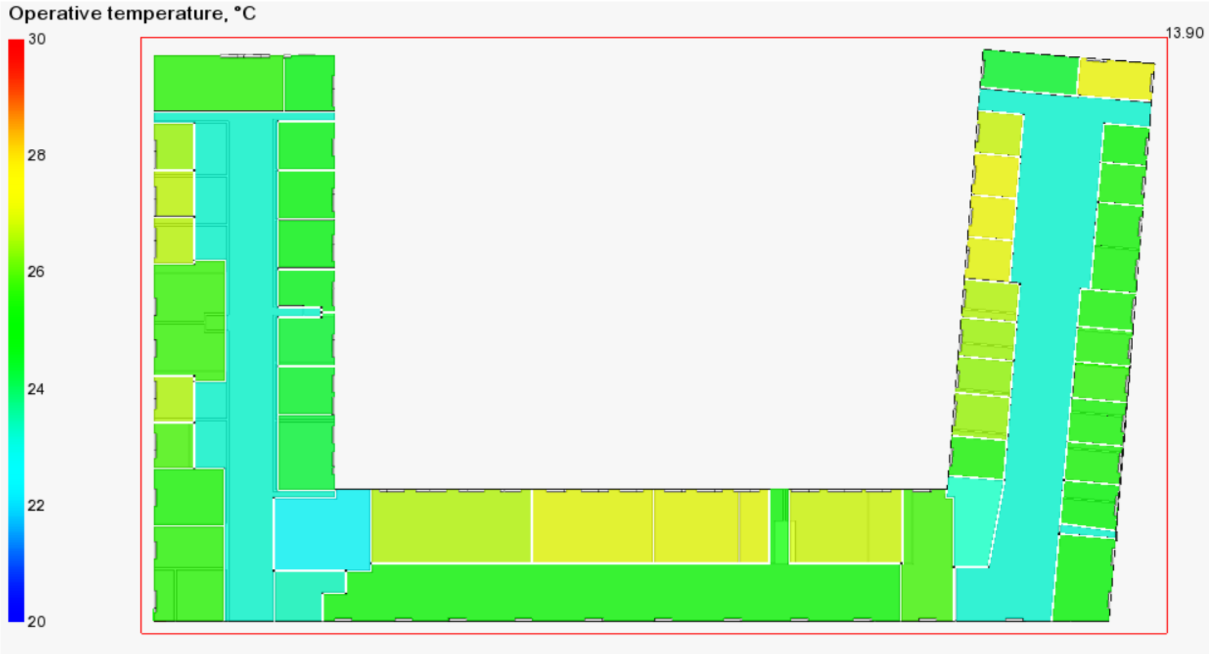
25ºC set point, 27 ºC outdoor temperature



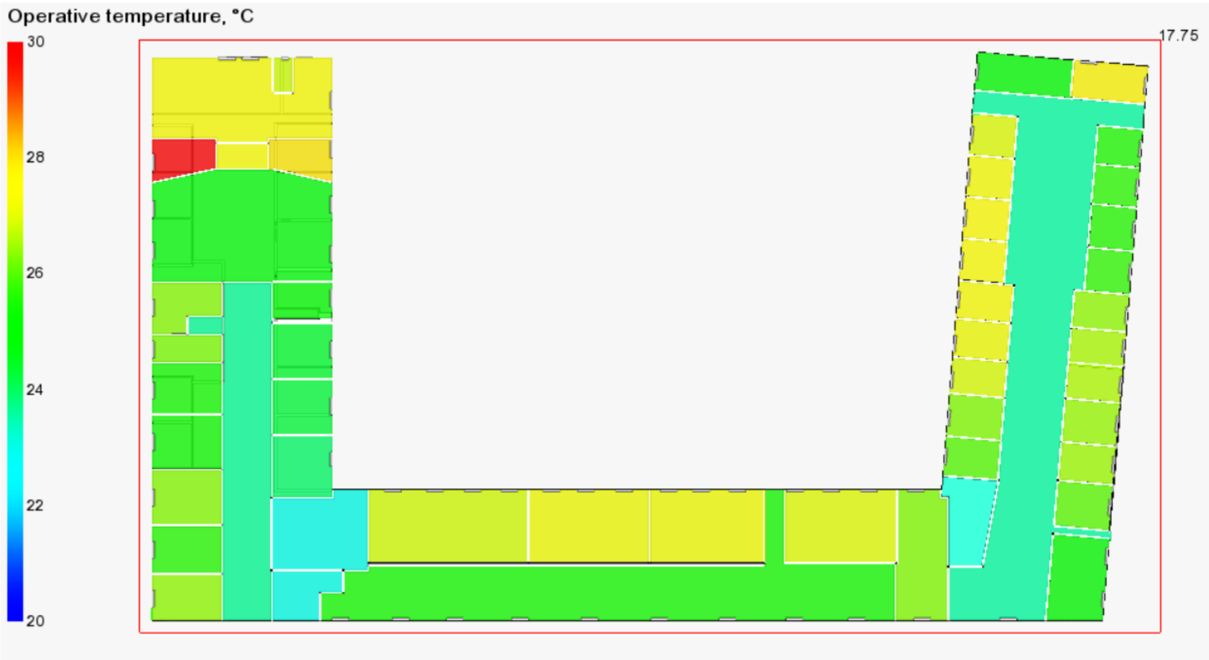
4th floor (25ºC set point)



5th floor (25ºC set point)



6th Floor (25°C set point)



7th floor (25°C set point)

APPENDIX F: Delivered energy

22ºC set point

Building Comfort Reference

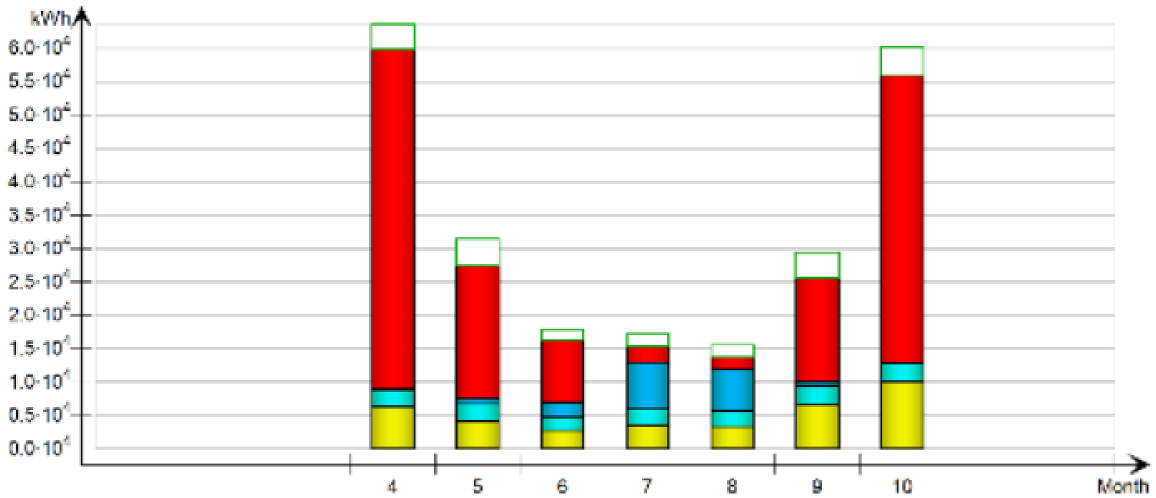
Percentage of hours when operative temperature is above 27°C in worst zone	2 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	8 %

Delivered Energy Overview

		Purchased energy		Peak demand
		kWh	kWh/m²	kW
	Lighting, facility	36572	4.1	62.0
	HVAC aux	17588	2.0	13.82
	Total, Facility electric	54160	6.1	
	Domestic hot water	0	0.0	0.0
	Total, Facility fuel*	0	0.0	
	District cooling	17051	1.9	97.0
	District heating	143192	16.1	311.6
	Total, Facility district	160243	18.0	
	Total	214403	24.1	
	Equipment, tenant	20964	2.4	21.81
	Total, Tenant electric	20964	2.4	
	Grand total	235367	26.5	

*heating value

Monthly Purchased/Sold Energy



25ºC set point

Building Comfort Reference

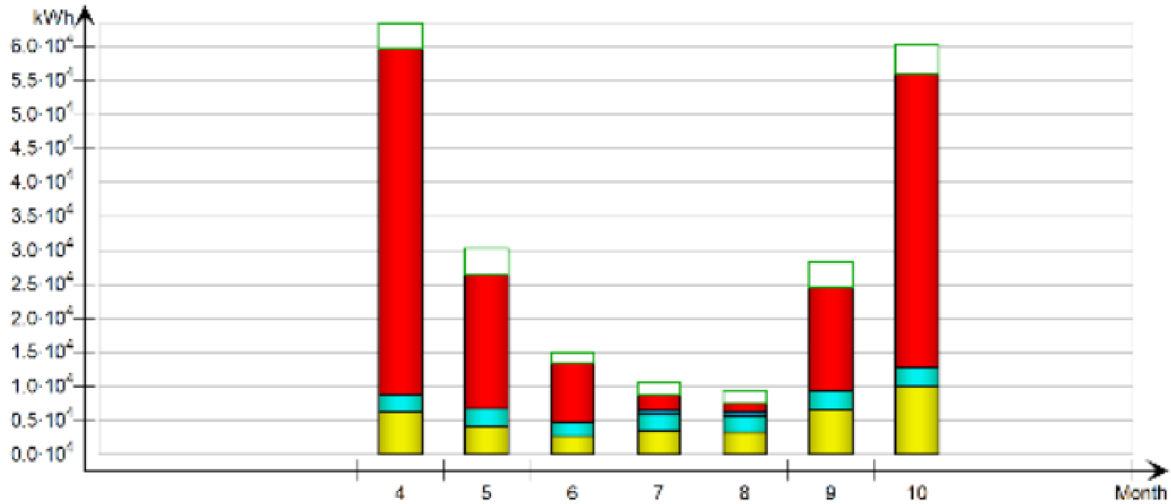
Percentage of hours when operative temperature is above 27°C in worst zone	6 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	8 %

Delivered Energy Overview

		Purchased energy		Peak demand
		kWh	kWh/m²	kW
	Lighting, facility	36570	4.1	61.97
	HVAC aux	17573	2.0	15.12
	Total, Facility electric	54143	6.1	
	Domestic hot water	0	0.0	0.0
	Total, Facility fuel*	0	0.0	
	District cooling	1115	0.1	85.25
	District heating	141406	15.9	312.2
	Total, Facility district	142521	16.0	
	Total	196664	22.1	
	Equipment, tenant	20964	2.4	21.81
	Total, Tenant electric	20964	2.4	
	Grand total	217628	24.5	

*heating value

Monthly Purchased/Sold Energy



APPENDIX G: Equipment used

Testo 810

Som ledande tillverkare av portabla mätinstrument kan Testo nu erbjuda snabba, robusta mätinstrument för daglig användning, som passar i fickan:

- Lufttemperatur och yttemperatur med IR-teknik
- Luftfuktighet och temperatur
- Materialfukt, luftfuktighet och temperatur
- Differenstryck
- Absoluttryck
- Varvtal
- Ljusstyrka
- Lufthastighet, temperatur, fukt

Sensorerna, som t.ex. Testos egen patenterade fuktsensor, uppfyller de hårdaste kraven vilket borgar för tillförlitliga och stabila mätresultat.

Alla instrument är mycket behändiga, små och enkla att använda. Den bakgrundsbelysta displayen och Auto Off-funktionen gör instrumentet komplett.

Ingår alltid:
Skyddskåpa, handledsrem och bälteshållare – oumbärliga och praktiska tillbehör.

Så här liten kan bara riktigt stor teknik vara!

testo 810

Lufttemperaturmätning och IR-mätning av yttemperatur i ett och samma instrument

- IR-mätning med 1-punktslaser för markering av mätfläck och 6:1-optik
- Lufttemperatur-mätning
- Visning av differens-temperatur t.ex. mellan fönster och luft
- Hold-funktion och min/max-värden

Yttemperatur	
Mätområde:	-30 ...+300 °C
Upplösning:	0,1 °C
Noggrannhet:	± 2,0 °C (-30 ... +100 °C) ± 2% av m.v. (övriga området)
Optik:	6:1
Lufttemperatur	
Mätområde:	-10 ...+50 °C
Upplösning:	0,1 °C
Noggrannhet:	±0,5 °C
Enheter:	°C/°F
Driftstemp.:	-10 ... 50 °C
Batterityp:	Alkaliska (2 st. AAA)
Batteriliv:	50 tim. (medelvärde, utan displaybelysning)
Mått (inkl. skyddskåpa):	119 x 46 x 25 mm

Medföljer vid leverans:
Kalibreringsprotokoll · Handledsrem
Bälteshållare · Skyddskåpa · Batterier

Best.nr. 0560 0810

testo 610

Luftfuktighet och temperatur

- Långtidsstabil fuktsensor från Testo
- Noggrannhet på 2,5 %RH med kalibreringsprotokoll
- Inkl. daggpunkts-beräkning och våt temperatur
- Hold-funktion och min/max-värden

Temperatur	
Mätområde:	-10 ...+50 °C
Upplösning:	0.1 °C
Noggrannhet:	±0.5 °C
Enheter:	°C/°F
Fukt	
Mätområde:	0 ... 100 %RH
Upplösning:	0.1 %RH
Noggrannhet:	±2.5 %RH (5 ... 95 %RH)
Enheter:	%RH, våt temperatur daggpunkt
Driftstemp.:	-10 ... 50 °C
Batterityp:	Alkaliska (2 st. AAA)
Batteriliv: utan	200 tim (medelvärde, displaybelysning)
Mått (inkl. skyddskåpa):	119 x 46 x 25 mm

Medföljer vid leverans:
Kalibreringsprotokoll · Handledsrem
Bälteshållare · Skyddskåpa · Batterier

Best.nr. 0560 0610

testo 606-1/2

Materialfukt, luftfuktighet och temperatur

- Precisionsmätning av materialfukt i trä med hjälp av interna karakteristikkurvor för t.ex. bok, gran, lärk, ek, tall och lönn
- Lufttemperatur- och fuktmätning för kontroll av tork-processer
- Karakteristikkurvor för cementputs, betong, gips, anhydrit spackel, cementbruk, kalkbruk och tegel
- Hold-funktion
- Självtestfunktion

Materialfukt	
Mätområde:	0 ... 90%
Upplösning:	0,1
Noggrannhet:	± 1% (konduktivitet)
Luftfuktighet (enbart 606-2)	
Mätområde:	0 ... 100 %RH
Upplösning:	0.1 %RH
Noggrannhet:	± 2,5 %RH (5 ... 95 °%RH)
Enheter:	%RH, våt temperatur, daggpunkt
Lufttemperatur (enbart 606-2)	
Mätområde:	-10 ...+50 °C
Upplösning:	0.1 °C
Noggrannhet:	±0.5 °C
Enheter:	°C/°F
Driftstemp.:	-10 ... 50 °C
Batterityp:	Alkaliska (2 st. AAA)
Batteriliv:	606-1: 200 tim. 606-2: 130 tim. (medelvärde, utan displaybelysning)
Mått (inkl. skyddskåpa):	119 x 46 x 25 mm

Medföljer vid leverans:
Kalibreringsprotokoll · Handledsrem
Bälteshållare · Skyddskåpa · Batterier

606-1: Best.nr. 0560 6060
606-2: Best.nr. 0560 6062

testo 410-1/-2

Lufthastighet, temperatur och fukt

- Integrerad mätning med 40 mm vinghjul
- Beräkning av tidsmedelvärde
- Hold-funktion och min/max-värden
- Beräkning av vindkylning för utomhusmätning

Lufthastighet	
Mätområde:	0,4 ... 20 m/s
Upplösning:	0,1 m/s
Noggrannhet:	± (0,2 m/s + 2% av m.v.)
Enheter:	m/s, km/h, fpm, mph, knop, upplevd temperatur °C/°F (vindkylning), Beaufort
Temperatur	
Mätområde:	-10 ...+50 °C
Upplösning:	0,1 °C
Noggrannhet:	±0,5 °C
Enheter:	°C/°F
Fukt (enbart testo 410-2)	
Mätområde:	0 ... 100 %RH
Upplösning:	0.1 %RH
Noggrannhet:	± 2,5 %RH (5 ... 95 %RH)
Enheter:	%RH, våt temperatur, daggpunkt
Driftstemp.:	-10 ... 50 °C
Batterityp:	Alkaliska (2 st. AAA)
Batteriliv:	testo 410-1: 100 tim. testo 410-2: 60 tim. (medelvärde, utan displaybelysning)
Mått (inkl. skyddskåpa):	133 x 46 x 25 mm

Medföljer vid leverans:
Kalibreringsprotokoll · Handledsrem
Bälteshållare · Skyddskåpa · Batterier

410-1: Best.nr. 0560 4101
410-2: Best.nr. 0560 4102

APPENDIX H: Measured temperature

	Room	Predict	Observe	diff
16-May	4128 trappa	22.8	22.9	0.1
	4171 miljö	21.9	22.5	0.6
	5103A rum	22	22.6	0.6
	5112B rum	22.3	22.4	0.1
	5106 kor	21.2	21.8	0.6
	5117 wc	21.1	21.3	0.2
	5147 wc	21.1	21.3	0.2
	5140 trappa	21.1	20.8	0.3
	6106A kor	21.3	21.5	0.2
	6142 wc	21.1	21.4	0.3
	7147 wc	21	21.1	0.1
	Unuse 1	21.4	21.1	0.3
	unuse 2	21.8	21.1	0.7
17-May	4131 cafe	23.4	22.3	1.1
	4128 trappa	21	22.2	1.2
	4165 trappa	20.6	20.3	0.3
	4171 miljö	20.6	20	0.6
	5140 trappa	20.6	20.3	0.3
	5133 L52	24	25	1
	5127 kor	22.1	21.5	0.6
	5123 trappa	20.8	21	0.2
	5106 kor	20.5	20.7	0.2
	5109B pentry	20.5	20.2	0.3
	5104 kopier	20.5	20.7	0.2
	6135 trappa	19.9	20.8	0.9
	6142 wc	20.5	20.6	0.1
	6125 koridor	21.9	20.7	1.2
	6132 L52	22.5	22.6	0.1
20-May	4131 cafe	23.4	23.5	0.1
	4128 trappa	21	20.5	0.5
	4165 trappa	20.5	20	0.5
	4171 miljö	20.6	20	0.6
	5140 trappa	20.6	21	0.4
	5133 L52			
	5127 kor	22	22	0
	5123 trappa	20.8	21.5	0.7
	5106 kor	20.5	20.7	0.2
	6135 trappa	19.9	19.2	0.7
	6142 wc	20.5	20.1	0.4
	6125 koridor	21.8	21.2	0.6
	6106 kor	20.5	20.5	0
	6108 kontor	21.7	21.3	0.4
	6132 L52	20.5	20.3	0.2
	6130 L35	21.1	21.2	0.1