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Climate change resilience of the built environment through simulation

A case study of an educational building in Finland

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Ilmastonmuutos aiheuttaa muutoksia sääilmiöissä, muun muassa lisääntynyttä säärasitusta rakennuksille ja muutoksia rakennusten lämmitykselle ja jäähdytykselle. Yhä useammat tutkijat ovat havainneet, että subarktisissa ilmastoissa, kuten Suomessa, ilmaston lämpötila kohoaa pitkittyneillä ja toistuvilla lämpöaalloilla maailmanlaajuista keskiarvoa enemmän.

Tämä tutkimus on tehty osana ILMARA-projektia, joka tarkastelee ilmastonmuutoksen aiheuttamia vaikutuksia ja riskejä Kanta-Hämeen alueen rakennettuun ympäristöön. Tämän opinnäytetyön tavoitteena oli selvittää tulevaisuuden ennakoitujen ilmasto-olosuhteiden vaikutuksia nykyisen rakennuskannan energiantarpeeseen Kanta-Hämeen alueella. Tapaustutkimukseksi valittiin vuonna 2024 rakennettu HAMK Smart Bio rakennus. Tulevia ilmasto-olosuhteita koskevat simulaatiot tehtiin IDA ICE -ohjelmistolla. Sääskenaarioita varten valittiin päästöskenaariot RCP4.5 ja RCP8.5 testivertailuvuosille TRY2030, TRY2050 ja TRY2080. Vertailukohtana käytettiin nykyistä sääskenaariota, TRY2020, johon tulevaisuuden sääskenaarioita vertailtiin saadakseen selville, miten energiantarve tulee muuttumaan vuosina 2030, 2050 ja 2080. Tulokset osoittivat, että verrattuna TRY2020-tilanteeseen, kaikissa skenaarioissa yleinen jäähdytystarve kasvoi, kun taas lämmöntarve pieneni. Mahdollisia ratkaisuja tulevien lisääntyneiden jäähdytystarpeiden vähentämiseen simuloitiin sen selvittämiseksi, vaikuttavatko ne jäähdytystarpeeseen. Tulokset osoittivat, että passiiviset jäähdytyksen lieventämisratkaisut vähensivät jäähdytysenergian tarvetta jossain määrin. Passiivisten jäähdytysratkaisujen takia lämmitysenergian tarve kuitenkin lisääntyi enemmän, mikä johti suurempaan kokonaisenergiantarpeeseen. Yhteenvetona tulokset osoittivat, että nykyisen Suomen rakennuslain 1010/2017 mukaiset koulutusrakennukset ovat riittävän varusteltuja kestämään tulevia lämpöaaltoja ja kohonneita ympäristön lämpötiloja.

Avainsanat Subarktinen ilmasto, energiatehokkuus, rakennusten energiasimulaatiot, IDA ICE, koulutusrakennukset
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Abstract

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Global warming is causing extreme weather phenomena resulting in a need to investigate the behaviour of buildings towards future changing weather conditions. A growing number of researchers have identified that subarctic climates, such as in Finland, will face increased ambient temperatures with prolonged and frequent heatwaves to a higher degree than the global average. This thesis was commissioned by the ILMARA project, which investigates the resilience of the built environment towards future climate changes in the Kanta-Häme area, Finland. The aim of this thesis was to investigate the effects of projected future climate conditions on the energy demand of the current building stock in the Kanta-Häme area. The HAMK Smart Bio building, built in 2024, was selected as a case-study. Simulations regarding future climate conditions were carried out using the IDA ICE software. The representative concentration pathways RCP4.5 and RCP8.5 for the test reference years TRY2030, TRY2050 and TRY2080 were selected for the future weather scenarios. The current weather scenario, TRY2020, was used as a comparison base, and subsequently the future weather scenarios were examined and compared to it for understanding how the energy demand will be changing in the future. The results showed that in all scenarios compared to the TRY2020 baseline, the overall cooling demand increased, while the heating demand decreased. Potential solutions for reducing future increased cooling needs were simulated to examine whether they would affect the cooling demand. The findings indicated that passive cooling mitigation solutions decreased the cooling energy demand to a certain extent. However, the heating energy demand increased more, resulting in an overall increased energy demand. In conclusion, the results showed that educational buildings that adhere to the current Finnish building code 1010/2017 are adequately equipped to face future heatwaves and increased ambient temperatures.

Keywords Subarctic climate, energy efficiency, building energy simulations, IDA ICE, educational buildings
Pages 46 pages

Table of Contents

Figures

Tables

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Abbreviations

AR	Assessment Report
BES	Building Energy Simulation
BEM	Building Energy Modelling
BPS	Building Performance Simulation
EU	European Union
EPC	Energy Performance Certificate
EPBD	Energy Performance of Buildings Directive
GCM	Global Climate Model
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
HVAC	Heating, Ventilating and Air-Conditioning
IDA ICE	IDA Indoor Climate and Energy
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard Organisation
LTRS	Long-Term Renovation Strategies
MVHR	Mechanical Ventilation system with Heat Recovery
NZEB	Nearly-Zero Energy Building
RCP	Representative Concentration Pathway
RF	Radiative Forcing
SYR	Synthesis Report
TRY	Test Reference Year
UN	United Nations
ZEB	Zero Emission Building

1 Introduction

The European Union (EU) highlights that *“buildings in the EU are responsible for 40% of energy consumption and 36% of greenhouse gas emissions, which mainly stem from construction, usage, renovation and demolition”* (EU, 2020a). The words consumption, use and demand related to energy are used interchangeable in this work.

Greenhouse gases (GHG) occur from any gas that absorbs infrared radiation emitted from the surface of the earth and reradiates it back again as net heat energy. Because of the high potential of the building sector to moderate energy use and reduce GHG emissions (Maduta et al., 2023a), the building sector has significant potential to impact the speed of the EU's GHG emission reduction target of 55% (compared to 1990 levels) to be reached by 2030 (EU, 2021) and climate neutrality by 2050 (EU, 2019).

The revised Energy Performance of Buildings Directive (EPBD) (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275) regarding building energy performance substantially contributes to this goal through its targeted policies. The directive emphasises:

- *“Buildings are responsible for greenhouse gas emissions before, during, and after their operational lifetime. The 2050 vision for a decarbonized building stock goes beyond the current focus on operational greenhouse gas emissions. The whole-lifecycle emissions of buildings should therefore progressively be considered, starting with new buildings"* (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275). Hence, a circular economy approach is now imperative in the built environment, both for new buildings and renovations. The end-of-life stage is of utmost importance for calculating the value of environmental impact caused by demolition and restoration (Siakas et al., 2023).

- “*Measures to improve further the energy performance of buildings should consider climatic conditions, including adaptation to climate change, local conditions, as well as the indoor climate and cost-effectiveness. Those measures should not affect other requirements concerning buildings, such as accessibility, fire safety, seismic safety and the intended use of the building"* (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275). The new HAMK Smart Bio building has been designed according to these requirements. This thesis will go a step further by simulating future weather stress on the building so that potential weaknesses can be identified at an early stage.

- “*The enhanced climate and energy ambition of the Union requires a new vision for buildings: the zero-emission building, with very low energy demand, zero on-site carbon emissions from fossil fuels, and zero or a very low amount of operational greenhouse gas emissions. All new buildings should be zero-emission buildings by 2030, and existing buildings should be transformed into zero-emission buildings by 2050”* (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275). The energy performance reference value (E-value) of the HAMK Smart Bio building is 81 $\text{kWh}_{\text{E}}/(\text{m}^2\cdot\text{a})$ in the energy performance certificate dated 16.10.2024, which classifies it as an A-Class building (Decree of the Ministry of the Environment on Energy Certificates for Buildings 1048/2017).

Energy policy and the energy efficiency of buildings need to be the main objectives for meeting the 2030 goals of Nearly-Zero Energy Buildings (NZEB) at the regional, national, and international levels (EU, 2020b). The main challenges for meeting the NZEB goal comprise the climate resilience of the built environment, increased requirements concerning building services (functionality, efficiency and safety) and thermal comfort levels, population growth, and increased time spent within buildings.

Each European Member State has the responsibility to support activities for the construction of NZEB. In order to meet these targets, an increasing number of countries have produced their own building aims and regulations to decrease their energy needs and energy consumption. One such example is Finland, that has created a national climate and energy strategy that aims at 60% reduction of GHG emission by 2030 and climate neutrality by 2035 (Carbon neutral Finland 2035, 2022) and the Finnish national building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017), which regulates requirements of new buildings, and which is used in this thesis.

Hirvonen et al. (2021) emphasised that in Finland totally 79% of buildings have been built before 2000, which means that they suffer from poorly insulated facades, lack of heat recovery (the process of regaining wasted heat), and dependence to a high degree on fossil energy. Taking this into consideration when trying to meet EUs energy targets diverse renovation scenarios have been developed, such as:

1. national level evaluations of power demands and GHG emissions of the entire building stock (Hirvonen et al., 2021);

2. city level district heating demand (Hietaharju et al., 2021);

3. energy demand of building level multi-department residential buildings (Doodoo et al., 2017);

4. detached houses (Hirvonen et al., 2020).

In 2021, a revision of the directive to move from the NZEB to Zero-Emission Buildings (ZEB) by 2030 was proposed by the commission (EU, 2020b), which also defined a zero-emission building as "*a building with a very high energy performance, with a very low amount of energy still required, fully covered by energy from renewable sources, and without on-site carbon emissions from fossil fuels*". According to the revised EPBD (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275) "*all new buildings should be zero-emission buildings by 2030, and existing buildings should be transformed into zero-emission buildings by 2050*".

Global warming, due to GHG emissions, is continuously causing changes to the climate, which is why reducing GHG emissions globally is an important and urgent matter. Temperatures are rising, particularly in the Arctic region, the rise being faster than the global average. Studies suggest that inadequate Arctic observation coverage may result in bias and eventual global warming underestimates (Ma et al., 2023). Nevertheless, the average temperature in Finland has risen by around two degrees since the 1880s according to Finland's environmental administration (Finland, 2024). In addition, very heavy rainfalls are a new phenomenon. The results of Rantanen et al. (2020) showed that the Arctic projects a four-fold warming ratio compared to the rest of the world during a time period of 1979–2021. This phenomenon is called Arctic amplification. Finland, with a subarctic climate is also warming to a considerable high degree. For example, Ruosteenoja & Jylhä (2023b) emphasize that for the period of 2040–2069 mean temperatures are projected to rise in Finland by 2,4°C in summer and 3,3°C in winter (under SSP2-4.5). Because of the increased temperature, several new weather phenomena occur, such as milder winters, longer and more frequent heat periods, heavy precipitation, longer and more intense drought periods, and rapid temperature fluctuations. These have a significant impact on nature and all living things.

In order to guarantee a future in which both people's well-being and climate goals are taken into consideration, it is necessary to develop ways to adapt to the alterations in the environment that have already taken place, and to future changes by creating and acting upon measures to curb the harmful impacts of climate change.

The research gap in this study can be considered contextual, since the built environment’s resilience to future climate change in the Kanta-Häme area, Finland, has not been investigated. This study aims to partially fill this gap by studying the impacts of the future climate change on the energy demand of a new contemporary smart educational building in the area.

The results of this thesis will bring new knowledge that can be used for planning the built environment in the Kanta-Häme area, but also for other comparable buildings in areas with similar climates.

Buildings are exposed to climate change and increased weather stress, leading to challenges regarding the energy-efficient implementation of heating and cooling. This study aims to investigate how the energy demand for heating and cooling is affected by a changing climate. The following research question arises:

- How are the different Representative Concentration Pathway (RCP) projections affecting the HAMK Smart Bio building?

The objective of this MSc thesis is to increase understanding and knowledge about the climate change impact regarding energy usage of an educational building in the Kanta-Häme area. This is done by investigating how future weather conditions may affect this particular building, and, subsequently, other existing similar buildings in the area. This study also investigates and proposes potential solutions regarding how this building can be adapted to future conditions.

To carry out this work, the design documentation of the educational building is examined, and a model is built in IDA ICE, where projections of future climate conditions are simulated to identify changes regarding energy use.

To examine the impact of future climate changes on this particular educational building and how it can be adapted to combat them, the following four issues have been identified:

1. What might the future climate in the Kanta-Häme area look like as a result of global temperature rise?

2. How does the increased future temperatures affect the energy use in this contemporary educational HAMK Smart Bio building?

3. How can the educational HAMK Smart Bio building be adapted to meet the increased temperatures of the future in terms of energy use?

4. How can the results of the simulations projecting the influences of future climate changes on the educational HAMK Smart Bio building be used for the built environment in the Kanta-Häme district in Finland?

In order to fit within the framework of a degree project, this study is concentrating on heating and cooling energy demand of the case building in current and future climate scenarios provided by the Finnish Meteorological Institute. The simulations are conducted without neighbouring buildings or vegetation.

The study is limited to the Kanta-Häme area for the Test Reference Years (TRY) TRY2020, TRY2030, TRY2050 and TRY2080. The IPCC's climate prediction scenarios RCP4.5 and RCP8.5 are used. The educational HAMK Smart Bio building investigated in the case study is located in the Kanta-Häme area in Finland. Finland is divided into four temperature zones, represented by weather observation stations located in Vantaa, Jokioinen, Jyväskylä and Sodankylä. The climate investigated in this study uses the Jokioinen observation station, which is the nearest station with projected future climate data supported by the Finnish Meteorological Institute.

The TRY2020 is compiled from observations over a 30-year period (1989–2018) and is used as current climate data (New weather datasets, 2020). The future periods are TRY2030 (2015–2044), TRY2050 (2035–2064), and TRY2080 (2065–2094).

Since the building is new there is no historical energy usage data for comparison and validation of results. We use the HAMK Smart Bio building issued Energy Performance Certificate for validation.

This thesis is organised as follows: in the introduction, a brief background of the subject is presented, followed by research gap, thesis objectives and scope of the study. In the following section, the related literature is introduced, starting with a short justification of climate change in general and in particular in the Nordic countries and Finland. The importance of climate change scenarios is emphasised for increasing understanding and awareness of forecasting potential future climate change and potential responses to combat it through effective mitigation and adaptation actions at an early stage. The "*representative concentration pathways*'' (RCP) are clarified, as is their use in different climate scenarios. Since the emphasis of this thesis is on energy efficiency in the building environment, building energy performance regulations are presented with an emphasis on European and Finnish regulations. Subsequently, energy simulations of buildings in general are presented. Section 3 shows how the building model in IDA ICE was created starting with the case study location and weather conditions, followed by a description of the case study, the contemporary educational HAMK Smart Bio building. In section 4 the results of the simulations are provided regarding the base model heating and cooling energy demand followed by two experiments to modify the base model of the building. Discussion, conclusions and further work complete the thesis.

2 Related Literature

In this section a detailed review of existing literature related to the topic of the thesis is presented. The first sub-section describes climate change, scenarios and RCPs, followed by building energy performance regulations, as well as energy performance and energy simulations of buildings.

2.1 Climate Change, Scenarios and RCPs

As a result of the 58th session of the United Nations (UN) in Switzerland in 2023, the Intergovernmental Panel on Climate Change (IPCC) created a Synthesis Report (SYR) concluding the 6th Assessment Report (AR6) (AR6 Synthesis Report: Climate Change 2023). The AR6 SYR outlines current evidence and knowledge regarding climate change, its prevalent risks and impacts, as well as needed mitigation and adaptation actions for diminishing the pace of climate change and its consequences for the eco-system and the human being. The AR6 SYR confirms that "*unsustainable and unequal energy and land use, as well as more than a century of burning fossil fuels have unequivocally caused global warming, with global surface temperature reaching 1,1°C above 1850–1900 in 2011–2020…This has led to widespread adverse impacts and related losses and damages to nature and people*" (IPCC, 2023a).

According to the Paris 2015 agreement (UN, 2015), the UN has set long-term goals to keep rise in global temperature under 1,5°C compared to 1850-1900 temperatures. The European Union's Copernicus Climate Change Service reported on 17th of July 2024 that global surface temperature reached / exceeded for 12 repeated months 1,5 °C above the 1850-1900 temperatures (Copernicus, 2024). This indicates that if we have not already surpassed the Paris agreement tipping points we are dangerously close to doing so. Also, the IPCC (2022b) report articulates that despite existing national efforts to decrease GHG, it is likely that during this century the temperature rise will be at a level of 1,5°C, with noticeable impacts of anthropogenic GHG on nature, eco-systems, and human systems (IPCC, 2022a).

Due to uncertainties and worries regarding future climate change and potential responses to combat it, climate modelling and the production of forecasts for future climate change are increasingly used. Knowledge and awareness regarding climate change and its effects on natural and human systems is necessary for understanding what proactive protective measures exist (O'Neill et al., 2016).

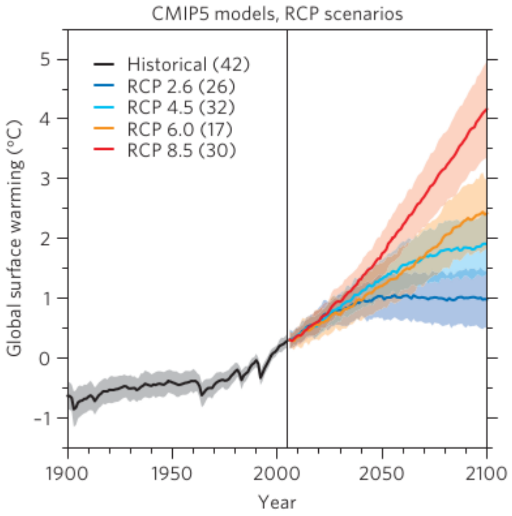
The IPCC acted as a catalyst for the development of various scenarios for future emission projections, which over the years have developed and become increasingly accurate. The use of future scenarios is essential for investigating the consequences that may occur depending on different responses to climate change (Moss et al., 2010) and for facilitating comparisons across diverse research outcomes. A central aspect of climate change analysis is approximations of future GHG emissions, aerosols, and other pollutants (Radiative Forcing of Climate Change, 2005).

Ruosteenoja & Jylhä (2023a) examined heatwave events in Europe at 0,5, 1,0, 1,5, and 2,0 ºC global warming levels by carrying out 60 simulations across 25 different global climate models (GCMs). Their findings show that "*we have to be prepared to adapt ourselves to at least the 2,0 ◦C global warming… under that warming level, the duration and extremity of European heatwaves increase substantially. In northern Europe, the average annual number of heatwave days is projected to become three to fourfold and the total annual heatwave extremity index is approximately fourfold*". These findings are pointing to the need for preparing and adapting to a 2,0°C global increase in temperature.

The Representative Concentration Pathways (RCP), consisting of different scenarios based on different assumptions regarding social development, were initially implemented in the Coupled Model Inter-comparison Project Phase 5 (CMIP5) (Moss et al., 2010; Taylor et al., 2012). In the IPCC’s 5th Assessment Report (AR5) published in 2014, climate change scenarios using RCP levels were universally endorsed.

Figure 1 visualises the increase in temperature in the future that can be expected based on CMIP5 and the different RCP scenarios. Historical data before 2005 (mean and one standard deviation shaded) are shown for comparison. In the parenthesis after the different RCP the number of models is shown. For the projection after year 2005 different colours highlight the differences in RCP scenarios showing the predicted global surface warming until year 2100.

Figure 1. Future global projections in temperature rise (Knutti & Sedlácek, 2012)



In the following phase, CMIP6 extended CMIP5 by developing additional climate change scenarios entitled Shared Socioeconomic Pathways (SSP). These complementary SSPs are based on projected global socioeconomic changes up to 2100. In this thesis we use climate scenarios based on RCPs as provided by the Finnish Meteorological Institute.

Scenarios based on RCP are denoted as RCPy, where ‘y’ refers to “*radiative forcing*” (RF) levels of 2,6, 4,5, 6,0, and 8,5 W/m² reached at the year 2100 (ICPP, 2023b, p. 562). The scenarios were created by taking specific changes in RF into consideration, which were established by diverse assumptions related to energy, emissions, and land use, such as rises in CO_2 concentration, temperature, and changes in precipitation (Calvin et al., 2019).

RF (measured in W/m²) is defined as “*measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, measured in* *watts per square meter*" (Wayne, 2013, p. 15) and is also described as "*the impact on the Earth's radiative balance*" (Clarke et al., 2009). RF is used for quantifying energy alterations in the atmosphere. It is a measure of additional heat captured due to influences on the atmosphere by air pollutants, such as GHGs created by, e.g., carbon dioxide, methane, aerosols, ozone etc. Hence, RF gives an indication of the significance of diverse forcing agents regarding climate change during a specific period (IPCC, 2013, p. 669; Bellouin et al., 2020).

The four most prominent RCPs are RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Calvin et al., 2019; Riahi et al., 2011; Thomson et al., 2011; van Vuuren, 2017) and described below:

RCP8.5: A high-emission scenario where high levels of carbon dioxide emissions continue to grow until they reach a three-fold higher level in the year 2100 than today. The technological and energy developments are modest, with a heavy dependence on fossil fuels. There is not any particular climate policy, which in turn leads to high energy demand and high GHG emissions.

RCP6.0: Radiative forcing at 6,0 W/m² soon after 2100 without overshoot. For reducing GHG emissions supporting strategies and technologies are utilised.

RCP4.5: Radiative forcing at 4,5 W/m² shortly after 2100, without overshooting the target level of radiative forcing. It is built on the notion that all countries undertake simultaneously effective emission mitigations covering all segments of the economy, such as emissions from agriculture and land use.

RCP2.6: Characterised by the most stringent climate policy actions where the Paris Agreement is fulfilled, and the use of fossil oil is reduced. The carbon dioxide concentration in the atmosphere culminates around year 2050 and is forecasted to be negative in 2100. For reaching these levels of radiative forcing, GHG emissions (and other air pollutants) need to be reduced radically, over time

2.2 Building Energy Performance Regulations

Kabansh et al. (2018) argue that "*heating, ventilating, and air-conditioning (HVAC)*" utilise the greatest proportion of energy in buildings, accounting for 50%. In extremely hot or cold climates, buildings' HVAC systems account for over 70% of the building's total energy consumption (Khoukhi et al., 2018). In 2023 Finnish households used 66,2% of the energy consumption for heating up spaces (Statistics Finland, 2024). Designers of today's buildings, in addition to innovative building components, also need to take into consideration the energy efficiency of buildings (Capozzoli et al., 2013).

Maduta et al. (2023a) assess the implementation degree of the EPBD (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275) requirements by the different EU member states. These requirements include long-term renovation strategies (LTRS), NZEB, EPC, and inspections of building systems. Despite the fact that they recognise many persisting challenges in the built environment, they suggest that the member states must increase their efforts towards achieving low emission buildings mainly through renovating the old building stock. Considering that 85% of the buildings in EU are built before year 2000 and 75% of them show poor energy performance (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275), emphasis should inevitably be put on renovations to reduce emissions.

Maduta et al. (2023a) postulate that different EPC methodologies in different EU countries, as was also confirmed by Salvala et al. (2015) and Sayfikar and Jenkins (2024), complicate comparisons. The revised EPBD (Directive of the European Parliament and of the Council on the Energy Performance of Buildings 2024/1275) suggests EPC harmonisation is necessary in order to enable improved comparability and reliability. It also supports member states by introducing enhanced requirements for decarbonisation of buildings.

Diverse indicators and criteria in the building code constitutes the standards and general conditions regarding the building sector. They have proven to be an "*effective policy tool*" regulating energy performance and decreasing energy use (Allard et al., 2021). However, national priorities and different national ambition levels influence the national indicators and measures used in the building code, and as a result, differences in the indicators can be found even within countries with similar climates (Salvala et al., 2015). Sayfikar & Jenkins (2024) report on the results of a Horizon-funded project that investigates the differences in Energy Performance Certificates (EPC) across Europe. The results of the comparisons show that there are considerable differences both in assessor qualifications and levels of standardisation.

Allard et al. (2021) distinguish between building code indicators and criteria. Indicators are "*parameters that are used to monitor the performance of a building component, e.g., U-value for windows (W/m² K) or the energy performance of a building as a system, e.g.,* *specific energy use kWh$_E$/(m^2·a)". Criteria are "the minimum/maximum required values for the indicators used for regulating building energy performance, e.g., a maximum specific energy use of 90 kWh$_E$/(m^2·a) and a maximum U-value for windows of 1,2 W/m^2 K"*.

In Finland, new building's energy performance is regulated by the Decree of the Ministry of the Environment on the Energy Performance of New Buildings (1010/2017) (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017).

2.3 Energy Performance and Energy Simulations of Buildings

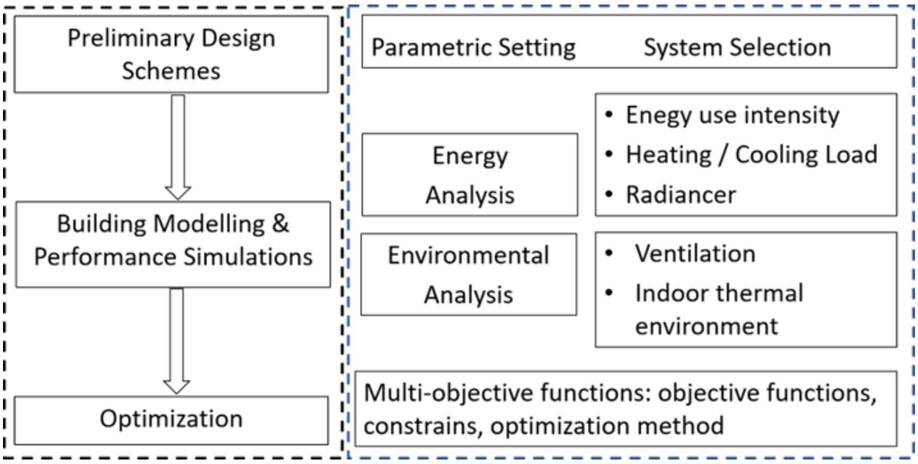
The revised EPBD (Directive of the European Parliament and of the Council on the energy performance of buildings 2024/1275) aims to increase the renovation percentage in the EU. According to the directive, 75% of the buildings in the EU are not energy efficient. The directive emphasises that *"measures to improve further the energy performance of buildings should take into account climatic conditions, including adaptation to climate change, local conditions, as well as the indoor climate and cost effectiveness".*

Nowadays, the emphasis on attaining sustainable buildings is on carbon mitigation, which strives for energy efficiency and improvements in the energy performance of buildings. Improvements in energy efficiency has proven to be a significant factor in decreasing energy consumption (Tsemekidi-Tzeiranaki et al., 2023). The achievement of energy efficiency in a cost-effective manner is, however, a considerable challenge, particularly in energy renovation projects (Dodoo et al., 2017).

The Finnish Ministry of Environment (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017 chapter 2, 4§) define that for building category 6 (educational buildings and day-cares) the E-value needs to be below 100 kWh$_E$/(m^2·a). In order to receive A-class certification educational buildings need to have an E-value below 90 kWh$_E$/(m^2·a).

Building performance simulation (BPS), with the reinforcement of building energy modelling (BEM) technology, has significantly contributed to carbon emission reduction and mitigation. Simulations are increasingly used to support the design of energy efficient new and retrofitted buildings, as well as system performance optimisations (Pan et al., 2023). BEM is used at various levels (building, system, and community) and stages (planning, design, operation). Figure 2 shows potential processes of a performance driven design.

Figure 2. A typical workflow of a performance driven design (Pan et al., 2022)



The left side within the dotted lines of the figure depicts the three main processes in performance driven design, and the right side depicts sub-processes. For example, building modelling is usually based on a prototype (new buildings) or on-site measures (existing buildings) aiming to reduce the building's heating and cooling demand, and its emissions.

Simulations with building energy simulation (BES) tools aim to support architects and construction engineers to evaluate and optimise building designs before construction. They also support improved decision-making resulting in more efficient and sustainable built environments.

BES tools, such as Energy Plus, IDA ICE, TRNSYS, Simulink libraries CarnotUIBK and ALMABuild, ModelicaDymola and DALEC etc., are increasingly used both in research and practice to predict energy performance of buildings (Magni et al., 2021). The different BES tools have different focus and level of detail. However, all of them promise high efficiency and high precision (Elhadad et al., 2020). For their model creation and analysis, they require detailed input regarding the building including complex building parameters (Chatzivasileiadi et al., 2018; Fonseca et al., 2018). Del Ama Gonzalo et al. (2023) emphasise that discrepancies ranging from 0,1% to 5,3% in annual results can be found among BES tools, because of non-identical inputs, misinterpretation of the building description, programming errors and different weather data processing (Magni et al. 2021).

Reducing building energy consumption is an important mitigation and adaptation action for reducing CO_2 emissions contributing to climate change. Pulkkinen et al. (2024) carried out simulations to study the impact of climate change in Finland on thermal performance on buildings. They used RCP climate scenarios from a short-term (2030), medium-term (2050) and long-term (2080) perspective. The calculations were performed according to directives of the European *“energy performance of buildings”* and data regarding future weather conditions available from the Finnish Meteorological Institute. Their results exhibit that *“in Finland in 2080, the reduction in heating demand will be higher than the growth in cooling demand, with a total decrease of 74,6 kWh/m² in thermal energy demand”*.

3 Building the Model

In this study we use IDA-ICE (developed by EQUA), a dynamic simulation tool, for modelling buildings and their climate control systems. It has mainly been created for studying energy and indoor climate performance of buildings by taking into consideration HVAC systems, envelope, plant and control strategies. The user interface is accessible, and the buildings can be investigated and studied in a 3D environment. Several predefined HVAC systems exist in IDA ICE, but also custom-made systems can be created. An important reason for choosing IDA ICE is that i) by selecting Finland as localisation, the parameters from the Finnish building code 1010/2017 are predefined and ii) IDA ICE uses dynamic simulation, as required by the Finnish building code for buildings with cooling net area greater than 50 m² or more than 10% of the building’s net area. It is an effective tool for studying annual thermal indoor climate and detailed energy consumption of an entire building. It can perform accurate simulations of current and future building behaviour according to weather and climate predictions and the building’s specific design parameters, such as building orientation, heating / cooling systems, construction materials etc.

Initially the IDA ICE building model in this study was created from the architectural .ifc file, but there were different issues with the model that prevented the creation of an adequate IDA ICE model. To overcome these issues the IDA ICE model was built based on the building AutoCAD drawings and design documentations, which requires that all the different structures need to be defined separately one by one. In addition, many of the materials included in the structures needed to be defined too, because they did not exist in the IDA ICE library. In section 3.3 some examples of such material creations are presented.

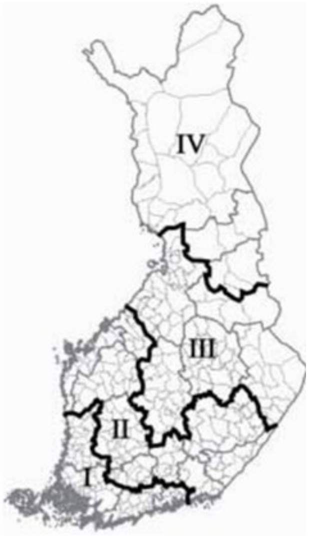
The RCP considered for the simulations of the HAMK Smart Bio building are RCP4.5 and RCP8.5. The RCP8.5 is the projection where humanity continues polluting in a similar pace as today without any particular technological developments or policy actions to minimise the emissions. The RCP4.5 is a middle ground scenario with the highest probability of materialising. TRY2020, TRY2030, TRY2050 and TRY2080 were used for the simulations.

3.1 The Kanta-Häme Region with Weather Conditions

In figure 3 we see the map of Finland with the Arctic circle and the city of Hämeenlinna (Kanta-Häme region), highlighted in red.

Figure 3. Map of Finland showing Arctic circle and Kanta-Häme region

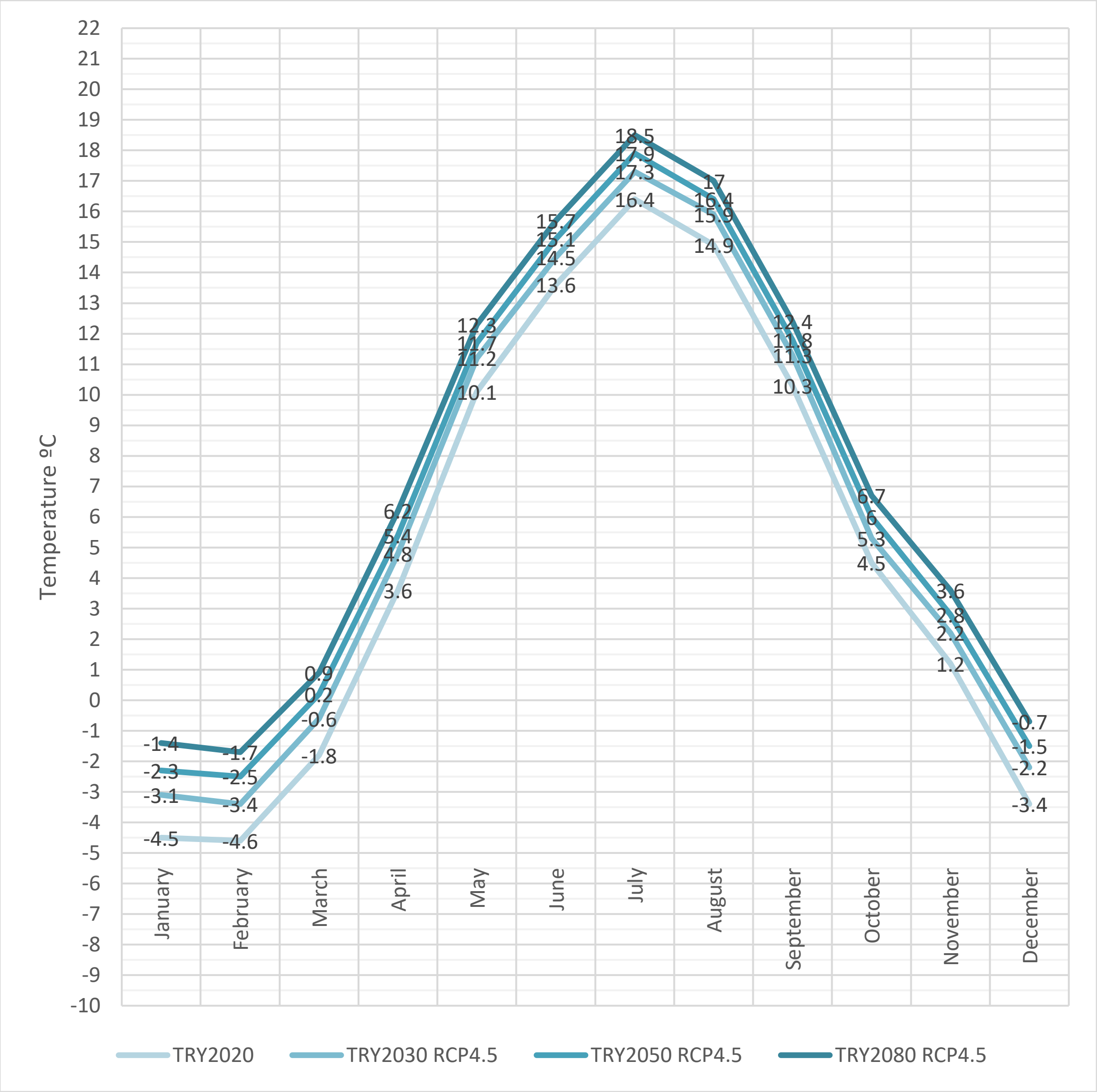
Figure 4. Map of Finland showing temperature zones (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017)



In figure 4 we can see Finland's four dimensioned outdoor temperature zones. The Kanta-Häme region belongs to temperature zone II. For zone II the calculation of the maximum heating power demand is calculated with dimensioned outdoor temperature of -29 °C. The Jokioinen observation station is used to project future climate for zone II, which includes the Kanta-Häme region, and is used in this study.

The data on average monthly temperatures in the Jokioinen observation station are shown in figure 5 for TRY2020 compared to RCP4.5 TRY2030, TRY2050 and TRY2080.

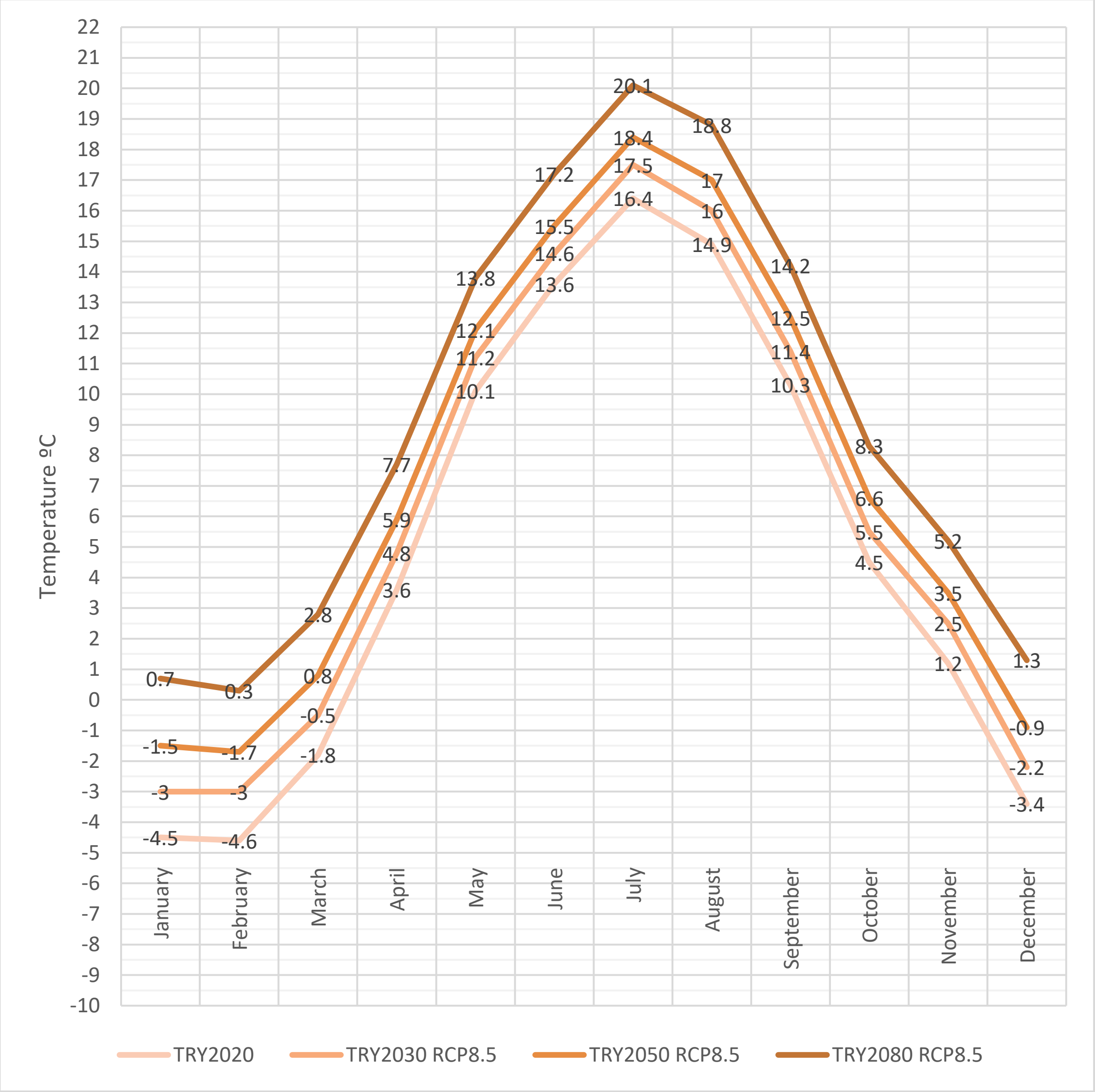
Figure 5. Monthly average temperature projections with RCP4.5



From figure 5 we can see that the average monthly temperature rises with every test reference year compared to TRY2020 by 0,5 - 1,5 ºC between the test years.

The data on average monthly temperatures in the Jokioinen observation station are shown in figure 6 for TRY2020 compared to RCP8.5 TRY2030, TRY2050 and TRY2080.

Figure 6. Monthly average temperature projections with RCP8.5



From figure 6 we can see that the average monthly temperature rises with every test reference year compared to TRY2020 by 1,0 - 2,5 ºC between the test years.

It should be observed that figures 5 and 6 show the average monthly temperatures. While the temperature peaks and heat waves are not shown, their increase in intensity and duration are directly proportional to the average temperature increments. For example, in 2024 the temperature in Finland was 3,4°C warmer than pre-industrial levels and higher than 25°C for 71 days (Blom, 2025).

3.2 The Case Building - The HAMK Smart Bio Building

In this section the case study for this thesis is described. The HAMK Smart Bio building was chosen as case study because it is a new contemporary educational building with advanced features and technical specifications that is expected to fulfil future requirements.

3.2.1 Building Description

Construction of the new educational and research building was completed in the middle of October 2024. The intended use of the building includes facilities for teaching, research and laboratories.

The building will host a degree programme in biotechnology, and food engineering, as well as activities of the smart-bio key ecosystem. Figure 7 shows a picture of the building taken in spring 2024.

Figure 7. The HAMK Smart Bio building on 09.04.2024

Figure 8. The HAMK Smart Bio building in Autumn 2024

The building height is 13m and consists of two floors and an attic, with a total net floor area of 2 156 m², measured from the master layouts. The building main construction material precast reinforced concrete. Figure 9 shows the HAMK Smart Bio building 3D view in IDA ICE

Figure 9. 3D view of the HAMK Smart Bio building in IDA ICE

Figure 9 shows the HAMK Smart Bio building 3D view in IDA ICE. In the right bottom corner, the direction of the building North-South can be seen.

Figure 10. The teaching laboratory 225, layout and built picture

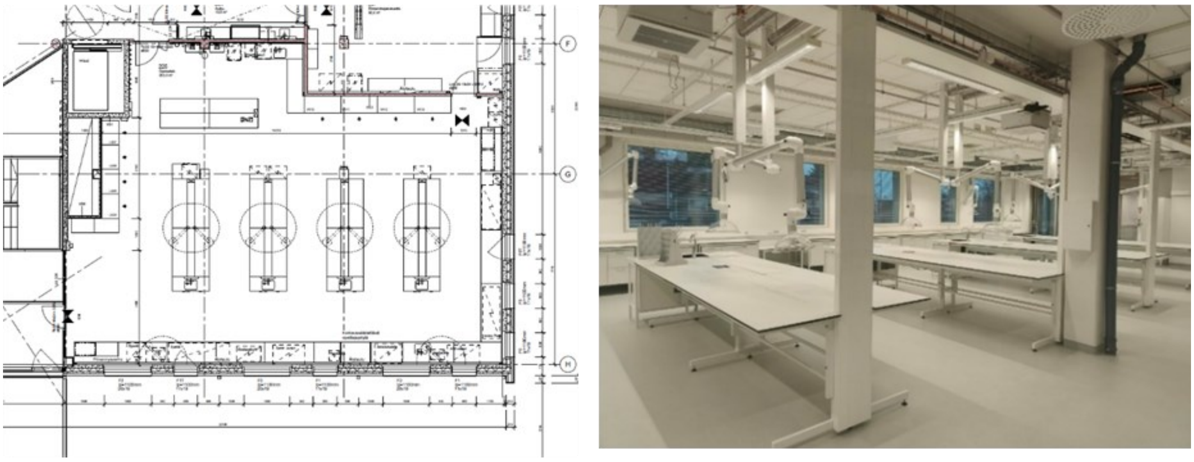
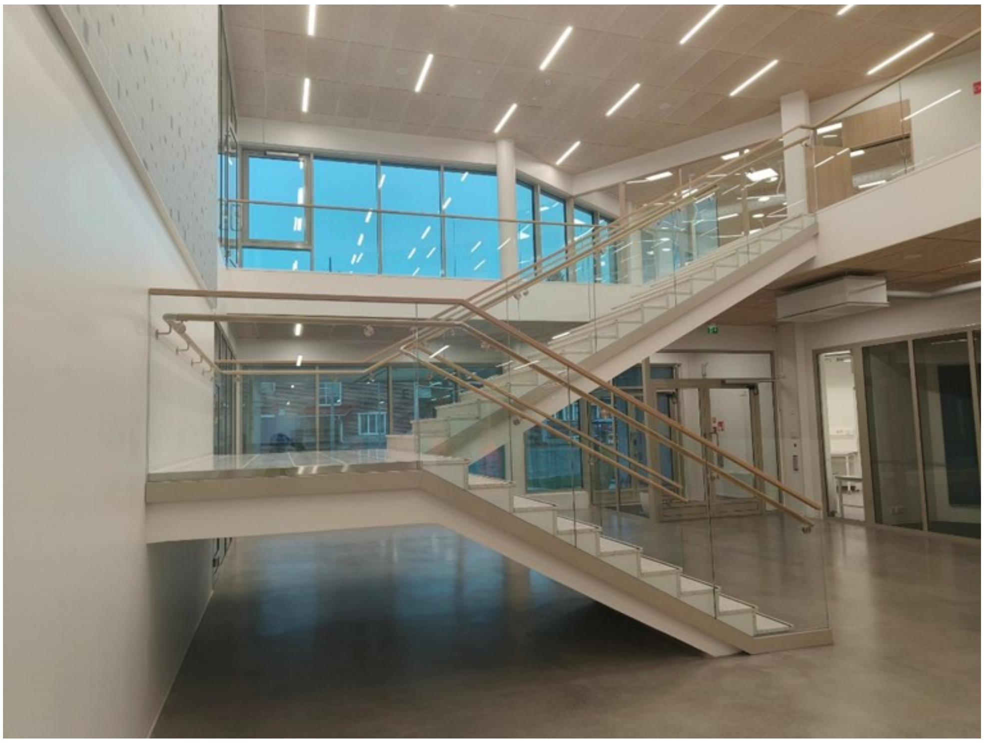


Figure 10 is an example from a room, namely the teaching laboratory 225. On the left side a layout of the laboratory room can be seen and on the right side a picture of the same space.

Figure 11. Picture of the Assemble Room / Lounge

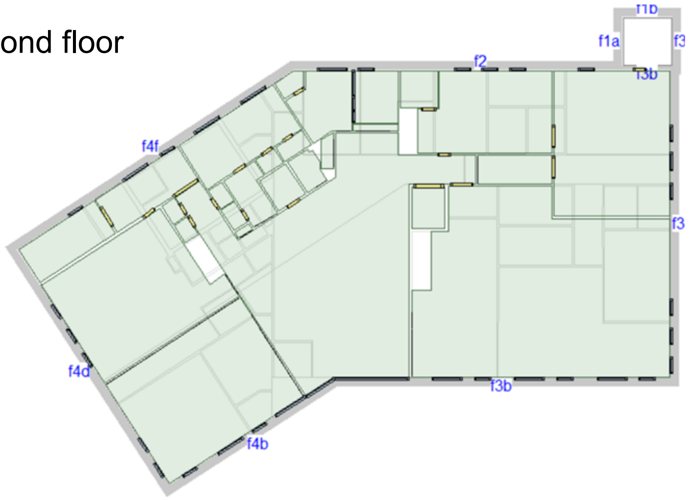


The picture shows the assemble room / lounge downstairs 102 and assemble room / lounge upstairs 202 that are connected with a staircase. The picture is taken from inside of the building towards the main entrance of the building towards the west direction.

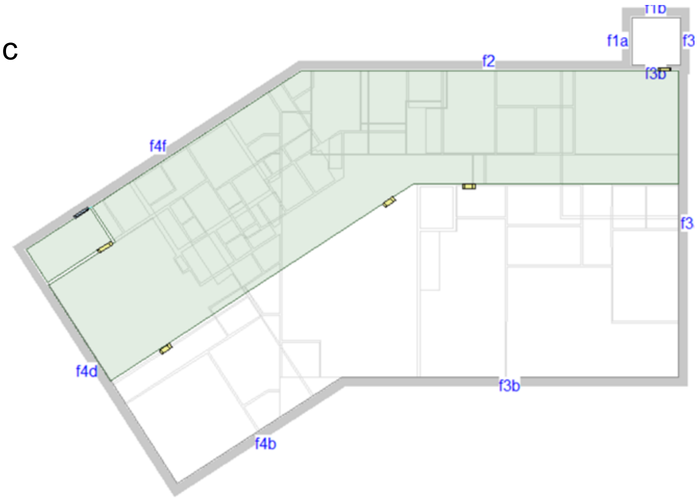
Figure 12. HAMK Smart Bio building plan views in IDA ICE

First Floor

Second floor



Attic



The building plan in figure 12 shows the different zones in light green.

3.2.2 Building Energy Performance Certificate

Energy performance requirements in Finland can be found in the regulations of the National Building Code (Decree of the Ministry of the Environment on Energy Certificates for Buildings 1048/2017). Since 1976 there are minimum requirements in Finland for thermal insulation and ventilation which are amended and enhanced when needed to improve the energy efficiency of buildings (Haakana et al., 2016).

The HAMK Smart Bio building received its energy performance certificate on 16.10.2024.

The building energy performance value (E-value) is 81 kWh$_E$/(m^2·a). In the Finnish building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017) educational buildings with E-value below 90 kWh$_E$/(m^2·a) are classified as A-Class buildings, hence the building is classified as an A-Class building.

The E-value of a building or part of a building kWh$_E$/(m^2·a) is calculated by multiplying the simulated energy consumption with an energy-form weighting factor divided by the building's net heated area.

The weighting factors are the following relevant to this study:

Electricity	1,2
District Heating	0,5

Table 1 shows a comparison between the simulated TRY2020 and the EPC issued 16.10.2024.

Table 1. Comparison of TRY2020 with EPC

	Unweighted energy demand		Weighted energy demand		
	Electrical kWh	District Heating kWh	Electrical kWh	District Heating kWh	E-Value kWh$_E$/(m^2·a)
Simulation TRY2020	115 788,30	95 181,50	138 945,96	47 590,75	86,52
EPC 16.10.2024	112 561,00	75 745,00	135 073,20	37 872,50	81,00

From table 1 we can see that the simulated E-value is 86,52 compared to the EPC E-value of 81. This means that the simulated value is 7% higher, but the building is still an A-class building. We decided that this is an acceptable difference.

The Finnish building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017 chapter 2, 9§) states that the E-value shall be calculated in accordance with the weather information for climate zone I described in Annex 1 of the building code. In this study we use zone II with climate data from Jokioinen observation station, the nearest station with projected future climate data supported by the Finnish Meteorological Institute. Using different climate zones are likely to cause discrepancy between calculated and in-situ energy efficiency of a building.

3.2.3 Envelope U-values

The U-value indicates the thermal transmittance through a material or combinations of materials, such as an external insulated wall that consists of different materials in different layers (Yu et al., 2024). The U-value is also known as a "*heat transfer coefficient*". The lower the U-value, the better the thermal insulation properties of the material.

The building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017) defines requirements for new buildings, such as u-values, based on regulations provided by the Ministry of the Environment, which in turn is accountable for implementing the EPBD in Finland (Haakana et al., 2016).

Table 2 shows the U-values of the envelope of the HAMK Smart Bio building.

Table 2. The building envelope U-values

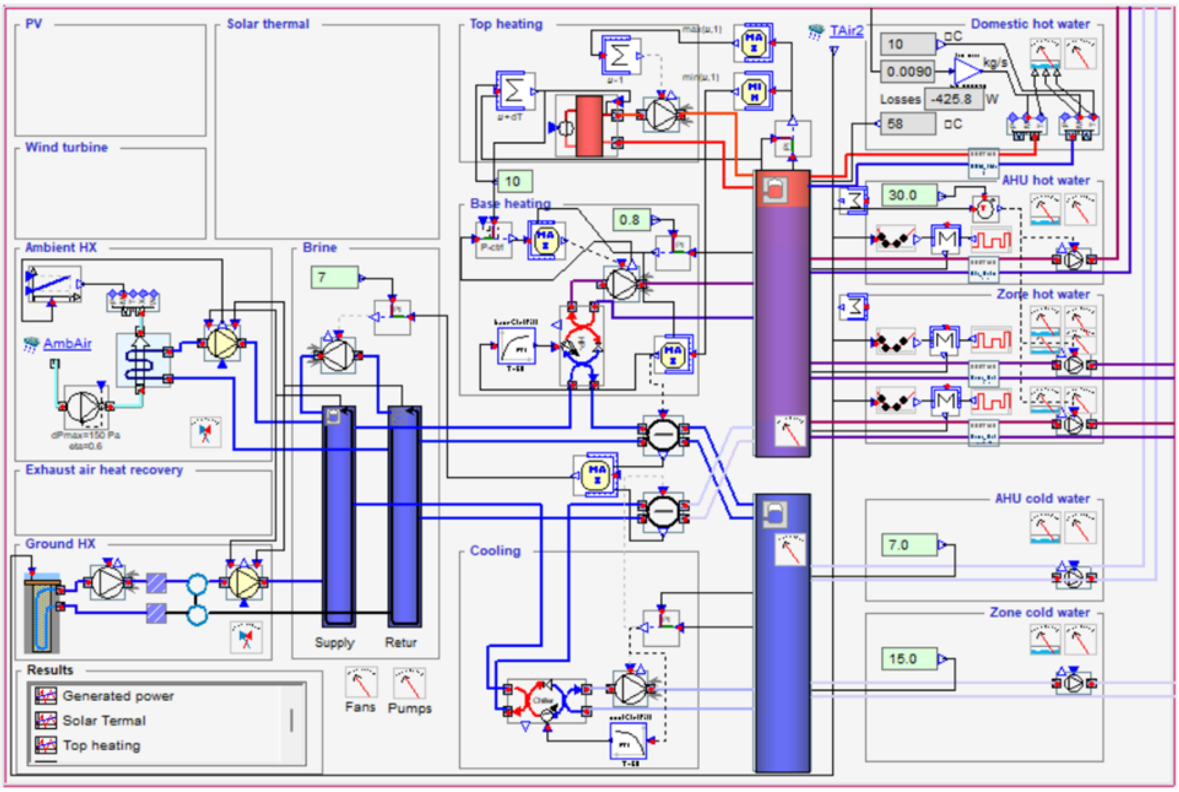
Building envelope parts	U-values W/m²K
External walls	0,16
Floor	0,16
Roof	0,09
Windows	0,80
Doors	1,00

The envelope U-values are defined according to the building design documents and are equivalent or better than the requirements by the Finnish building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017).

3.2.4 Building Plant

The building plant is depicted in figure 13. The heating system of the building consists of a ground source heat pump (GSHP) with 6 boreholes 330m deep and district heating (DS) as a top-up heat source used when needed. In addition, there is a heat pump connected to an ambient heat exchanger supplying the air handling units (AHU) cooling coils. Ground cooling is also utilized, with the ground source heat pump providing cooling to space specific fan coil units.

Figure 13. The building plant (IDA ICE)



3.2.5 The building's air handling units

Table 3 list the different rooms, their areas, their air flows (supply and exhaust), and the AHUs they are serviced by. The content of the table is assembled from the building design documents.

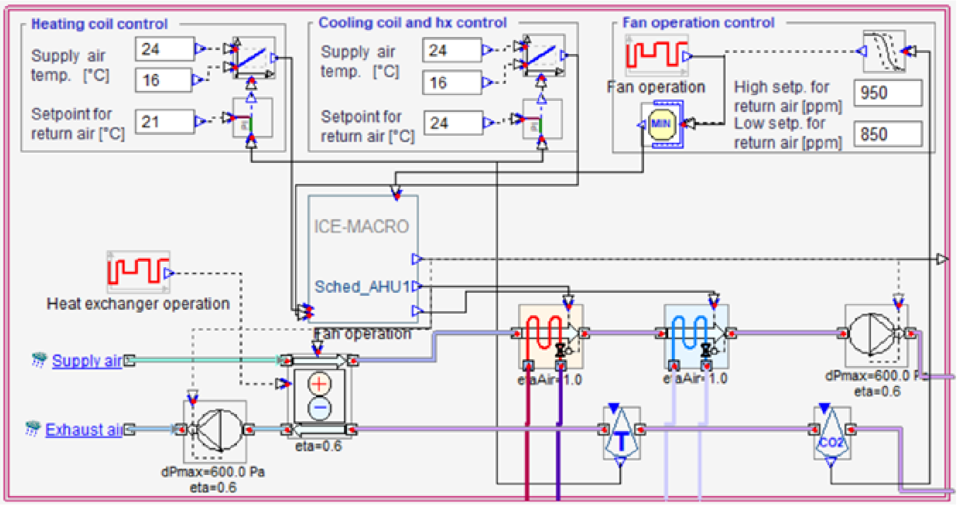
Table 3. HAMK Smart Bio building room names, areas, air flows and AHUs

Room name	Area, m²	Supply air, L/s	Exhaust air, L/s	AHU
100 Elevator shaft	7,4	0,0	30,2	AHU 6303 Socialising spaces
101 Air lock	6,6	0,0	0,0	No central AHU
102 Assemble room / Lounge	153,0	185,0	60,0	AHU 6303 Socialising spaces
103 Air lock	6,1	0,0	0,0	No central AHU
104 Disabled WC	8,0	0,0	20,0	AHU 6303 Socialising spaces
105 WC	3,0	0,0	20,0	AHU 6303 Socialising spaces
106 WC	2,6	0,0	20,0	AHU 6303 Socialising spaces
107 Meeting room	22,7	80,0	80,0	AHU 6303 Socialising spaces
108 LHJ - Plant room	20,1	15,0	95,2	AHU 6303 Socialising spaces
109 SPK - Electrical room	9,1	0,0	20,1	AHU 6303 Socialising spaces
110 Main cleaning room	8,0	0,0	30,0	AHU 6302 Clean labs
111 Corridor	41,6	90,0	0,0	AHU 6303 Socialising spaces
112 Grow room	21,3	80,0	80,0	AHU 6302 Clean labs
113 Storage / single use	9,1	0,0	20,6	AHU 6302 Clean labs
114 Freezer room	9,5	0,0	0,0	No central AHU
115 Microscope space	13,4	121,9	121,9	AHU 6302 Clean labs
116 Analysis lab	41,4	120,7	120,7	AHU 6302 Clean labs
117 Equipment maintenance space	14,6	130,0	149,9	AHU 6302 Clean labs
118 Storage glassware	14,6	0,0	20,0	AHU 6302 Clean labs
119 Bio processing lab	63,8	345,0	340,0	AHU 6302 Clean labs
120 Smart lab	73,5	360,0	360,0	AHU 6302 Clean labs
121 Smart workshops	29,4	80,5	80,5	AHU 6302 Clean labs
122 Cold storage room	7,4	0,0	0,0	No central AHU
123 Chemical storage	6,9	46,5	46,5	AHU 6302 Clean labs
130 Corridor	3,3	0,0	0,0	No central AHU
131 Dressing room	5,3	40,0	0,0	AHU 6301 Dirty labs
132 Shower	2,7	0,0	19,8	AHU 6301 Dirty labs
133 WC	2,0	0,0	19,7	AHU 6301 Dirty labs
134 Office	6,0	10,8	0,0	AHU 6301 Dirty labs
135 WC	2,0	0,0	19,7	AHU 6301 Dirty labs
136 Cold storage	7,2	0,0	0,0	No central AHU
137 Freezer room	7,8	30,0	30,0	AHU 6301 Dirty labs
138 Pantry	0,6	0,0	0,0	No central AHU
139 Bomb shelter / Storage room	40,2	20,0	20,0	AHU 6301 Dirty labs
140 Bomb shelter equipment room	4,5	0,0	0,0	No central AHU
141 Stairwell	24,2	30,0	0,0	AHU 6304 (enthalpy wheel)
142 Biorefinery space	91,6	360,2	360,2	AHU 6301 Dirty labs
143 Muffle room	20,8	80,9	60,7	AHU 6301 Dirty labs
144 Environment lab	43,6	280,0	280,0	AHU 6301 Dirty labs
145 Scale room	4,4	0,0	20,0	AHU 6301 Dirty labs
201 Assemble room / Lounge	178,7	119,7	29,9	AHU 6303 Socialising spaces
202 Assemble room / Lounge	19,0	40,1	0,0	AHU 6303 Socialising spaces
203 Stairwell	17,6	0,0	0,0	AHU 6304 (enthalpy wheel)
204 Safety	0,7	0,0	9,7	AHU 6303 Socialising spaces
205 Teaching space	83,0	250,0	250,0	AHU 6301 Dirty labs
206 Teaching space	90,8	270,0	270,0	AHU 6301 Dirty labs
207 WC	1,9	0,0	20,0	AHU 6303 Socialising spaces
208 WC	1,9	0,0	20,1	AHU 6303 Socialising spaces
209 WC	2,0	0,0	20,0	AHU 6303 Socialising spaces
210 HK-WC	2,2	0,0	20,0	AHU 6303 Socialising spaces
211 Disabled WC	6,1	0,0	20,0	AHU 6303 Socialising spaces
212 Pantry	1,8	0,0	10,0	AHU 6303 Socialising spaces
213 IT	2,3	0,0	9,7	AHU 6303 Socialising spaces
214 Dressing room	9,0	19,9	0,0	AHU 6303 Socialising spaces
215 Coffee room	28,8	100,0	116,0	AHU 6303 Socialising spaces
216 Phone booth	2,1	8,0	0,0	AHU 6303 Socialising spaces
217 Phone booth	3,0	8,0	0,0	AHU 6303 Socialising spaces
218 Workstation area	16,9	32,0	40,0	AHU 6303 Socialising spaces
219 Phone booth	2,6	8,0	0,0	AHU 6303 Socialising spaces
220 Office	11,5	14,9	14,9	AHU 6303 Socialising spaces
221 Storage	5,0	0,0	19,8	AHU 6303 Socialising spaces
225 Teaching lab	205,0	700,1	720,0	AHU 6302 Clean labs
226 Corridor	11,2	25,0	20,0	AHU 6302 Clean labs
227 Food processing space	81,2	335,0	340,0	AHU 6302 Clean labs
228 Fermentation labs	50,1	180,0	150,0	AHU 6302 Clean labs
229 Storage	6,9	0,0	19,9	AHU 6302 Clean labs
301 Stairwell	15,0	0,0	30,0	AHU 6304 (enthalpy wheel)
302 Ventilation equipment room	412,9	0,0	206,5	No central AHU

The building’s ventilation consists of four different air handling units (AHU). Three of them are equipped with cross plate heat recovery (AHU 6301 Dirty labs, AHU 6302 Clean labs, and AHU 6303 Socialising spaces) and one with heat recovery wheel (enthalpy wheel / AHU 6304 Staircase). All of them are equipped with variable air volume control (fans).

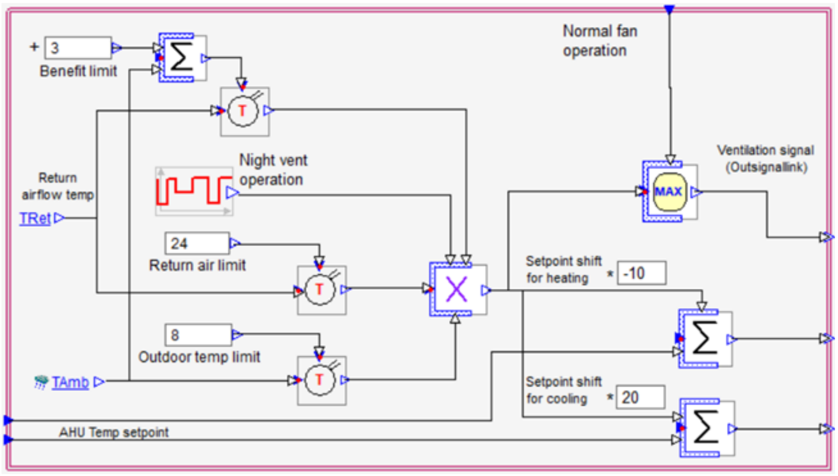
In table 3 we can see which AHUs service which rooms. Figure 14 shows an example of VAV type AHU in IDA ICE and figure 16 shows the enthalpy wheel AHU. In addition, the building has some special ventilation solutions for the laboratories, such as fume cupboards and fume trunks that are ventilated straight outdoors when needed. They are not included in the IDA ICE model.

Figure 14. VAV AHU (IDA ICE)



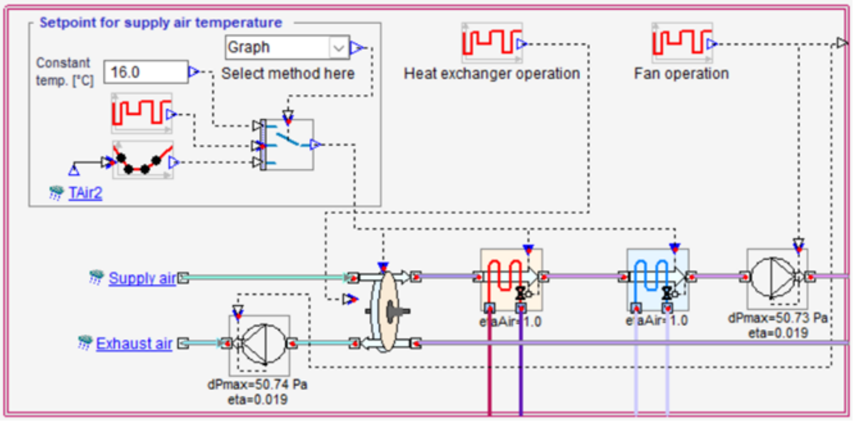
In figure 14 we can see in the top part of the figure the setpoints for temperature and CO_2 control. In the middle there is a box wit with the night ventilation control macro (ICE MACRO). This box is showed in figure 15 in more details. At the bottom of figure 14 we can see the AHU unit’s different components like the intake and exhaust ventilation funs, the air-to-air heat exchanger, the heating and cooling coils, as well as temperature and CO_2 sensors.

Figure 15. Night flush ventilation control (IDA ICE)



The night flush ventilation operates Monday to Friday from 1st if May until 30th of September between 00:00 and 07:00. In figure 15 we can see that the night flush ventilation will be on when the following conditions are all fulfilled: i) outdoor temperature is above 8°C, ii) outdoor air is at least 3°C below return air and iii) return air is above 24°C. While night flush ventilation is operating, the setpoint for the heating is lowered by 10°C and the cooling setpoint is raised by 20°C to avoid cooling or heating the night flush ventilation air.

Figure 16. Enthalpy wheel AHU (IDA ICE)

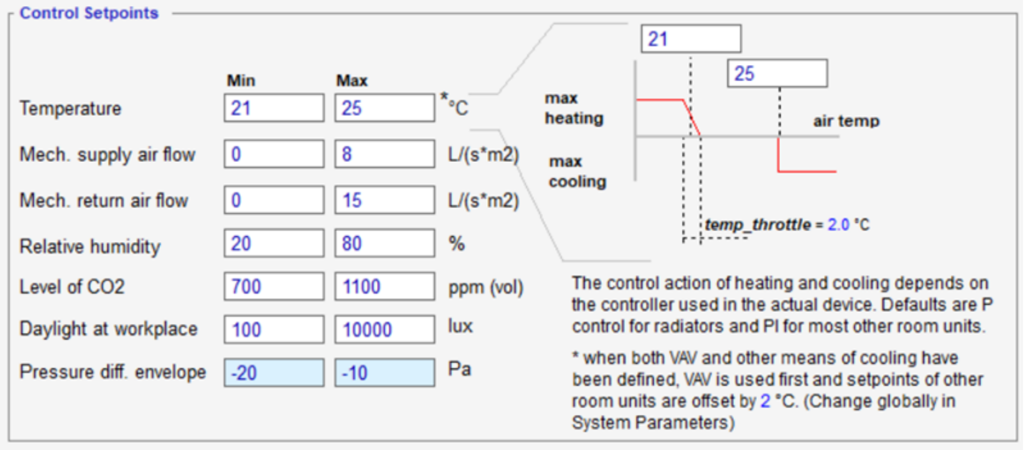


In the upper part of the figure 16 the setpoints for temperature control can be found. At the bottom we can see the AHU unit’s different components like the intake and exhaust ventilation funs, the enthalpy wheel heat exchanger, as well as the heating and cooling coils.

3.2.6 Zone controller setpoints

The set points for heating and cooling are provided by the Finnish building code 1010/2017 for conducting energy use calculations.

Figure 17. Zone controller setpoints (IDA ICE)



Control Setpoints

	Min	Max	
Temperature	21	25	*°C
Mech. supply air flow	0	8	L/(s*m2)
Mech. return air flow	0	15	L/(s*m2)
Relative humidity	20	80	%
Level of CO2	700	1100	ppm (vol)
Daylight at workplace	100	10000	lux
Pressure diff. envelope	-20	-10	Pa

temp_throttle = 2.0 °C

The control action of heating and cooling depends on the controller used in the actual device. Defaults are P control for radiators and PI for most other room units.

* when both VAV and other means of cooling have been defined, VAV is used first and setpoints of other room units are offset by 2 °C. (Change globally in System Parameters)

For educational buildings the setpoints for heating is 21°C and for cooling 25°C.

3.2.7 Zone heating and cooling units

The building is heated by hot water circulating from the plant to the floor heating of the zones. Zones 101 Air lock, 103 Air lock, 139 Bomb shelter/Storage room,141 Stairwell, and 302 Ventilation equipment room are heated by waterborne radiators. The cooling demand is handled by the plant’s GSHP that provides the zone fan coil units with chilled water. In addition, part of the heating and cooling demand is handled by the AHU units.

3.2.8 Internal gains

Heat generated within a building by lighting, equipment, and people are referred to as Internal gains. In this study, the internal gains are according to the Finnish building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017)

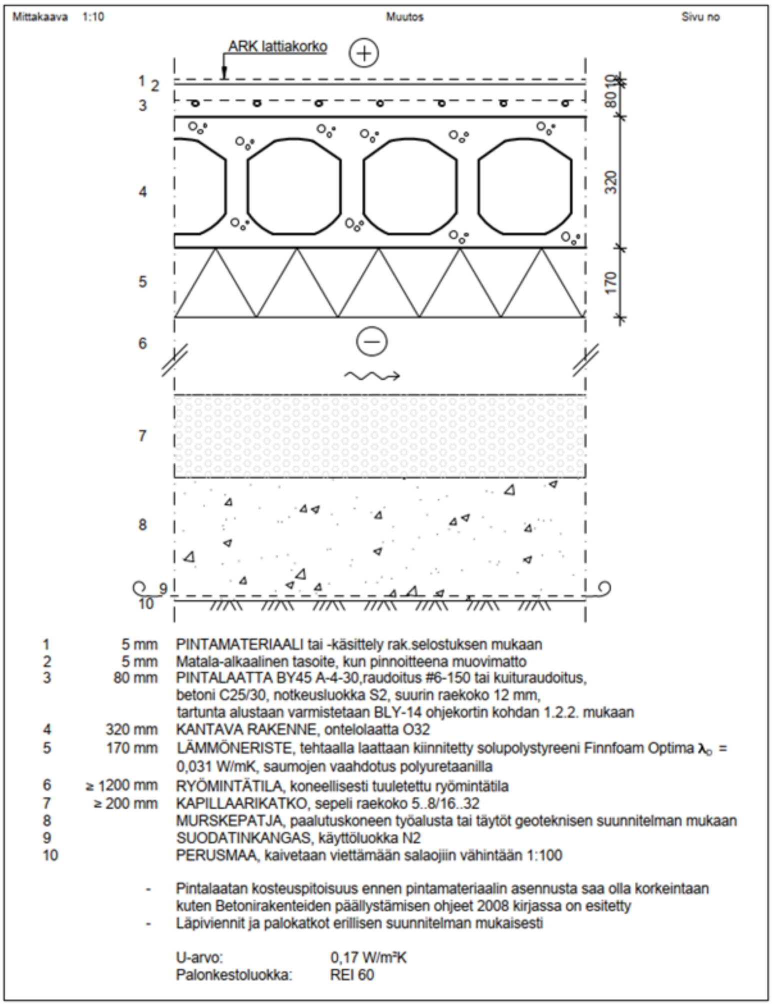
3.3 Material creation in IDA ICE

The building uses Hollow Concrete Slab O320 in some of the floor constructions as shown in figure 18. This type of material could not be found from the pre-defined materials in IDA ICE so it needed to be defined separately.

To define a material in IDA ICE the following parameters were used:
λ: Thermal conductivity W/(m K)
ρ: Density kg/m3
c: Specific heat J/(kg K)

The values used in IDA ICE for defining the O32 Hollow concrete slab are exacted from tables 4 and 5 (RAK/2657, 2022) and figures 19 and 20 show how it is created in IDA ICE.

Figure 18. Floor construction detailed including hollow concrete slab O320



1	5 mm	PINTAMATERIAALI tai -käsittely rak.selostuksen mukaan
2	5 mm	Matala-alkaalinen tasoite, kun pinnoitteena muovimatto
3	80 mm	PINTALAATTA BY45 A-4-30,raudoitus #6-150 tai kuituraudoitus, betoni C25/30, notkeusluokka S2, suurin raekoko 12 mm, tartunta alustaan varmistetaan BLY-14 ohjekortin kohdan 1.2.2. mukaan
4	320 mm	KANTAVA RAKENNE, ontelolaatta O32
5	170 mm	LÄMMÖNERISTE, tehtaalla laattaan kiinnitetty solupolystyreeni Finnfoam Optima λ_0 = 0,031 W/mK, saumojen vaahdotus polyuretaanilla
6	≥ 1200 mm	RYÖMINTÄTILA, koneellisesti tuuletettu ryömintätila
7	≥ 200 mm	KAPILLAARIKATKO, sepeli raekoko 5..8/16..32
8		MURSKEPATJA, paalutuskoneen työalusta tai täytöt geoteknisen suunnitelman mukaan
9		SUODATINKANGAS, käyttöluokka N2
10		PERUSMAA, kaivetaan viettämään salaojiin vähintään 1:100

- Pintalaatan kosteuspitoisuus ennen pintamateriaalin asennusta saa olla korkeintaan kuten Betonirakenteiden päällystämisen ohjeet 2008 kirjassa on esitetty
- Läpiviennit ja palokatkot erillisen suunnitelman mukaisesti

U-arvo: 0,17 W/m²K
Palonkestoluokka: REI 60

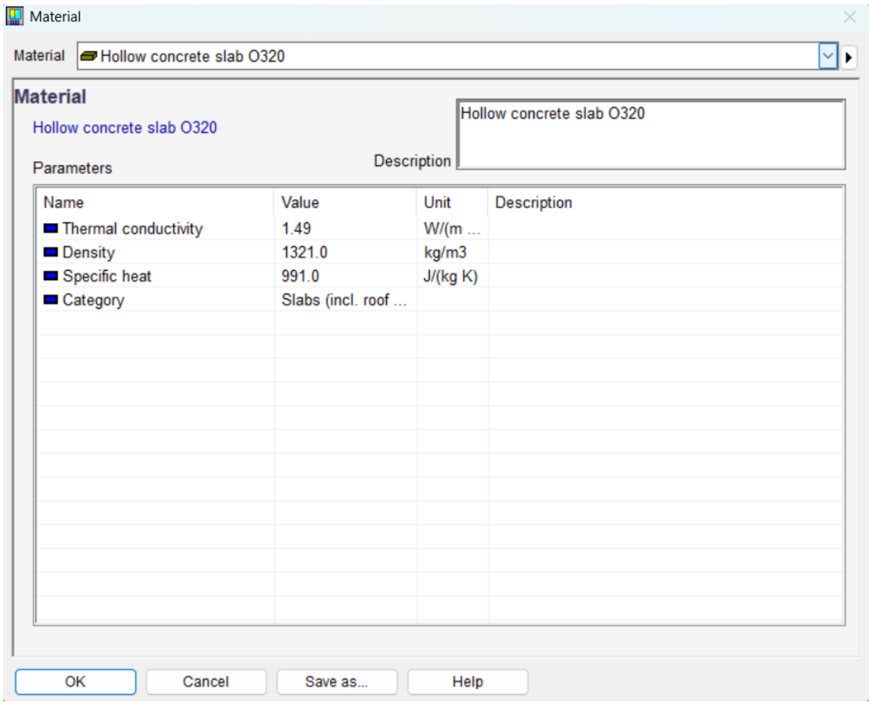
Table 4. Effective densities for hollow slabs (RAK/2657, 2022).

		Koko ontelolaatta		Keskiosa	
Ontelolaatta	Onteloiden osuus poikkileikkusalasta, %	$m_{OL,}$ kg/m^2	$P_{eff\ OL,}$ kg/m^3	$M_{ko,}$ kg/m^2	$P_{eff\ ko,}$ kg/m^3
020	44	277	1 385	77	642
027	42	382	1 442	182	984
032	47	423	**1 321**	223	928
037	44	517	1 396	317	1 091
040	54	458	1 146	258	808
050	51	608	1 215	408	970

Table 5. Effective thermo-technical material properties (RAK/2657, 2022).

Ontelolaatta	$\lambda_{eff,\ käsin,}$ W/(mK)	$R_{eff,\ käsin}$ m^{2}K/W	$C_{eff,\ käsin,}$ J/(kgK)
020	1,21	0,17	991
027	1,38	0,19	993
032	**1,49**	0,21	**991**
037	1,64	0,23	993
040	1,76	0,23	992
050	2,01	0,25	994

Figure 19. IDA ICE Dialogue for material data



Material

Material: Hollow concrete slab O320

Material

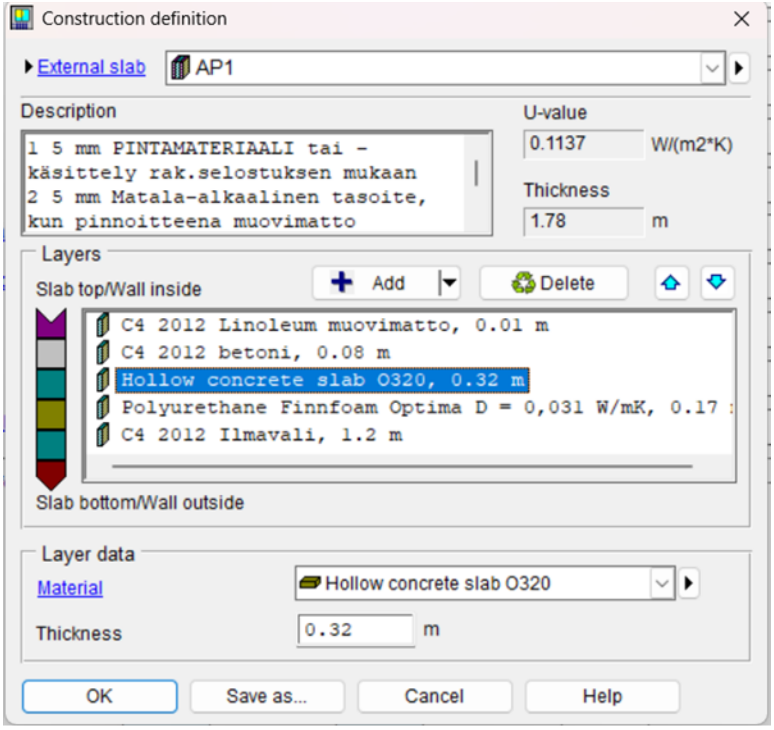
Hollow concrete slab O320

Description: Hollow concrete slab O320

Parameters

Name	Value	Unit	Description
Thermal conductivity	1.49	W/(m ...	
Density	1321.0	kg/m3	
Specific heat	991.0	J/(kg K)	
Category	Slabs (incl. roof ...		

Figure 20. IDA ICE Dialogue for construction type definition



Construction definition

External slab: AP1

Description

1 5 mm PINTAMATERIAALI tai –
käsittely rak.selostuksen mukaan
2 5 mm Matala-alkaalinen tasoite,
kun pinnoitteena muovimatto

U-value: 0.1137 W/(m2*K)

Thickness: 1.78 m

Layers

Slab top/Wall inside

- C4 2012 Linoleum muovimatto, 0.01 m
- C4 2012 betoni, 0.08 m
- Hollow concrete slab O320, 0.32 m
- Polyurethane Finnfoam Optima D = 0,031 W/mK, 0.17
- C4 2012 Ilmavali, 1.2 m

Slab bottom/Wall outside

Layer data

Material: Hollow concrete slab O320

Thickness: 0.32 m

4 Results

In this section the results from the simulations of the HAMK Smart Bio building with IDA ICE are presented. The building that is modelled according to the design documentation is simulated to examine the effects of current and future weather conditions on it.

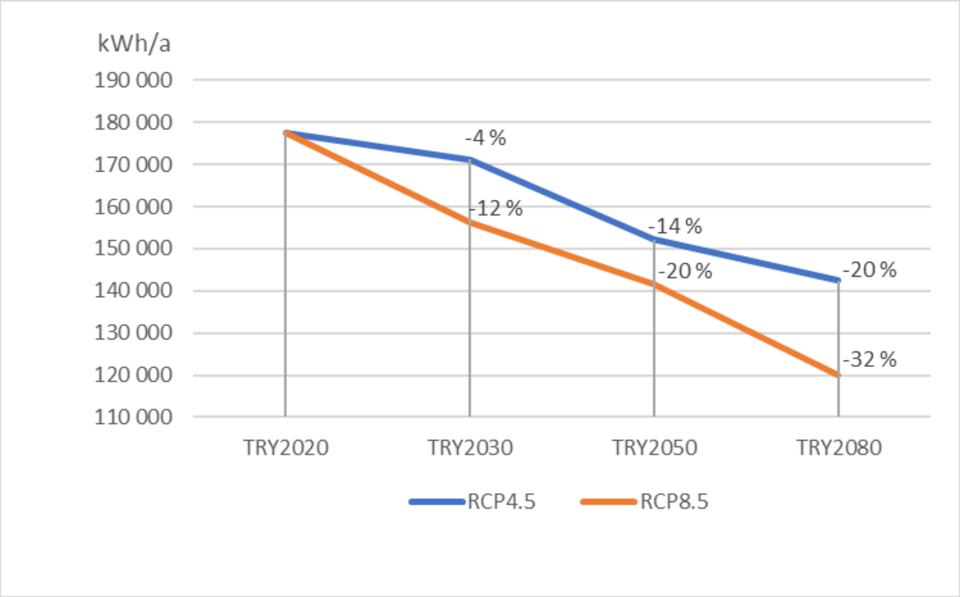
The simulation year TRY2020 corresponds to the current weather condition and is used as the base reference scenario to which the future weather scenario simulations based on RCP4.5 and RCP8.5 for TRY2030, TRY2050 and TRY2080 are compared.

The initial simulations test the building and compares the heating and cooling energy consumption changes.

4.1 Base model heating and cooling energy consumption

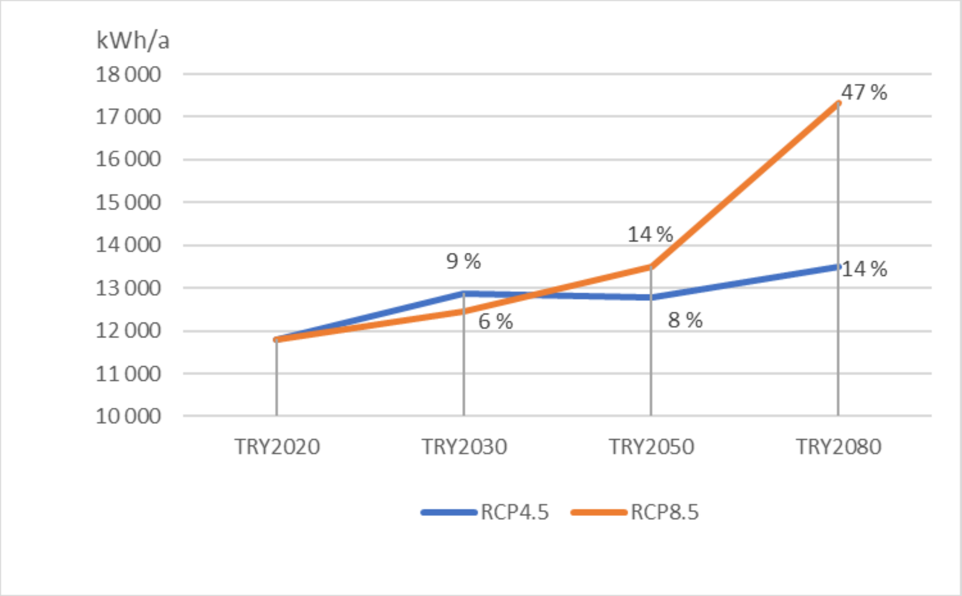
The results from the initial simulations show the changes in energy consumption for heating in figure 21 and for cooling in figure 22.

Figure 21. Heating energy consumption under RCP4.5 and RCP8.5



In figure 21 we can see that the heating energy consumption declines over time for both RCP scenarios. TRY2020, which is the starting point, has a heating energy consumption of 177 528 kWh. The results of the RCP8.5 scenario (orange colour line) show that the building's heating energy consumption declines rapidly in the future around 20 000 kWh between the different test years. The results of the RCP4.5 scenario (blue colour line) also show a decline in the heating energy consumption but at a slower pace. The heating energy consumption at TRY2080 for RCP4.5 is 142 454 kWh (-20%) and for RCP8.5 119 993 kWh (-32%).

Figure 22. Cooling energy consumption under RCP4.5 and RCP8.5



In figure 22 we can see that the cooling energy consumption increases over time for both RCP scenarios. It should be observed that the changes in cooling consumption is 10-fold smaller than for the heating energy consumption. TRY2020, which is the starting point, has a cooling energy consumption of 11 803 kWh. The results show the building's cooling energy consumption with the RCP8.5 scenario (orange colour line) increases slower than with the RCP4.5 scenario (blue colour line) until TRY2030. Between TRY2030 and TRY2050 the cooling energy consumption with the RCP4.5 scenario (blue colour line) declines marginally, while the cooling energy consumption with the RCP8.5 scenario (orange colour line) picks up speed and surpasses it. Between TRY2050 and TRY2080 the cooling energy consumption increases faster for both scenarios, with the cooling energy consumption for the RCP8.5 scenario (orange colour line) reaching 17 330 kWh (+47%) and with the RCP4.5 scenario (blue colour line) reaching 13 505 kWh (+14%).

The results above show how the building without any modifications will behave in future weather conditions. Although there is a moderate increase in cooling energy consumption, the significant future reductions of heating energy consumption result in an overall lower building energy consumption.

4.2 Modifications to the base model

The HAMK Smart Bio building showed good resilience to future climate changes with its energy consumption reducing as the climate is warming up. In general, we can say that new educational buildings following the current Finnish building code 1010/2017 will not be faced with future increased energy consumption. Despite the fact that the overall energy consumption is reducing the simulations showed that the cooling demand is increasing to some degree.

For this reason, we made some attempts to mitigate this increasing cooling demand, which we report on in the following sub-sections.

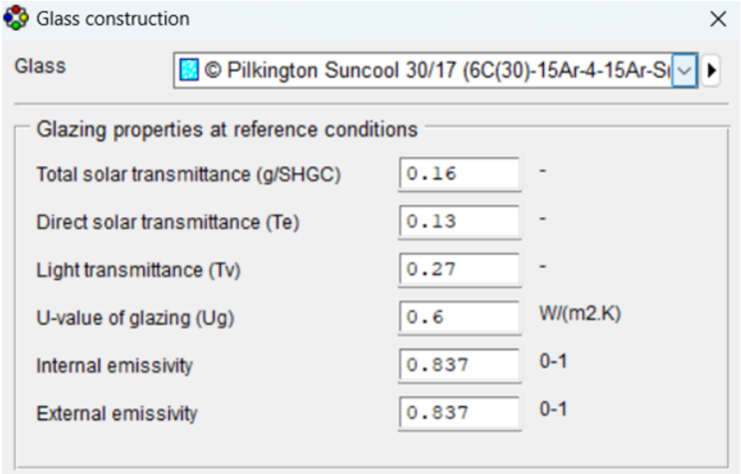
4.2.1 Windows with solar control glass

Passive cooling and its zero-emission nature is recommended by the EU (BUILD UP, 2024), because of its energy saving potential. It consists of cooling techniques that rely on natural heat gain control (e.g. shading and insulation) and natural heat dissipation techniques (e.g. thermal mass and passive ventilation). It is used for decreasing the need for conventional air-conditioning systems, which rely on external energy sources. Pereira et al. (2020) carried out a literature review regarding a particular passive solution, namely performance of solar control films (SCF) on building glazing. They found that glazing systems with SCFs were reported to promote cooling energy savings compared to clear glazing in hot climates and postulate that "*the evaluation of the performance of SCFs should also be carried out for temperate and cold climates*".

Solar radiation at high latitudes, such as in subarctic regions including Finland, comes at low solar angles during mornings and evenings with extended periods of daylight in the summers (Sukanen et al., 2024). This has a significant impact on building overheating and cooling demand. The low solar angles bring more solar radiation through the windows to the living spaces resulting in overheating of the affected spaces.

The HAMK Smart Bio building showed increased cooling demand in the future weather scenarios. To understand if passive cooling by solar control windows will bring satisfactory results we run simulation at TRY2020 and at TRY2080 RCP8.5 with Pilkington Suncool 30/17 glazing according to the parameters shown in figure 23.

Figure 23. Solar control glass with Pilkington Suncool



Glass: © Pilkington Suncool 30/17 (6C(30)-15Ar-4-15Ar-S

Glazing properties at reference conditions

Total solar transmittance (g/SHGC): 0.16 -

Direct solar transmittance (Te): 0.13 -

Light transmittance (Tv): 0.27 -

U-value of glazing (Ug): 0.6 W/(m2.K)

Internal emissivity: 0.837 0-1

External emissivity: 0.837 0-1

Two test cases were run, one with TRY2020 and one with RCP8.5 for TRY2080. The results are shown in table 6.

Table 6. Results of solar control glass

	Heating energy demand		Cooling energy demand		Total thermal energy demand	
	TRY2020	TRY2080 RCP8.5	TRY2020	TRY2080 RCP8.5	TRY2020	TRY2080 RCP8.5
Normal glazing kWh/a	177 528	119 993	11 804	17 329	189 331	137 332
Pilkington 30/17 kWh/a	178 856	120 955	11 749	16 444	190 605	137 400
Difference kWh/a	1 329	963	-55	-885	1 274	78
Difference %	0,7 %	0,8 %	-0,5 %	-5,1 %	0,7 %	0,1 %

As we can see in table 6 the heating demand increases with 1 329 kWh/a when using the Pilkington 30/17 glazing compared to normal glazing in TRY2020 (0,7% increase) and 963 kWh/a in TRY2080 RCP8.5 (0,8% increase).

The cooling demand is decreased with 55 kWh/a when using the Pilkington 30/17 glazing compared to normal glazing in TRY2020 (0,5% decrease) and 885 kWh/a in TRY2080 RCP8.5 (5,1% decrease).

Since the heating demand is around 10-fold higher than the cooling demand the total energy demand increases with 0,7% in TRY2020 and 0,1% in TRY2080 RCP8.5, which is the most extreme scenario. Based on the findings we conclude that using solar control glass in the case of the HAMK Smart Bio building for decreasing total energy demand is not feasible. The reason is that despite the fact that the cooling demand is decreasing in the summer, the heating demand in the winter increases more.

Similar results from Finnish climate were found by Sukanen et al. (2023) who conclude that different glazing types can be applied at both the design and retrofit stage, but may be expensive and may reduce winter solar gains. Also, Andersson & Larsson (2021, p. 46) modified a building by applying new windows designed to minimize solar heat gain. This resulted in better values in all rooms but increased energy consumption since "*the house loses the incoming solar heat during wintertime, making the demand for heating larger during the colder months than before, resulting in an increased total energy demand*".

4.2.2 Overheating control of a single zone

According to the Finnish building code (Decree of the Ministry of the Environment on the Energy Performance of the New Building 1010/2017) for educational buildings, overheating is calculated from 1st of June to 31st of August, when room temperature exceeds the upper limit of 25°C by more than 150 degree hours.

A zone is considered overheated when the temperature in the zone exceeds 25°C by more than 150 degree hours (the amount of °C degrees that exceed 25°C multiplied by the time it occurs in hours). E.g. 28°C for 2 hours is equivalent with 6 degree hours.

The simulations of the HAMK Smart Bio building with TRY2020, TRY2030 RCP4.5, TRY2050 RCP4.5, TRY2080 RCP4.5, TRY2030 RCP8.5, TRY2050 RCP8.5 showed that the building behaved good without overheating zones. Simulation with the TRY2080 RCP8.5, which is the most extreme weather scenario, had one overheated zone, namely room 145 (scale room), that overheated with 353,5 degree hours, which surpasses the limit of 150 degree hours.

In order to overcome the overheating issue in the zone we experimented with the following solutions:

1. We increased the return air flow for the zone from 20 l/s to 30 l/s.

   The overheating became 205,7 degree hours

2. We changed the window glazing of that room to Pilkington 30/17.

   The overheating became 56,1 degree hours indicating that the overheating problem is solved.

3. Combination of solution 1 and 2.

   The overheating became 24,4 degree hours.

From this experiment we conclude that overheating in certain zones can be controlled by particular solutions targeting that zone.

5 Discussion

The effects of the climate change are already visible to a high degree with extended and prolonged heatwaves and other extreme weather phenomena occurring more and more frequently. The warming climate has a bigger impact and shows a higher temperature increase in the arctic and subarctic climates than in the rest of the world. A potential solution proposed to combat future global warming is to reduce anthropogenic GHG emissions. The built environment is responsible for a substantial portion of these emissions, therefore recently studies are conducted regarding how to reduce these emissions, e.g. by minimizing energy usage and in particular energy coming from fossil fuels.

The standard for new buildings will be changed from "*nearly-zero energy buildings*" to "*zero-emission buildings*" in 2030. The energy efficiency measures today primarily target the decrease of the energy usage of the building's operation and the subsequent GHG emissions, and the emissions from the complete lifecycle of the building are not considered (Maduta et al., 2023b). The lifecycle of a building include design, production of materials that will be used, construction, use, and end-of-life. In the energy classification of buildings all stages of the building lifecycle should be included. In particularly, considering the end-of-life stage, which is totally neglected today, the cost of demolition and environmental restauration could be planned and calculated in forehand regarding emissions and who will finance the decommissioning.

In Finland, that has a subarctic climate, a future challenge will be how to mitigate the effects of hotter summers under climate change, in particular for existing buildings.

The questions that arose in the beginning of the study will be answered below:

1. What might the future climate in the Kanta-Häme area look like as a result of global temperature rise?

   In the Kanta-Häme area a warmer future climate is projected requiring less heating energy, however, summers will be hotter with many heatwaves requiring more cooling.

2. How does the increased future temperatures affect the energy use in this contemporary educational HAMK Smart Bio building?

   Our study showed that the heating energy consumption of the HAMK Smart Bio building will decrease, and the cooling energy consumption will increase. The total annual energy consumption will decrease because the cooling energy consumption increases less than the heating energy consumption is decreasing.

3. How can the educational HAMK Smart Bio building be adapted to meet the increased temperatures of the future in terms of energy use?

   The HAMK Smart Bio building has adequate building specifications according to the current Finnish building code 1010/2017 and does not need any specific adaption measure to meet the increased temperatures of the future in terms of energy use. In the future, however, the requirements of a building performance may change, such as the zero-emission goal at 2030 and 2050. This might change future adaption needs.

4. How can the results of the simulations projecting the influences of future climate changes on the educational HAMK Smart Bio building be used for the built environment in the Kanta-Häme district in Finland?

> The main results of this study revealed an increased cooling need in all future climate scenarios carried out. This means that the built environment in the Kanta-Häme area needs to prepare new and existing buildings to face more intensive, more prolonged and more frequent future heatwaves. The HAMK Smart Bio Building has cooling systems, but many existing buildings in the district will show significant overheating, in particular in rooms facing towards the south.

The results from this study showed how the HAMK Smart Bio building will behave in future weather conditions. The overall building energy consumption is reduced despite the increase in cooling energy consumption. This happens because of the significant reduction in heating energy consumption. Similar results from subarctic climates have been found by Farahani et al. (2024a; 2024b; 2024c; 2021); Pulkkinen et al. (2024); Sammeli (2022) and Sukanen et al. (2024). Hence, our results confirm that in subarctic climates, such as in Finland, the building cooling demand in the summers will increase, while the heating energy demand in the winter will decrease.

By following the current Finnish building code 1010/201, new buildings will be quite well equipped to meet the new weather challenges. For existing buildings, the increased cooling needs will be the main challenge. Passive measures are solutions promoted by the EU because their operation is free of cost and does not require any energy. The only costs are the installation costs, which however can be quite expensive depending on the solution selected. Examples of passive measures to heat gain control, are solar shading, insulation and natural heat dissipation techniques. Passive solutions, such as neighbouring deciduous trees are suitable solutions, since the leaves provide shadow in the summer and in the winter the leaves fall allowing for the needed heat radiance to reach the building, however, the height of the building needs to be considered.

Preparing to meet future climate changes, close cooperation between architects, construction engineers and energy specialists throughout the building design process is needed. Additionally, more attention needs to be given to the education of existing and future professionals of the building construction and renovation fields, regarding new solutions and rules that are promoting energy efficiency. Also, the continuation of the current research in the field is very important, as are policy measures for accelerating it.

Regarding the research question “*How are the different Representative Concentration Pathway (RCP) projections affecting the HAMK Smart Bio building?”* the answer is as follows.

The simulations of the HAMK Smart Bio building were carried out with TRY2020, as current weather projection, and future weather projections with RCP4.5 and RCP8.5 for TRY2030, TRY2050 and TRY2080.

The results showed that the heating energy consumption declined from TRY2020 in course of time for both the RCP4.5 and the RCP8.5 scenarios. The results of the RCP8.5 scenario showed that the building’s heating energy consumption declines rapidly in the future between the different test reference years. The building’s heating energy consumption with the RCP4.5 scenario also declines but at a slower pace.

The cooling energy consumption on the contrary increases in course of time for both the RCP4.5 and the RCP8.5 scenarios. The results of the RCP8.5 scenario show that the building’s cooling energy consumption increases slower than the RCP4.5 scenario until TRY2030. Between TRY2030 and TRY2050 the RCP4.5 scenario declines marginally, while the cooling consumption with the RCP8.5 scenario increases considerable and exceeds the RCP4.5 scenario. Between TRY2050 and TRY2080 the cooling energy consumption increases faster for both scenarios, with the cooling energy consumption with the RCP8.5 scenario showing considerable higher energy consumption than with the RCP4.5 scenario.

The results show that despite the fact that there is a moderate increase in cooling energy consumption, the significant future reductions of heating energy consumption result in an overall lower building energy consumption.

The results of this thesis bring new knowledge that can be used for planning the built environment in the Kanta-Häme area, but also for other comparable buildings in areas with similar climates.

6 Conclusion and Future Research

The aim of this study was to investigate the impact of future climate change on energy consumption of buildings in the Kanta-Häme area, Finland.

The built environment is responsible for a considerable share of environmental degradation. Because of this and corresponding to EU's GHG targets of 55% reduction compared to 1990 levels by 2030 and climate neutrality by 2050, the ILMARA project considers solutions that can reinforce climate resilience of the Kanta-Häme built environment. The current study was commissioned by the ILMARA project aimed to investigate the impact of future climate change on energy consumption of buildings in the area. The HAMK Smart Bio building, an educational building completed in Autumn 2024 with state-of-the-art technical systems, was selected as a case study.

The main results of this study confirmed earlier findings by Campagna & Friorito (2024), Farahani et al. (2024a; 2024b; 2024c; 2021); Pulkkinen et al. (2024); Sammeli (2022) and Sukanen et al. (2024), that global warming worldwide, but particularly in subarctic areas, such as Finland, leads to i) decreased heating consumption and ii) increased cooling consumption.

Since the passive cooling solution with solar control glass windows that we tested did not bring any improvements in energy demand, further work could include a deeper analysis of solar control glazing, that utilizes smart windows for dynamically adjusting incoming solar radiation aiming to reduce heating and cooling energy demands. There are different technologies being developed for smart windows, including electro-reflective and electro-thermo- mechano- photochromic smart windows.

In conclusion, the results showed that educational buildings that adhere to the current Finnish building code 1010/2017 are adequately equipped to face future heatwaves and increased ambient temperatures. For existing buildings (which are not relevant to the scope of this thesis), especially those lacking cooling systems, the increased cooling needs will be the main challenge requiring innovative energy-efficient, climate-friendly cooling solutions.

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