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Ventilative cooling for schools and kindergartens

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Submission date: June 2014
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NTNU
Norges teknisk-
naturvitenskapelige universitet

Institutt for energi- og prosessteknikk

EPT-M-2014-132

MASTEROPPGAVE

for

Student Yngvar Grimsbo Øgård

Våren 2014

Ventilasjonskjøling for barnehager og skoler
Ventilative cooling for schools and kindergartens

Bakgrunn og målsetting

Moderne bygninger som er meget godt isolert og med lave luftlekkasjer vil lett varmes opp så mye at det oppstår behov for kjøling. Dette skjer store deler av året.

Ved ventilasjonskjøling eller "Ventilative Cooling" anvendes ventilasjonsluft for å redusere eller eliminere behovet for mekanisk kjøling. Ventilative Cooling benytter kjølepotensialet som er i uteluften i samspill med bygningen. Luftens drivkraft kan være naturlig, mekanisk eller en kombinasjon av disse.

Løsningene kan anvendes både nye og renoverte bygninger.

Oppgaven innebærer simuleringer og målinger i bygninger som har ventilasjonsbasert kjøling.

Oppgaven er en videreføring av prosjektoppgaven gjennomført høsten 2013. I prosjektoppgaven ble det blant annet utarbeidet modeller i programmet IDA ICE av klasserom i en rehabilitert skole, hvor en løsning med motorstyrte vinduer benyttes til ventilasjon og klimatisering. I masteroppgaven føres arbeidet videre ved at det knyttes til en nyere lavenergi barnehage (Solstad barnehage i Larvik) som har en kombinasjon av mekanisk balansert ventilasjon og automatiske motorstyrte vinduer. Ventilasjonen gjennom vinduene brukes i hovedsak til kjøling.

Oppgaven er tilknyttet pågående forskningsaktiviteter ved SINTEF og NTNU: e-CONIIAQ og FME ZEB. Det er ønskelig at oppgaven skrives på engelsk.

Mål

Målet med oppgaven er å påvise om en løsning av den type som er brukt ved Solstad barnehage gir like godt eller bedre termisk og atmosfærisk inneklima med lavere energibruk enn konvensjonell mekanisk balansert ventilasjon. Kostnader ved løsningene skal også vurderes.

Oppgaven kan bearbeides ut fra følgende punkter

1. Det lages en plan for gjennomføring av oppgaven
2. Litteraturundersøkelse fra prosjektoppgaven videreføres/oppdateres
3. Innsamling av underlag og data fra Solstad barnehage
4. Lage modell for simulering av termisk inneklima, luftkvalitet og energibruk
5. Verifisere modellen
6. Utføre simuleringer og vurdere inneklima og energibruk ved Solstad barnehage
7. Vurdere hvor godt løsninger av denne type er egnet for barnehager og skoler i norsk klima

" - "

Senest 14 dager etter utlevering av oppgaven skal kandidaten levere/sende instituttet en detaljert fremdrift- og eventuelt forsøksplan for oppgaven til evaluering og eventuelt diskusjon med faglig ansvarlig/veiledere. Detaljer ved eventuell utførelse av dataprogrammer skal avtales nærmere i samråd med faglig ansvarlig.

Besvarelsen redigeres mest mulig som en forskningsrapport med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse etc. Ved utarbeidelsen av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelsen legges det stor vekt på at resultatene er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte, og at de er diskutert utførlig.

Alle benyttede kilder, også muntlige opplysninger, skal oppgis på fullstendig måte. For tidsskrifter og bøker oppgis forfatter, tittel, årgang, sidetall og eventuelt figurnummer.

Det forutsettes at kandidaten tar initiativ til og holder nødvendig kontakt med faglærer og veileder(e). Kandidaten skal rette seg etter de reglementer og retningslinjer som gjelder ved alle (andre) fagmiljøer som kandidaten har kontakt med gjennom sin utførelse av oppgaven, samt etter eventuelle pålegg fra Institutt for energi- og prosessteknikk.

Risikovurdering av kandidatens arbeid skal gjennomføres i henhold til instituttets prosedyrer. Risikovurderingen skal dokumenteres og inngå som del av besvarelsen. Hendelser relatert til kandidatens arbeid med uheldig innvirkning på helse, miljø eller sikkerhet, skal dokumenteres og inngå som en del av besvarelsen. Hvis dokumentasjonen på risikovurderingen utgjør veldig mange sider, leveres den fulle versjonen elektronisk til veileder og et utdrag inkluderes i besvarelsen.

I henhold til "Utfyllende regler til studieforskriften for teknologistudiet/sivilingeniørstudiet" ved NTNU § 20, forbeholder instituttet seg retten til å benytte alle resultater og data til undervisnings- og forskningsformål, samt til fremtidige publikasjoner.

Besvarelsen leveres digitalt i DAIM. Et faglig sammendrag med oppgavens tittel, kandidatens navn, veileders navn, årstall, instituttnavn, og NTNUs logo og navn, leveres til instituttet som en separat pdf-fil. Etter avtale leveres besvarelse og evt. annet materiale til veileder i digitalt format.

☐ Arbeid i laboratorium (vannkraftlaboratoriet, strømningsteknisk, varmeteknisk)
☒ Feltarbeid

NTNU, Institutt for energi- og prosessteknikk, 14. januar 2014

Olav Bolland
Instituttleder

Hans Martin Mathisen
Faglig ansvarlig/veileder

Medveileder(e):
Maria Justo Alonso

Preface

This thesis serves as the final assignment for a degree in energy and environmental civil engineering, and is considered a continuation of a previously conducted project study on ventilative cooling. The thesis revolves around an extensive case study of Solstad kindergarten in Larvik, Norway, and was conducted at the Department of Energy and Process Engineering (EPT) at the Norwegian University of Science and Technology (NTNU) in Trondheim during the spring of 2014. Main supervisor was Professor Hans Martin Mathisen, and research assistant Maria Justo Alonso served as co-supervisor.

I would like to thank my supervisors for their contribution towards the project in the form of useful input and ideas. I would also like to thank the architects at Pushak for providing me with necessary drawing of Solstad kindergarten, and civil engineer Arne Førland-Larsen, formerly of Energetica Design, for providing useful input data and information regarding the kindergarten. Special thanks to Arvid Bruflot, operation manager at Solstad kindergarten, for his substantial contributions towards the project, including providing crucial information as well as showing me around at Solstad, introducing me to the systems and the kindergarten in general.

12. Jun. 2014 Trondheim, Norway

Yngvar Grimsbo Øgård

Sammendrag

Ettersom bygningsindustrien strever mot å nå målet om nullenergihus, er nye og renoverte moderne bygninger utsatt for stadig strengere krav hva angår energieffektivitet og energiforbruk. Dette har resultert i godt isolerte og tette bygg som tilbyr reduserte varmebehov, men som til gjengeld har lett for å blir varmet opp i så stor grad at for å opprettholde et akseptabelt termisk inneklima, er fjerning av overskuddsvarme en nødvendighet. Dette blir ofte utført ved hjelp av mekanisk kjøling, men energiforbruket knyttet til mekanisk kjøling er ikke betraktet som forenelig med ønsket om å oppnå nullenergihus. Det er her ventilasjonskjøling kommer i spill.

Ventilasjonskjøling refererer til bruken av ventilasjonsluft for å redusere eller eliminere bruken av mekanisk kjøling. Dette er en teknikk som stadig øker i popularitet, og den er av mange betraktet som avgjørende dersom nullenergihus skal oppnås.

Denne oppgaven utforsker bruken av systemer for ventilasjonskjøling i skoler og barnehager gjennom et grundig studium av Solstad barnehage i Larvik, Norge. Barnehagen er utstyrt med et mixed-mode ventilasjonssystem som integrerer mekanisk balansert ventilasjon med naturlig ventilasjon fra motorstyrte vinduer. Hovedmålet er å evaluere ventilasjonsløsningen benyttet av Solstad som en helhet i forhold til både inneklima, energiforbruk og til en viss grad økonomi. For å evaluere dette, er løsningen hele tiden sammenlignet opp mot et konvensjonelt mekanisk ventilasjons system.

Som et verktøy i prosessen er inneklima- og energisimuleringer utført ved hjelp av simuleringsprogrammet IDA ICE. Undersøkelser av inneklimaet er utført ved hjelp av å se på innendørstemperatur og CO_2-nivåer som mål for termsik komfort og luftkvalitet.

Simuleringsresultater indikerer at en løsning lik den som er benytte i Solstad barnehage kan redusere det årlige energiforbruket med 14 % sammenlignet med en konvensjonell mekanisk løsning, noe som gjør den litt billigere i drift enn det mekaniske motstykket. Det er dog tenkelig at investerings- og vedlikeholdskostnandene for en mixed-mode løsning som denne er dyrere ettersom den består av to fullverdige ventilasjonssystemer som arbeider i samspill.

Alt i alt virker det som om løsningen til Solstad barnehage har små problemer med å tilfredsstille akseptabel luftkvalitet, i alle fall med tanke på CO_2-nivåer. Resultater angående det termiske klimaet viser at på ekstremt varme dager er det vanskelig å opprettholde akseptable temperaturnivåer uten mekanisk kjøling. For moderat sommerklima kan resultater tyde på at løsninge til Solstad gir et bedre inneklima med hensyn på innendørstemperatur samtidig som energiforbruket er redusert. Bakdelen er at denne løsningen også gir større temperaturintervaller i løpet av driftstiden.

Abstract

As the building industry strives towards the goal of ZEB (zero emission/energy buildings), new and refurbished modern day buildings have to relate to ever increasing standards regarding energy efficiency and energy consumption. This result in well insulated buildings with low air leakages offering reduced heating demands. One of the downsides of well insulated buildings is that they are easily warmed up to such a degree that in order to sustain an acceptable indoor climate, removal of excess heat becomes a necessity. Ridding the excess heat is often done through means of mechanical cooling, however, energy consumption for mechanical cooling is not considered compatible with the desire to achieve ZEB. Here, ventilative cooling comes in to play.

Ventilative cooling refers to the use of ventilation air in order to reduce or eliminate the need for mechanical cooling. The technique is increasingly gaining in popularity, and is by many considered crucial in realizing ZEB.

This thesis examines the application of ventilative cooling systems in schools and kindergartens through a thorough case study of Solstad kindergarten in Larvik, Norway. The kindergarten is fitted with a mixed-mode ventilation system integrating mechanically balanced ventilation with natural ventilation from motor controlled windows. The overall aim is to evaluate the ventilation solution applied at Solstad as a whole in regards to both indoor climate, energy consumption and to some degree economics. This is achieved by a comparison with a conventional mechanically balanced ventilation system.

As a tool in the process, indoor climate and energy simulations were performed utilizing the computer software, IDA ICE, and in order to investigate the indoor climate, indoor temperature and CO_2-levels were utilized as the defining measure in regards to thermal comfort and air quality.

Simulation result indicate that solutions like that present at Solstad could cut the annual energy consumption by as much as 14 % compared to a conventional solution, making the operation slightly cheaper than its all mechanical counterpart. However, it is thought that installation and maintenance of a mixed-mode system such as the one studied, is more expensive seeing that it consists of two separate, fully fledged systems working in combination. Overall, it seems that the Solstad solution have little problems in satisfying an acceptable air quality, at least not in regards to CO_2-levels. When looking at the thermal environment and indoor temperatures, it is found that for really warm days, it is hard to sustain acceptable temperatures without the use of mechanical cooling. However, for moderate summer climates, the Solstad solution looks to outperform that of conventional solutions in terms of temperature and energy consumption. The exception is that larger temperature spans are experienced during the hours of occupancy.

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Glossary

Name	***Description***
CAV	Constant air volume
clo	A measure for the thermal resistance between skin surface and outside clothing surface. 1 clo = $0.155 m^2K/W$
COP	Coefficient of performance
HVAC	Heating, ventilation, and air conditioning
met	Heat dissipation from a person per m^2 of body surface. Highly dependent on the activity level. 1 met = 58 W/m^2.
PMV	Predicted mean vote
PPD	Predicted percentage dissatisfied
ppm	Parts per million
SFP	Specific fan power [$kW/m^3/s$]
VAV	Variable air volume
ZEB	Zero emission/energy building

1 Introduction

As the building industry strive towards the goal of ZEB (zero emission/energy buildings), new and refurbished modern day buildings have to relate to ever increasing standards regarding energy efficiency and energy consumption. This result in well insulated buildings with low air leakages offering reduced heating demands. One of the downsides of well insulated buildings is that they are easily warmed up to such a degree that in order to sustain an acceptable indoor climate, removal of excess heat becomes a necessity. Ridding the excess heat is often done through means of mechanical cooling, however, energy consumption for mechanical cooling is not considered compatible with the desire to achieve ZEB. Therefore, smart integration of passive cooling measures in order to reduce, and preferably eliminate, the cooling demand is a much desired feature in modern buildings. One such cooling measure is ventilative cooling.

Ventilative cooling refers to the use of ventilation air in order to reduce or eliminate the need for mechanical cooling. The technique is increasingly gaining in popularity, and is by many considered crucial in realizing ZEB. [1] Ventilative cooling strategies can be applied through both mechanical and natural ventilation strategies, as well as a combination of these. In order for ventilative cooling to be effective while still achieving an acceptable thermal climate, the first step is to include measures that provide minimization of heat gains. Ventilative cooling should therefore be perceived as an integrated part of an overall system including solar protections, minimization of internal heat gains as well as intelligent use of thermal mass. [1]

This thesis examines the application of ventilative cooling systems in schools and kindergartens through a thorough case study of Solstad kindergarten in Larvik, Norway. Solstad kindergarten is a new low-energy building put into operation in January 2011. The kindergarten is fitted with a mixed-mode ventilation system integrating mechanically balanced ventilation with the cooling benefits of fresh outdoor air through motor controlled window ventilation. The overall aim is to evaluate the ventilation solution applied at Solstad in regards to indoor climate and energy consumption compared to that of a conventional mechanically balanced ventilation system, and assess whether solutions like the one applied at Solstad is suited for schools and kindergartens in Norwegian climate. Economic aspects are also taken into consideration.

One of the main tools utilized when examining the Solstad solution is a computer software called IDA ICE (IDA Indoor Climate and Energy). This is used extensively throughout the thesis in order to evaluate the indoor climate and energy consumption for both the actual solution as well as a building with the exact same geometry and user patterns, but with a conventional mechanically balanced ventilations system without operable windows. In order to make weighed reflections in regards to the overall aim, the scope of the thesis, besides climate and energy simulations, consist of a literature study on theory relevant for the case study as well as acquisition of relevant data and information on the kindergarten necessary to underline theory and create accurate simulation models.

Seeing that the thesis essentially revolves around the ventilation system present at Solstad kindergarten, the paper starts out with a section on relevant theory regarding ventilation systems in order to present an outline of, and understand some of the ideas behind, the Solstad solution. With the Solstad solution as a baseline, theory regarding indoor climate and ventilative cooling considered of interest when evaluating and understanding the mechanisms at play, mixed with literature on experiments and studies regarding technologies similar to that of Solstad, is presented, before truly directing the attention towards the simulation work conducted.

The thesis is associated with ongoing research activity at SINTEF and NTNU: e-CONIAAQ (Reduced energy consumption in buildings – impacts on indoor air quality), a collaborative research project by SINTEF and NTNU, as well as FME ZEB (Centre for environmental-friendly energy research: The research centre on zero emission buildings). It is also considered a part of IEA EBCs (the International Energy Agencys's Energy in Buildings and Communities Programme) upcoming Annex 62 on ventilative cooling.

2 Ventilation systems

A general description of the ventilation system present at Solstad kindergarten is considered a baseline for the paper. This section will first provide some theory on ventilation systems relevant to the Solstad solution before taking a more detailed look at the actual solution itself.

The primary objective of ventilation in a building is to sustain satisfying air quality and thermal comfort. Supply of fresh air and extraction of used air can happen by either mechanical or natural driving forces, or a combination of both, known as hybrid ventilation. [2] Where a natural ventilation system relies on natural driving forces created by buoyancy (stack effect) and wind, a mechanical system relies on electrically driven fans in order to create a driving pressure. [3] Figure 2.1 shows a naturally ventilated house to the left, and a mechanically balanced ventilated house to the right.

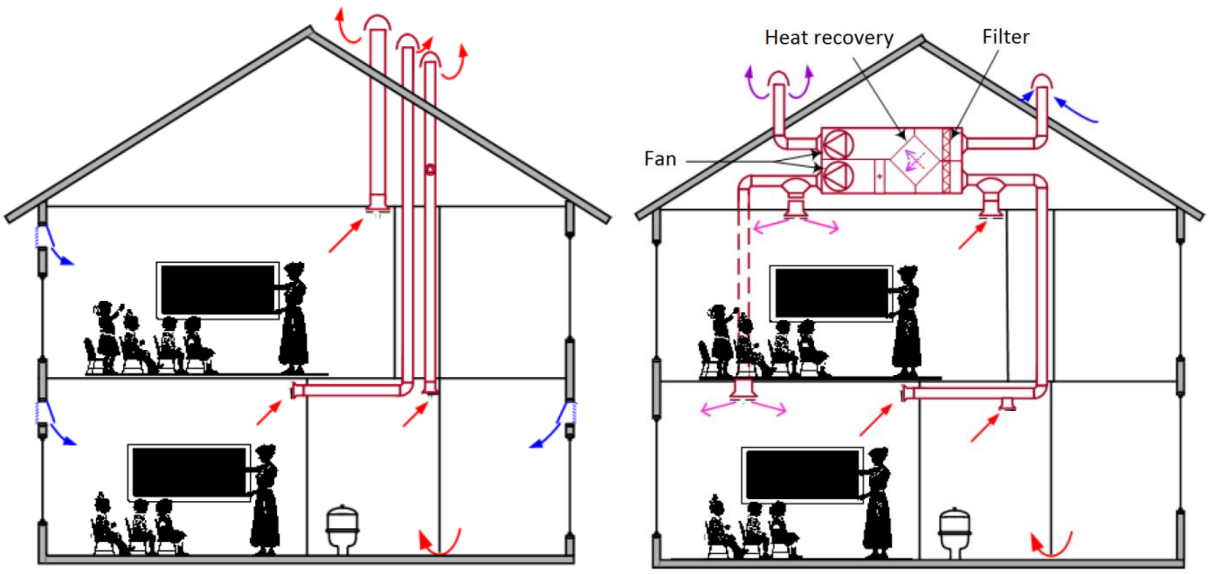


Figure 2.1: To the left, a sketch showing the principle of a natural ventilation system. To the right, a sketch showing the principle of mechanically balanced ventilation. From SINTEF and NTNU [3]

Both natural and mechanical ventilation has its advantages and disadvantages. A natural ventilation system is usually simpler and sturdier, thereby offering lower costs related to installation, operation and maintenance. It also typically offers greater degrees of user influence through operable vents and/or windows. However, natural systems are highly dependent on outdoor conditions resulting in less control of air flow rates which again may result in periodically poor air quality and thermal comfort. Also, in cold climates, large amounts of energy are required to heat the supply air, and the solution provides no practical opportunity for heat recovery. Mechanical ventilation on the other hand, has the advantage that it can supply a stable amount of filtered and tempered air relatively unaffected by climatic conditions outside as well as offering the option of heat recovery. [2]

Disadvantages of both conventional mechanical systems and natural ventilation have resulted in a compromise between the two types of system utilizing the advantages of each. Hybrid ventilation is a system aiming to provide a comfortable indoor environment utilizing a combination of both mechanical and natural ventilation. Different features of each system are utilized on different times of day or season or year. Mechanical and natural driving forces are combined in a two-mode system, and due to intelligent controls, hybrid ventilation switches automatically between natural and mechanical mode in order to minimize energy consumption. [4]

The ventilation system present at Solstad kindergarten can be categorized as a hybrid solution more commonly known as mixed-mode ventilation.

2.1 Mixed-mode ventilation

Mixed-mode ventilation refers to a hybrid ventilation approach combining natural ventilation from operable windows (manually and/or automatically controlled) or other passive inlet vents, with mechanical ventilation. [5] Systems of this nature are considered appropriate both in the design of new buildings, as well as the retrofit of ventilation systems into older naturally ventilated buildings. A well-designed mixed-mode building often includes advanced controls allowing zones to be naturally ventilated during periods of the day or year when it is feasible and desirable, and supplements with mechanical means when natural ventilation is not sufficient. [6]

Mixed-mode buildings are often classified in terms of their operation strategies. These are typically changeover-, concurrent- and zoned systems. [6] When characterizing the Solstad solution, a combination of changeover- and concurrent mixed-mode is considered most applicable, though there is some degree of zoned operation as well.

A changeover building periodically switches between natural and mechanical ventilation depending, for instance, on outdoor conditions. [6] Figure 2.2 illustrates a changeover mixed-mode system in mechanical mode. When set conditions are met, the mechanical system shuts down, and window ventilation takes over.

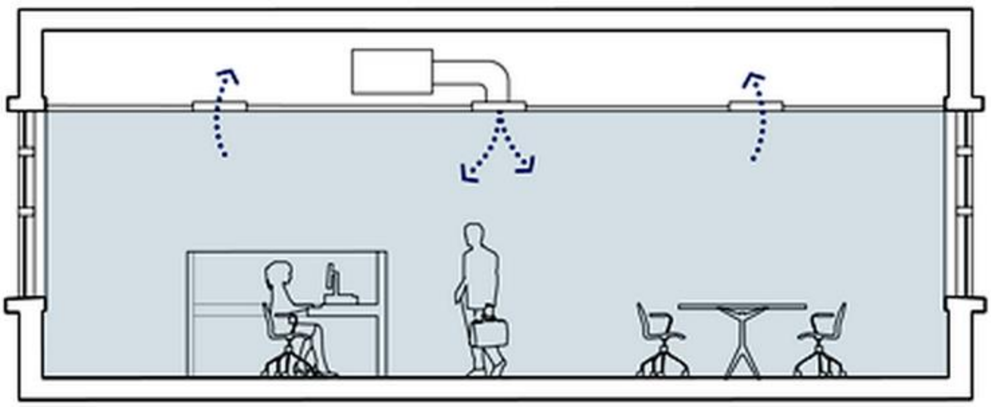


Figure 2.2: Example of a changeover mixed-mode system running in mechanical mode. From CBE. [7]

In a concurrent building, the mechanical and natural ventilation systems operate in the same space and at the same time. The mechanical system may serve as supplemental or background ventilation and cooling while occupants are free to open windows based on individual preferences. [6] Figure 2.3 illustrates an example of a concurrent mixed-mode system.

As for a zoned mixed-mode system, this refers to a solution where different zones within a building have different ventilation strategies. [6]

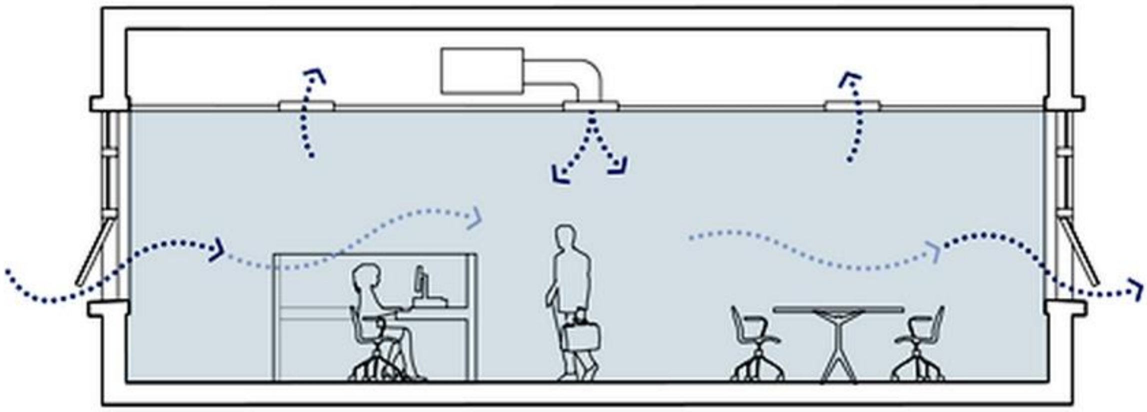


Figure 2.3: Example of a concurrent mixed-mode system. From CBE. [7]

Choosing a mixed-mode system offer some clear advantages compared to that of a traditional system. Firstly, if properly designed and operated, the system allows for decreased energy consumption as it can decrease or eliminate the need for mechanical cooling and ventilation throughout large portions of the year with subsequent reduction in pollution, greenhouse gas emissions and operating costs. [6] Secondly, as mixed-mode buildings often offer occupants higher degree of control over their local ventilation and thermal conditions through operable vents and windows, higher occupant satisfaction can be expected. Several studies have found that people are more tolerant to fluctuations in interior conditions when they are provided with some degree of personal control. [6] Thirdly, mixed-mode strategies can contribute to the mechanical system being redundant for large periods, which again result in potentially increased lifetime expectancy. [6]

On the other hand, mixed-mode strategies may be ill-suited in climates with very high humidity, or sites with high levels of outside noise or pollutants. [5] Also, mixed-mode buildings may require advanced and complex automatic and manual control strategies. [6] Another concern is that the potential for smoke migration in a commercial building designed to incorporate wind-driven or stack-driven ventilation may be unfavourable, and commercial buildings with operable windows might pose a threat in regards to security and occupant safety. [6]

2.1.1 Control strategies

In order to benefit from the advantages normally associated with mixed-mode ventilation, proper control and operation is crucial. There are several parameters used in order to control the ventilation operation in a building. Some examples are CO_2, temperatures, time and occupancy. In many cases, the air flow rate is controlled by more than one parameter in order to achieve both good air quality and thermal comfort.

Also important in mixed-mode ventilation and hybrid ventilation in general, is user influence. There are pros and cons with both fully automated systems and systems with higher degrees of personal control. While a complex automated system may provide the highest benefits in regards to energy consumption, it will risk the loss of occupant adaptability provided by higher degrees of personal control, and may also result in higher costs for installation and maintenance. [5]

Mixed-mode systems will typically have at least two different seasonal control schemes in order to satisfy demands. This is also the case at Solstad kindergarten.

During the winter season a building is in need of heating, and air is supplied in order to sustain satisfying air quality. Low air flow rates result in poor air quality whereas high air flow rates makes for increased energy use for heating. It is therefore necessary to control the air flow rates in a relatively strict manner in order to optimize between these two opposing requirements. [2]

During the summer season a building often has a cooling demand, and air is supplied in order to sustain acceptable thermal comfort. Optimization regarding energy usage is, in this case, of less importance because of increased outdoor temperatures. For situations where removal of excess heat is a necessity, user controlled ventilation is applicable, as a person can determine thermal conditions relatively good. [2]

Aside these, the transitional seasons in spring and autumn can pose problems as it is possible for a building to be in need of both heating and cooling in the same day. This can also require own advanced control strategies. [2]

It is the design of these strategies that determines at what point a changeover system alter between natural and mechanical ventilation, or determines the window ventilation to mechanical ventilation ratio in a concurrent system.

2.2 The Solstad solution

To better support upcoming theory, this section will provide an outline of the ventilation system present at Solstad kindergarten. More detailed descriptions of both the kindergarten itself and the control of the ventilation system will be explained in Chapter 5.

Solstad kindergarten is fitted with an intelligent ventilation system provided by WindowMaster A/S, a company specializing in indoor climate solutions benefitting from natural ventilation. [8] The solution at Solstad can be defined as a mixed-mode system combining motor controlled operable windows with balanced mechanical ventilation. Mechanical cooling is in no form provided to the kindergarten. There are in total five separate mechanical ventilation systems at Solstad, each consisting of supply- and exhaust air terminals, ductwork, and an air handling unit with exhaust air heat recovery and a heating coil. The mechanical system is highly demand controlled with the exception of bathrooms and locker rooms which is always provided with exhaust ventilation. The VAV operation of the mechanical systems is controlled by speed control of the fans and pressure sensors in the ducts.

Natural ventilation is performed as a combination of cross- and stack ventilation. There is a large common room called Agora, in the centre of the kindergarten, and air hatches connecting it to all the branches of the kindergarten. Agora has a fairly large ceiling height and operable windows placed at the top. This way, air is supplied in the branches and exits through the windows of Agora. This principle is shown in Figure 2.4.

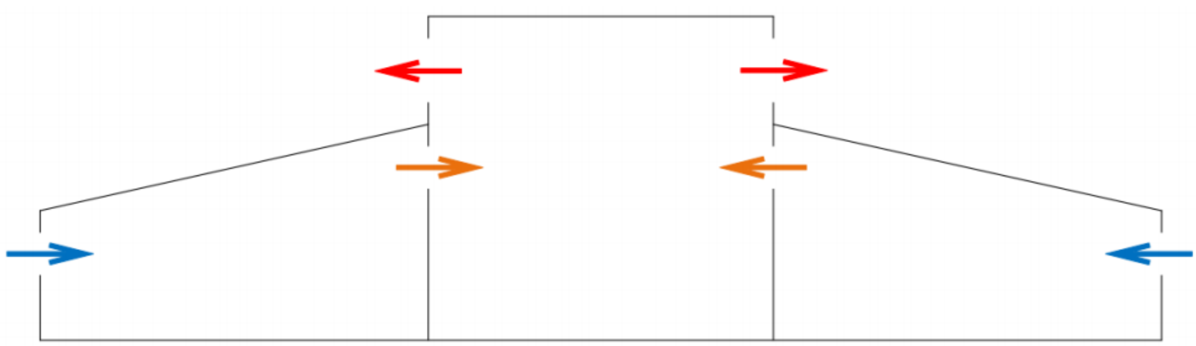


Figure 2.4: Sketch illustrating how air enters through windows in the branches (blue arrows), proceeds into Agora through air hatches (orange arrows), and exits through windows at the top of Agora (red arrows). From Vodsgaard [9]

The main control parameters for the system are indoor temperature and CO_2-levels. This means that indoor temperature is the defining measure on thermal comfort, and the level of CO_2 the defining measure regarding air quality. Indoor temperature is one of the most important parameters in relation to the indoor climate of a building, and is therefore often used as a control parameter for ventilation systems. Controlling only in regards to indoor temperature is however unusual as this will result in little or no air supply in periods with little cooling demands, again leading to poor indoor air quality. Therefore, CO_2-levels are also utilized as this can result in both acceptable thermal comfort and air quality being sustained at all times. [2] There are several guidelines providing recommendations regarding CO_2-values and indoor temperatures in commercial buildings. This will be further addressed in Chapter 3.

When earlier stating that the system could be described by both the changeover-, concurrent- and, to some degree, zoned mixed-mode system, this is entirely dependent on the operation and control strategies. The system mainly operates at two different seasonal strategies. During the summer season, sustaining thermal comfort is the main priority. This normally entails that there is little to no mechanical ventilation, and if the indoor temperature in a zone exceeds that of a set value, the operable windows connected to that zone will start to open and provide cooling. If, however, this set value is never exceeded and CO_2-levels in the zone rise above a relatively high set limit, mechanical ventilation will start. Cooling by night-time window ventilation is also a possible feature when in summer operation.

During the winter season, achieving satisfying air quality is the main priority. Direct fresh air supply from the windows during the cold season places large demand on the heating system and drastically increases energy consumption. Therefore, during winter season, window operation is limited. The mechanical system is controlled by a CO_2 set value that is lower than the setpoint for window operation. Window operation will therefore only occur when the mechanical system is insufficient in decreasing the CO_2-levels and the indoor temperature is higher than a set value. Also, during the winter season, the maximum degree of window opening is restricted.

Though indoor temperature and CO_2 are the main control parameters there are other factors taken into consideration. For instance, the automatic switch from summer to winter operation occurs when the average outdoor temperature through the course of a day is lower that a set value. Wind speed, wind direction and precipitation also contribute to limit the maximum degree of window opening in order to prevent material damage and over ventilation as a result of high wind speeds and driving rain. Another aspect of the window operation is that the control schemes are designed to have short periods of fresh air supply on a timed basis.

Only a portion of all windows at Solstad kindergarten are operable. In total, the kindergarten consists of 54 motor controlled windows in different shapes and sizes. The system is highly user influenced, and the larger portion of all windows can be manually overridden by the occupants through switches placed in the zones. If manually overridden, it will stay at set position for 30 minutes before resuming automatic operation. Figure 2.5 shows a detail photo of one of the motor controlled windows.

Figure 2.5: Detail photo of one of the motor controlled windows at Solstad kindergarten.

When summarizing the system, though complex, it basically has a changeover from an all mechanical system to a natural system when going from winter to summer operation. However, it will operate as a concurrent system during periods throughout both seasons. Though the system is the same for all zones, it can still operate differently due to differences in zone conditions, and therefore could be partly described as zoned mixed-mode as well.

In order to have a comparable counterpart when later performing simulations on indoor climate and energy consumption for the Solstad solution, the exact same building, but with what is referred to as a “conventional” ventilation system, is utilized. The conventional solution refers to a system with mechanically balanced demand controlled ventilation controlled on the basis of temperature and CO_2 with no operable windows.

3 Indoor climate

Indoor climate is considered one of the key elements in the investigation of mixed-mode ventilative cooling solutions like the one present at Solstad kindergarten. When evaluating the solution, it is firstly necessary to identify in what way it can influence the indoor climate in comparison to more conventional solutions. The following chapter will focus on aspects related to indoor climate that is considered relevant for mixed-mode ventilative cooling solutions, with a special emphasis on physical parameters utilized when evaluating simulation results.

The term indoor climate is defined by WHO (the World Health Organization) to consist of thermal-, atmospheric-, acoustic-, actinic- and mechanical environment. [3] The environments considered most prone to alteration as a result implementing mixed-mode ventilation are the thermal and atmospheric. Ventilative cooling mainly affects the thermal environment within a building, but when evaluating the Solstad solution as a whole, its effect on the atmospheric environment also needs to be considered. Arguments can be made for the alteration of acoustic environment as well, due to outdoor noise from open windows. This will not be considered other than mentioning it as a possible downside of window ventilation.

3.1 Thermal comfort

A vital point when it comes to the thermal environment is thermal comfort. Thermal comfort plays an important part in how the indoor environment is perceived by a person, and is, as with comfort parameters in general, very subjective. [10] Thermal comfort is a state of mind where we express complete satisfaction with the thermal environment. [3] A person’s perception of thermal comfort is influenced by several parameters. These consist of an occupant’s level of clothing, level of activity as well as thermal indoor climate. [11] Clothing and activity level can be regarded as external parameters, while the thermal indoor climate consists of physical parameters including temperatures, air velocity and humidity.

A necessary, but not sufficient condition for thermal comfort is that the surroundings provide thermal neutrality for the body, a state in which a person would not prefer it to be neither warmer nor colder. This is evaluated by the PMV- (predicted mean vote) and PPD-index (predicted percentage dissatisfied). [3] The PMV-index predicts the mean vote of a larger group of people on a seven-point scale ranging from hot (+3) to cold (-3), where 0 indicates thermal neutrality. PMV can be determined for scenarios with different activity level, clothing level, air temperature, mean radiant temperature, air velocity and humidity. [12] The PPD-index predicts the percentage of a group of people who will feel dissatisfied with a given thermal climate at a given level of activity and clothing. [11] The PPD-index is found on the basis of the PMV-index. NS-EN ISO 7730 [13] specifically addresses aspects regarding the analytical determination and interpretation of thermal comfort on the basis of PMV and PPD.

Worth noting is that while a state of thermal neutrality is a necessity in order to achieve thermal comfort, local thermal discomfort may occur even when in a thermally neutral state. Causes for local thermal discomfort can be that of draught, radiation asymmetry or large temperature gradients between head and ankles. [3]

Though implementation of mixed-mode ventilation in a building will not affect the external parameters (clothing and activity) related to thermal comfort, the physical parameters can be severely affected. Therefore these need to be taken in to account when evaluating the Solstad solution. The focus will mainly be on temperatures as this is the defining measure for thermal comfort of the control system at Solstad. Air velocities are also considered extremely important, especially in regards to draught and local thermal discomfort. Unfortunately, simulation results and data gathered in the thesis gives no real indication of air movement and velocities experienced at the kindergarten. Humidity is considered of no noteworthy interest.

3.1.1 Temperatures

The Solstad solution is, as mentioned in the system description, controlled largely on the basis of temperatures. The use of ventilative cooling techniques is very much temperature related. In respect to thermal indoor climate, there are several different temperature aspects to consider. The most common temperature measure is the air temperature. Air temperature is the temperature measured, shielded from the influence of thermal radiation. [11] When stating that the Solstad solution is controlled by indoor temperature, this, more precisely, refers to the indoor air temperature.

Air temperature is considered the most crucial measure in regards to the thermal indoor climate, and without the presence of significant radiation sources, it can be utilized when analysing thermal indoor climate, if not, the operative temperature is considered instead. [11] In order to define the operative temperature, thermal radiation needs to be accounted for. Surfaces with different temperatures will exchange heat through thermal radiation. A cold surface will absorb heat from surrounding surfaces with higher temperatures, while warm surfaces will radiate heat towards colder surfaces. This is also the case for a person and its surroundings.[3] The mean radiant temperature refers to an imaginary uniform temperature of the surrounding surfaces resulting in the same heat loss as the actual, non-uniform, surface temperatures, and is calculated as an average of all the surface temperatures in a room weighted in regards to the surface areas directed towards a given viewpoint. [11]

The operative temperature combines air temperature and radiant temperature and is defined as the uniform temperature of surrounding air and surfaces, which results in the same heat loss as the actual environment. [12] In many situations, the operative temperature is calculated as the arithmetic middle of mean radiant temperature and air temperature. [11] This is viable for air velocities below 0.2 m/s or when the difference between mean radiant temperature and air temperature is less than 4 °C.

When it comes to operative temperatures, the guidelines for the technical requirements for building works (TEK10) [14] gives some recommendation based on the work intensity. These recommendations are listed in Table 3.1.

Table 3.1: Recommended values for operative temperature (combined effect of air temperature and thermal radiation), for given levels of work intensity. Reprinted from TEK10 guidelines. [14]

Activity group	Light work	Medium work	Heavy work
Temperature [°C]	19-26	16-26	10-26

The guidelines given in the table gives a large temperature span to operate in, however recommendations from Byggforsk Byggdetaljer 421.505 [15], gives more specific values for different building types and categories. These recommendations are listed in Table 3.2. The categories, 1, 2 and 3, represent the ambition level for the indoor climate in regards to PPD. Category 2 is equivalent to that of the technical requirements for building works (TEK10).

Table 3.2 Recommended values for operative temperature during summer and winter season for a selection of different building and ambition categories. Reprinted from Byggforsk Byggdetaljer 421.505. [15]

Type of building	Category	Operative temperature [°C]	
		Summer	**Winter**
School, classroom	1	24.5 ± 0.5	22.0 ± 1.0
	2	24.5 ± 1.5	22.0 ± 2.0
	3	24.5 ± 2.5	22.0 ± 3.0
Kindergarten	1	23.5 ± 1.0	20.0 ± 1.0
	2	23.5 ± 2.0	20.0 ± 2.5
	3	23.5 ± 2.5	20.0 ± 3.5

Research on adaptive thermal comfort suggests that the temperature that is perceived as most comfortable inside a building is a function of the outdoor temperature. This means that with high outdoor temperatures a higher indoor temperature is both accepted and preferred. [2] This is illustrated by the recommendations in the table above where recommended temperatures are higher during summer than during winter.

The concept of asymmetric radiation is also crucial when it comes to thermal comfort. This is often based on differences in plane radiant temperatures. Plane radiant temperature is the uniform temperature of surrounding surfaces resulting in the same irradiance on one side of a plane surface as the actual non-uniform surface temperatures. [11] In order to characterise the asymmetry in the radiation a person is exposed to, the radiant temperature asymmetry is utilized. Radiant temperature asymmetry is the difference between the plane radiant temperatures on opposite sides of a small, plane surface. [11] Asymmetric thermal radiation can be the cause of local thermal discomfort. Sources of asymmetric thermal radiation can be that of cold surfaces, like windows or inner structures with high thermal mass being slowly heated after being exposed to low temperatures. [12] Humans are in general more sensitive to asymmetry caused by warm ceilings or cool walls. [13] The guidelines to the technical regulations (TEK10) [14] states that radiation from cold or warm surrounding surfaces providing discomfort must be avoided.

Radiant temperature asymmetry can also be utilized as an advantage when considering ventilative cooling solutions like the one at Solstad kindergarten. Though it might be the cause of discomfort it could have the opposite effect. For instance by using night-time ventilation in order to cool down thermal mass within a building in warm summer periods, the radiant temperature asymmetry of a cool ceiling could have a comfortable cooling effect on the occupants. NS-EN ISO 7730 [13] states that the radiant temperature asymmetry for a cool wall (window) should not exceed 10 °C, and 14 °C for a cool ceiling.

Both high and low indoor temperatures can be the source of comfort and health problems. High and low air temperature may reduce the muscle functions leading to decreased work performance as well as increased risk of accidents. A feeling of dry air resulting in discomfort is often related to high indoor temperatures. [14]

In the guidelines to the technical requirements for building works [14] it is recommended that the indoor temperature as far as possible is kept under 22°C when there is a heating demand. An air temperature difference above 3-4 °C between feet and head can cause unacceptable discomfort. This is also the case for daily or periodical temperature variations exceeding approximately 4 °C. On days with high outdoor temperatures it is hard to avoid that the indoor temperature succeeds that of the recommended values. Exceeding the upper limit is therefore accepted in hot summer periods with an outdoor temperature higher than that which is exceeded for 50 hours in a normal year.

In the evaluations performed in this thesis, only indoor air temperature is considered as a measure for thermal comfort as no viable procedures in regards to evaluating other temperature aspects have been performed. They need to be considered however, as they can greatly affect the thermal environment as a whole.

3.1.2 Air velocities

Air velocity has the possibility of being very important when it comes to ventilative cooling by window ventilation as is the case at Solstad kindergarten. A common technique for ventilative cooling is heat removal by increased ventilation airflow rates. Naturally, increased airflow rates also have the potential to result in higher air velocities in a room.

Air movements influence the convective heat and mass exchange between a person and its surroundings. This again has an effect on general thermal comfort and local thermal discomfort. The most common reason for thermal complaints in office building is draught. [12] Draught is defined as unwanted local cooling of the body caused by air movement. [13] Humans are most sensitive towards draught on bare skin. Discomfort due to draught is therefore normally concentrated to areas such as face, neck and hands. Typical causes are ventilation systems creating large air movements, cold draught due to convective cooling from cold surfaces, or air leakages in the building body. [11]

Discomfort due to draught is not solely related to the heat loss caused by local cooling. Ever changing skin temperature due to fluctuations in air velocities are also of significance. These fluctuations are caused by air turbulence. High air turbulence is more uncomfortable than low air turbulence even though the total heat loss is the same. [11] Air turbulence is described by the turbulence intensity. Turbulence intensity is defined as the standard deviation of the air velocity divided by the average air velocity. [12] Turbulence intensity in a room with mixing ventilation is normally in the region of 30 - 60 %. In rooms with natural ventilation and displacement ventilation, both turbulence intensity and air velocities are usually lower. [11] The fact that the turbulence intensity usually is lower in naturally ventilated rooms may be an advantage for ventilative cooling measures utilizing direct outdoor air seeing that lower turbulence intensity allows higher air velocities.

The Norwegian Labour Inspection Authority (Arbeidstilsynet) [16] gives a recommendation that air velocities should not exceed 0.15 m/s in workplaces with physically light work in order to prevent draught. Recommendations from Byggforsk Byggdetaljer 521.505 [15] give more specific values for different building types and categories. These recommendations are listed in Table 3.3, and the categories, 1, 2 and 3, follow the same criteria as for Table 3.1.

Table 3.3 Recommended values for maximum air velocity during summer and winter season for a selection of different buildings and ambition categories. Reprinted from Byggforsk Byggdetaljer 421.505. [15]

Type of building	Category	Maximum air velocity [m/s]	
		Summer	**Winter**
School	1	0.18	0.15
	2	0.22	0.18
	3	0.25	0.21
Kindergarten	1	0.16	0.13
	2	0.20	0.16
	3	0.24	0.19

There are no minimum values for air velocity necessary to sustain thermal comfort. However, increased air velocity can be utilized in order to decrease the warmth sensation caused by high temperature. [13] In warm periods, high air velocities increase the rate of evaporation from the skin resulting in an enhanced cooling sensation. By this principle, increased air velocities can alter the thermal comfort region to that of higher temperatures. By utilization of this, a person can achieve good thermal comfort even at high temperatures. [10]

NS-EN ISO 7730 [13] states that *"under summer conditions, the temperature can be increased above the level allowed for comfort if a means is provided to also elevate the air velocity*". Figure 3.1 shows how much the temperature may be increased as a function of air velocity. The solid curves defining the combination of air velocity and temperature all result in the same total heat transfer from the body. Increase in air velocity and temperature is dependent on clothing and activity. The graphs represented in the figure correspond to typical summer comfort with sedentary activities (0.5 clo, 1.2 met).

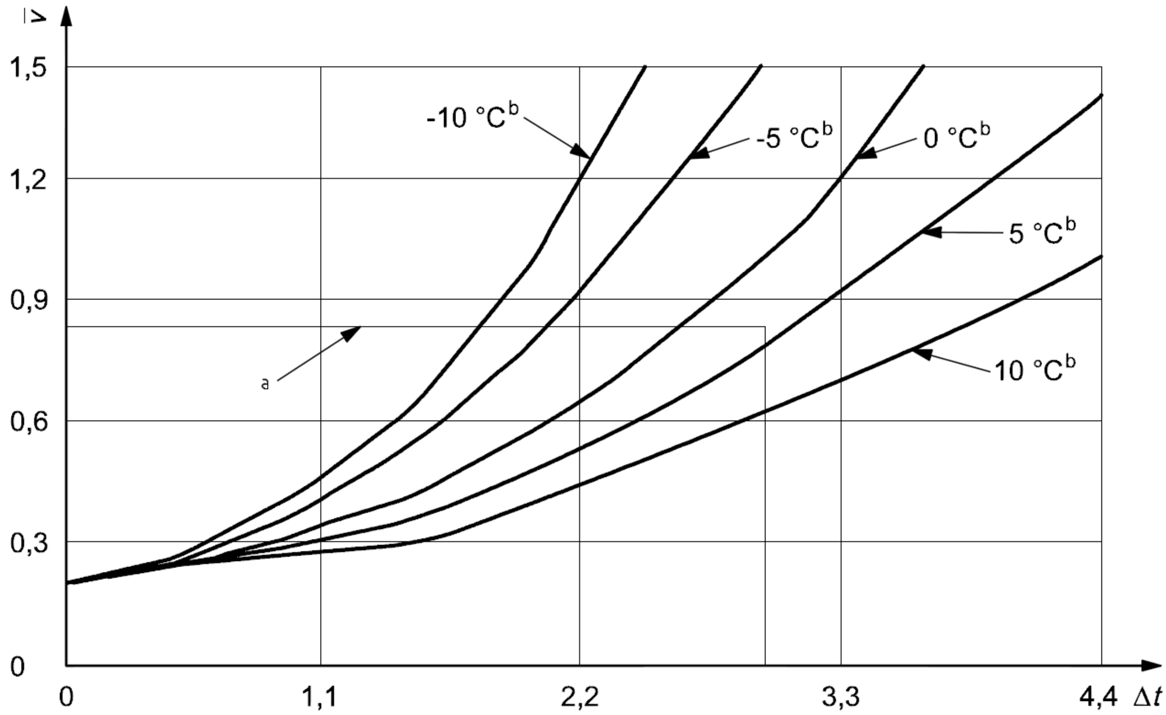


Figure 3.1: Relation between increased air velocity and increase in temperature above 26 °C. From NS-EN ISO 7730. [13]

Δt is the rise in operative temperature above 26 °C

$\bar{v}$ is the mean air velocity [m/s]

b = ($\overline{t_r}$ – t_a) [°C] (t_a is the air temperature; $\overline{t_r}$ is the mean radiant temperature)

The line marked as "a" is the limits for light, primarily sedentary, activity (Δt < 3 °C and $\bar{v}$ < 0.82 m/s). Increasing temperature and air velocity above this level is not accepted for such activity levels.

Worth noting is that the solid curves are valid for an increase of temperature above 26 °C with both $\overline{t_r}$ and t_a increasing at the same rate. With a low mean radiant temperature and high air temperature, increased air velocity is less effective at increasing heat loss. The opposite is the case for high mean radiant temperature and low air temperature. Therefore the temperature difference between mean radiant temperature and air temperature (marked with a "b") must be considered.

Another important demand in NS-EN ISO 7730 [13] is that because of large individual differences between people in regards to preferred air velocity, the elevated air velocity must be under direct control of the affected occupants and adjustable in steps no greater than 0.15 m/s.

The principle of increased air velocity allowing higher indoor comfort temperatures is supported by an experiment by Cattarin [17]. In the experiment, the effect of higher air velocity was investigated through tests in a climatic chamber where 32 Scandinavians were exposed to an increased air movement generated by desk fans under three fixed conditions (operative temperature equal to 26 °C, 28 °C and 30 °C with constant absolute humidity). Results showed that increased air velocity under personal control makes the indoor environment acceptable at higher temperatures. There were significant individual differences regarding preferred air velocities, which indicate that personal control is important.

The effect of elevated air velocities allowing higher temperature is something that can be considered beneficial in regards to ventilative cooling seeing that standard means for ventilative cooling is increased air flow rates which again may lead to increased air velocities.

3.2 Air quality

The atmospheric environment revolves around air quality, and sustaining acceptable air quality along with thermal comfort are the vital points when it comes to ventilation operation. Ventilative cooling mostly aims on sustain thermal comfort, but when evaluating a solution such as the one present at Solstad as a whole, the effects on air quality also need to be considered.

Indoor air quality is a function of several factors. These are pollution sources, both outdoor and indoor as well as source strength and source location, the ventilation system, in regards to type and capacity along with control, operation and maintenance, the room layout, including furnishing and equipment, and cleanliness in terms of procedure and accessibility. [3] For evaluation of the Solstad solution, the ventilation system is considered most prone to altering indoor air quality when compared to a conventional solution.

In regards to the indoor climate, there are recommendations for air flow rates needed in order to sustain an acceptable indoor air quality. In commercial buildings, the technical regulation on building works [14] states that the fresh air supply as a result of pollution from people with light activity should be minimum 26 m^3/h per person, or approximately 7 L/s per person. Also, fresh air supply should be a minimum of 2.5 m^3/h per m^2 floor area (0.7 L/s) during operating hours, and 0.7 m^3/h per m^2 floor area (0.2 L/s) outside operating hours. The demands are set to accommodate the need to ventilate smell along with emissions from building materials. Also, a set exhaust ventilation air flow rate is required for bathrooms, toilets and similar rooms. Demands are often set based on common sense and experience as they require knowledge regarding pollutant sources and emission conditions. [3]

A common measure for indoor air quality is CO_2-levels. This is also one of the key parameters for the ventilation operation at Solstad kindergarten, and also the only measure regarding air quality utilized in the evaluation of the overall solution.

3.2.1 CO_2

CO_2 is usually measured in ppm (parts per million), where 1 ppm equals 1.8 mg/m^3. In a building, humans are usually the only source of CO_2 production, and therefore, CO_2-levels are traditionally utilized as an indirect indicator on air quality in zones. This is also the case for the Solstad solution. [3]

CO_2 is dependent on the metabolism (activity level). [3] A person produces between 15 to 20 L CO_2 per hour through respiration. The concentration of CO_2 is therefore dependent on the room size and the degree of ventilation. The CO_2-level in the air should not exceed 1000 ppm according to current norms in order to satisfy indoor air quality. [3] Generally, CO_2-levels below 1000 ppm indicate satisfying ventilation levels. An air flow rate of 7 L/s per person is usually required in order to stay below norm value. It is however important to note that CO_2-levels above norm is only an indication on insufficient ventilation in relation to the number of people present. A CO_2 concentration within normal levels for indoor climate is not a health hazard. Administrative norm given by Arbeidstilsynet is 5 000 ppm. [3] First when exceeding 10 000 ppm is it possible to see negative effects, and when exceeding 20 000 ppm these effects become problematic. [3]

4 Ventilative cooling

Though the main focus in the thesis revolves around Solstad kindergarten and the solution applied there, the overall topic is ventilative cooling in schools and kindergartens. With the building industry striving towards ZEB, ventilative cooling has become an increasingly popular topic. In October 2012 Venticool [1], an international platform for ventilative cooling, was launched. The overall goal of the platform is to increase communication, networking and raising awareness to mobilize the untapped energy savings potential of ventilative cooling, and it aims to be the international meeting point for ventilative cooling related activities. Also, the International Energy Agency's Energy in Buildings and Communities programme (IEA EBC) in November 2013 approved Annex 62 on Ventilative Cooling. [1] This is an international collaborative research project aiming to make ventilative cooling an attractive and energy efficient solution to avoid overheating of both new and renovated buildings.

Venticool [1] describes ventilative cooling as the use of natural or mechanical ventilation strategies to cool indoor spaces. Effective use of outside air reduces the energy consumption of cooling for a system while still maintaining thermal comfort. The most common ventilative cooling techniques are the use of increased ventilation airflow rates and night-time ventilation.

In a study by Pellegrini [18], the potential improvement of summer comfort and reduction of energy consumption by passive ventilative cooling solutions, such as daytime comfort ventilation with increased air velocities and night-time ventilation in domestic buildings was investigated. Through simulation in the IDA ICE based software EIC Visualizer, performance of various cooling strategies in four different climatic zones (Athens, Rome, Berlin and Copenhagen) was tested. The study revealed that thermal comfort can be achieved by passive means for all four locations, and in general, natural ventilation turned out to be capable of achieving a very good indoor air quality and a reduction in energy consumption for all locations when comparing with mechanical ventilation or mechanical cooling. This bodes well for the potential of ventilative cooling.

When removing heat surplus by air, the cooling effect is determined by the air flow rate and the temperature difference between supply air and room air. [12] Figure 4.1 illustrates the cooling capacity of air at different air flow rates and temperature differences. With no temperature difference, there is no cooling potential, however, increased air velocities might alter the thermal comfort zone as described in Chapter 3.1.2. Also, if occupants are in direct control of ventilation openings, the benefit of adaptive thermal comfort can help shift the thermal comfort zone.

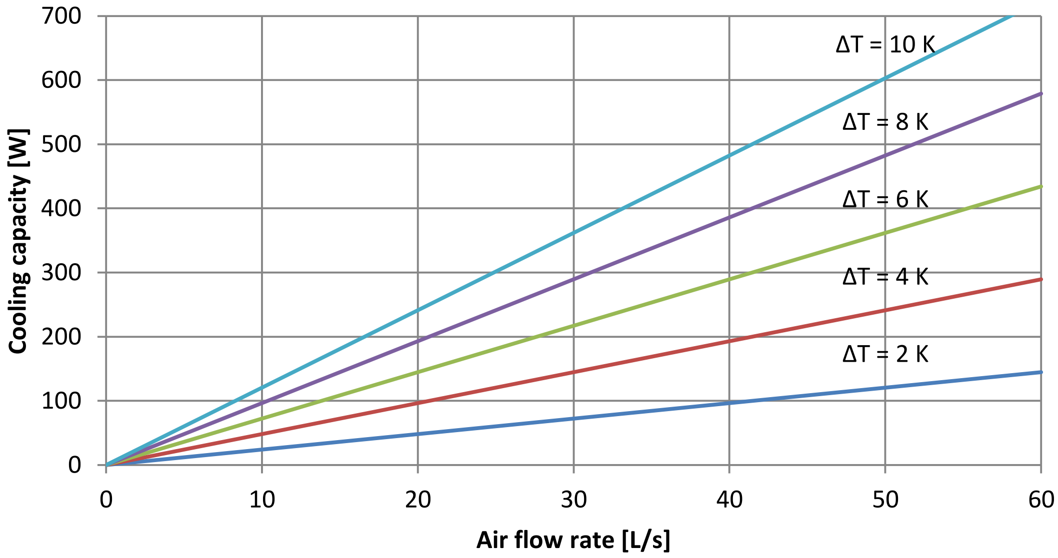


Figure 4.1: Graphs illustrating the cooling capacity of air at different air flow rates and temperature differences.

The use of ventilation in order to rid of excess heat is, as mentioned, becoming an increasingly used technology in order to prevent overheating. In many cases, overheating is unavoidable due to all the heat gain a building is subjected to. A heat gain refers to the “unintentional” internal heat gain delivered to a building as a by-product of energy used for other purposes than heating (lighting, equipment and people) along with heat delivered from solar radiation. [3] Ventilation rates required in order to surpass heating loads are often higher than what is needed in order to obtain good indoor air quality in respect to pollutants. Often, natural principles are used in order to provide enough air to rid the excess heat, but hybrid solutions as well as implementation of thermal mass for heat/cold storage are gaining in popularity. [19]

An important note is that minimization of heat gains is the first step towards improvement of the thermal comfort conditions in the interior of buildings [20] Ventilative cooling should therefore be conceived as an integral part of an overall design strategy including adequate solar protections, intelligent use of thermal mass and sometimes support of active cooling which can help improve thermal comfort. [1]

The Solstad solution offer ventilative cooling in the form of mixed-mode cooling and night-time ventilation and these will be further elaborated in the following sections.

4.1 Mixed-mode cooling

One of the main advantages with mixed-mode systems, like that at Solstad kindergarten, is the option of naturally ventilating the structure with outside air in order to remove surplus heat with limited energy use. Mixed-mode cooling strategies can take many forms, but they generally involve an intelligent control strategy and a building design that serves as a crucial part of the system. [6]

In most conventional buildings, the building envelope is sealed, and ventilation and cooling is provided by mechanical means leaving occupants with little or no opportunity to adjust the system in relation to their own, highly subjective, personal comfort preferences. In these situations, natural ventilation has clear advantages over mechanical ventilation and cooling, yet mechanical cooling may be desirable to cover seasonal peak cooling and zones with especially high cooling demands.[6] Naturally ventilated buildings tend to use far less energy than mechanically ventilated and cooled buildings. Also, occupants often have a degree of control over personal comfort conditions, as well as there being a distinct connection between the outdoor and indoor environments. Though the thermal environment in naturally ventilated buildings is typically more variable and less predictable than those found in conventional buildings it is not necessarily less comfortable. [6]

Theory on adaptive thermal comfort shows that great degrees of personal control allows occupants to fine-tune their thermal climate to match personal preferences, and also allows for a wider range of acceptable temperatures within a building. [5] The benefits of adaptive thermal comfort in relation to personal control of the indoor environment are well documented through research and studies. Brager [21] performed an extensive field study in a naturally ventilated building in both summer and winter season where occupants had varying degree of control over operable windows. The objective of the work was to investigate how operable windows affected the indoor thermal environment and occupant comfort. Results showed that occupants experienced surprisingly similar thermal environments, independent of the proximity to and degree of control they had over the operable windows, however, their reactions were significantly different. Ideal comfort temperatures for the occupants with higher degrees of control were much closer to the temperature they actually experienced, providing support to that thermal preferences are based, not just on conventional heat balance factors, but also of a shifting of expectations resulting from higher degrees of control over their own environment. Adaptive comfort theory leans towards simpler control systems, instead relying on operational education of the occupants. [5]

A mixed-mode system aims to put the benefits of both mechanical and natural systems to use. By utilizing natural ventilation to remove surplus heat and provide the occupants with some control over the thermal environment as well as having the option to rely on mechanical means when natural driving forces are failing or the system is inadequate in covering the cooling needs, it potentially makes for a reliable and energy efficient system. If well-designed and properly operated, a mixed-mode building can reduce or eliminate the need for mechanical cooling throughout much of the year. [6]

Ideally, mixed-mode systems should benefit from the use of natural ventilation as much as possible, and encourage maximum occupant control of the windows in order to realize the benefit of adaptive comfort. When mechanical ventilation and cooling is utilized, it should be as a supplement, not the primary form of control to keep thermal conditions from rising above the adaptive comfort zone. [5]

4.2 Night-time ventilation

As previously stated, the ventilation system present at Solstad kindergarten has the opportunity of benefitting from night-time ventilation. Night-time ventilation is based on slab cooling. In slab cooling, the basic principle is to utilize the thermal inertia of the building mass in order to store energy, using air as primary heat transfer medium. [19] The building structure absorbs heat when the room temperature increases and emits heat when the room temperature decreases. With varying outdoor temperatures, the corresponding variations of heat flow through the building envelope are slowed by the inertia of the thermal mass. [12]

Night-time ventilation can be conducted through both mechanical and natural measures. By utilizing the thermal mass in the structure, night-time ventilation strategies can be implemented in order to cool down the surfaces of the building fabric and in that way store cooling energy in the thermal mass during night-time when outdoor temperatures are low. The slab can then be utilized as a heat sink during daytime when heat gains and outdoor temperature are higher. [19] The sink absorbs the heat gains from solar radiation, occupancy, lighting and equipment contributing to maintenance of an acceptable indoor climate. [10] Naturally, night-time ventilation is more effective when a building includes reasonably high thermal mass. [19] At Solstad, night-time ventilaton is performed by natural ventilation measures through window operation.

Night-time ventilation can affect the indoor environment in several different ways. The main objectives are reducing peak air temperatures during the day, reducing indoor air temperature throughout the day, and especially in the morning hours, reducing the temperature of the slab, as well as creating a time lag between indoor and outdoor temperature. [19]

In a study by Artmann [22], the potential for passive cooling by night-time ventilation in Europe was evaluated by analysing climatic data, without considering any building-specific parameters. Results showed a high potential for night-time ventilative cooling over the whole of Northern Europe, and also a significant potential in Central, Eastern and even some regions of Southern Europe.

4.3 Case studies on applied ventilative cooling solutions

As a tool in order to shed light on applied ventilative cooling solution, this section presents a few case studies of buildings utilizing ventilative cooling considered of interest in the evaluation of Solstad kindergarten.

In a study, Karava [23] explored the application of mixed-mode cooling strategies for hybrid ventilated building with high levels of exposed thermal mass through a full-scale experimental set-up in an occupied institutional building in Montreal, Canada. The key mechanism of the ventilation system was motorized façade openings integrated with an atrium. Results showed that free cooling covered a significant part of the cooling requirements while still maintaining a comfortable indoor environment.

Tanholm [24] presents a case study of an existing shopping centre in Copenhagen, Denmark. In a desire to improve the thermal climate in the hallways of the centre, and, at the same time reduce the energy consumption for ventilation, the owner considered natural ventilation. WindowMaster conducted a number of simulations suggesting a significant energy saving potential (60 % reduction) and a significant improved thermal indoor climate (70 % reduction of annual hours above 28 °C) by adding natural ventilation to the ventilation strategy. As a result, automatically controlled natural ventilation was installed in the hallways of the shopping centre in addition to the existing mechanical ventilation system with an idea of operating by the same principles as Solstad kindergarten with natural operation in summer, and mechanical operation during winter. Measurements for the first year of operation showed a significant improvement in indoor climate outperforming the expected results from the simulations.

In Hirtshals, Denmark, a kindergarten utilizes some of the same technology to that applied at Solstad. [25] The kindergarten has an all-natural ventilation system by WindowMaster similar to the Solstad solution, asides there being no mechanical ventilation with the exception of toilets and kitchens which have mechanical exhaust as per Danish building regulations. Supply air enters from open windows and inlet vents in the windows, and exhaust air leaves through window hatches placed in the roof serving the same function as the windows in Agora at Solstad. The natural ventilation is automatically controlled, but users have the possibility for manual control by opening windows. The control strategy for the system is based on CO_2-levels and indoor temperature, as well as the windows providing fresh air pulses according to a time schedule. The degree of window opening is also dependent on wind direction and outside temperature. Just as Solstad kindergarten, cooling by night-time ventilation is utilized. Long-term measurements regarding the indoor climate at the kindergarten in general show a satisfactory indoor temperature and acceptable CO_2 values. Surveys conducted shows that the occupants are generally satisfied with the indoor environment in summer and slightly less satisfied in winter. Solstad operates very similar to this system during summer, but is mostly ventilated by mechanical means during winter.

5 Solstad kindergarten

Solstad kindergarten is a low-energy building put in to operation in January 2011. It is located in Larvik, Norway, and is one of several schools and kindergartens in the municipality of Larvik utilizing hybrid ventilation solutions. Solstad kindergarten is the first new building in the municipality fitted with a mixed-mode ventilation system, but some refurbished buildings utilize similar solutions, and new hybrid ventilated schools are being built. This section will describe the entirety of the kindergarten and present necessary data for modelling the building. The basis of the Solstad solution is presented in Chapter 2.2, and will to some degree be repeated, however, now in a more detailed manner also taken actual setpoints in to account.

As already known, Solstad kindergarten is fitted with a mixed-mode ventilation system combining motor controlled operable windows with balanced mechanical ventilation. Pushak was the architectural firm behind the kindergarten, and they have provided drawings utilized in the making of the simulation models (see Appendix A for façade drawings). Planning and design of the ventilation solution was done by Energetica Design, who served as HVAC consultants on the project, and WindowMaster A/S was in charge of the system delivery. Figure 5.1 shows an exterior view of the north façade of the kindergarten.

Figure 5.1: Picture showing the north façade of Solstad kindergarten.

Solstad was designed to be a low-energy building meaning that there are high standards in regards to the net energy demand of the building placing large demands on the building body and technical installations. NS 3701 [26] provides further information on criteria for passive houses and low energy non-residential buildings. Some of the key data defining the building body and technical installations are presented in Table 5.1. The SFP value listed in the table is valid for the fans of each air handling unit as taken out of the data sheet for the system. The average yearly SFP for the ventilation system as a whole is estimated by Energetica Design to be 0.7 kW/m^3/s based on assumptions regarding the distribution of mechanical, natural and hybrid operation through the course of a year.

Table 5.1: Key data for Solstad kindergarten

Heated usable floor space [m^2]	788
U-value exterior walls [W/m^{2}K]	0.18
U-value roof [W/m^{2}K]	0.11
U-value floor [W/m^{2}K]	0.06
U-value windows and exterior doors [W/m^{2}K]	0.92 – 1.0
Normalized thermal bridge value [W/m^{2}K]	0.05
Specific fan power (SFP) [kW/m^3/s]	1,87
Infiltration number (n50) [h^{-1}]	1
Temperature efficiency, heat exchangers [%]	85
Lighting control by presence detectors [W/m^2]	6.4
Coefficient of performance (COP), heat pump	~ 2.4

The kindergarten consists of two storeys, where the 1st floor houses four branches; two for large children (3 to 6 years of age), and two for small children (1 to 3 years of age). It also contains common areas including locker rooms and toilets. The four branches are called Gullhår, Tyrihans, Rødhette and Askeladden, where the first two are for small children, and the last two, large children. Table 5.2 list the number of occupants associated with each of the branches.

Table 5.2: Number of occupants associated with each of the four branches at Solstad kindergarten.

Branch	**Number of occupants**
Gullhår	16 children, 4 adults
Tyrihans	14 children, 4 adults
Rødhette	18 children, 4 adults
Askeladden	18 children, 3 adults

The four branches are, as can be seen in the plan view presented in Figure 6.1, all connected to a large common area, called Agora. Above the doors between each branch and Agora there are placed large open hatches so that air can flow freely between the branches and Agora. Seeing that Agora has approximately double the ceiling height of the branches, and windows placed at the top, this room functions like a large “chimney” benefiting from stack effect thus letting air enter from windows in the branches and exit through windows at the top of Agora. Figure 5.2 shows a detail photo of the hatch separating Agora and Rødhette.

The 2nd floor is much smaller than the first, and mainly contains two offices and a meeting room as well as a break room for the employees at the kindergarten. A plan view of the 2nd floor can be seen in Figure 6.2.

Figure 5.2: Photo showing the hatch separating Rødhette and Agora.

As earlier mentioned, the mixed-mode ventilation system at Solstad consists of in total 54 motor operated windows and five separate mechanically balanced ventilation systems. Mechanical cooling is in no form present at the kindergarten, and removal of excess heat is achieved through ventilative cooling measures. There is one air handling unit with accompanying ductworks and supply and exhaust terminals for each of the four branches, and one for the entire 2nd floor. The 1st floor ventilation systems also provide ventilation to the common rooms and locker room areas. The system having five separate air handling units make it more flexible in regards to operation. Instead of having one large centralized air handling unit, the five smaller air handling units makes it easier for each of the units to shut down entirely. Other advantages are shorter pathways for the ductwork along with easier and more flexible placement of air handling units. However, it will likely raise the overall investment cost and generate higher maintenance costs.

The kindergarten has a hydronic floor heating distribution system with a ground source heat pump covering the base load, and an electric boiler covering the peak load. The system is designed so that the electric boiler covers 10 % of the heating demand and 50 % of the hot water demand (pre-heating). Heating is provided to the building 24 hours a day, 7 days a week. The exception is complete shutdown of heat pump and boiler from May to September when there is little to no heating demand. During this period, hot water will be provided solely from the built-in electric heater in the hot water storage tank.

Energetica Design has performed energy measurements on delivered energy to the kindergarten after it was put in to operation. Delivered energy for 2011 can be seen in Table 5.3, next to the calculated net demand of the kindergarten. The net demand has been calculated in SIMIEN by Energetica Design on the basis of NS 3031 [27]. The section on heating includes both space heating and ventilation heat, and in the section for other electricity, equipment, lighting and energy for window operation is taken in to account. Worth noting is that the calculated net energy demand is defined by NS 3031 as the buildings energy demand without regards to the efficiency of the energy supply and losses in the energy chain, and the delivered energy represent the actual electricity bought from the grid. Some of the posts in the delivered energy include estimations based on experience as there were problems with a few of the energy meters when logging the data. The section regarding heating is supposedly a bit less than what is presented in the table.

Table 5.3: Delivered and calculated energy demand for Solstad kindergarten. Logged and calculated by Energetica Design.

	Delivered energy 2011		Calculated net demand	
	kWh	kWh/m^2	kWh	kWh/m^2
Heating	23 010	29.2	36 555	46.4
Domestic hot water	7 361	9.3	7 900	10.0
Fans	6 498	8.2	5 017	6.4
Pumps	8 336	10.6	1 424	1.8
Other electricity	15 953	20.2	17 283	21.9
Total	**61 158**	**77.6**	**68 179**	**86.5**

The total delivered energy has also been logged for the operating years of 2012 and 2013. The monthly distribution of this is shown in Figure 5.3. Delivered energy for each year sums up to a grand total of 69 545 kWh in 2012, and 65 958 kWh in 2013.

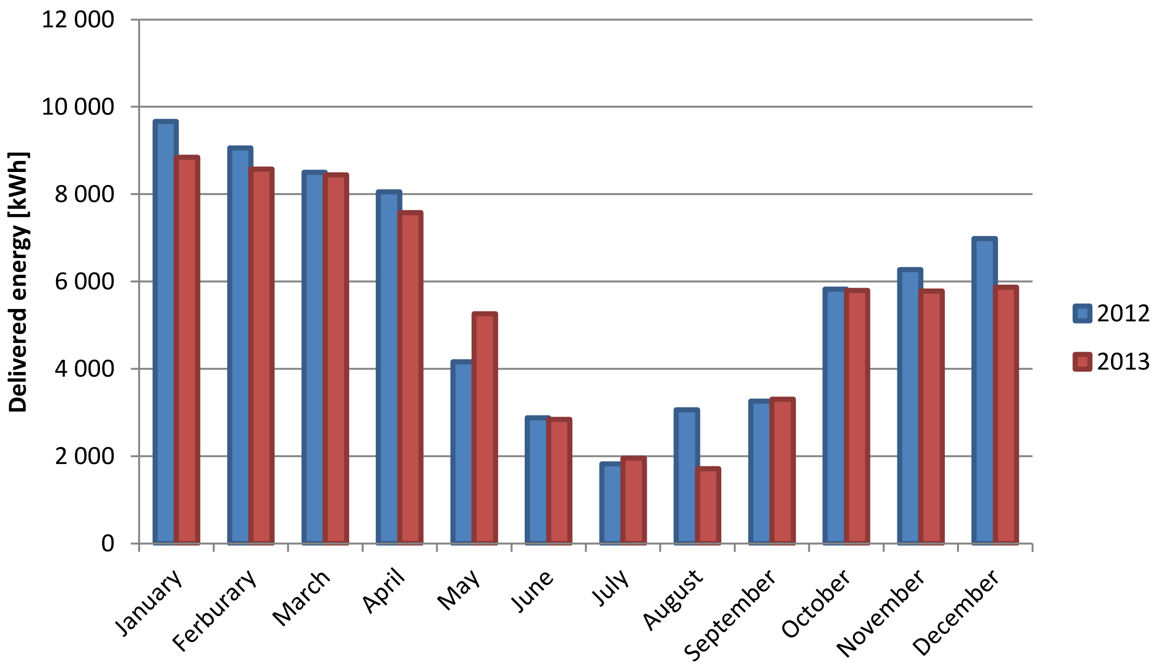


Figure 5.3: Monthly breakdown of delivered energy to Solstad kindergarten for 2012 and 2013. Logged by Energetica Design.

An important note regarding the delivered energy is that experience from talks with the operation manager at Solstad has highlighted that there have been a bit of trial and error in terms of optimizing the overall operation of the system during the first couple years of operation. The operation manager has been, and still is, flexible in altering setpoints and operation strategies according to feedback from the employees and optimization of energy consumption, and is clear on the fact that setpoints and operation might not be 100 % optimal.

In regards to the indoor climate, though no survey has been performed in relation to this thesis, talk with the kindergarten staff suggests there is a general satisfaction with the solution. The aspect of manually overriding the system by window switches is highlighted as a positive feature, providing support to theory on adaptive thermal comfort. Vodsgaard [9] performed a survey on indoor climate among the kindergarten employees at Solstad in 2013. Results from this survey indicate some degree of dissatisfaction in regards to, among other, noise, it being too hot, the feeling of dry air and large temperature variations. However, the percentage of people dissatisfied with one or more of these claims were 20 % at most.

5.1 Control strategies

In Chapter 2.2, the overall functionality of the ventilation solution installed at Solstad kindergarten is explained. In this section a more detailed view on control and operation of the system will be portrayed.

The Solstad solution consist of two separate ventilation systems collaborating in a tight manner in order to optimize operation in terms of both indoor climate and energy consumption. One system relies on natural ventilation from motor controlled windows, and the other on electrically powered fans. Control of air flow rates through the windows is managed by opening and closing the windows. Control of the air flow rates in the mechanical system is achieved through speed control of the fans and pressure sensors in the ductworks. The system has no fixed air flow rates, but varies in order to sustain set criteria regarding air quality and thermal comfort. Air handling units have of course been designed and sized according to the people load in the zones along with recommended values for air flow rate. The key parameters are CO_2-level as a measure for air quality, and indoor temperature as a measure for thermal comfort. The kindergarten is divided into several ventilation zones where CO_2-level and indoor temperature is measured by strategically placed sensors in each zone, and air flow rates are controlled for each individual zone in respect to these measurements.

There are mainly two different seasonal control strategies for the system; one for summer operation and one for winter operation, where the summer strategy prioritizes thermal comfort, and the winter strategy, air quality. It is possible to apply different strategies in the transitional seasons during spring and autumn, but only the main strategies will be covered as the transitional strategies are not predefined for the system. As a rule of thumb, the ventilation works as a changeover system utilizing window ventilation during the summer season, and mechanical ventilation during winter.

During winter, the aim is to limit window operation as this can cause both cold draught and result in large heating demands. Therefore, it is preferable to ventilate mechanically during this period. The mechanical ventilation operates in regards to CO_2-levels in the ventilation zones. The winter setpoint for fan operation is 900 – 1200 ppm. For window operation, the CO_2 setpoint is 950-1500 ppm, thus making the mechanical system responsible for sustaining acceptable air quality. If however, the mechanical system is insufficient in sustaining setpoint values, the operable windows can assist provided that the indoor temperature is above 19 °C. The degree of window opening will then be limited to a maximum of 50 % of the total possible opening. This is always the case for winter operation.

During summer, thermal comfort is the main priority. As the outdoor temperature is higher, window ventilation will not be a cause for increased heating demands. Therefore, window ventilation is preferable seeing that it does not consume energy other than that of the window motors, as well as providing ventilative cooling of the kindergarten. Windows will start to operate when the temperature in a ventilation zone exceeds 21 °C. There are no limitations in regards to the opening limit, and as long as zone temperatures are above the set value, the windows will stay open. If zone temperatures never exceed the setpoint, the windows will not open, and CO_2-levels may start to rise. The mechanical system will then take control of limiting the CO_2-level. CO_2-setpoint for fan operation during summer is 900 – 1300 ppm. The summer strategy also provides the option of ventilative cooling in the form of night-time ventilation. The criterion for this is a zone temperature above 23 °C after operating hours. The system will then allow the zone to cool down to a limit of 18 °C with a maximum degree of window opening set to 50 %. Night-time cooling could cause problems with the setpoint for the heating system, however during night and weekends, reduced temperature setpoints are used, and also, the heating system is shut down during the warmest months.

CO_2 and indoor temperature are not the only parameters defining the control schemes Outdoor conditions are also taken in to account. For instance, an automatic switch between summer and winter operation occurs when the average outdoor temperature through the course of a day is over/under 12 °C. Outdoor conditions are measured by a weather station placed on the roof of the kindergarten. Besides outdoor temperature, this measures wind speed, wind direction and precipitation. Wind speed, wind direction and precipitation are utilized in order to limit the maximum degree of window opening to avoid high indoor air velocities and material damage. An overview of these setpoints can be viewed in Table 5.4.

Table 5.4: Setpoints for window opening limitation as a result of precipitation and wind speeds.

With rain		**Without rain**	
Wind speeds exceeded [m/s]	**Maximum degree of window opening [%]**	**Wind speeds exceeded [m/s]**	**Maximum degree of window opening [%]**
3	50	10	50
8	25	12	30
		14	10

Another aspect of both the winter and summer control schemes is fresh air periods. These are short, scheduled periods where windows open in order to provide fresh outdoor air to the zones. A prerequisite for this is that the indoor temperature exceeds 19 °C. During winter, a fresh air period lasts 120 seconds, with the degree of window opening still limited to 50 %. During summer, a period usually lasts 10 minutes with no limitation to the opening. How often these periods are scheduled depends on the zones, but usually 3 to 5 times spread evenly across a day.

Manually overriding the window operation is also an option for the occupants. This is done by pressing switches placed in the zones. When a window is overridden, it will resume automatic operation after 30 minutes.

Table 5.5 presents a summary of the most important setpoints in regards to emulating the Solstad control schemes in a simulation models.

Table 5.5: An overview of some of the key controller setpoints for ventilation operation at Solstad kindergarten.

	Winter	**Summer**
Ventilation setpoints, CO_2	900-1200 ppm	900-1300 ppm
Window setpoints, CO_2	950 -1500 ppm	
Window setpoints, temperature	Min 19 °C inside when opening	Min. 21 °C inside
Opening limit	50 %	100 %
Switch, winter to summer	Average outdoor temperature through the course of a day exceeds 12 °C	

An important note is that the setpoints listed in this section are setpoints at the time of writing. These parameters are based on experience in regards to energy consumption and wishes from the occupants and are not necessarily ideal. The operation manager at Solstad is flexible in changing setpoints according to feedback in regards to energy consumption and indoor climate.

6 Simulations

As the main part in the evaluation of Solstad kindergarten, computational simulations were performed. These were conducted in IDA ICE version 4.6 (IDA indoor climate and energy). IDA ICE is a computer software simulation tool, developed by EQUA Simulation AB, used for detailed and dynamic multi-zone simulations for study of thermal indoor climate and energy consumption in buildings. This chapter aims to shed light on, and clarify the procedure and method used in creating models of Solstad kindergarten, and also give an overview of key input data, all in a systematic and comprehensible manner.

The first step in creating a model in IDA ICE is defining the building body, and separating the building in to zones. In order to do this, plan drawings of the kindergarten were used as a surface, and façade drawings (see Appendix A) were used for height reference. Zone division is based partly on the actual ventilation zones of the system, and partly on equality in user patterns. Figure 6.1 shows a plan drawing of the 1st floor at Solstad kindergarten with set zone division and zone names applied for future reference.

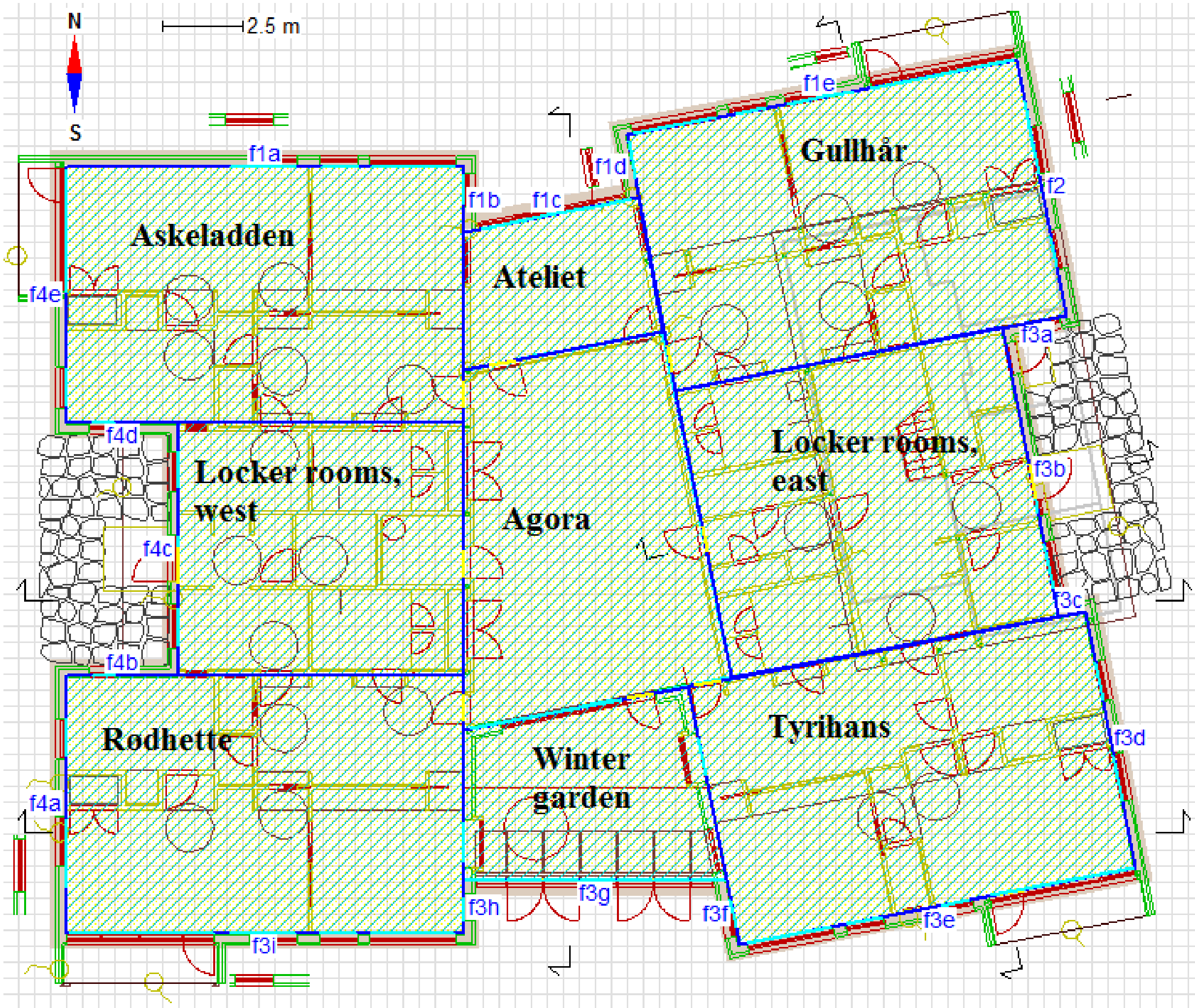


Figure 6.1: Plan drawing with zone division for the 1st floor at Solstad kindergarten.

The 2nd floor plan drawing with zone division and names is shown in Figure 6.2. As seen in the figure, Agora extends beyond the first floor as a result of its large ceiling height.

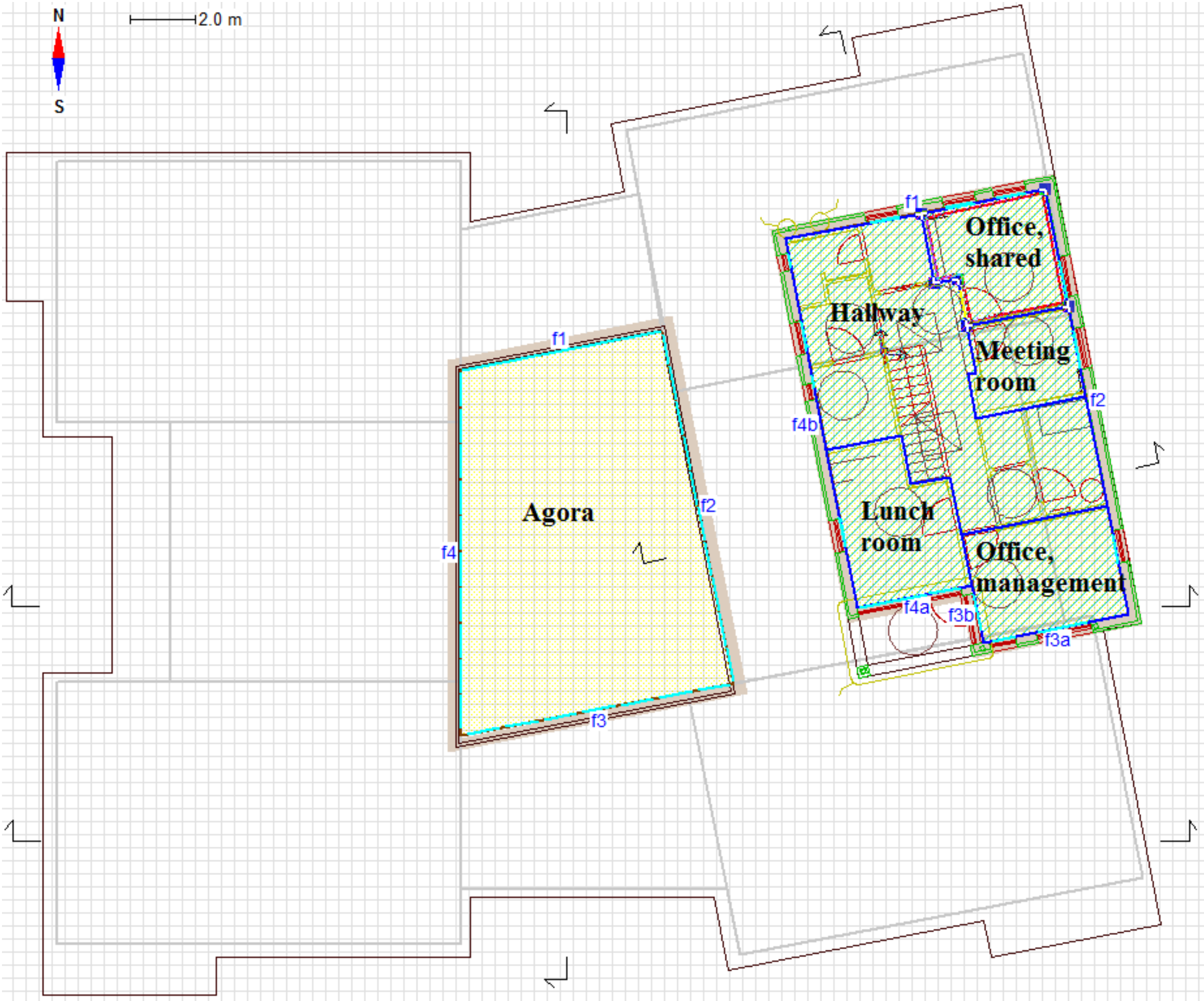


Figure 6.2: Plan drawing with zone division for the 2nd floor at Solstad kindergarten.

Solstad kindergarten has several angles and roofs sloping in different directions. In real life, the 1st floor roof is pitched, but due to difficulties when creating the 2nd floor on top of a pitched roof, it is created flat in the model. To compensate for this, the ceiling height of the 1st floor is set so that the model volume is approximately the same as it is in reality.

The next step in creating the building body is placement of exterior windows and doors as well as internal doors and openings of relevance for the simulations. Exterior placement is done according to façade drawings. Internal openings of interest are the previously mentioned hatches connecting each branch with Agora, and also the door between the 2nd floor management office and the hallway as this is a door that is usually open during operating hours. Most of the windows at the top of Agora are angled, but IDA ICE can only create squared windows and openings. This is handled by approximating the total window surface area towards each of the cardinal directions.

Another aspect of the kindergarten geometry is that there are in total four 1st floor niches adding solar shading to some of the window area, and a couple of roof headwaters doing the same. These need to be taken into account as it contributes to lower the heat gain from solar radiation. The same goes for internal blinds in several of the large southward facing windows.

After creating the building body, dividing up the zones and adding windows, doors and said shading, the model appears as shown in Figure 6.3.

Figure 6.3: A 3D view of Solstad kindergarten as it appears from the south façade in IDA ICE.

6.1 Input data

With the baseline for the model done, a large part of the process is providing IDA ICE with the right input data in order for the model to have the desired properties and demonstrate wanted functionality and behaviour. Set input data for the model with corresponding explanations will be presented in the following section. In order to have decent comparison, three models were created. One with the WindowMaster solution present at Solstad today, and two with a conventional mechanical ventilation system. The two conventional models only differ in that one offers mechanical cooling of supply air, and one does not. The following information applies for all models. Aspects where the conventional models deviate from the WindowMaster model will be pointed out.

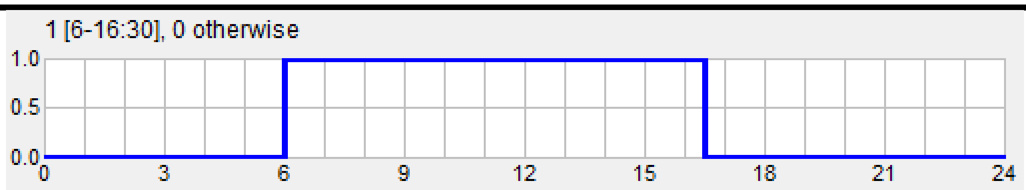
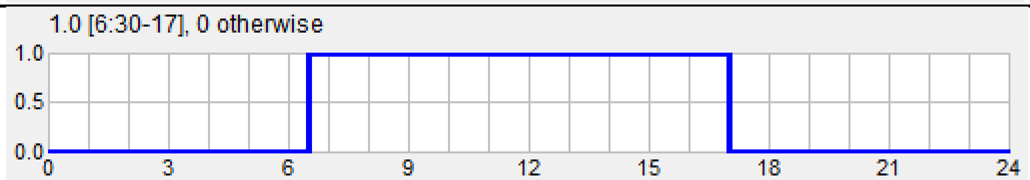
First off, the location of Solstad kindergarten is in Larvik, Norway, however, the predefined location and climate file closest to the actual site available in IDA ICE is Oslo/Fornebu, Norway. Simulations are also performed for a synthetic summer and winter climate in order to map the extremes, along with a moderate summer climate, but when looking at whole year energy consumption, Oslo/Fornebu climate is used. Also, as the kindergarten is located in a somewhat secluded area, a suburban wind profile is chosen. The compass in the top left corner of Figure 6.1 and Figure 6.2 indicates the orientation of the kindergarten.

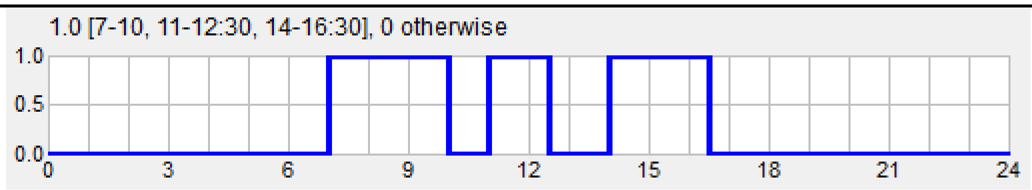
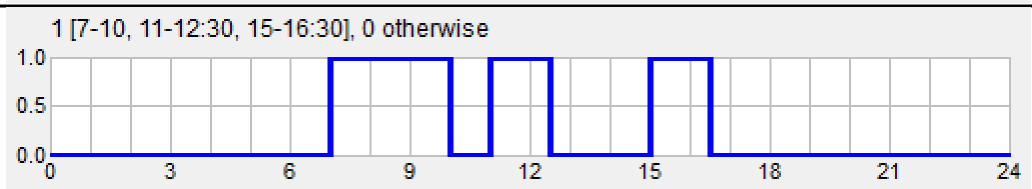
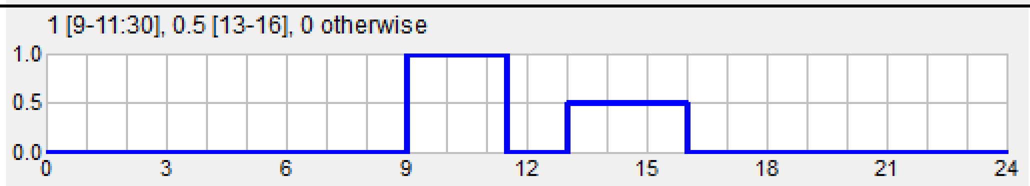
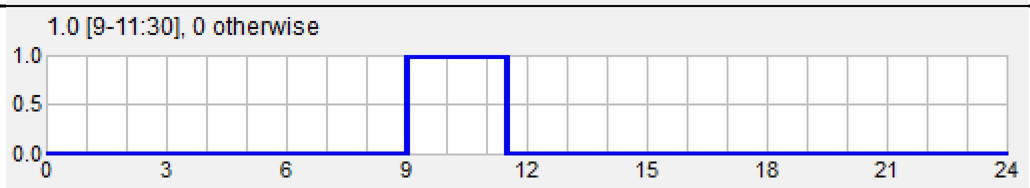
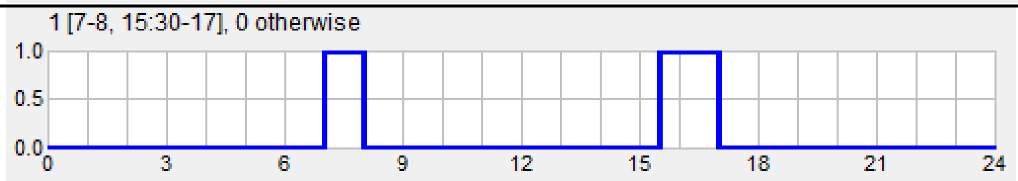
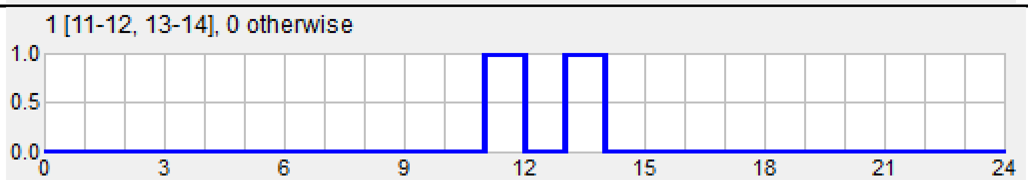
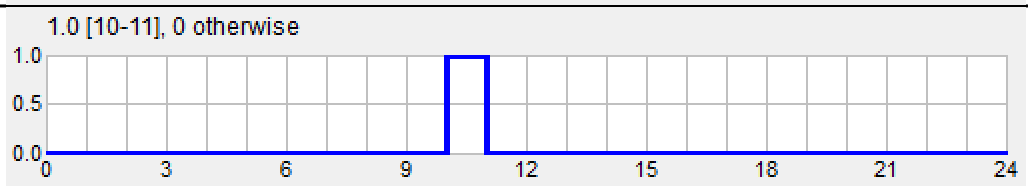
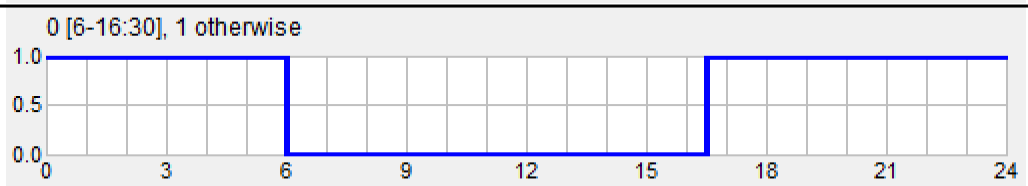
Wall, door, roof and floor constructions are built in order to correspond with U-values presented in Table 5.1. The exception is the windows where a glazing U-value of 0.8 W/m^{2}K is utilized. The overall U-value of the windows corresponds however as the frame to glazing ratio is 10 % and the frame U-value is 2.0 W/m^{2}K making the overall window U-value 0.92 W/m^{2}K. Values for infiltration and thermal bridges are set according to the same table.

When it comes to space heating, all zones except the winter garden is fitted with an ideal heater. The ideal heater ensures that the zones are provided with enough heat to sustain setpoint temperatures at all times. This is considered a viable solution as the heating system is not considered a large part of the thesis, and maintaining setpoints will give a decent picture of the heating demand. Setpoints for space heating is usually in the region of 20 – 21 °C, and in the model, 20 °C is used for all zones in order to avoid conflict with window operation. As said heating system is not considered a large part of the thesis, the standard plant in IDA ICE is utilized. This plant consists of both a chiller and a boiler. As there is no mechanical cooling present at Solstad, the chiller operation is turned off completely for all but the conventional solution with cooling, whereas the boiler operates at all times all year round. In the actual operation, the boiler is switched off for a period from May to September, but test simulations have shown that there is no heat provided during this period either way. The heating efficiency of the boiler is set according to an approximate COP of 2.4 for the heat pump covering 90 % of the heating demand, and 1.0 for the electric boiler covering 10 % of the heating demand. This result in a set COP for the overall system of 2.25.

Each zone in IDA ICE has its own individual template defining the user patterns in terms of occupancy, lighting and equipment. Zone specific setpoints and ventilation strategies can also be defined in said template, but this will be covered in Chapter 6.2. User patterns are based on dialogues with the kindergarten employees mapping how much, and at what times of day, activity is normally expected in each zone. Schedules for user patterns are a bit hard to define as there is much outdoor play, and no standard indoor and outdoor hours for the children, but a set of time schedules have been defined trying to emulate the "average" operating day. These are presented in Table 6.1.

Table 6.1: List of time schedules defined in IDA ICE for different operation and user patterns at Solstad kindergarten.

	Time schedule
Operating hours, ventilation	
Opening hours	

<table>
<tr><td>Branch, small children</td><td>
</td></tr>
<tr><td>Branch, large children</td><td>
</td></tr>
<tr><td>Agora</td><td>
</td></tr>
<tr><td>Ateliet</td><td>
</td></tr>
<tr><td>Office, shared</td><td>
</td></tr>
<tr><td>Lunch room</td><td>
</td></tr>
<tr><td>Meeting room</td><td>
</td></tr>
<tr><td>Night-time ventilation</td><td>
</td></tr>
</table>

The ventilation system operates from 06:00 to 16:30, and there are people present at the kindergarten from 06:45 to 17:00. As IDA ICE does not deal in quarters, the schedule for opening hours is set from 06:30 to 16:00. The schedules presented are only viable for workdays. During weekends and holidays, there is no activity or operation other than for the heating system. All regular Norwegian holidays are added to the simulation model. These include the entirety of the Christmas and Easter season as well as the kindergarten being closed down for two weeks in July. The schedule for night-time ventilation is only utilized in the design of the window control scheme as will be elaborated in Chapter 6.2. The Agora schedule is set to 0.5 from 13:00 to 16:00. This because before noon, Agora often houses an entire branch, and past noon only small groups of children occupy the room. By setting the schedule to 0.5 instead of 1, the set maximum number of occupants in the zone is halved during this period.

One occupant in the model refers to the equivalent of a lightly dressed office worker (1.2 met, 0.7 clo). This refers to an adult, but in the kindergarten there are mostly children. As the activity level is thought to be higher for the children, the large children are considered to contribute just as much in terms of CO_2 and heat production. The small children are considered to contribute 2/3 of an adult. In zones where occupancy is considered temporary (hallway, locker rooms), the number of occupants is set to 0.

The setup for each zone is presented in Table 6.2. The schedules in the table refer to the schedules presented in Table 6.1.

Table 6.2: Overview of user patterns for the different zones at Solstad kindergarten. Schedule corresponding with Table 6.1.

Zone	Maximum, occupancy [Nr]	Schedule, occupancy	Maximum, equipment [W]	Schedule, equipment	Maximum, lighting [W/m^2]	Schedule, lighting
Gullhår	15	Branch, small children	1050	Opening hours	6.4	Branch, small children
Tyrihans	14	Branch, small children	1050	Opening hours	6.4	Branch, small children
Rødhette	21	Branch, large children	1050	Opening hours	6.4	Branch, large children
Askeladden	21	Branch, large children	1050	Opening hours	6.4	Branch, large children
Agora	15	Agora	450	Opening hours	6.4	Agora
Ateliet	5	Ateliet	450	Opening hours	6.4	Ateliet
Locker rooms, east	0	Never present	450	Opening hours	6.4	Opening hours
Locker rooms, west	0	Never present	450	Opening hours	6.4	Opening hours
Winter garden	0	Never present	0	Always off	0	Always off
Office, management	2	Opening hours	375	Opening hours	6.4	Opening hours
Office, shared	2	Office, shared	375	Opening hours	6.4	Office, shared
Lunch room	6	Lunch room	150	Lunch room	6.4	Lunch room
Meeting room	6	Meeting room	250	Meeting room	6.4	Meeting room
Hallway	0	Never present	480	Opening hours	6.4	Opening hours

Lighting is based on the fact that there is presence controlled lighting with an installed power of 6.4 W/m^2 corresponding with the information in Table 5.1. Zones with temporary occupancy, is considered to have the lights on during the entire opening hours. Equipment is spread out through the kindergarten based loosely on what could be expected in each zone so that the total of lighting and equipment approximates that of the measured delivered energy in Table 5.3. Energy consumption for domestic hot water is also set to correspond with measured delivered energy. As these parts of the energy consumption is practically “chosen” in IDA ICE, coordinating them according to the real life measurements is considered applicable.

The winter garden has no heating, ventilation, lighting or technical equipment and does not count as a part of the heated usable floor space. Here the children usually spend time when the outdoor weather does not allow for outdoor play. This zone only affects the model in terms of altering the total heat transfer through the adjacent walls with Agora, Rødhette and Tyrihans. Being a glazed enclosure, it can naturally suffer high temperatures due to solar radiation.

6.2 Modelling the ventilation system

What makes the Solstad solution challenging to model is the complexity of the ventilation system. This section aims to shed light on the process of modelling the ventilation system in IDA ICE.

The control scheme for window operation is naturally only valid for the WindowMaster model. All 54 automatically operated windows at Solstad kindergarten have been mapped, and applied the following control strategy.

IDA ICE offers the opportunity to design unique controls for a variety of operations, and this is utilized in order to replicate the automatic window operation at Solstad kindergarten. Figure 6.4 shows the end product for the window control strategy as it appears in IDA ICE.

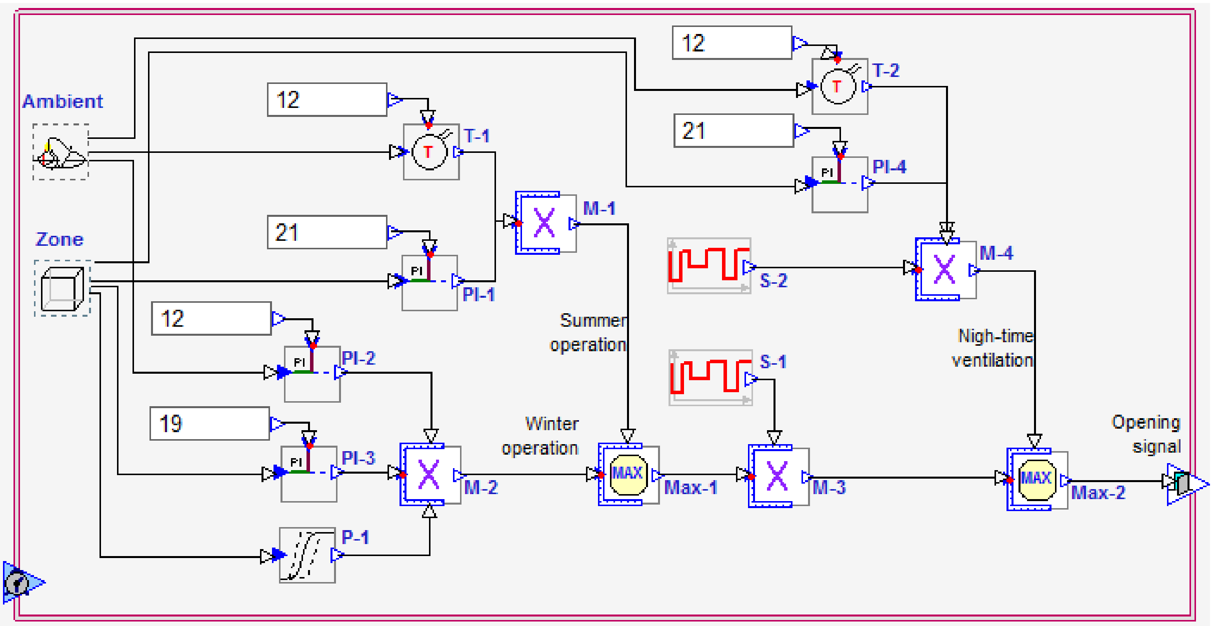


Figure 6.4: Visualization of the window operation control scheme for the WindowMaster model as it appears in IDA ICE.

Because of the complexity of the operation along with software limitations, the modelled control scheme does not include limitation in the degree of window opening based on wind and perception, and also does not include fresh air periods on a timed basis.

Each of the lines illustrated in the figure carries a signal. For explanatory purposes these can be separated between measure signals and control signals. Signals exiting from the box marked “Ambient” are measurements of the outdoor temperature, and signals from the box marked “Zone” are measurements of the indoor conditions (CO_2-level and temperature) in the zone the window operates in. All other signals can be described as control signals. A control signals is a signal from 0 to 1, where 0 means window completely closed, and 1 means window fully open. The control scheme can be broke down to three different sections; summer operation, winter operation and night-time ventilation. For the following descriptions T indicates a thermostat, PI indicates a PI-controller, P indicates a proportional controller, M indicates a multiplier multiplying all in-signals, Max indicates a logic operator always choosing the maximum of several in-signals, and S indicates a set operation schedule.

T-1 and PI-1 defines the summer operation of the system. The thermostat will give an out-signal of either 1 or 0 dependent on the outdoor temperature being over or under 12 °C, and the PI-controller will try to keep a setpoint temperature of 21°C in the current zone. In other words, once the temperature exceeds 21 °C, it will give an opening signal in the range from 0 to 1 in an effort to keep the indoor temperature at 21 °C. Out-signals from these two controllers is then multiplied in M-1 creating a new out-signal that will either be 0 or defined entirely by PI-1 dependent on the outdoor temperature. This way, if the outdoor temperature is below 12 °C, out-signal from M-1 will always be 0, and there will be no summer operation. The switch from winter to summer operation occurring once the outdoor temperature exceeds 12 °C is a compromise as a result of limitations in IDA ICE. In real life the automatic switch occurs when the average outdoor temperature through the course of a day exceeds 12 °C.

The winter operation is defined by PI-2, PI-3 and P-1. PI-2 serves the same purpose as T-1 except it will give an opening signal once the outdoor temperature is below 12 °C instead of above. The maximum out-signal from this controller is limited to 0.5 as the actual system limits window opening to 50 % during winter operation. PI-3 serves the same purpose as PI-1 allowing window opening once the indoor temperature exceeds 19 °C. P-1 takes the CO_2-level in current zone into account. The controller setpoint is 950 – 1500 ppm allowing opening in order to keep CO_2-levels somewhere in that range. All three out-signals are multiplied in M-2 and the result is that if the outdoor temperature is below 12 °C, and the indoor temperature is above 19 °C, window operation will be defined by the CO_2-level in the zone. As this setpoint is higher than the CO_2-setpoints for mechanical ventilation, it normally entails no window opening when in winter mode.

In Max-1, the largest of the signals from M-1 and M-2 is chosen and thereafter multiplied with the schedule signal from S-1. The schedule from S-1 is set to “operating hours, ventilation” (see Table 6.1).

The third section of the control scheme is the one determining night-time ventilation. This setup is exactly the same as for summer operation except that out-signals from T-2 and PI-4 are multiplied with the schedule signal from S-2, and the maximum T-2 out-signal is limited to 0.5, as the degree of window opening during night-time ventilation is limited to 50 %. The S-2 schedule is set to “night-time ventilation” (see Table 6.1). The current night-time ventilation strategy does not correspond entirely with the real case scenario, but is thought to be a viable compromise.

In Max-2, the maximum signal from M-3 and M-4 is chosen and the resulting signal is the one defining the actual window position. Outside of ventilation operating hours, M-3 will always be zero and indoor and outdoor temperatures will determine whether or not to utilize night-time ventilation.

The other part of the overall ventilation system is mechanical ventilation operation. Here, the individual models have some differences. For the two conventional, all mechanically ventilated models, a predefined air handling unit have been chosen in IDA ICE, only differing in that one contains a cooling coil, and one does not. The COP of the cooling system in the conventional model with a cooling coil is set to 3. Each zone is then set to have VAV ventilation controlled on the basis of CO_2-levels and indoor temperature with respective setpoints of 900 – 1200 ppm CO_2, and temperatures in the region of 20 – 26 °C. Mechanical ventilation at Solstad kindergarten is in real life only controlled on the basis of CO_2-levels, but here the windows take cooling needs into account. As there are no operable windows considering the cooling needs for the conventional models, mechanical ventilation is controlled also on the basis of indoor temperature.

Similarities between all three models are that the supply air temperature is set to 19 °C, as this is within the normal range for real life operation, the SFP for all fans are set to 1.87 $kW/m^3/s$, according to value in Table 5.1, and exhaust ventilation is provided to all zones containing toilets and locker rooms according to regulations. Also, one air handling unit serves as a substitute for all five air handling units in the real life case. The fact that there in reality are five units and only one in the simulation models is considered of no significance as air flow rates are set for each zone individually.

In the WindowMaster model, there have been some alterations to the mechanical ventilation operation seeing that it differs slightly in operation on a seasonal basis. In the design of the control scheme, the predefined air handling unit provided in IDA ICE was utilized as a starting point. The end result of the control scheme for mechanical ventilation is presented in Figure 6.5.

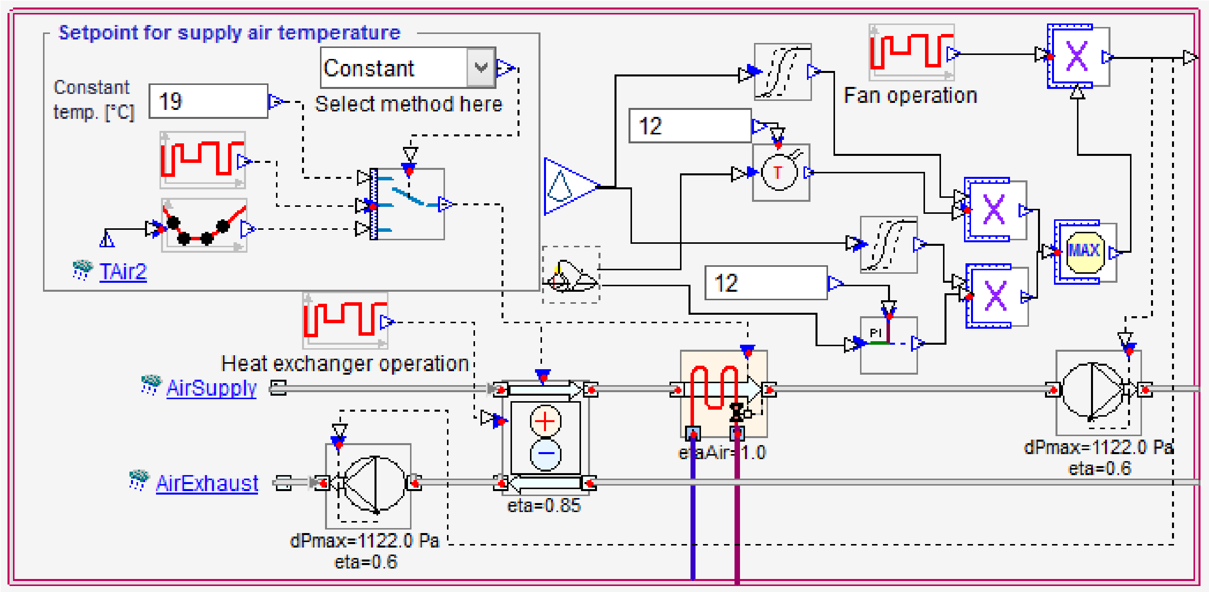


Figure 6.5: Visualization of the mechanical ventilation operation control scheme for the WindowMaster model as it appears in IDA ICE.

The design of the operation is based on the same mechanics as the window control scheme. Alterations made to the predefined system are mainly what can be seen in the top right section of the figure. Defining summer operation is a thermostat measuring the outdoor temperature, allowing operation when the temperature exceeds 12 °C. The thermostat is linked up with a proportional controller measuring CO_2-levels in current zone operating with a setpoint of 900 – 1300 ppm. For winter operation, a PI-controller allows operation when the outdoor temperature is below 12 °C, and this is combined with a proportional controller operating with a setpoint of 900 – 1200 ppm. The maximum signal from these two operations is then chosen in a logic operator, and thereafter linked up with a schedule signal for fan operation. Explained briefly, the system allow for a switch between two different CO_2-setpoints on a seasonal basis.

With the current setup, each zone is set to have CAV ventilation with fixed air flow rates. However, it functions as a demand controlled VAV system based on setpoints from the above mentioned control scheme.

6.2.1 Proof of concept

In order to illustrate the functionality of the overall control schemes for the WindowMaster model, test simulations were performed for a day with variations in both indoor and outdoor conditions. The results of one zone are here presented in order to demonstrate the operation strategy.

Figure 6.6 illustrates the temperature distribution during the simulated day of operation. Note that the temperature is both above and below the setpoint for seasonal switch at 12 °C.

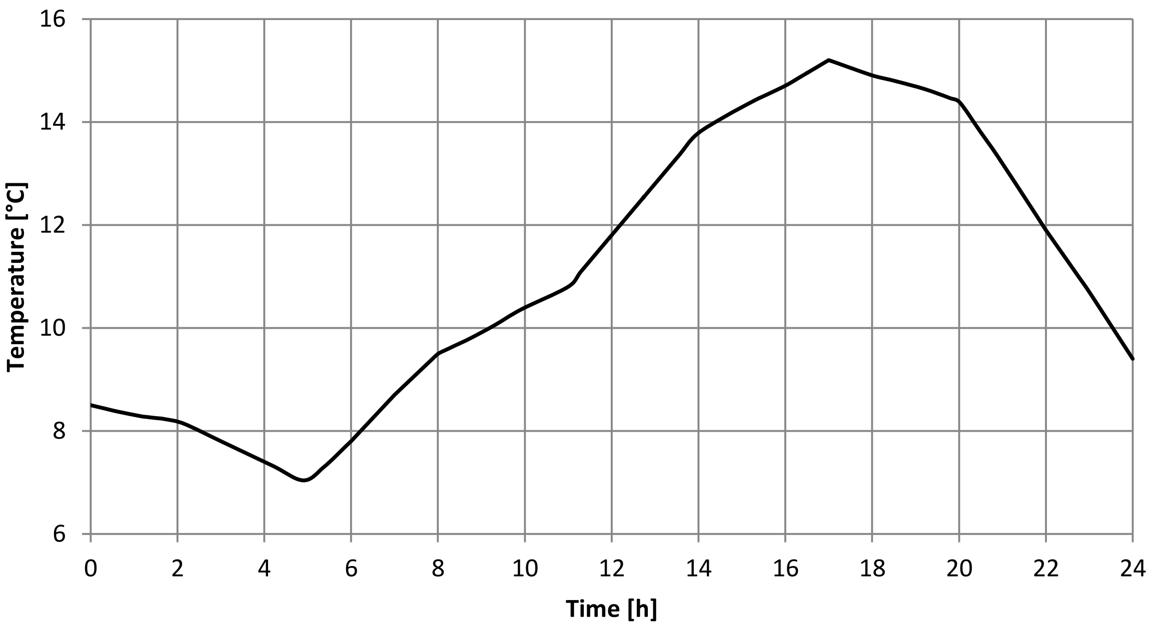


Figure 6.6: Outdoor temperature distribution during simulated day of operation.

Figure 6.7 shows the mean indoor temperature distribution in the zone during the simulated day of operation. Note that the indoor temperature is both above and slightly below the window operation setpoint for summer operation at 21 °C.

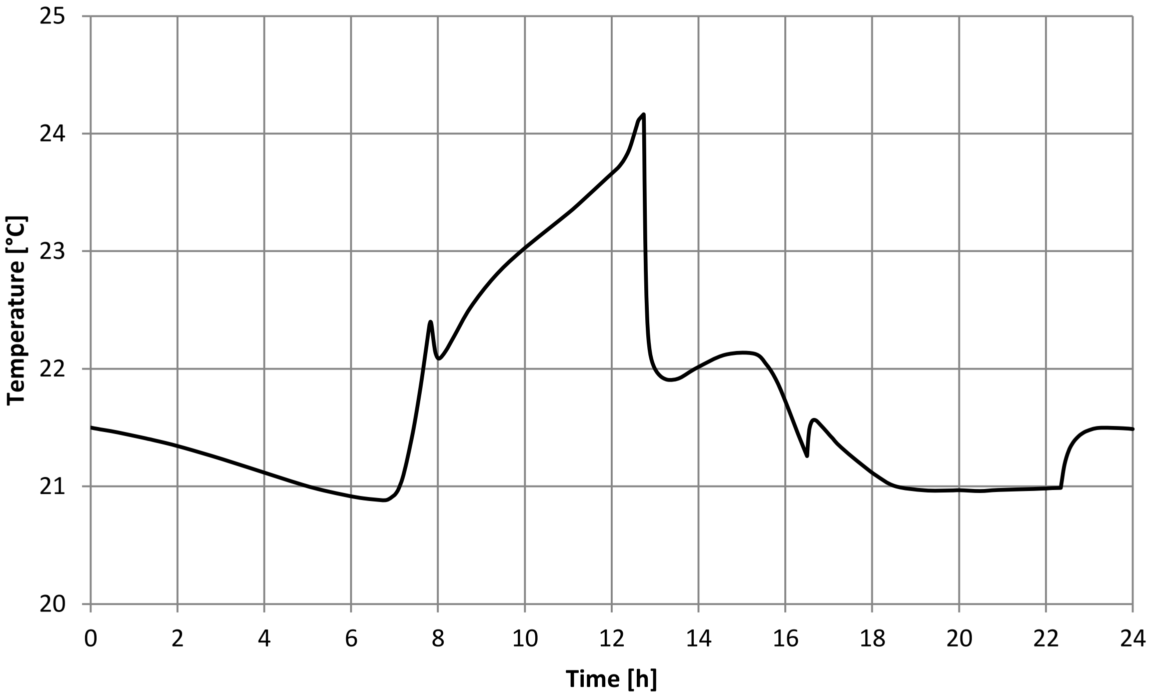


Figure 6.7: Mean indoor temperature distribution in zone during simulated day of operation

Figure 6.8 shows the mean indoor CO_2-level distribution in the zone during the simulated day of operation. Note that CO_2-levels are within the region of setpoint limits for both mechanical and natural ventilation.

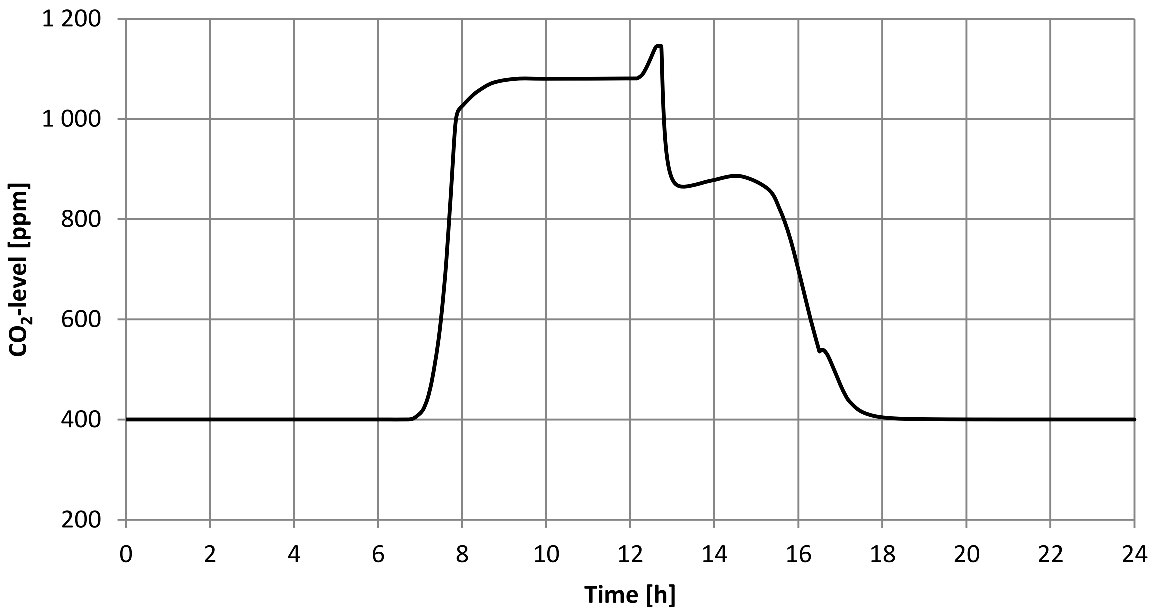


Figure 6.8: Mean indoor CO_2-level distribution in zone during simulated day of operation.

With indoor and outdoor conditions presented, the distribution of mechanical and natural ventilation can be shown to illustrate control scheme functionality. Figure 6.9 shows the operation of the mechanical ventilation system alongside the window operation during the simulated day of operation.

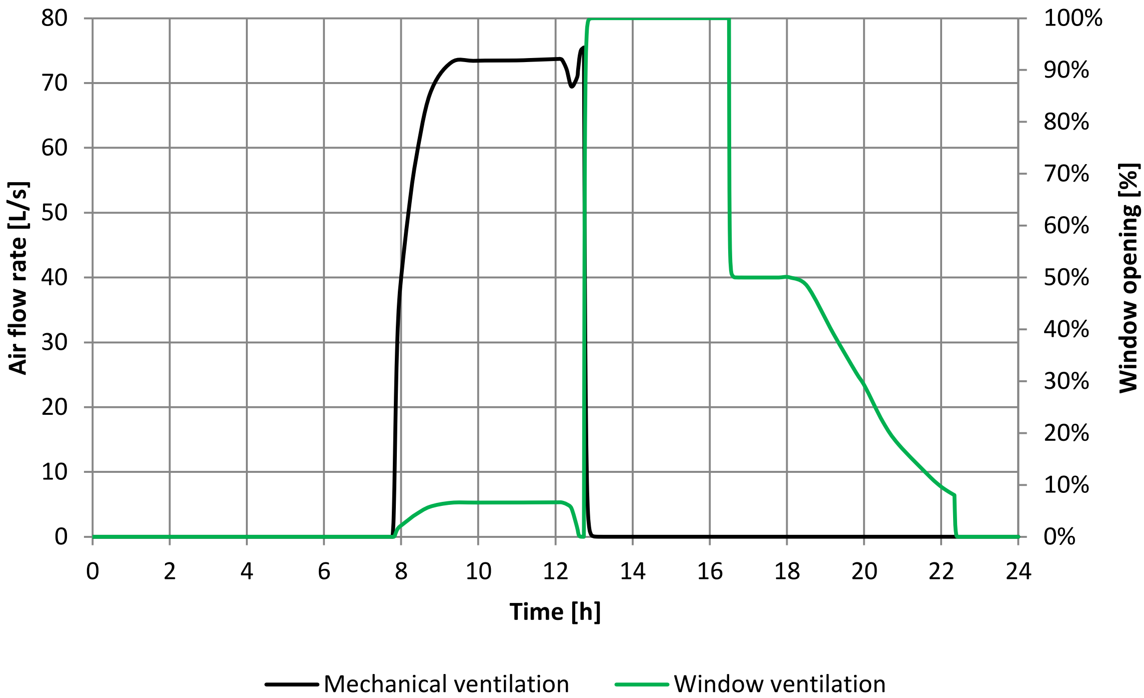


Figure 6.9: Distribution of mechanical- and window ventilation in zone during simulated day of operation.

What can be seen is that, as the outdoor temperature does not exceed 12 °C until a little past noon, the system operates almost entirely by mechanical means up until then. There is some degree of window operation as a result of the mechanical ventilation being insufficient in coping with the CO_2-levels during this period. Once the outdoor temperature exceeds 12 °C, window operation kicks in. As the indoor temperature is far above 21 °C at this point, the windows open to maximum position. This result in CO_2-levels dropping and a subsequent shut down of the mechanical ventilation. Windows stay in maximum position until the end of the operating hours. Now, the indoor temperature is still above 21 °C, and outdoor temperature still above 12 °C, and therefore night-time ventilation starts. During night-time, the degree of opening is limited to 50 %, as can be seen in the figure. Window operation would here normally continue until the indoor temperature drops below the 21 °C setpoint, but at around 22:00, the outdoor temperature drops below 12 °C and the windows are shut.

7 Results

For evaluation of energy consumption, whole year energy simulations were performed for all three models. The conventional models is in this chapter referred to as MV (mechanical ventilation), and marked “cooling” or “no cooling” based on whether or not it offers mechanical cooling of the supply air. In order to assess the indoor climate, one day simulations were performed for three different outdoor conditions; synthetic summer climate and synthetic winter climate in order to map the extreme, as well as a moderate summer climate. Results regarding the indoor climate are presented for three zones considered of particular interest. These are Tyrihans, Agora and the management office on the 2nd floor. Tyrihans is chosen seeing that it is the branch with the largest total heat load in terms of solar radiation and occupancy, Agora as it is the key rooms for the natural ventilation operation, and the office as it separates a bit from the others in terms of functionality, and it is exposed to high solar radiation due to its orientation. Heat from solar radiation is presented for all zones in order to see how the individual zones differs in heat gains from the sun, and also to show the difference in solar heat gains for the different simulated climates.

All model specific results are colour coded. Blue indicates mechanical ventilation with cooling, red indicates mechanical ventilation without cooling, and green indicates the WindowMaster solution. Results are gathered from IDA ICE models and processed in Microsoft Excel.

7.1 Whole year energy simulation

Table 7.1 shows the yearly energy consumption and power demand broken in to sections for the three different simulation models. The entirety of the results from a whole year energy simulation in the WindowMaster model can be found in Appendix B. Note that results regarding area specific consumption in the appendix does not correlate with the area specific consumption listed in the following table. This is because results in the appendix consider the winter garden as part of the heated usable floor space.

Table 7.1: Simulated delivered energy and power demand for the three IDA ICE models.

	MV - cooling			**MV - no cooling**			**WindowMaster**		
	Delivered energy		Power	Delivered energy		Power	Delivered energy		Power
	kWh	kWh/m^2	kW	kWh	kWh/m^2	kW	kWh	kWh/m^2	kW
Electric heating	13 500	17.1	24.2	13 503	17.1	24.2	13 914	17.7	24.2
Electric cooling	571	0.7	13.2	0	0.0	0.0	0	0.00	0.00
HVAC auxiliary	8 116	10.3	15.6	8 648	11.0	15.6	1 969	2.5	15.6
Domestic hot water	7 360	9.3	0.8	7 360	9.3	0.8	7 360	9.3	0.8
Lighting	4 951	6.3	2.9	4 951	6.3	2.9	4 951	6.3	2.9
Equipment	10 781	13.7	4.5	10 781	13.7	4.5	10 781	13.7	4.5
Total	**45 279**	**57.5**		**45 243**	**57.4**		**38 975**	**49.5**	

Figure 7.1 shows a monthly break down of the energy consumption for the three solutions.

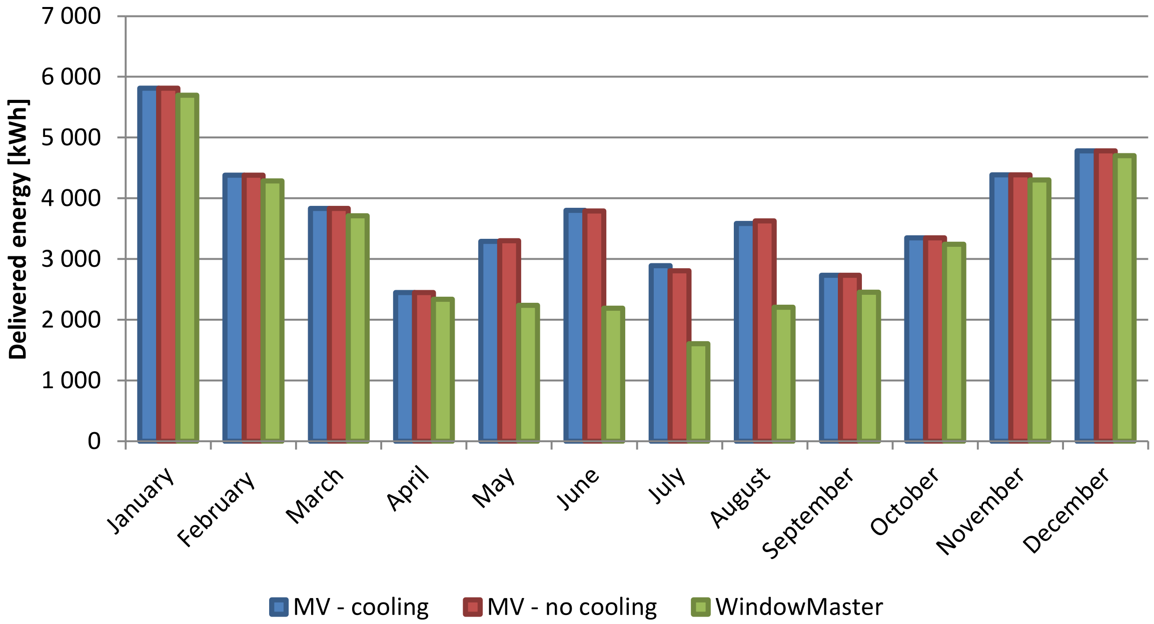


Figure 7.1: Monthly breakdown of delivered energy for the three IDA ICE models.

7.2 Synthetic summer climate

This section present the results of simulations performed during a day with synthetic summer climate. Outdoor temperature distribution throughout the simulated day is presented in Figure 7.2.

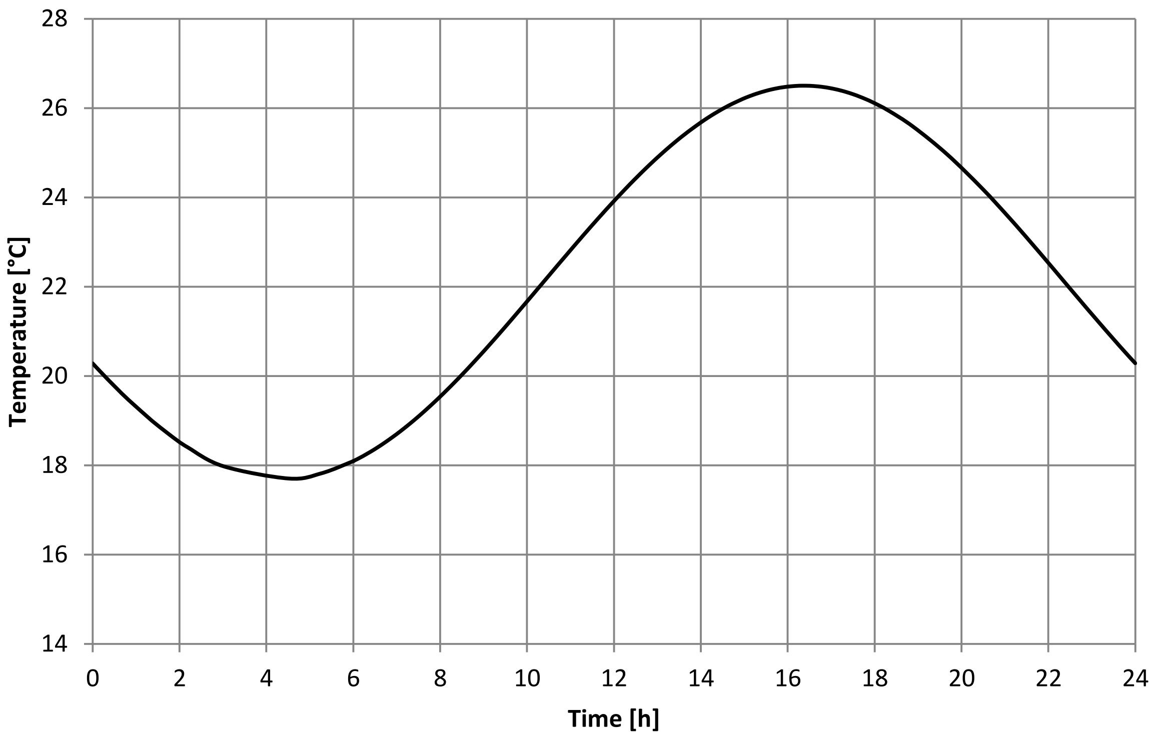


Figure 7.2: Outdoor temperature distribution throughout a day of synthetic summer climate.

7.2.1 Agora

This sub-section consists of simulation results from Agora throughout a day of synthetic summer climate.

Figure 7.3 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

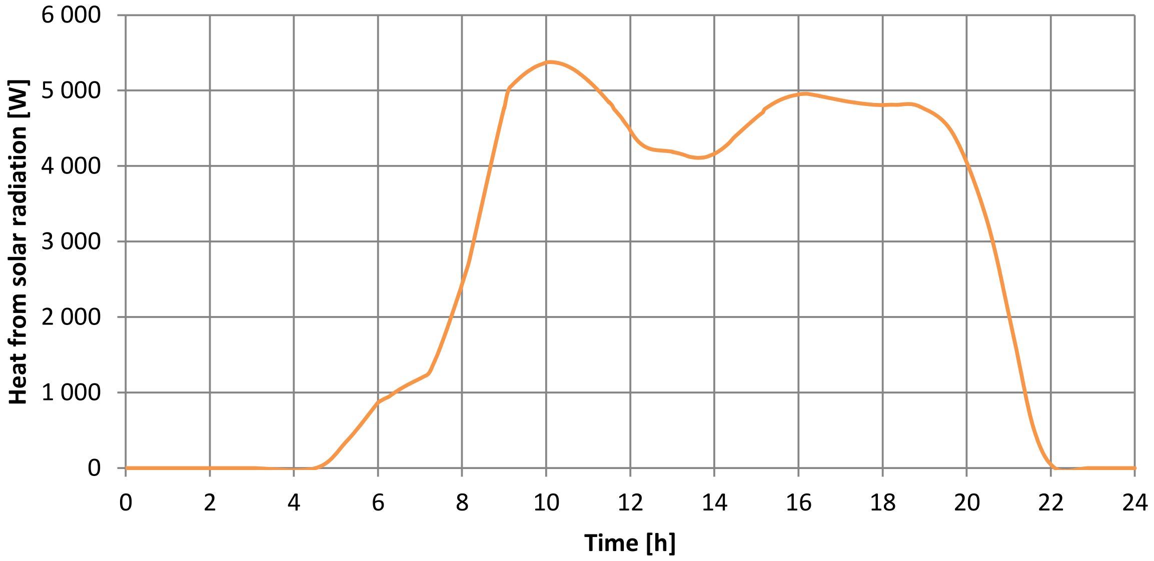


Figure 7.3: Heat gain to Agora from solar radiation (direct and diffuse) throughout the simulated day of synthetic summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.4.

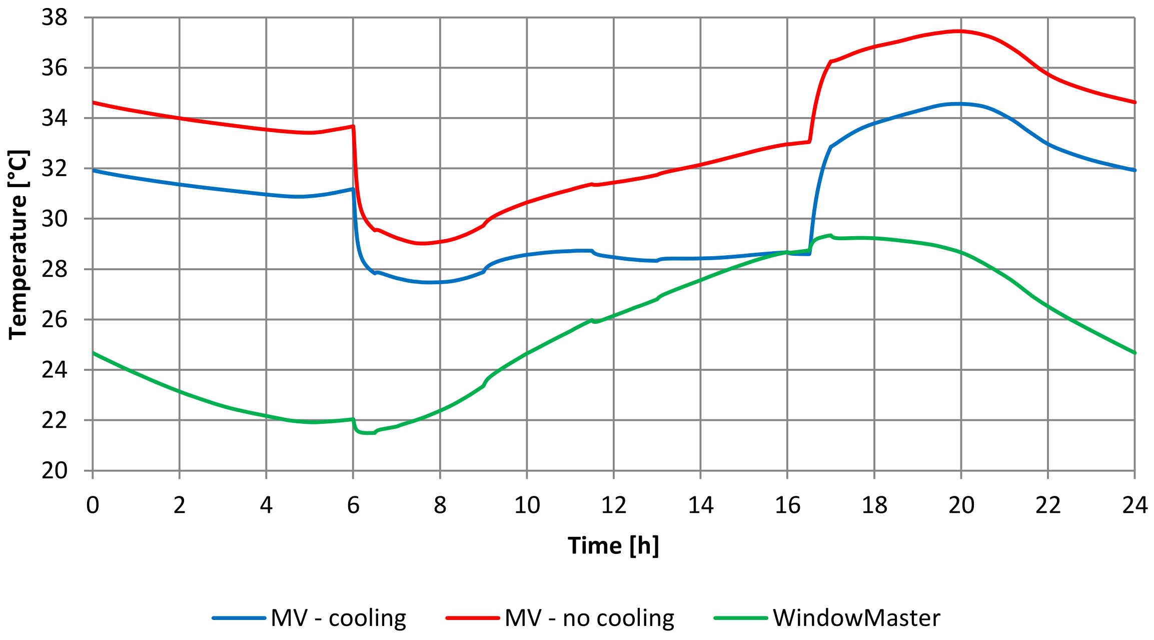


Figure 7.4: Mean indoor temperature distribution in Agora for all three models throughout a day of synthetic summer climate.

Figure 7.5 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

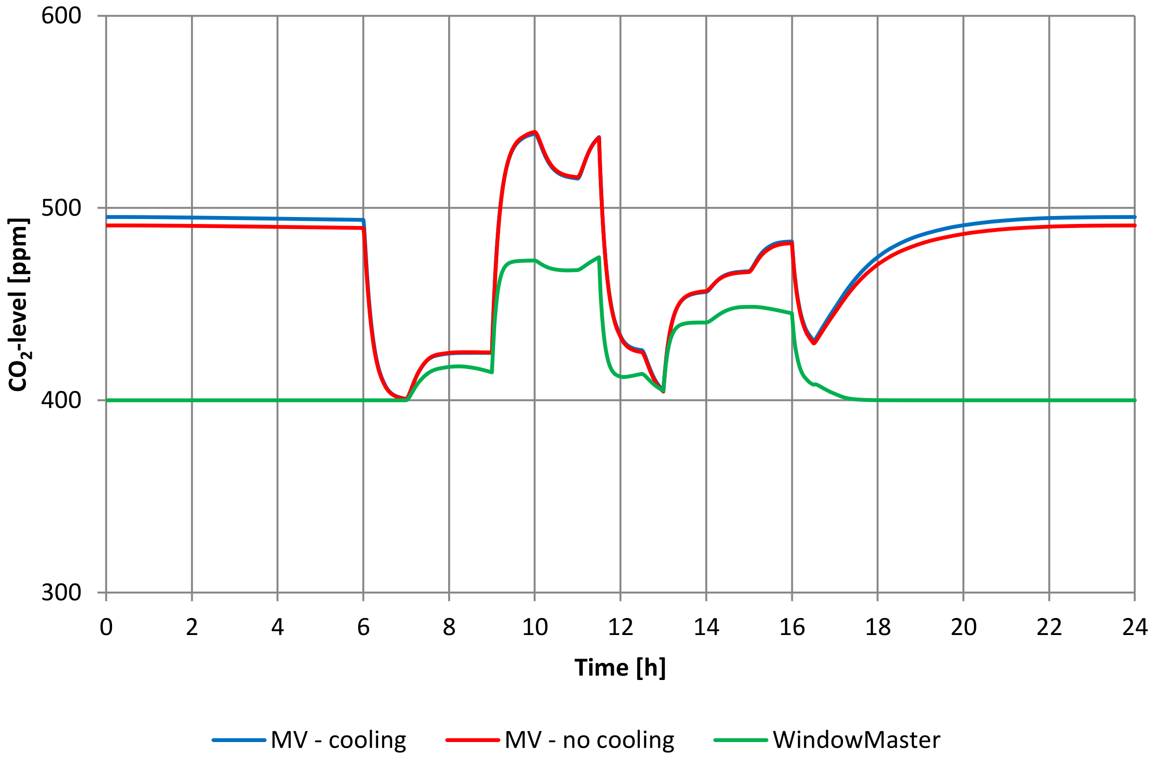


Figure 7.5: Mean CO_2-level distribution in Agora for all three models throughout a day of synthetic summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.6.

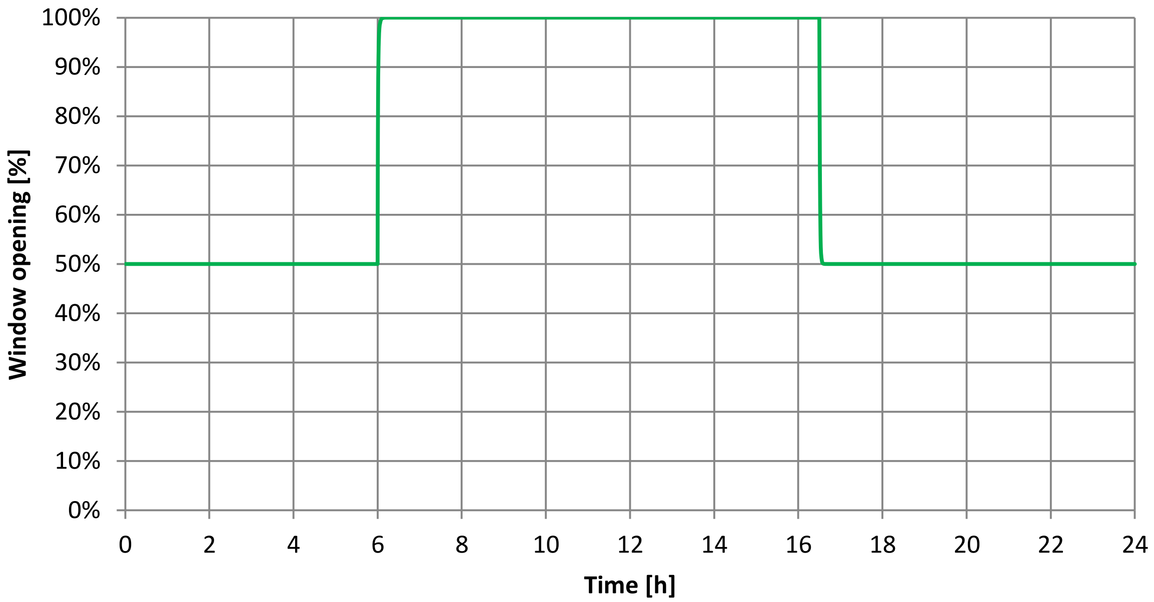


Figure 7.6: Degree of window opening for the operable windows in Agora throughout a day of synthetic summer climate in the WindowMaster model.

7.2.2 Tyrihans

This sub-section consists of simulation results from Tyrihans throughout a day of synthetic summer climate.

Figure 7.7 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

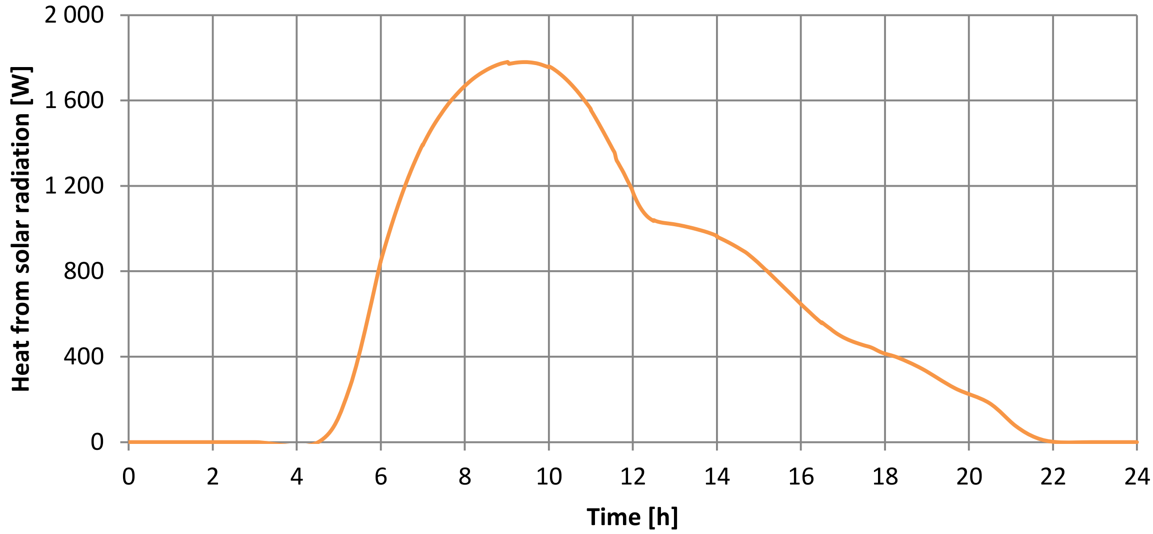


Figure 7.7: Heat gain to Tyrihans from solar radiation (direct and diffuse) throughout the simulated day of synthetic summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.8.

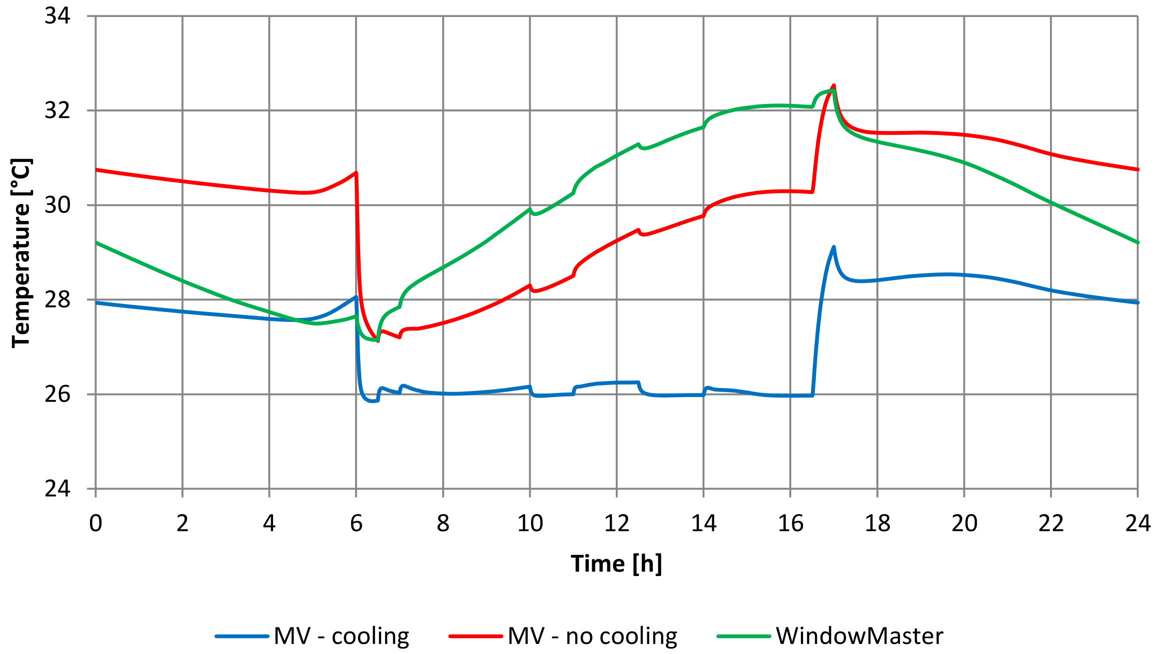


Figure 7.8: Mean indoor temperature distribution in Tyrihans for all three models throughout a day of synthetic summer climate.

Figure 7.9 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

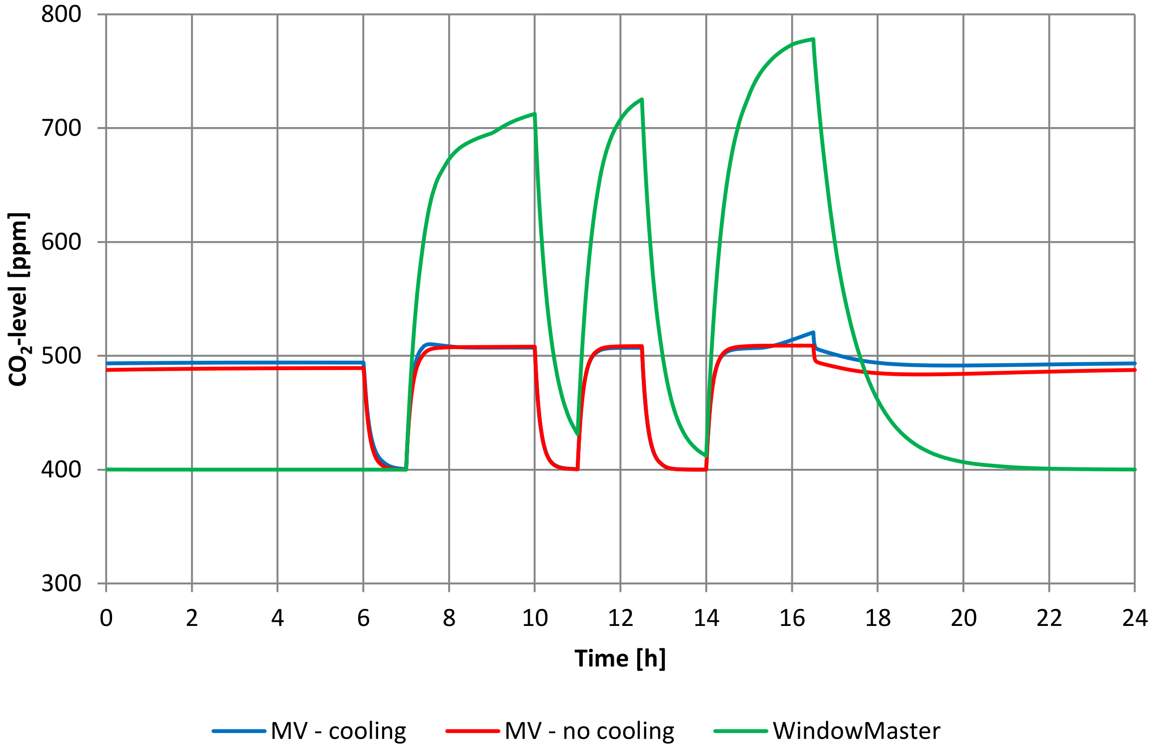


Figure 7.9: Mean CO_2-level distribution in Tyrihans for all three models throughout a day of synthetic summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.10.

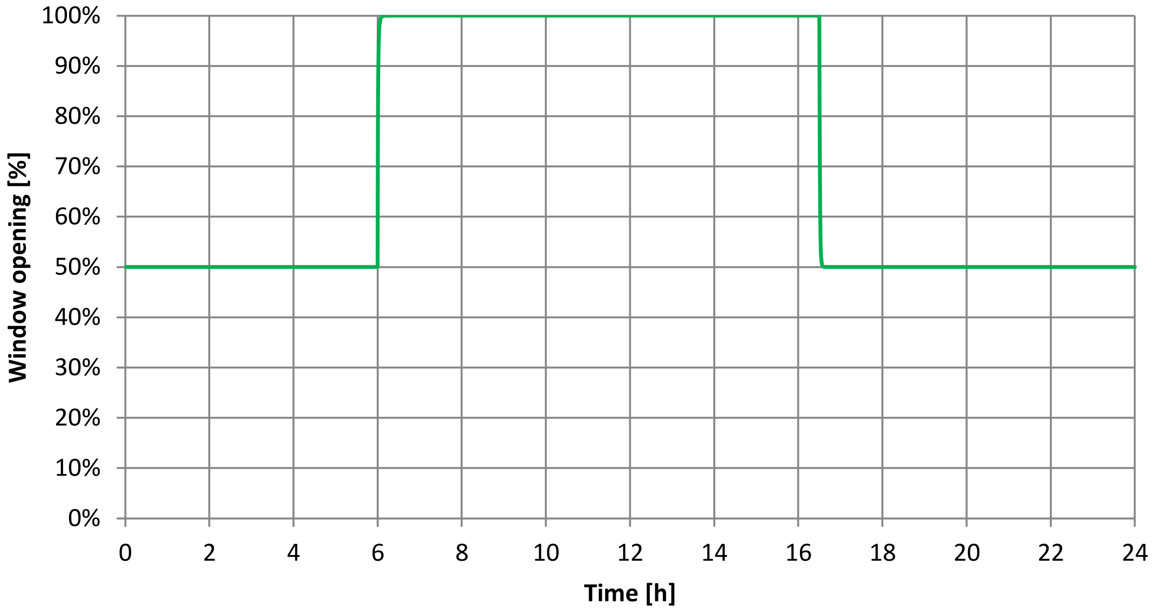


Figure 7.10: Degree of window opening for the operable windows in Tyrihans throughout a day of synthetic summer climate in the WindowMaster model.

7.2.3 Office, management

This sub-section consists of simulation results from the management office throughout a day of synthetic summer climate.

Figure 7.11 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

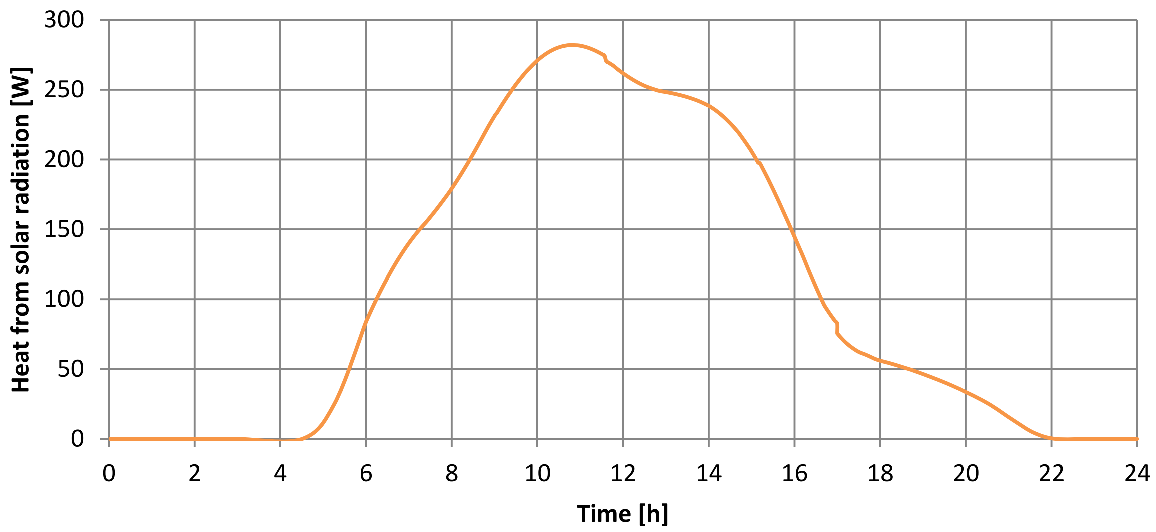


Figure 7.11: Heat gain to management office from solar radiation (direct and diffuse) throughout the simulated day of synthetic summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.12.

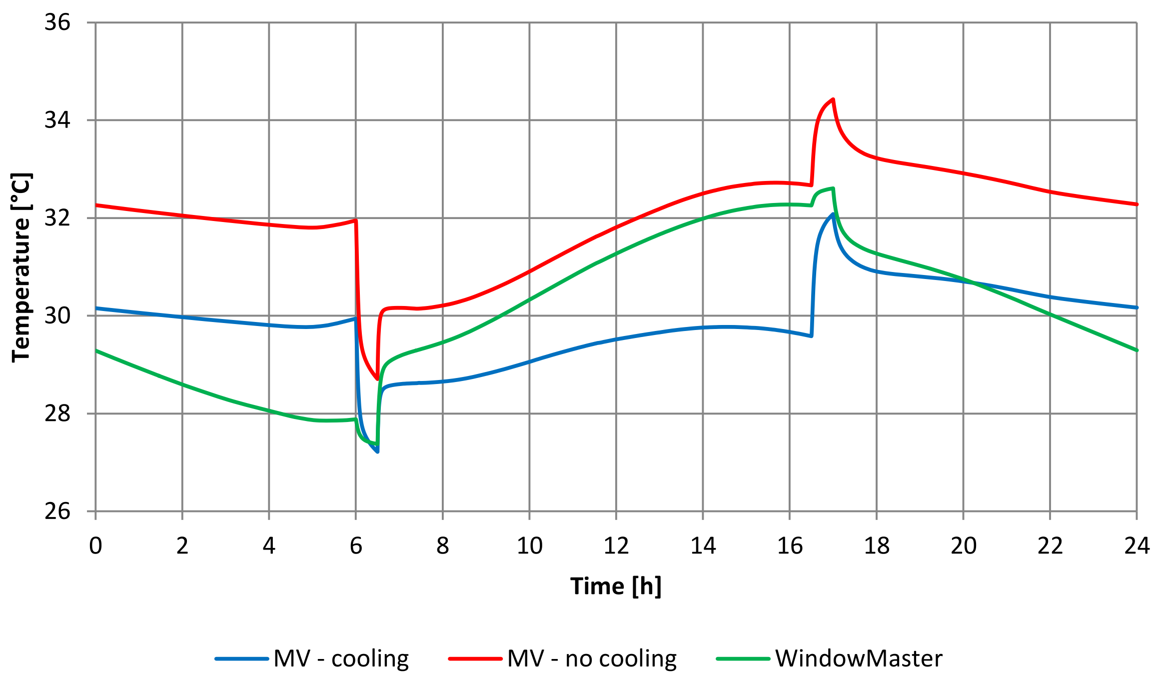


Figure 7.12: Mean indoor temperature distribution in management office for all three models throughout a day of synthetic summer climate.

Figure 7.13 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

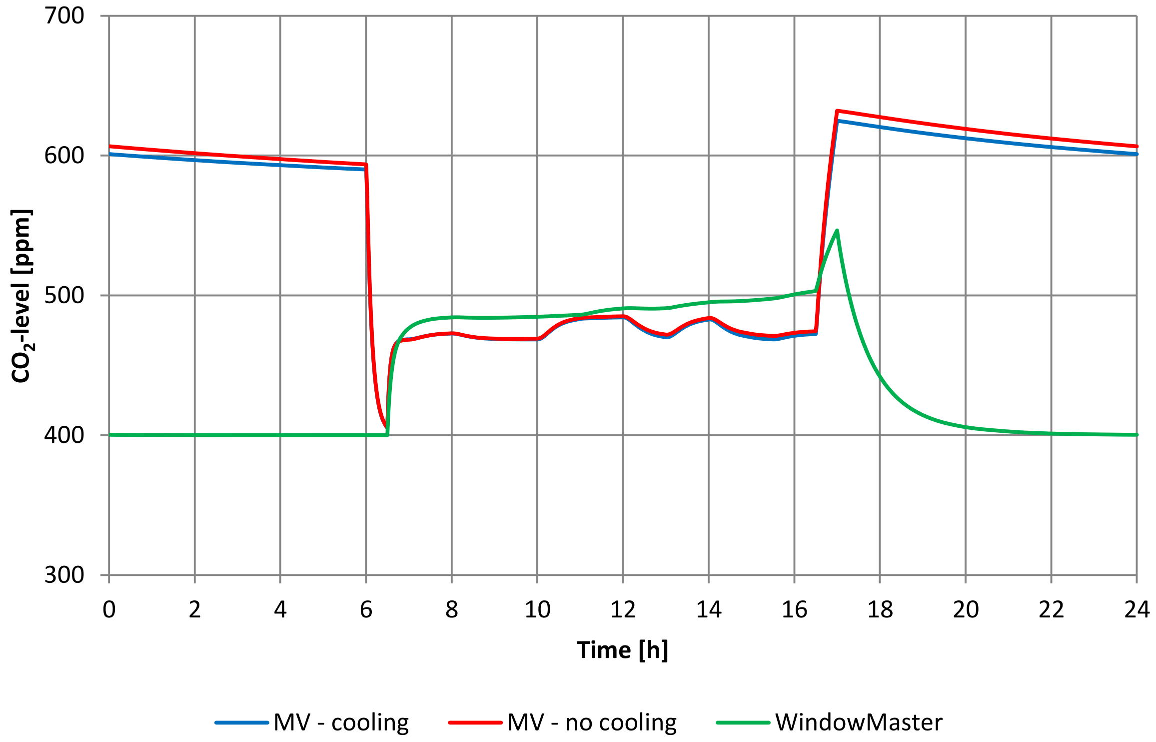


Figure 7.13: Mean CO_2-level distribution in management office for all three models throughout a day of synthetic summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.14.

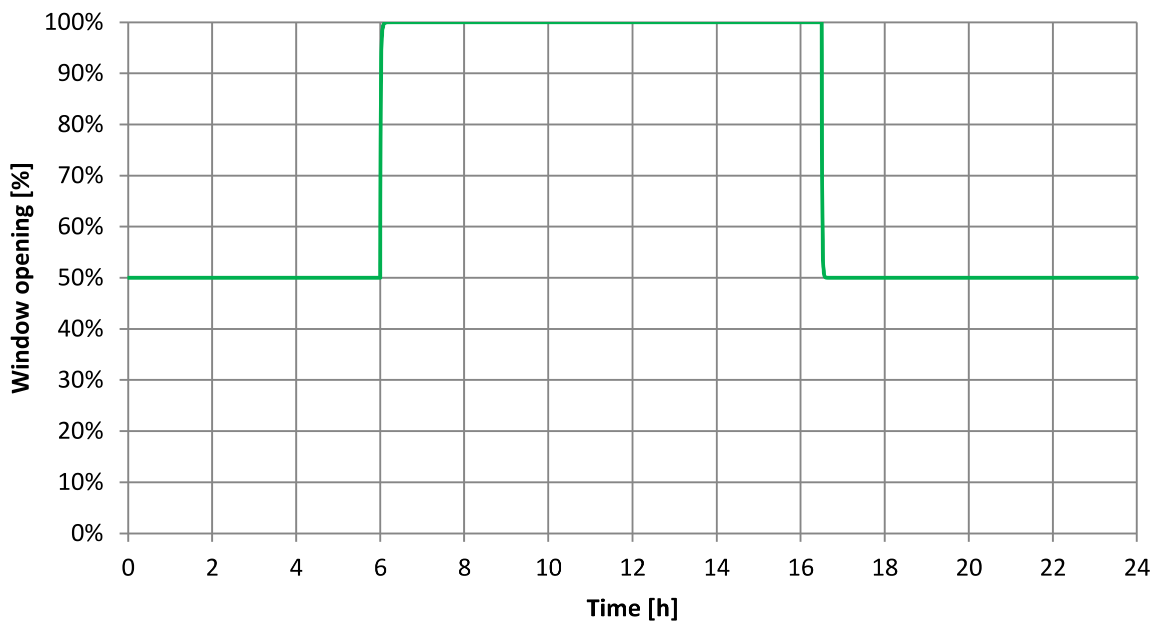


Figure 7.14: Degree of window opening for the operable windows in management office throughout a day of synthetic summer climate in the WindowMaster model.

7.3 Moderate summer climate

This section present the results of simulations performed during a day with moderate summer climate. Outdoor temperature distribution throughout the simulated day is presented in Figure 7.15.

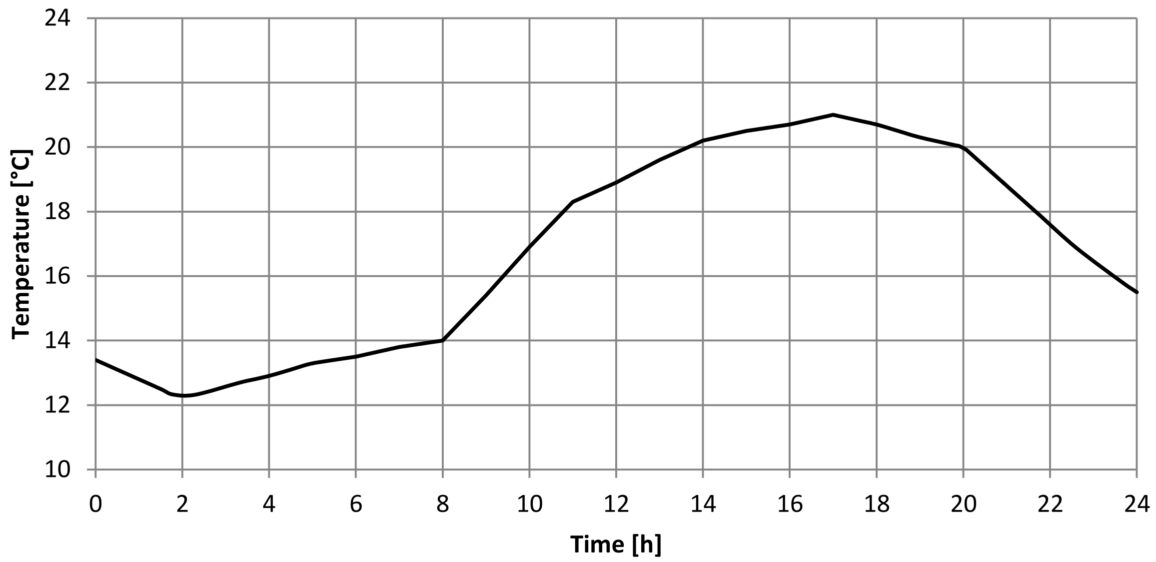


Figure 7.15: Outdoor temperature distribution throughout a day of moderate summer climate.

7.3.1 Agora

This sub-section consists of simulation results from Agora throughout a day of moderate summer climate.

Figure 7.16 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

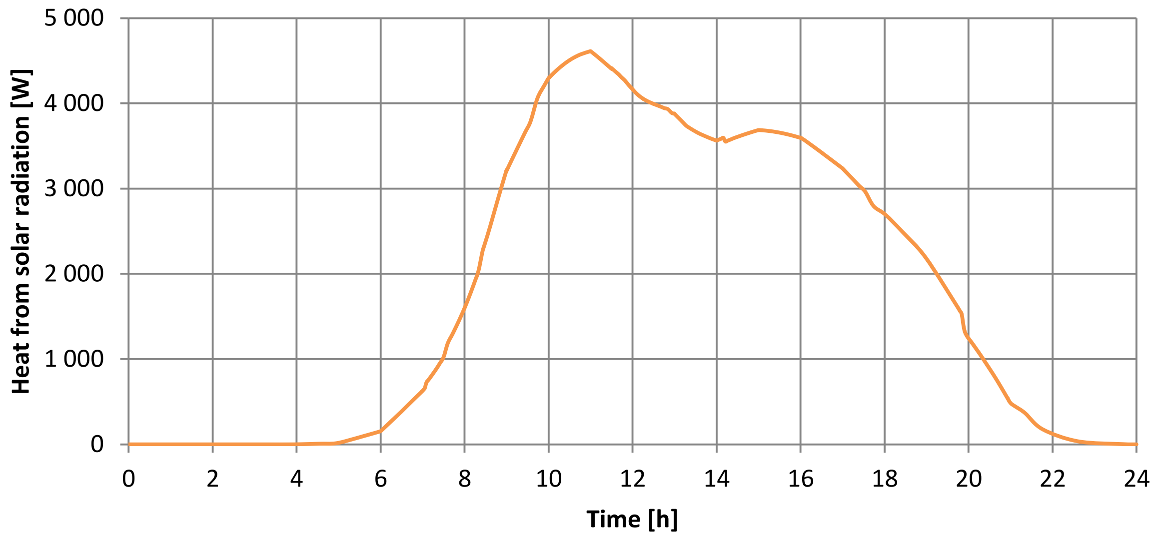


Figure 7.16: Heat gain to Agora from solar radiation (direct and diffuse) throughout the simulated day of moderate summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.17.

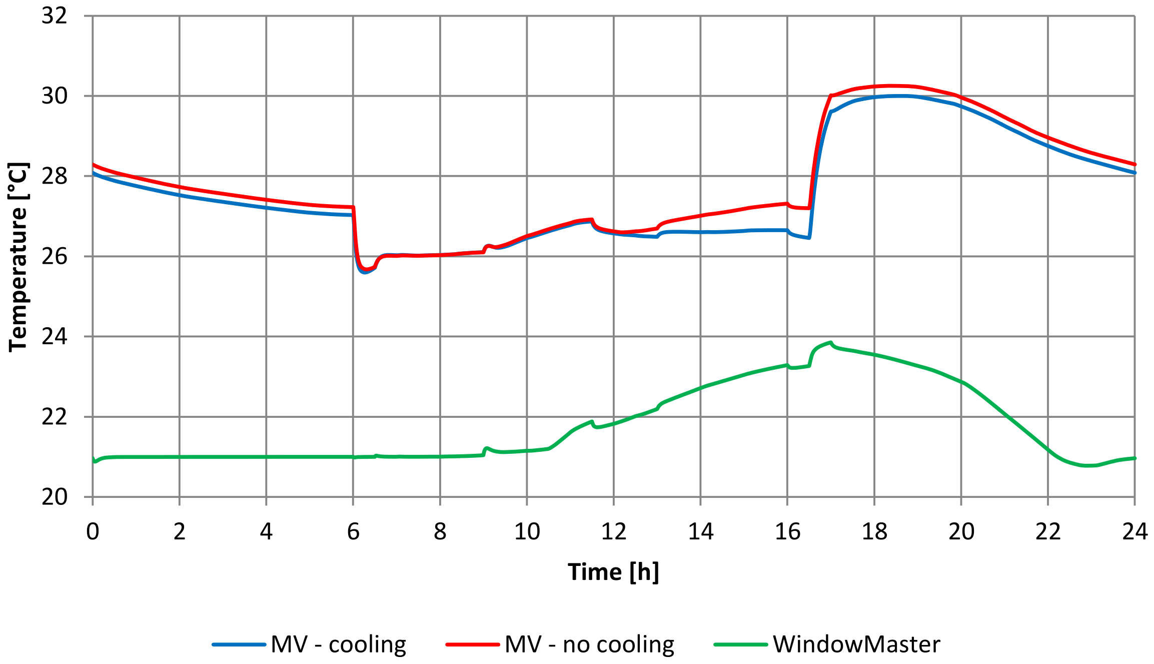


Figure 7.17: Mean indoor temperature distribution in Agora for all three models throughout a day of moderate summer climate.

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Figure 7.18 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

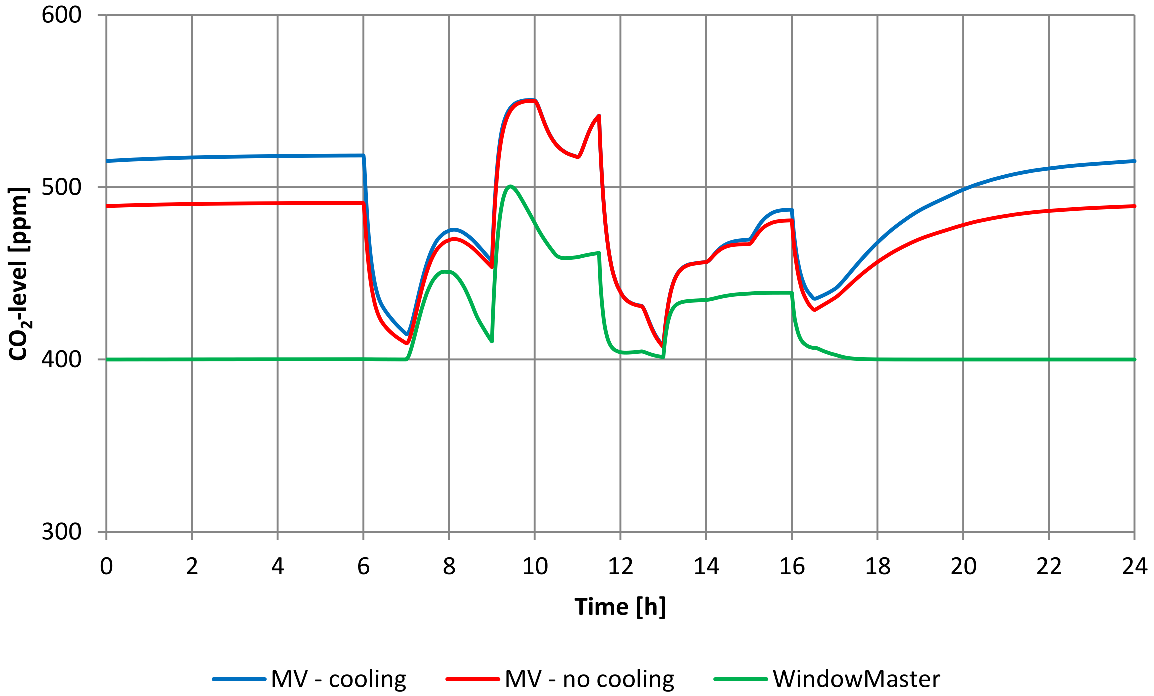

Figure 7.18: Mean CO_2-level distribution in Agora for all three models throughout a day of moderate summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.19.

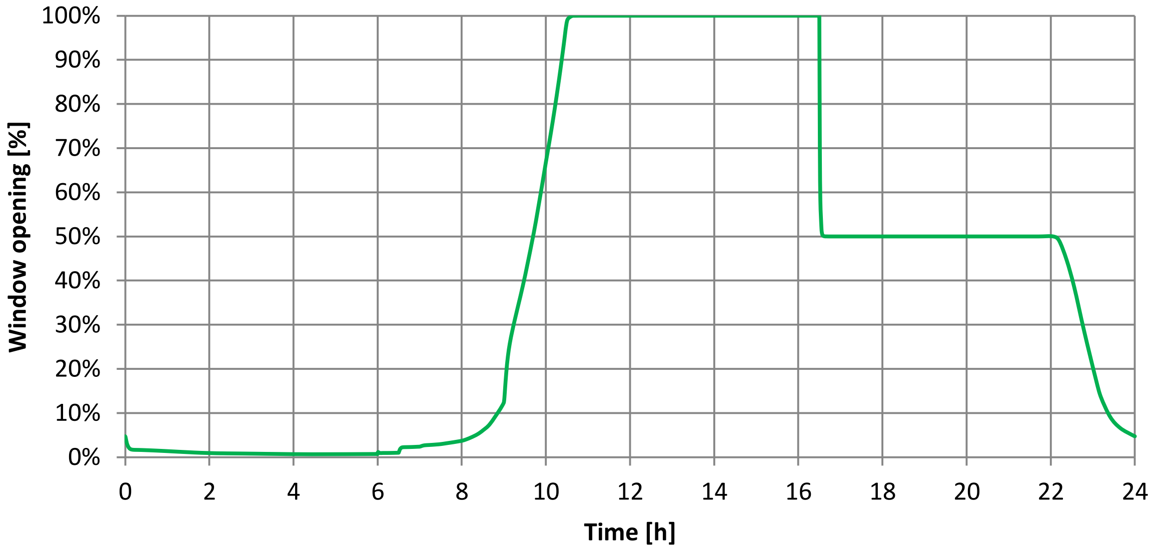

Figure 7.19: Degree of window opening for the operable windows in Agora throughout a day of moderate summer climate in the WindowMaster model.

7.3.2 Tyrihans

This sub-section consists of simulation results from Tyrihans throughout a day of moderate summer climate.

Figure 7.20 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

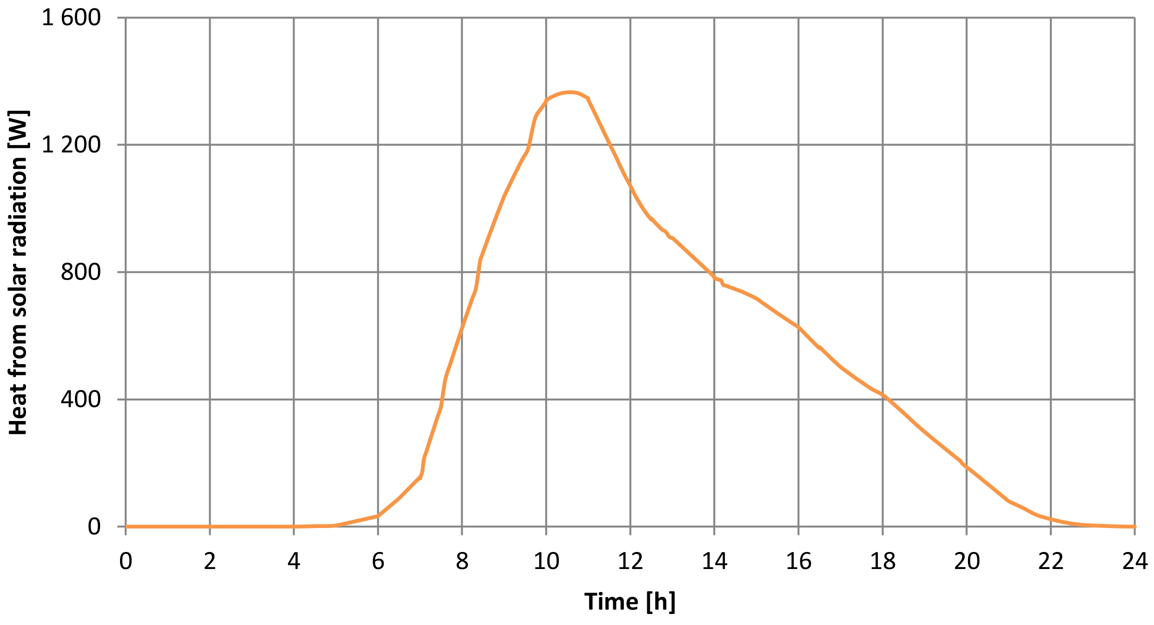

Figure 7.20: Heat gain to Tyrihans from solar radiation (direct and diffuse) throughout the simulated day of moderate summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.21. Note that the temperature curves for the two conventional models are completely identical and therefore overlapping.

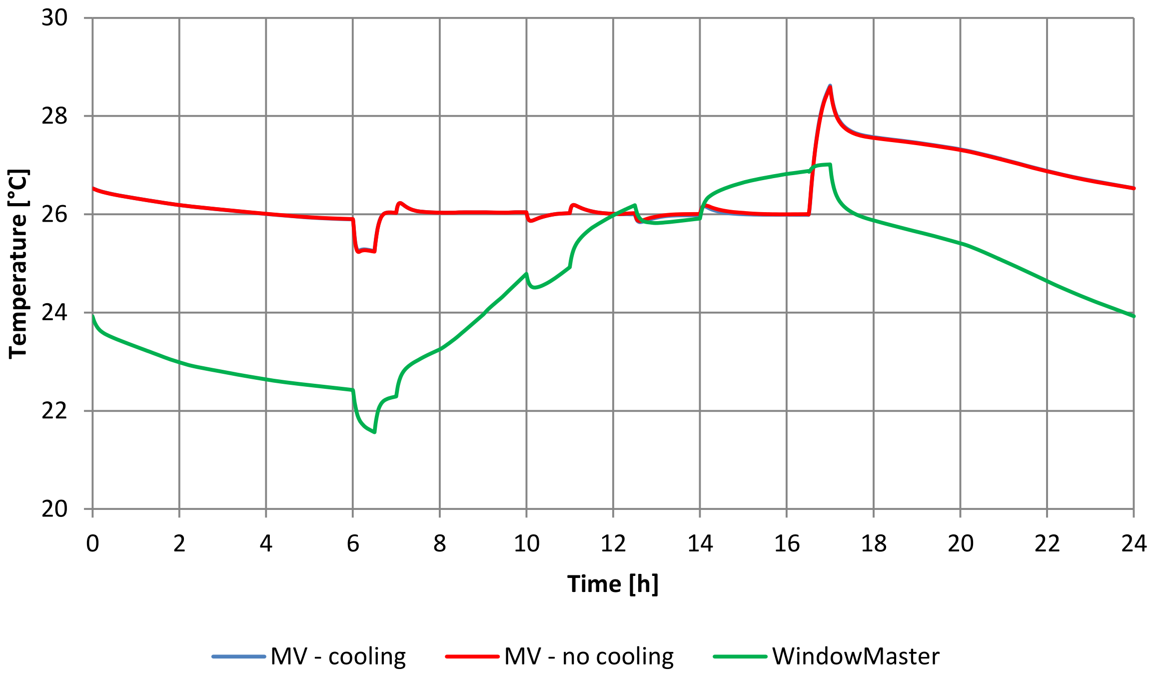

Figure 7.21: Mean indoor temperature distribution in Tyrihans for all three models throughout a day of moderate summer climate.

Figure 7.22 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

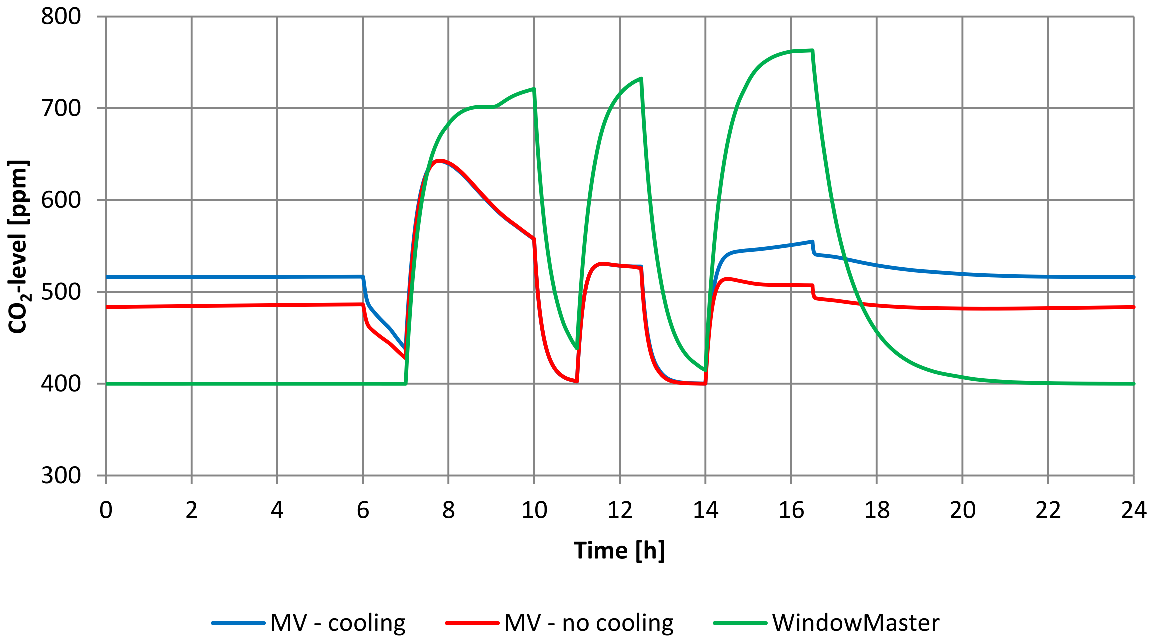

Figure 7.22: Mean CO_2-level distribution in Tyrihans for all three models throughout a day of moderate summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.23.

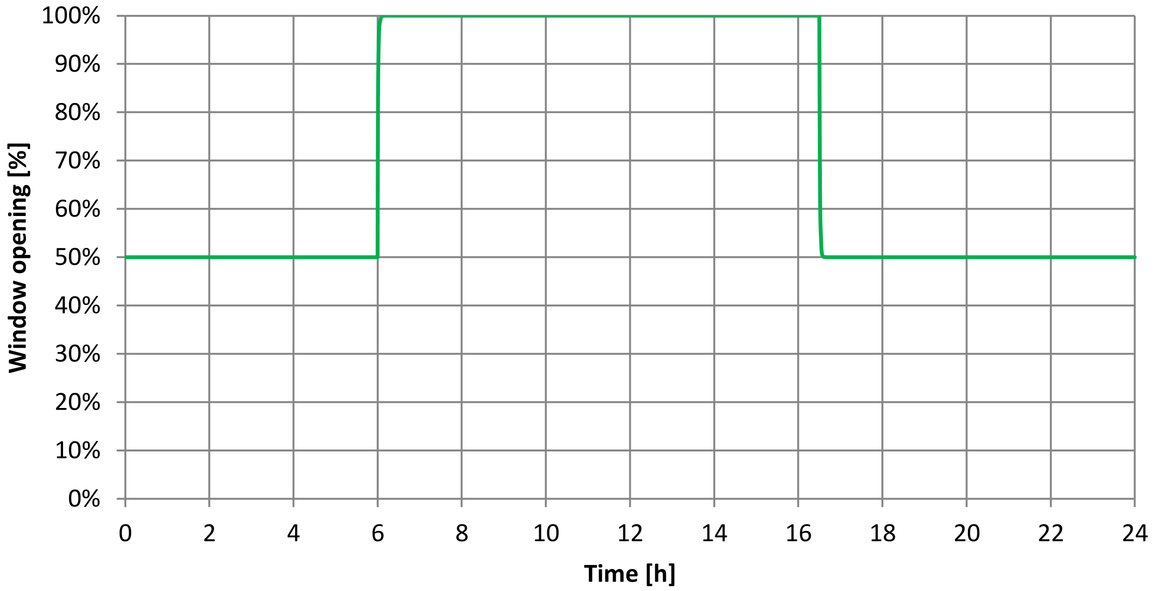

Figure 7.23: Degree of window opening for the operable windows in Tyrihans throughout a day of moderate summer climate in the WindowMaster model.

7.3.3 Office, management

This sub-section consists of simulation results from the management office throughout a day of moderate summer climate.

Figure 7.24 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

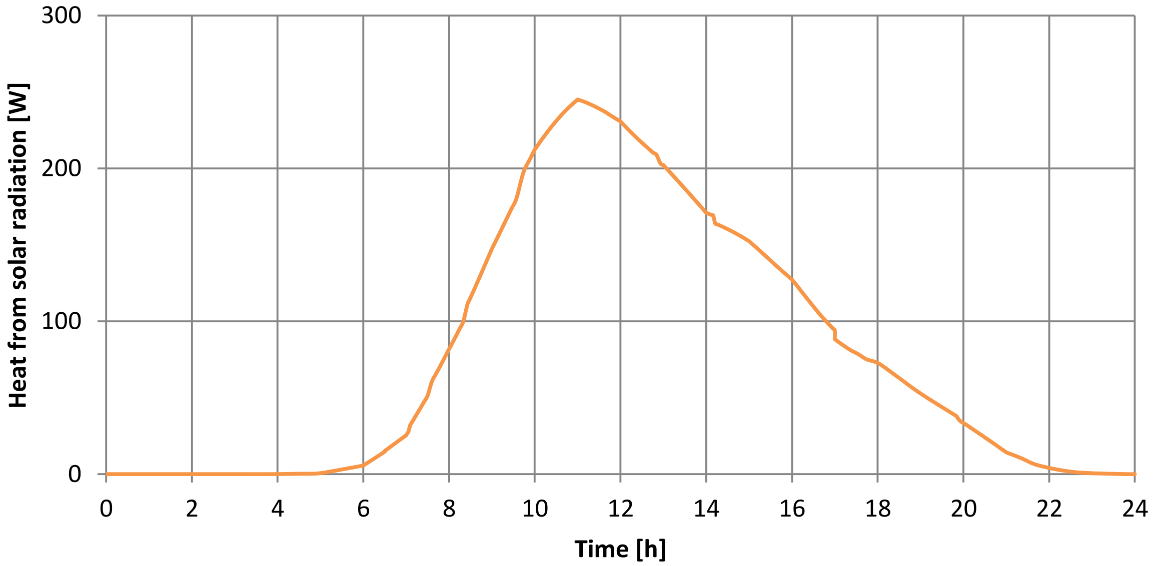

Figure 7.24: Heat gain to management office from solar radiation (direct and diffuse) throughout the simulated day of moderate summer climate.

The mean indoor temperature distribution in the zone for all three models throughout the simulated day is presented in Figure 7.25.

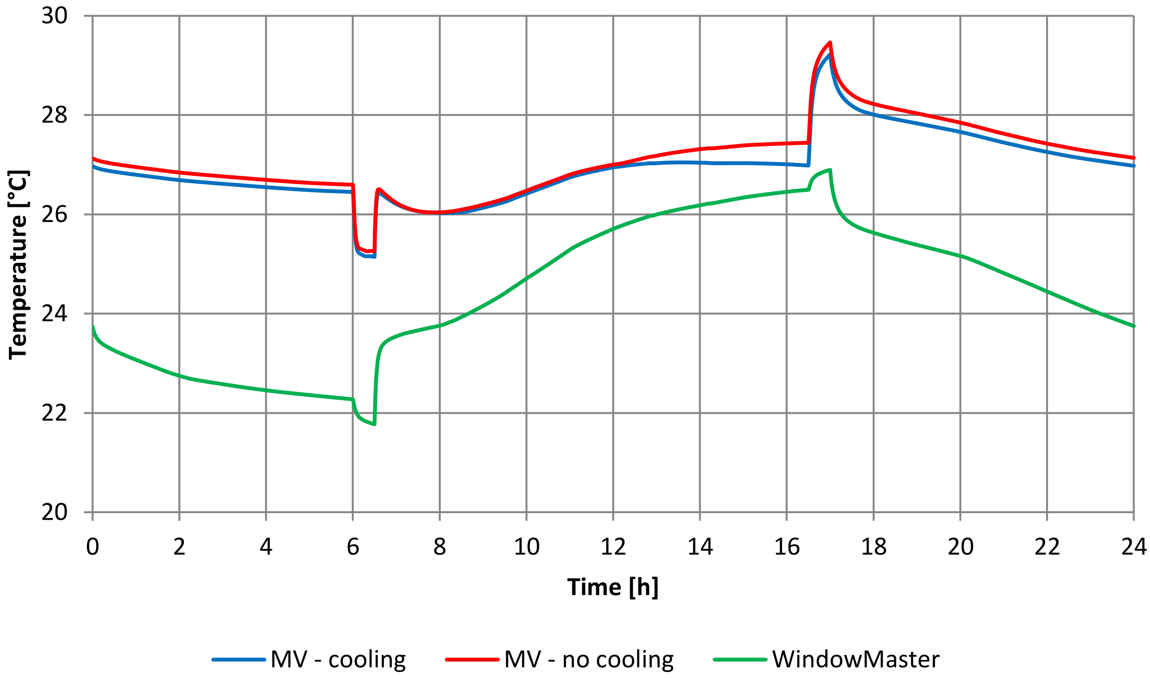

Figure 7.25: Mean indoor temperature distribution in management office for all three models throughout a day of moderate summer climate.

Figure 7.26 presents the mean CO_2-level distribution in the zone throughout the simulated day for all three models.

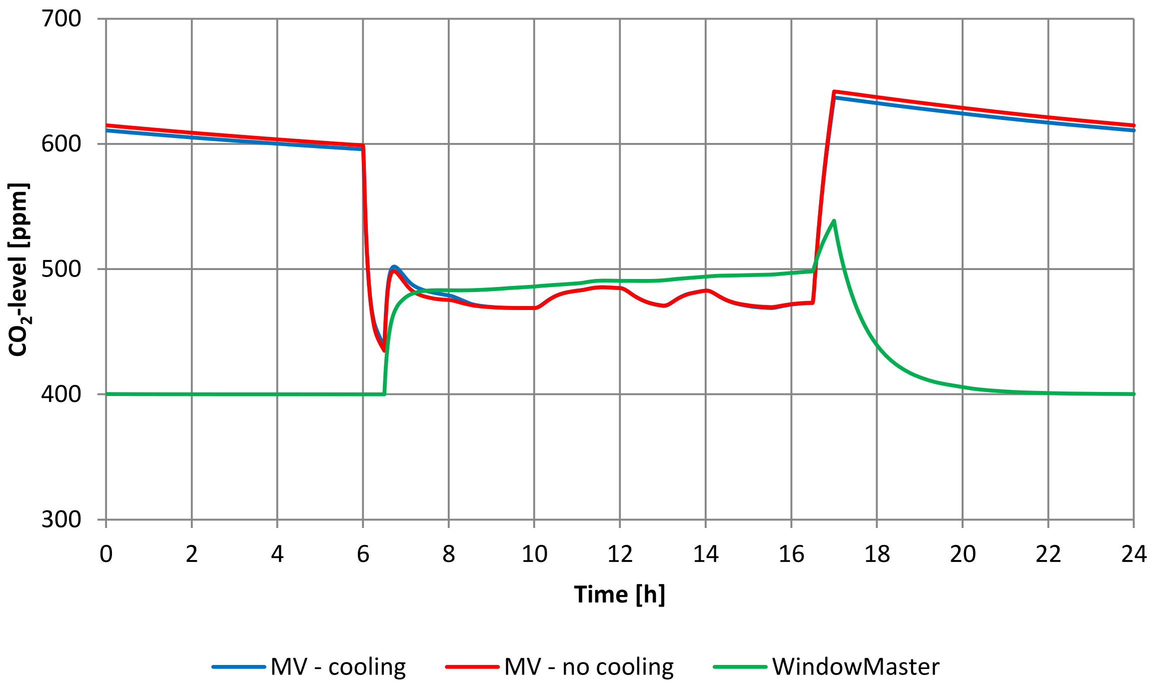

Figure 7.26: Mean CO_2-level distribution in management office for all three models throughout a day of moderate summer climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.27.

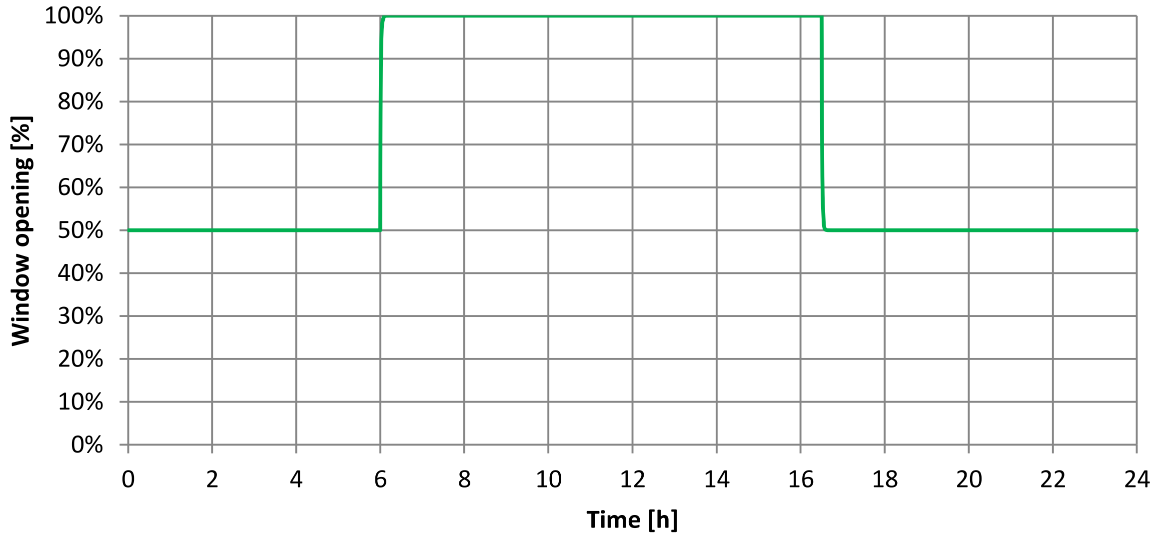

Figure 7.27: Degree of window opening for the operable windows in Tyrihans throughout a day of moderate summer climate in the WindowMaster model.

7.4 Synthetic winter climate

This section present the results of simulations performed during a day with synthetic winter climate. Outdoor temperature distribution throughout the simulated day is presented in Figure 7.28.

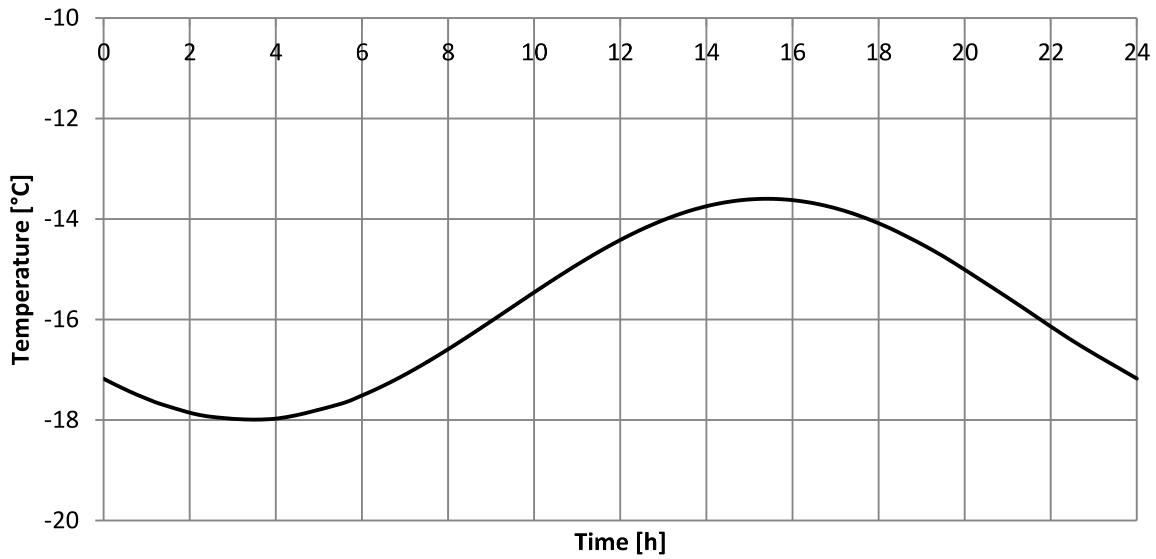

Figure 7.28: Outdoor temperature distribution throughout a day of synthetic winter climate.

As there is no cooling demand during the winter season, the two conventional models generate the exact same results and therefore will be presented only as one set of data named MV.

7.4.1 Agora

This sub-section consists of simulation results from Agora throughout a day of synthetic winter climate.

Figure 7.29 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

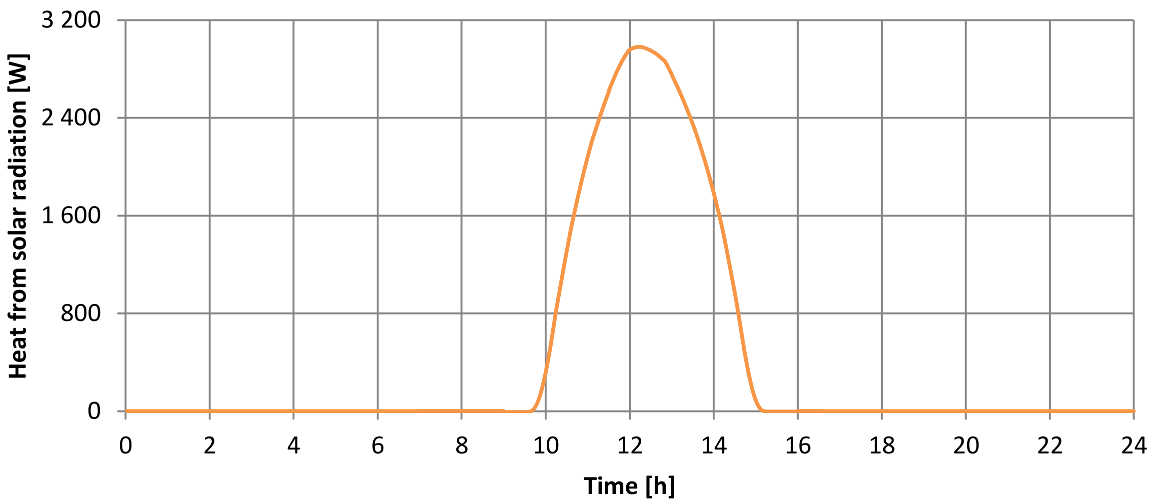

Figure 7.29: Heat gain to Agora from solar radiation (direct and diffuse) throughout the simulated day of synthetic winter climate.

The mean indoor temperature distribution in the zone for all models throughout the simulated day is presented in Figure 7.30.

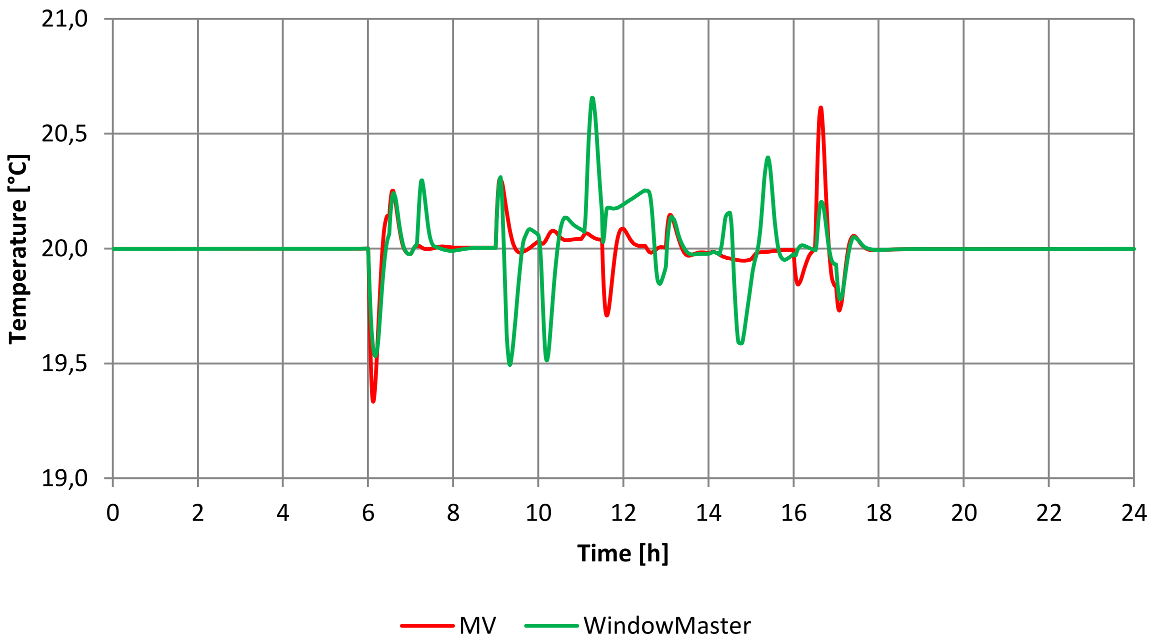

Figure 7.30: Mean indoor temperature distribution in Agora for all models throughout a day of synthetic winter climate.

Figure 7.31 presents the mean CO_2-level distribution in the zone throughout the simulated day for all models.

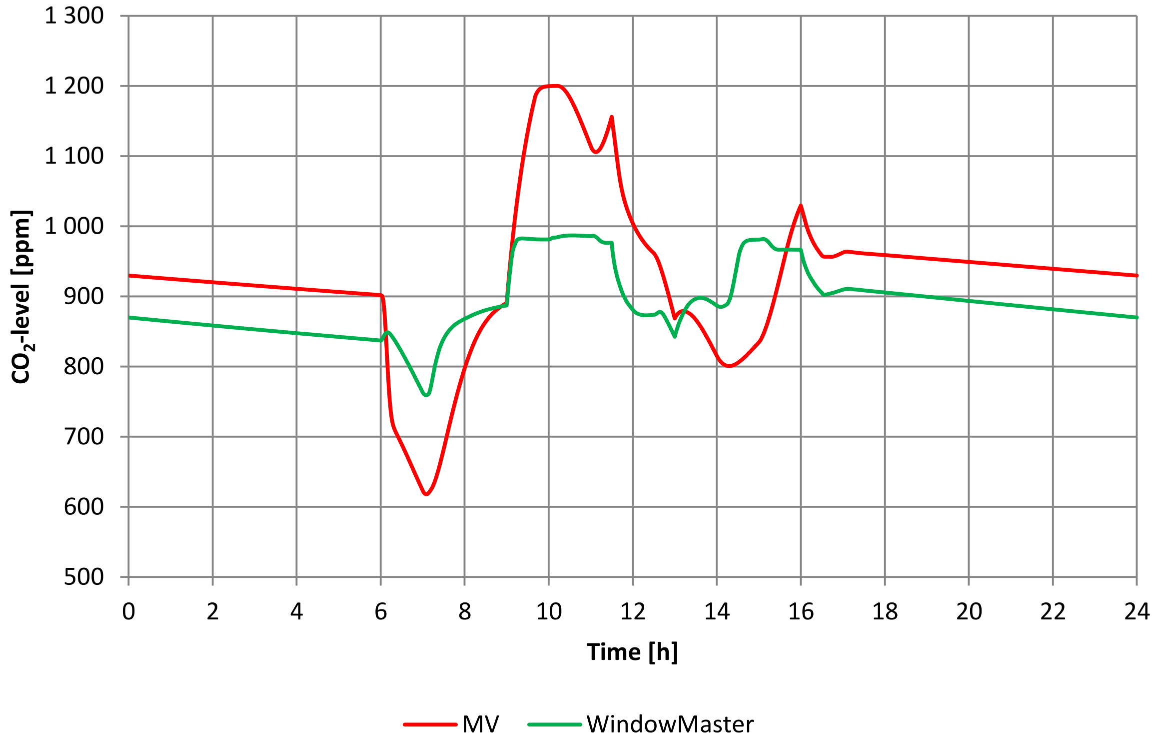

Figure 7.31: Mean CO_2-level distribution in Agora for all models throughout a day of synthetic winter climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.32.

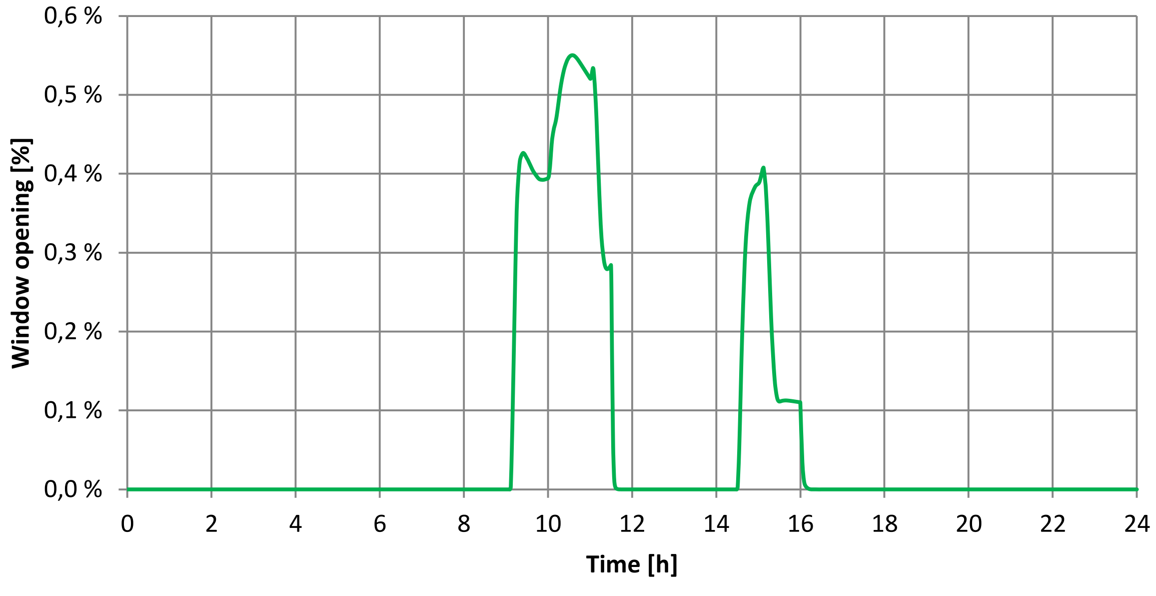

Figure 7.32: Degree of window opening for the operable windows in Agora throughout a day of synthetic winter climate in the WindowMaster model.

7.4.2 Tyrihans

This sub-section consists of simulation results from Tyrihans throughout a day of synthetic winter climate.

Figure 7.33 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

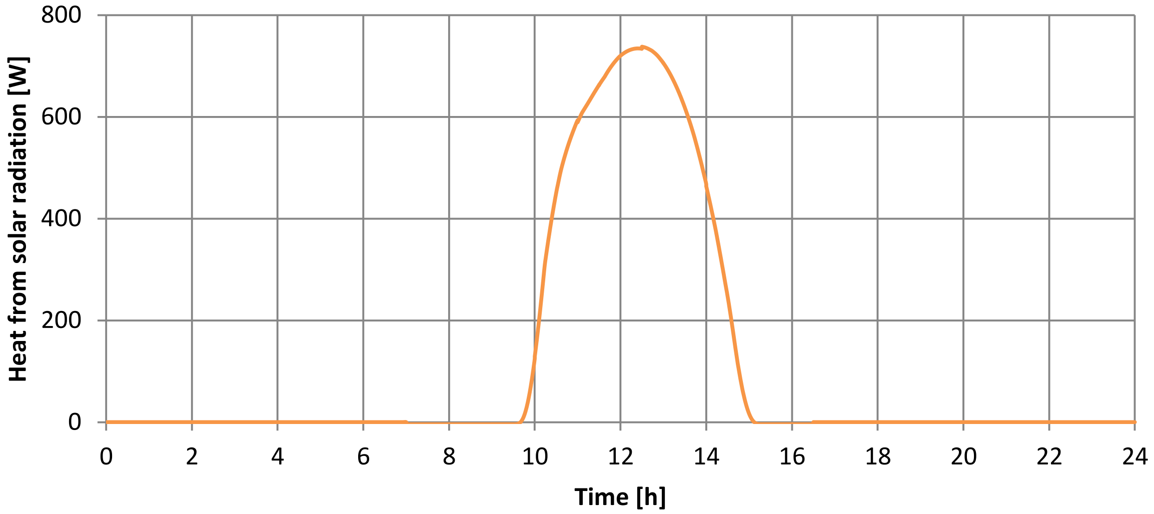

Figure 7.33: Heat gain to Tyrihans from solar radiation (direct and diffuse) throughout the simulated day of synthetic winter climate.

The mean indoor temperature distribution in the zone for all models throughout the simulated day is presented in Figure 7.34.

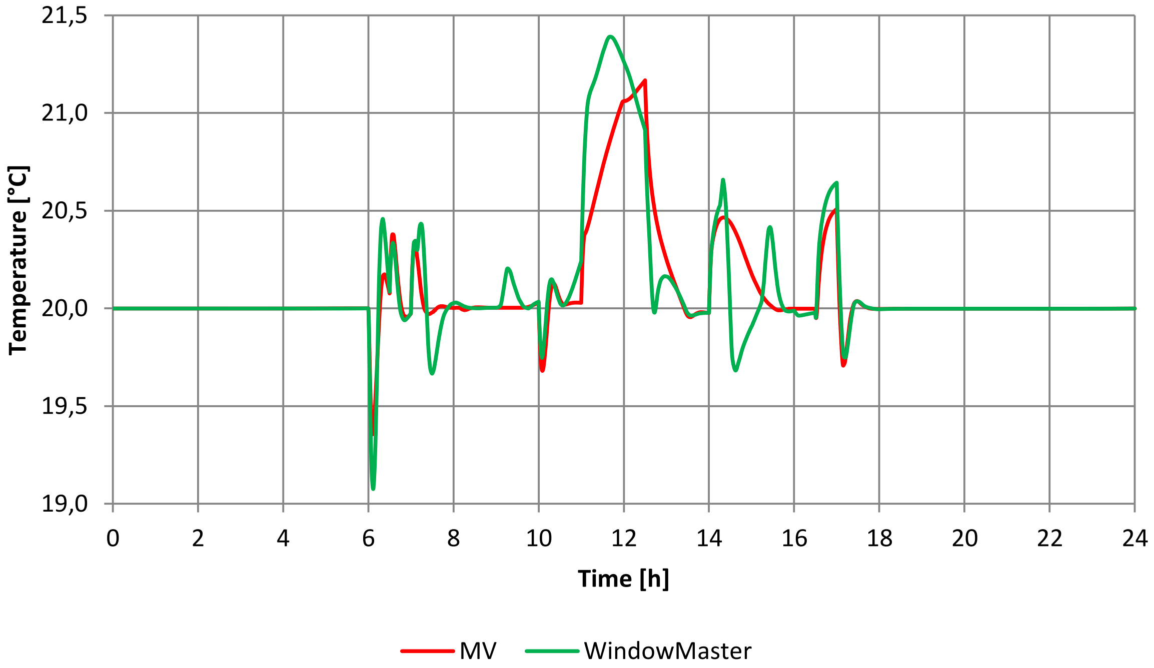

Figure 7.34: Mean indoor temperature distribution in Tyrihans for all models throughout a day of synthetic winter climate.

Figure 7.35 presents the mean CO_2-level distribution in the zone throughout the simulated day for all models.

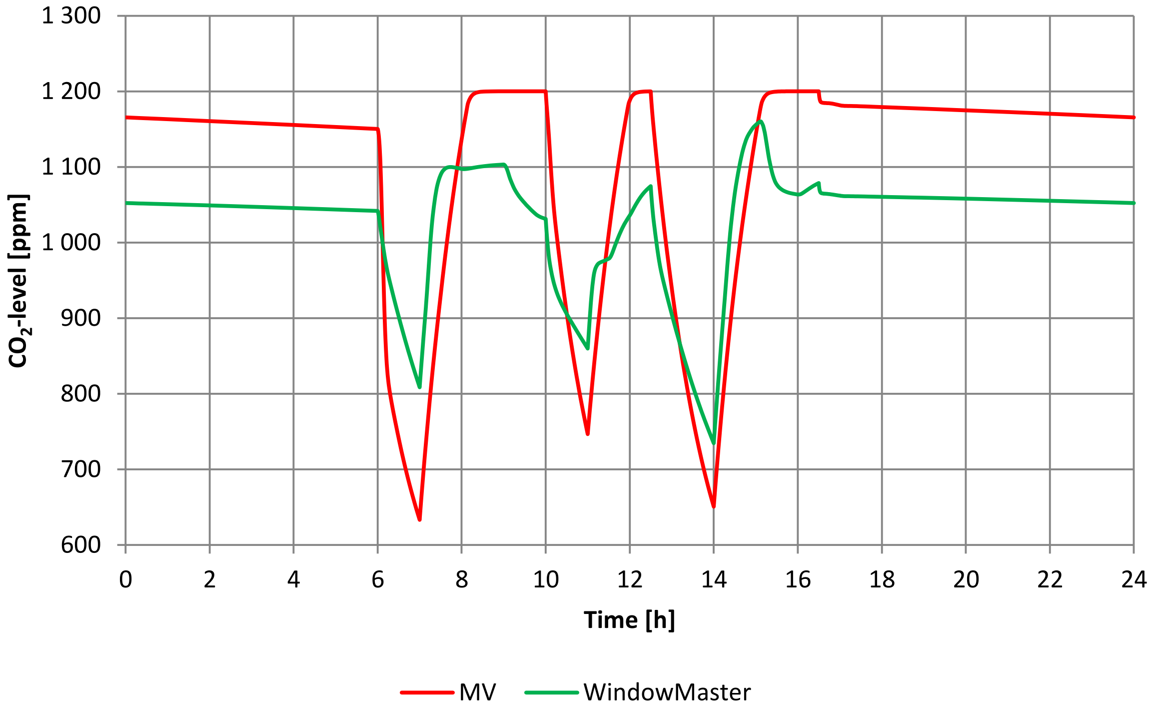

Figure 7.35: Mean CO_2-level distribution in Tyrihans for all models throughout a day of synthetic winter climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.36.

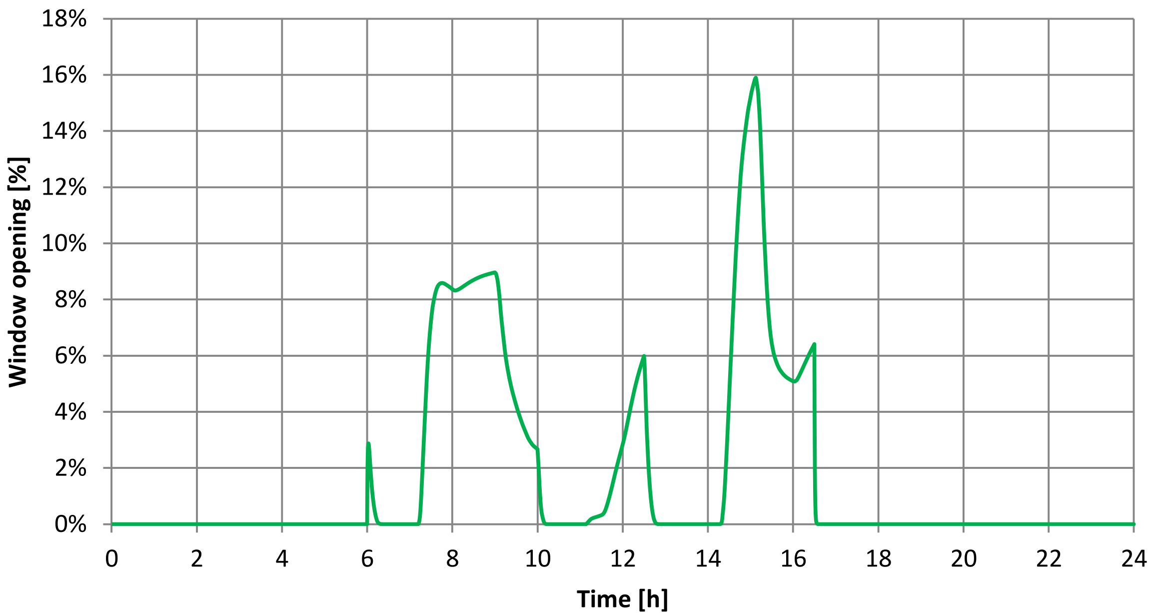

Figure 7.36: Degree of window opening for the operable windows in Tyrihans throughout a day of synthetic winter climate in the WindowMaster model.

7.4.3 Office, management

This sub-section consists of simulation results from the management office throughout a day of synthetic winter climate.

Figure 7.37 shows the amount of heat from solar radiation (direct and diffuse) the zone is subjected to throughout the simulated day.

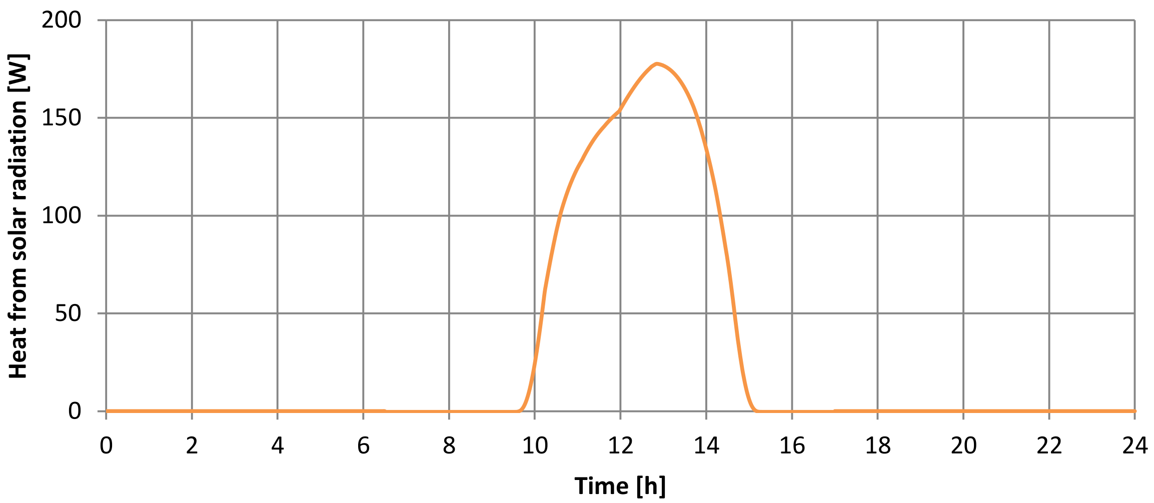

Figure 7.37: Heat gain to management office from solar radiation (direct and diffuse) throughout the simulated day of synthetic winter climate.

The mean indoor temperature distribution in the zone for all models throughout the simulated day is presented in Figure 7.38.

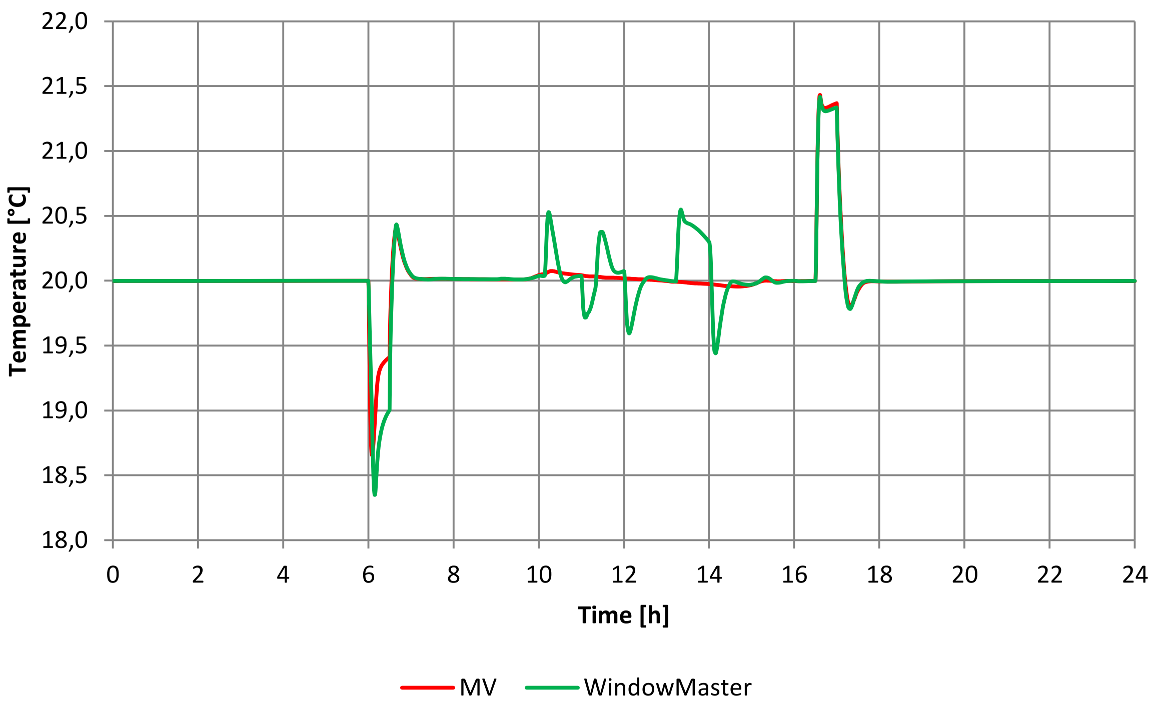

Figure 7.38: Mean indoor temperature distribution in management office for all models throughout a day of synthetic winter climate.

Figure 7.39 presents the mean CO_2-level distribution in the zone throughout the simulated day for all models.

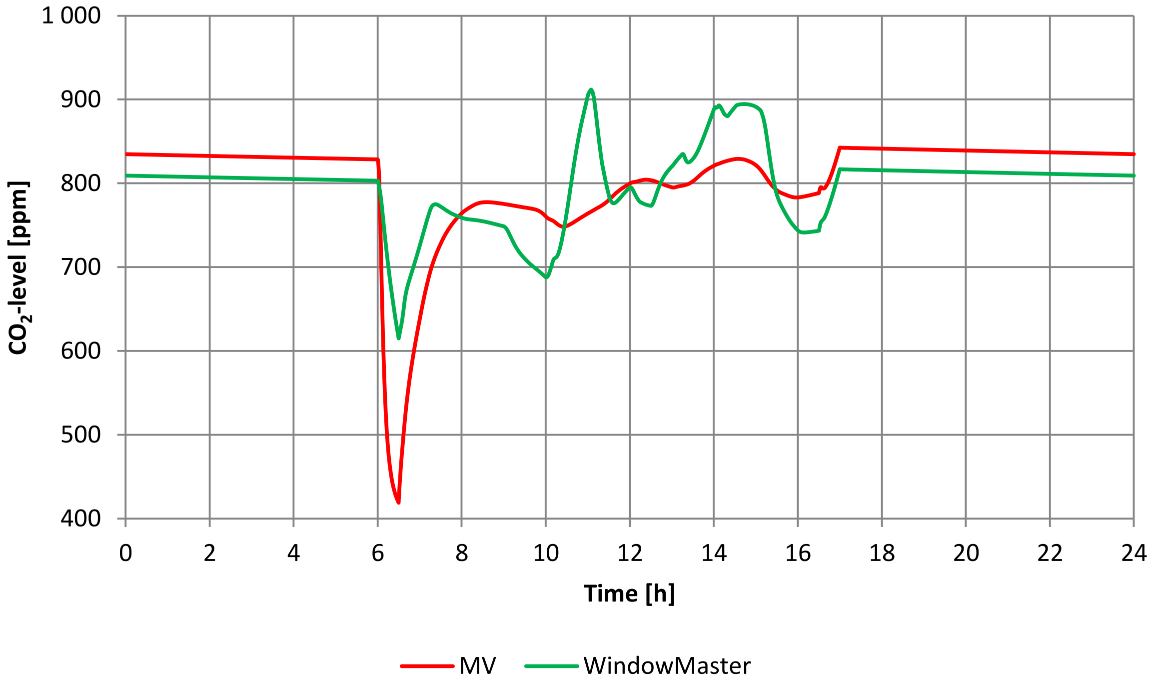

Figure 7.39: Mean CO_2-level distribution in management office for all models throughout a day of synthetic winter climate.

The degree of window opening for the operable windows in the zone throughout the simulated day in the WindowMaster model is presented in Figure 7.40.

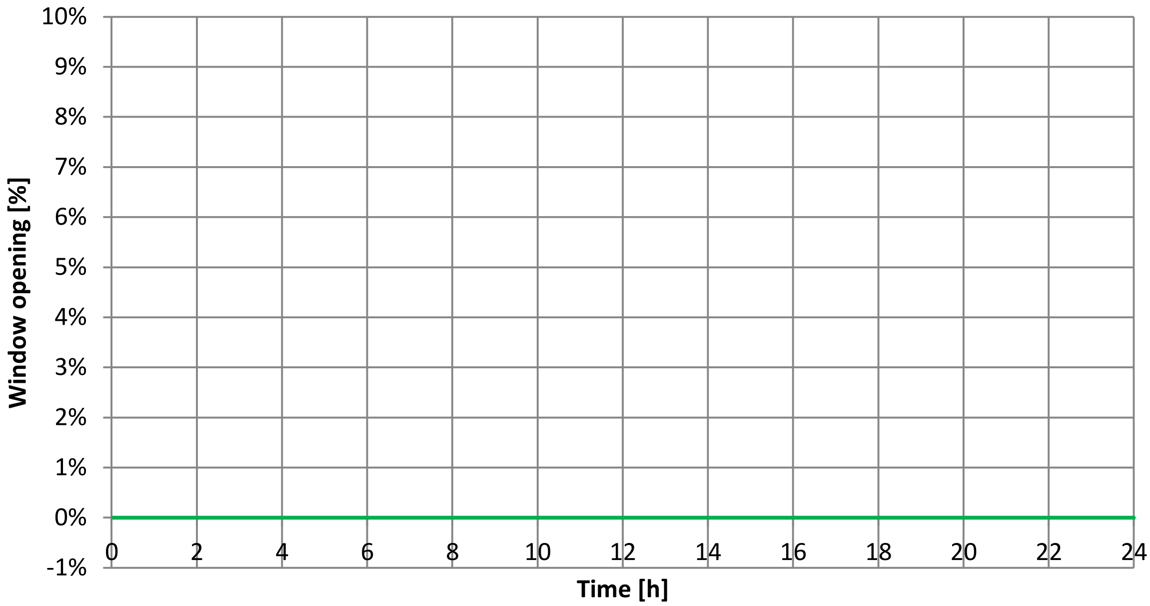

Figure 7.40: Degree of window opening for the operable windows in management office throughout a day of synthetic winter climate in the WindowMaster model.

8 Discussion

When evaluating a mixed-mode ventilation solution like the one present at Solstad kindergarten, there are several benefits, and some drawbacks, compared to that of a conventional mechanical ventilation solution. First off, adaptive thermal comfort theory suggests that people are more tolerant to fluctuation in interior conditions when they are provided with some degree of personal control. This suggests that a ventilative cooling system utilizing window ventilation from operable windows has a wider comfort range to operate within, which would also make thermal comfort easier to sustain.

It is believed that an intelligent ventilative cooling solution starts with an intelligent design including adequate solar shading and limitation of internal heat gains as well as implementing thermal mass through night-time ventilation strategies. This entails that the strategy should be on the agenda early in the design phase so that smart solutions can be integrated from day one.

Ridding excess heat by natural window ventilation has the potential of increasing air flow rates in the zone of occupancy above that of comfort. However, these solutions have the potential to benefit from the heightened air velocities. It is stated in NS-EN ISO 7730 [13] that under summer conditions, the temperature can be increased above the level allowed for comfort if a means is provided to also elevate the air velocity. This is also supported by research and experiments, however, if utilized the occupants will have the need for personal control of the thermal conditions

A solution like the one present at Solstad is not considered applicable everywhere. Constant opening of windows at sites with high degrees of outdoor pollution and noise, for instance in an urban city area, would not benefit the indoor environment.

8.1 Model validation

To validate the WindowMaster model up against the real case scenario proved a difficult task as the model contains several well-known flaws and weaknesses compared to the real life case. The reason for this is difficulties along with software limitations causing problems when emulating the actual control strategies in IDA ICE. The end result is some degree of accurate operation, a series of compromises, and some parts of the operation being completely left out of the model. Also, actual setpoints for the system may have been altered during the time the thesis was conducted.

This aside, a comparison between the real case and the model have been conducted in order to see if there are any trends to be observed.

Figure 8.1 shows a comparison of the monthly energy consumption measured for the real case in 2012 and 2013 along with the simulated energy consumption of the WindowMaster model.

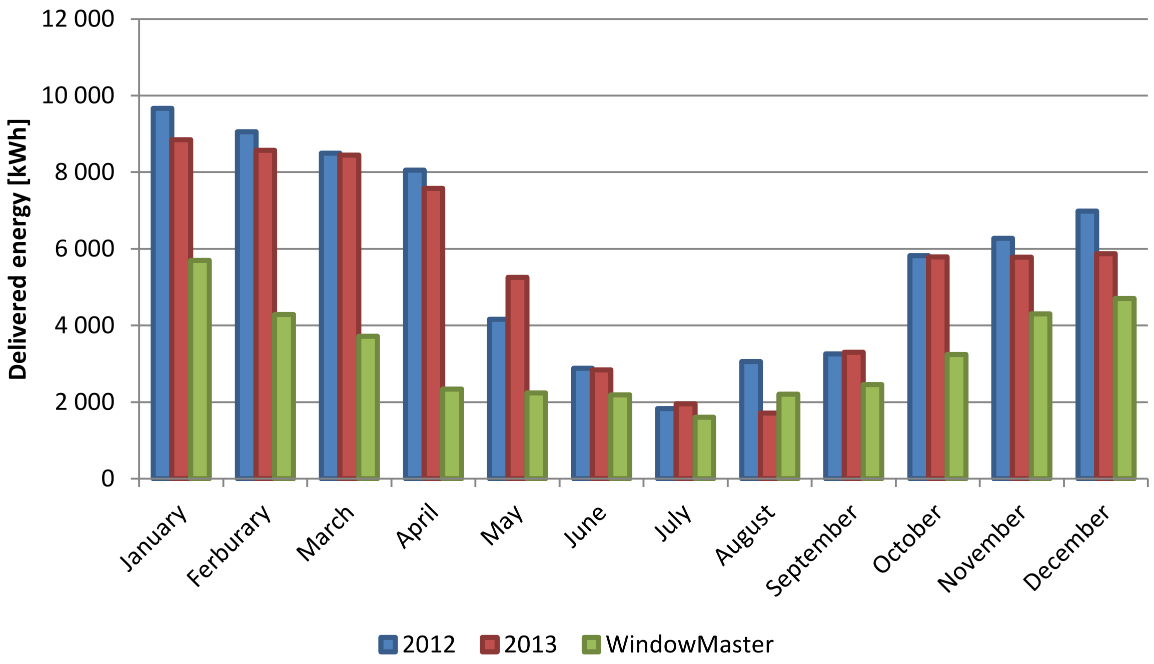

Figure 8.1: Comparison between monthly simulated energy consumption for the WindowMaster model and measured energy consumption for 2012 and 2013.

As can be seen in the figure, energy consumption is far less for the WindowMaster model during all months of operation. When comparing the breakdown of the energy consumption for the actual system, listed in Table 5.3, and the simulated energy consumption for the WindowMaster model, listed in Table 7.1, the most notable differences are in the posts regarding HVAC auxiliary and electric heating. The other posts are quite similar though this is no surprise as consumption related to lighting, equipment and hot water is highly user defined in IDA ICE. A possible explanation for the lack of resemblance regarding electric heating is the set efficiency of the heating system. The simulated heating demand without regards to the efficiency is 31 308 kWh, not too far off the net heating demand listed in Table 5.3. Also, the heat load for the simulated model might be unrealistically high as the combination of equipment and lighting in the simulated model is set to match that in the electric post of the delivered energy in Table 5.3.

Regarding HVAC auxiliary, the heating system might yet again be a source of error. As the heating system is greatly simplified in the simulation model, the electricity related to pump operation may be unrealistically low. Also, there might be differences in the SFP for the fans, and the mechanical system in the simulated model might have fewer operating hours than what is the real life case. However, the difference in the HVAC auxiliary post is still the most significant when comparing the two situations.

Another source for error is that the kindergarten is also sometimes used outside operating hours. At this time the system is set in an operating mode designed for such cases. This is not taken into account during simulations.

A comparison of the indoor climate for the real and simulated case has also been conducted. In an attempt to validate the model, logged data from the actual system for a summer day matching that of the simulated day of moderate summer climate was gathered. The data was obtained from the WindowMaster control system at Solstad. Outdoor temperature distribution during the selected day is shown in Figure 8.2.

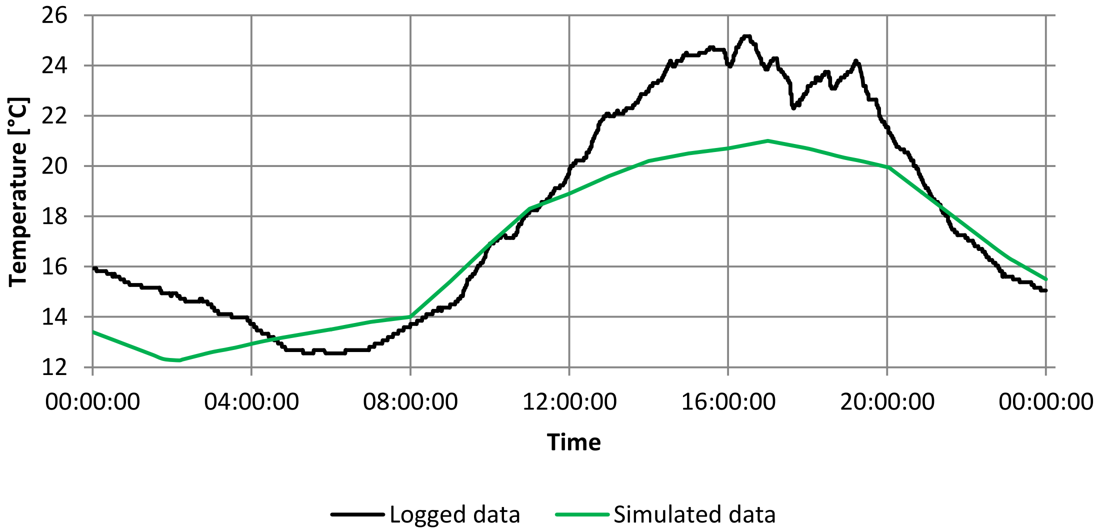

Figure 8.2: Logged outdoor temperature distribution at Solstad during May 19. 2014 and simulated outdoor temperature distribution in moderate summer climate.

It can be seen in the figure that the outdoor temperature distribution matches reasonably well with the simulated day though the maximum temperatures are a fair bit higher.

Logged and simulated indoor temperature distribution during the selected day is shown in Figure 8.3.

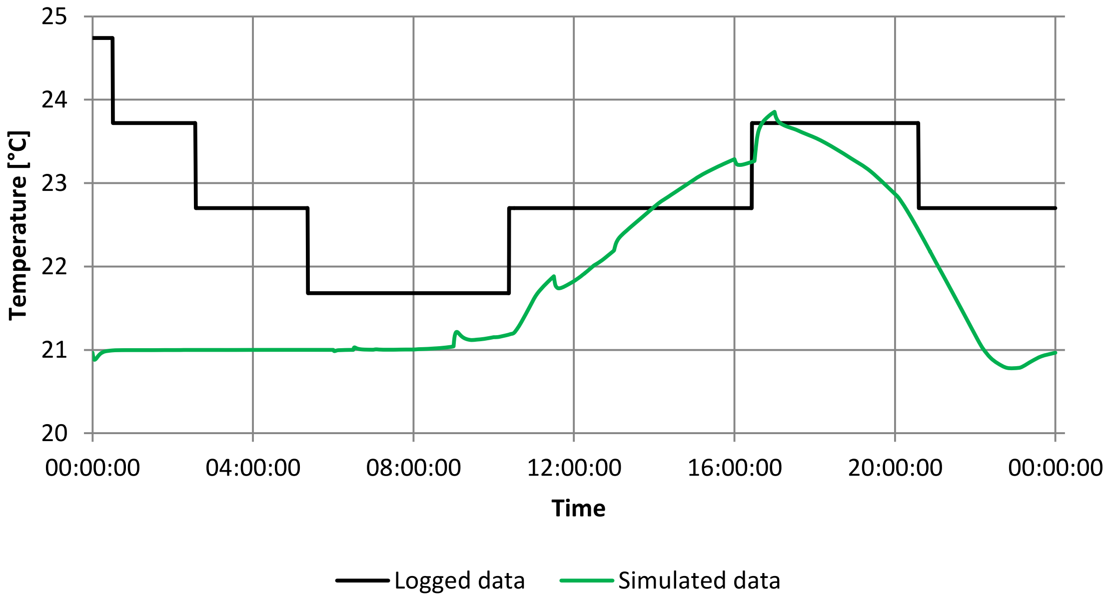

Figure 8.3: Logged indoor temperature distribution for Agora during May 19. 2014 and simulated indoor temperature distribution for Agora in moderate summer climate.

When looking at the indoor temperature distribution, some similarities can be seen. Especially that the indoor temperature rises at a similar rate, and up to a similar temperature during the afternoon. The initial conditions for the simulated and measured day are however very different. The indoor temperature from the logged data is way higher than the simulated temperature. When performing a one day simulation, the initial condition is an extension of the end conditions, but for the logged data, the temperature is dependent on the day before. In this case, the day before was a Sunday, meaning no operation, and with a reasonably high outdoor temperatures, it is expected that the indoor temperature becomes fairly high.

The logged and simulated distribution of CO_2-levels during the selected day is shown in Figure 8.3.

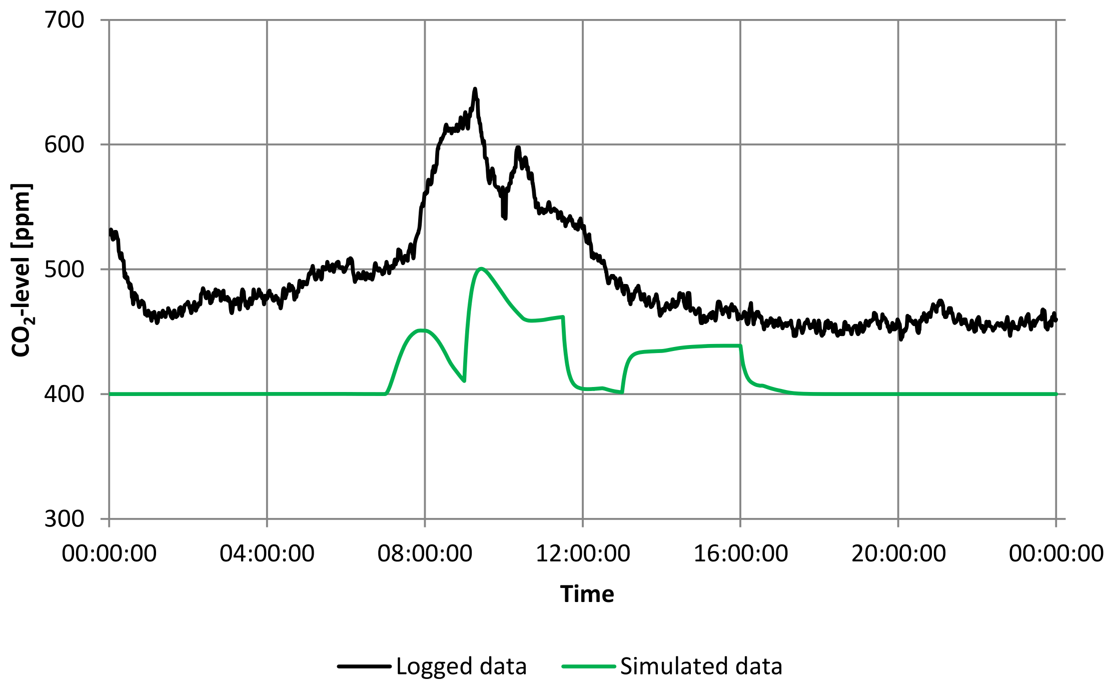

Figure 8.4: Logged CO_2-level distribution for Agora during May 19. 2014 and simulated CO_2-level distribution for Agora in moderate summer climate.

Measured CO_2-levels illustrate a similar trend to that of the simulated CO_2-levels with a peak around 10:00. However, the simulated CO_2-level is in average approximately 100 ppm lower. This could be a result of differences between outdoor CO_2-levels for the measured and simulated case.

Figure 8.5 shows the simulated and logged degree of window opening throughout the selected day.

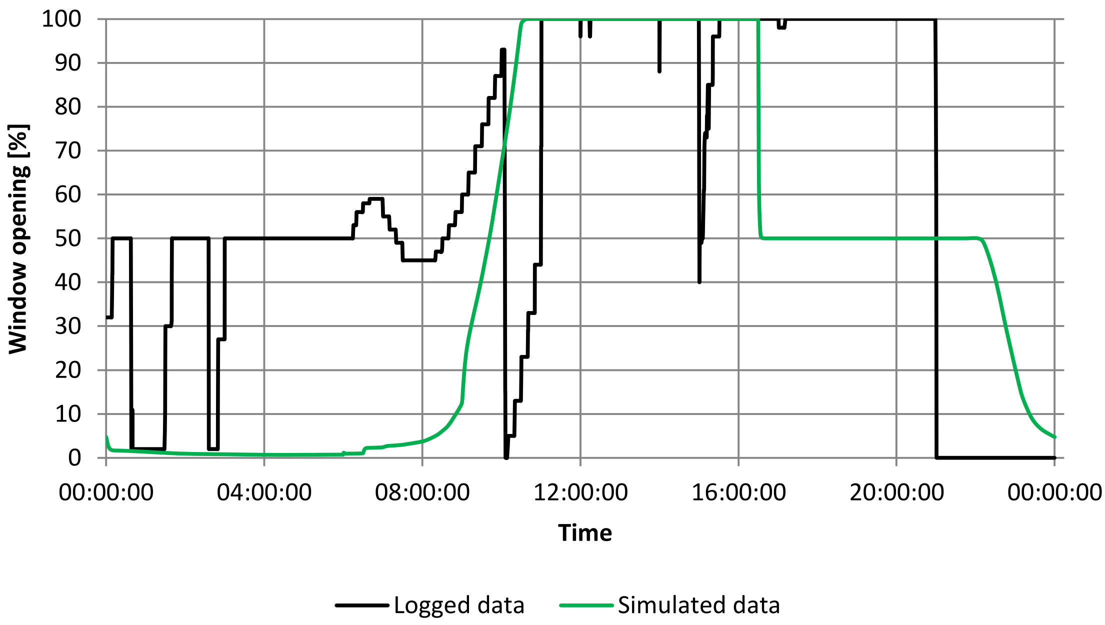

Figure 8.5: Logged window opening for the southward facing windows of Agora during May 19. 2014, and simulated window opening for Agora during a day of moderate summer climate.

When looking at the window openings, it I clear that the night before the measured day, the kindergarten utilized night-time ventilation. Besides this, the window operation for both the measured and simulated operation show several similar trends, for instance increasing to maximum opening a little before noon. One difference is that the logged window opening stays at 100 % after operating hours, but is limited in the control scheme of the simulation model to 50 %. This is also the case for most windows in the real scenario, but apparently not for the selected window logged here. This could explain the window closing a bit before that in the simulated model.

When looking at the data presented, there are several similar trends between the actual system and the simulated system, however, it is still a known fact that there are some significant differences between the two cases.

8.2 Simulation results

When evaluating the simulation result presented in Chapter 7, several trends and conclusions can be extracted.

Analysis of the energy consumption shows that the WindowMaster model's total annual energy consumption is approximately 14 % lower than that of the conventional models. The main difference is in the post of HVAC auxiliary. This is natural as fan operation in the WindowMaster model is limited compared to the conventional models. The WindowMaster model has a slightly higher heating demand, but this makes sense because of periods of window operation even during the winter season.

An interesting point is that the total energy consumption for the two conventional solutions is almost exactly the same. The difference is that energy used for electric cooling in the model providing mechanical cooling, is moved to HVAC auxiliary for the model with no cooling.

When looking at the indoor climate, results from the synthetic summer climate simulation show that the WindowMaster solution provides lowest temperature for Agora, but also the highest temperature span during operating hours. Still, the temperature in the zone is above 26 °C for large portions of the occupant hours. It is however hard to sustain temperatures below 26 °C on a day as warm as is the case for the synthetic summer climate. The conventional solutions both suffer temperature above 26 °C for the entirety of the occupant hours, though the cooling solution fares a great deal better than the one without. In Tyrihans, the conventional solution with cooling is by far the best, almost keeping the 26 °C setpoint during the entire occupant hours. Here the other conventional solution also fares better than the WindowMaster model providing both a lower indoor temperature and temperature span during the entire hour of operation. In the management office, again the cooling solution proves to be the best, but now the WindowMaster solution is slightly better than the plain mechanical solution. CO_2-levels are within a more than acceptable range for all solutions in all zones during synthetic summer simulation. When looking at the window operation, windows operate at maximum opening all the time for the WindowMaster model, making it reasonable to think that high air velocities could be experienced in the zones.

For the moderate summer climate simulations, the WindowMaster model shows the most promise in regards to temperature for all zones, though it once again provides higher degrees of temperature variations throughout the day. It does however paint an unfair image, as the WindowMaster solution will initiate cooling operation once indoor temperatures exceed 21 °C, while for the conventional solutions this won’t be initiated until indoor temperatures reach 26°C. However, the conventional solution only manages to sustain a temperature of 26 °C in Tyrihans, and initiating cooling operation at lower indoor temperatures would further increase the energy consumption. Naturally, the solution that provides supply air cooling fares slightly better than the one that doesn’t. Also during moderate summer climate, all solutions provide more than acceptable CO_2-levels. This provide support to ventilation air flow rates required in order to surpass heating loads often being higher than what is needed in order to obtain good indoor air quality in respect to pollutants. As it was for the synthetic summer climate, windows are also now at maximum opening at almost all times in the WindowMaster model.

During simulations in synthetic winter climate, the indoor temperature stays in the region of the setpoint value for the heating system (20 °C) for all zones. There is however a little more temperature fluctuation for the WindowMaster solution as a result of small degrees of window operation. The simulations show fairly high CO_2-levels for all zones, but they are all within the setpoint values. As expected, there is little to no window operation during this simulation.

Overall, it seems that the Solstad solution have little problems in satisfying an acceptable air quality, at least not in regards to CO_2-levels. When looking at the thermal environment and the indoor temperature it can be seen that for really warm days, it is hard to keep acceptable temperatures without the use of mechanical cooling. This is as expected because of heat removal by air being highly dependent on the temperature difference between supply air and room air. However, for moderate summer climates, the Solstad solution looks to outperform that of conventional solutions in terms of temperature and energy consumption. The exception is that larger temperature spans are experienced during the hours of occupancy.

8.3 Economic aspects

Evaluating the economic aspects for solutions such as the on at Solstad up against a conventional ventilation solution is hard to investigate, and no actual numbers have been gathered for this purpose in the thesis. However, some thoughts have been made around the subject.

Steiger [28] performed a study comparing natural, mechanical and hybrid ventilation systems in school buildings through simulations. Calculation of the total investment of the different systems including maintenance, operation (electricity and heating) and capital costs (products and installation) showed that in the first year, mechanical ventilation was found to be 2.5 to 4 times more expensive than natural ventilation. By selecting hybrid ventilation, 25 % of the total investment could be saved compared to a mechanical system. Hybrid ventilation enabled 44 – 52 % energy savings compared to mechanical ventilation, and fan electricity could be reduced by 75 % for hybrid ventilation compared to mechanical ventilation. The calculations were performed for Munich, Copenhagen and London.

Steiger's study is however not thought to be very applicable for the Solstad solution, at least not in terms of total investment. The systems investigated by Steiger was a mechanical system with three smaller decentralized air handling units, a natural ventilation system with operable windows similar to that at Solstad, and a hybrid solution being a mix of both. The Solstad solution however, consists of two fully fledged systems each capable of doing a decent ventilation job on its own; one natural and one mechanical. Looking at Steiger's study, it would entail that the cost of the natural system comes on top of the costs of the mechanical system making the Solstad solution (when utilizing Steiger's numbers) 1.25 times more expensive in terms of investment compared to the conventional mechanical counterpart.

Also, having two whole systems would increase the costs for maintenance and operation, as well as the possible need for more advanced control systems. Another aspect is that hybrid solutions might place larger demands on the building design possibly increasing the costs in this phase as well.

Simulation results show that there are potential annual energy savings for the WindowMaster system compared to a conventional solution. Not in as high a region as for Steiger's study, but the question will be whether or not these annual saving can justify the increased investment and maintenance cost when viewed over a reasonable period of time.

It is also possible to argue that if the Solstad solution provide better indoor climate than a mechanical system, less sick days might be expected. This is however hard to evaluate.

8.4 Future work

As it is already stated, the WindowMaster simulation model has several well-known flaws, and also compromises have been made in the control scheme design phase. Naturally, this part of the model has a potential for improvement, both in expanding the control allowing fresh air pulses and taking the outdoor wind conditions in to account, and developing a night-time ventilation strategy a little closer to the real life case.

Also, the heating system of the model has not been prioritized to great extents. Here, there is much room for improvement, and this could possibly help in getting more accurate results regarding energy consumption.

When it comes to thermal climate and air quality, the only parameters considered have been indoor temperature and CO_2-levels. It would however be interesting to look at other aspects where the solution could alter the indoor climate. Air velocities in the zone of occupancy while windows are open are considered of much interest.

The economic aspect of it all has not been mapped very thoroughly. This is a result of it being hard to determine actual numbers, and it not being the main focus in the thesis. It would be interesting to gather real economic numbers, for real life projects, both conventional and similar to the Solstad Solution in order to make a more thorough comparison.

9 Conclusion

As part of an overall aim to evaluate whether ventilative cooling solutions is applicable for schools and kindergartens in Norwgian climate, a practical approach consisting of a thorough case study of Solstad kindergarten in Larvik, Norway, has been conducted. The investigations involved looking at the Solstad solution as a whole, and not just the ventilative cooling aspect of it. Key points of interest were a comparison against a more conventional mechanically ventilated counterpart, and elements considered were energy consumption, indoor climate as well as economics. As a tool in the process, indoor climate and energy simulations were performed utilizing the computer software, IDA ICE, and in order to investigate the indoor climate, indoor temperature and CO_2-levels were utilized as the defining measure in regards to thermal comfort and air quality.

Looking at the theory indicates that ventilative cooling solutions like the one at Solstad have several benefits, including high degrees of user influence which has, on several points, been proven to increase occupant adaptability making them tolerant to higher temperatures as well as a larger degree of temperature fluctuation.

The model created in order to emulate the Solstad solution consists of several well-known flaws, and compromises have been made in the design of the control strategies. It is however considered good enough in evaluating trends regarding indoor climate and energy consumption.

Simulation result indicate a solution like that present at Solstad could cut the annual energy consumption by as much as 14 % compared to a conventional solution, making the operation slightly cheaper than its all mechanical counterpart. However, it is thought that installation and maintenance of a mixed-mode system such as the one studied, is more expensive seeing that it consists of two separate, fully fledged systems working in combination. Overall, it seems that the Solstad solution have little problems in satisfying an acceptable air quality, at least not in regards to CO_2-levels. When looking at the thermal environment and indoor temperatures, it can be seen that for really warm days, it is hard to keep acceptable temperatures without the use of mechanical cooling. This is as expected because of heat removal by air being highly dependent on the temperature difference between supply and room air. However, for moderate summer climates, the Solstad solution looks to outperform that of conventional solutions in terms of temperature and energy consumption. The exception is that larger temperature spans are experienced during the hours of occupancy. It is however thought that high air velocities as a result of window opening can have a severe impact on the thermal environment for a solution such as this.

When looking at Solstad kindergarten as a whole, it has already shown it is a viable solution for schools and kindergartens in Norway, and no results from this thesis have proved otherwise.

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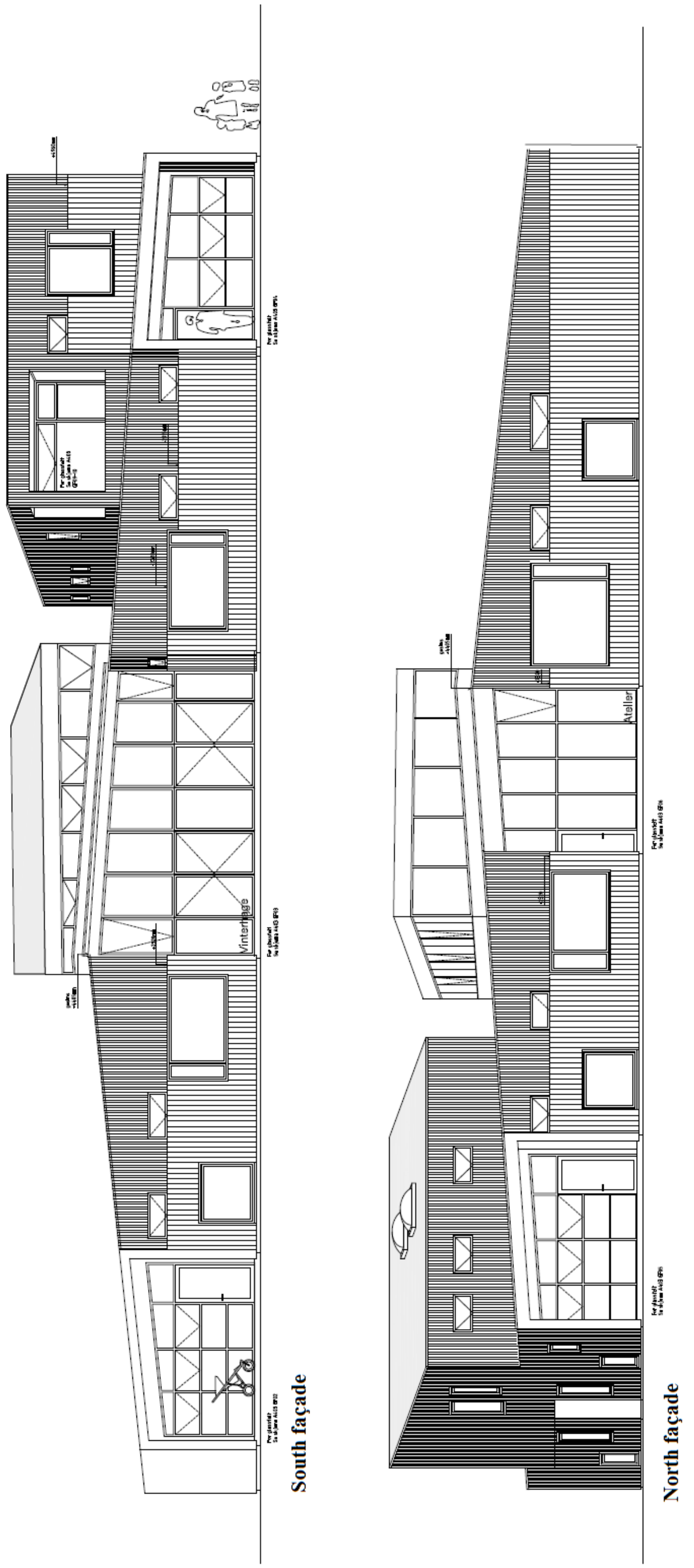
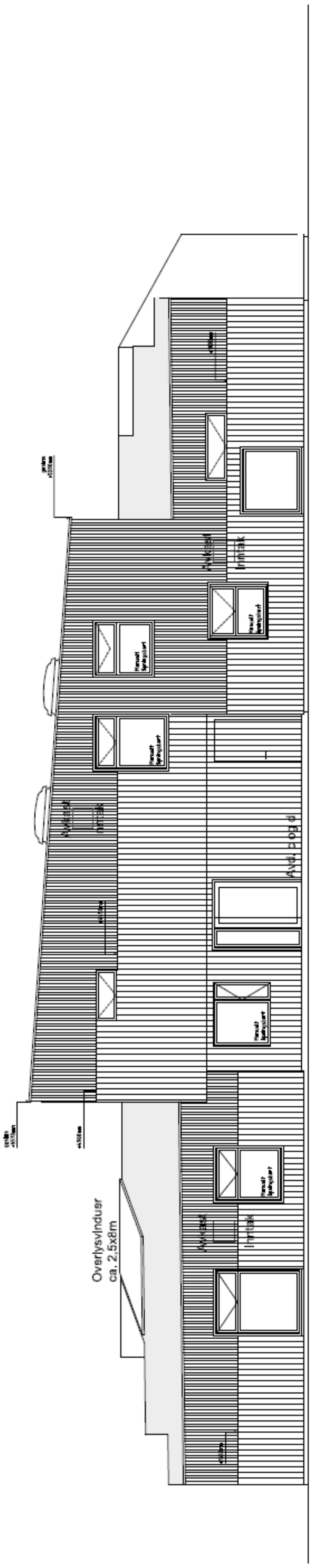
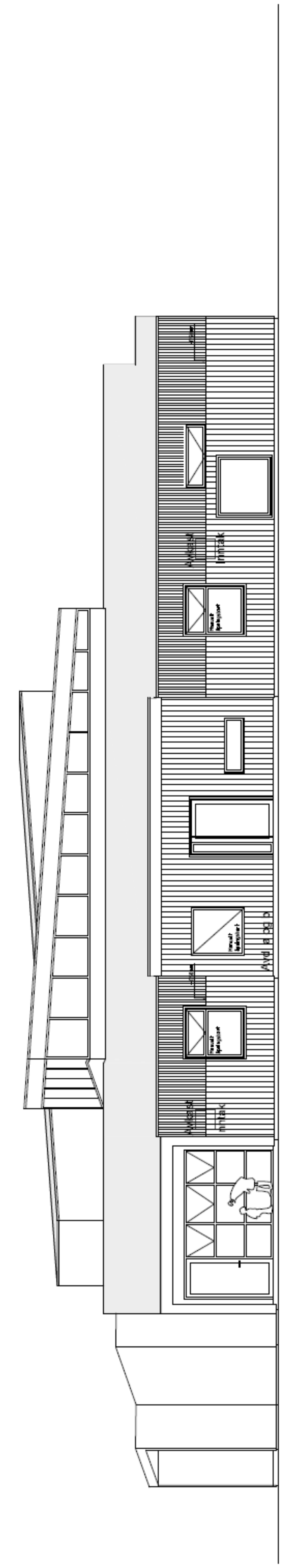
Appendix A – façade drawings





East façade



West façade

Appendix B – Simulation results (WindowMaster)

IDA Indoor Climate and Energy vers. 4.6

License: IDA40:ED172/S4D9E (educational license

Simulated by Yngvar Øgård

Date 06.06.2014 18:35:44 [9978]

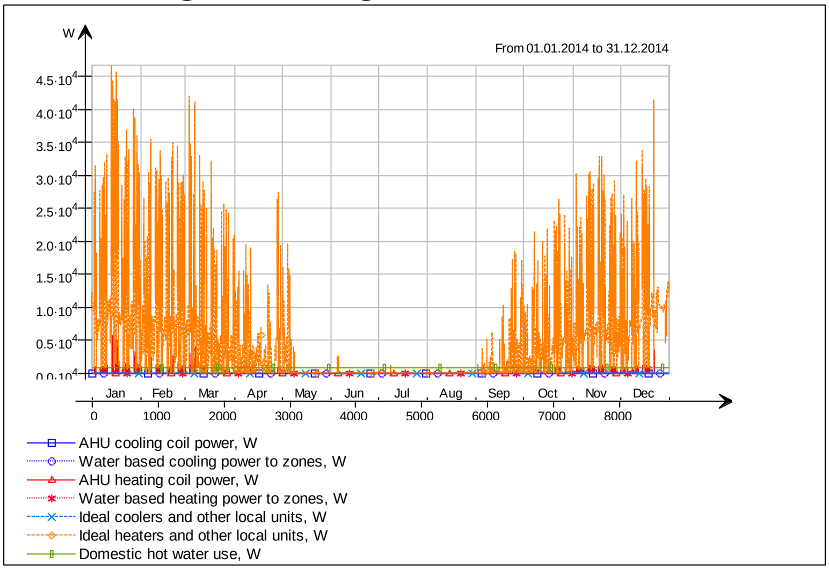
SIMULATION TECHNOLOGY GROUP

Project Data

Project name	Solstad WM
Customer	
Description	
Location	Oslo (Fornebu)
Climate	Climate file Oslo/Fornebu_ASHRAE
Simulation type	Whole-year energy simulation
Simulation period	01.01.2014 - 31.12.2014

Simulation results

Total heating and cooling



Delivered Energy Report

Building Comfort Reference

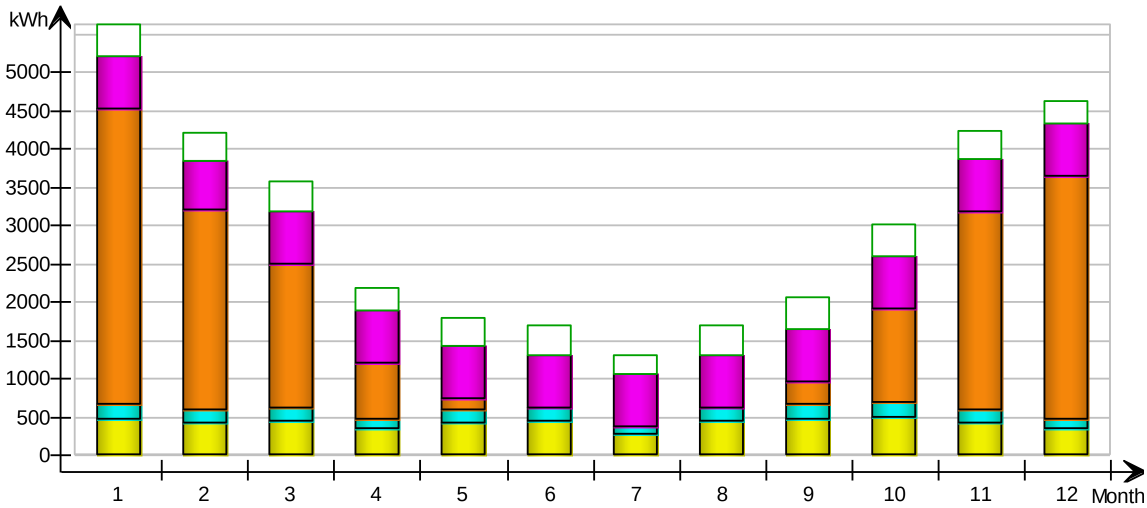
Percentage of hours when operative temperature is above 27°C in worst zone	3 %
Percentage of hours when operative temperature is above 27°C in average zone	1 %
Percentage of total occupant hours with thermal dissatisfaction	9 %

Delivered Energy Overview

		Delivered energy		Demand
		kWh	**kWh/m²**	**kW**
	Lighting, facility	4951	6.1	2.9
	Electric cooling	0	0.0	0.0
	HVAC aux	1970	2.4	0.82
	Electric heating	16555	20.3	20.41
	Total, Facility electric	23476	28.7	
	Domestic hot water	8177	10.0	0.93
	Total, Facility fuel*	8177	10.0	
	Total	31653	38.7	
	Equipment, tenant	4326	5.3	1.87
	Total, Tenant electric	4326	5.3	
	Grand total	35979	44.0	

*heating value

Monthly Delivered Energy



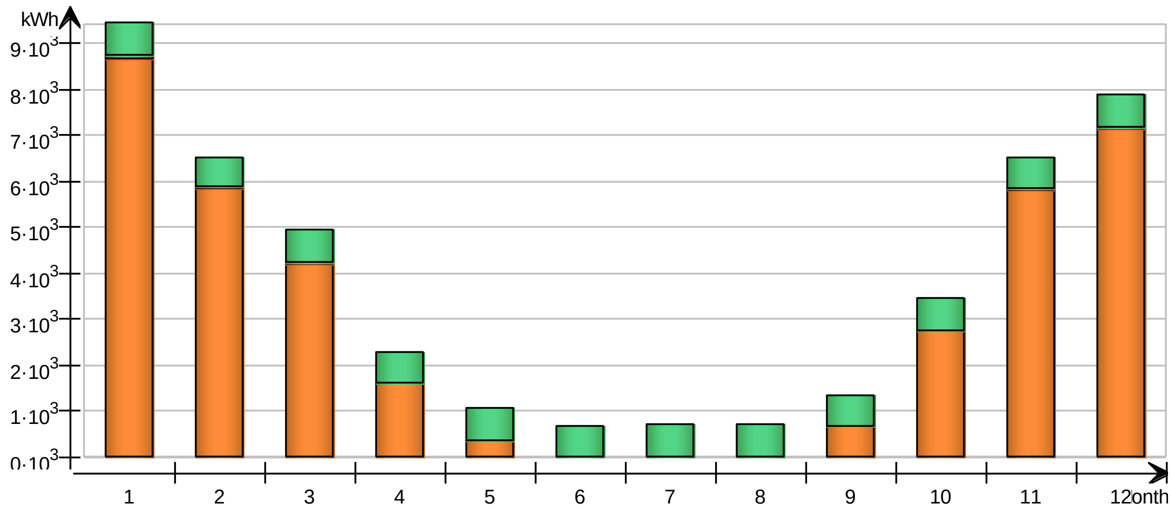
Month	Facility electric				Facility fuel (heating value)	Tenant electric
	Lighting, facility	**Electric cooling**	**HVAC aux**	**Electric heating**	**Domestic hot water**	**Equipment, tenant**
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	463.5	0.0	184.6	3872.0	694.5	405.0
2	421.3	0.0	167.8	2615.0	627.3	368.2
3	442.4	0.0	176.2	1883.0	694.5	386.6
4	337.1	0.0	134.2	726.2	672.1	294.6
5	421.3	0.0	167.5	151.4	694.5	368.2
6	442.4	0.0	175.8	1.9	672.1	386.6
7	273.9	0.0	108.8	0.3	694.5	239.3
8	442.4	0.0	175.7	0.2	694.5	386.6
9	463.5	0.0	184.3	305.1	672.1	405.0
10	484.5	0.0	192.9	1229.0	694.5	423.5
11	421.3	0.0	167.8	2587.0	672.1	368.2
12	337.1	0.0	134.2	3184.0	694.5	294.6
Total	4950.7	0.0	1969.8	16555.1	8177.2	4326.4

Systems Energy

Used energy

kWh (sensible and latent)

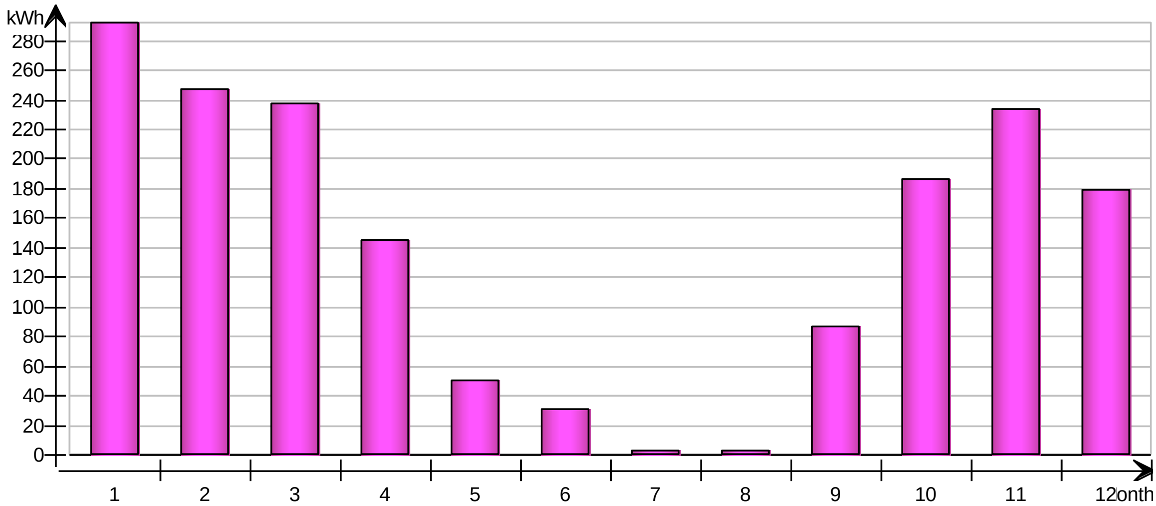
Month	Zone heating	Zone cooling	AHU heating	AHU cooling	Dom. hot water
1	8648.0	0.0	64.4	0.0	694.5
2	5852.0	0.0	32.3	0.0	627.3
3	4210.0	0.0	25.8	0.0	694.5
4	1626.0	0.0	8.0	0.0	672.1
5	339.2	0.0	1.5	0.0	694.5
6	4.1	0.0	0.3	0.0	672.1
7	0.4	0.0	0.2	0.0	694.5
8	0.3	0.0	0.2	0.0	694.5
9	683.8	0.0	2.6	0.0	672.1
10	2754.0	0.0	12.6	0.0	694.5
11	5794.0	0.0	26.4	0.0	672.1
12	7139.0	0.0	23.8	0.0	694.5
Total	37050.8	0.0	198.0	0.0	8177.2



Utilized free energy

kWh (sensible and latent)

Month	AHU heat recovery	AHU cold recovery	Plant heat recovery	Plant cold recovery	Solar heat	Ground heat	Ground cold	Ambient heat	Ambient cold
1	291.7	0.0							
2	246.7	0.0							
3	237.2	0.0							
4	144.7	-0.0							
5	49.6	-0.0							
6	30.6	-0.0							
7	2.2	-0.0							
8	2.3	-0.0							
9	86.6	-0.0							
10	186.2	0.0							
11	233.5	0.0							
12	178.6	0.0							
Total	1689.8	-0.0							



Generated electric energy

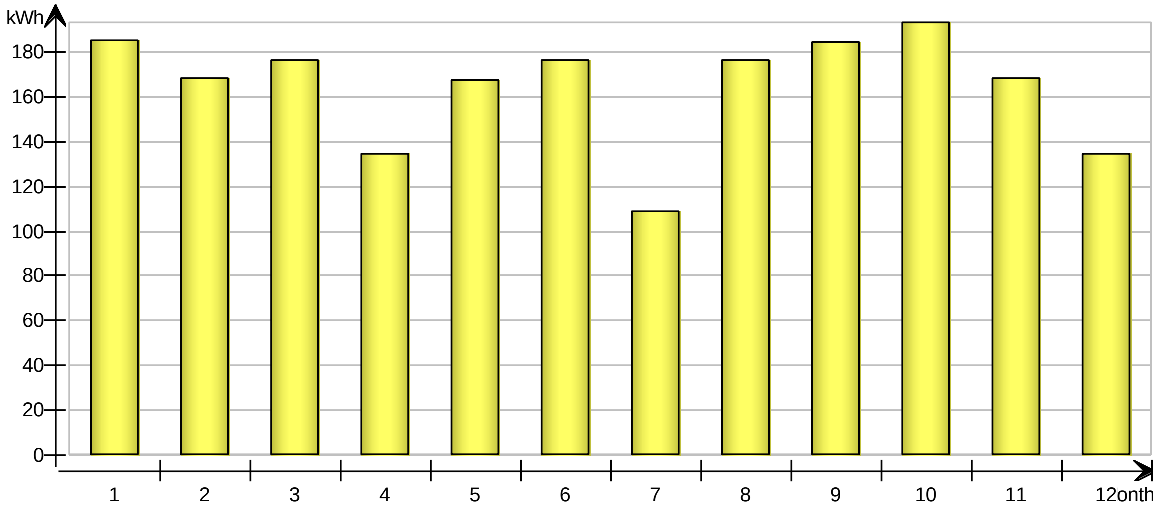
kWh

Month	Solar (PV)	Wind turbine	CHP
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Total			

Auxiliary energy

kWh

Month	Humidification	Fans	Pumps
1		184.5	0.0
2		167.8	0.0
3		176.1	0.0
4		134.2	0.0
5		167.4	0.0
6		175.8	0.0
7		108.8	0.0
8		175.7	0.0
9		184.3	0.0
10		192.9	0.0
11		167.8	0.0
12		134.2	0.0
Total		1969.6	0.1



Input data Report

Wind driven infiltration airflow rate			731.508 l/s at 50.000 Pa	
Building envelope	**Area [m²]**	**U [W/(K m²)]**	**U*A [W/K]**	**% of total**
Walls above ground	424.93	0.18	76.49	16.73
Walls below ground	0.00	0.00	0.00	0.00
Roof	716.11	0.11	78.77	17.23
Floor towards ground	716.15	0.05	32.62	7.13
Floor towards amb. air	18.13	0.18	3.26	0.71
Windows	170.52	0.92	156.88	34.31
Doors	25.90	0.99	25.69	5.62
Thermal bridges			83.53	18.27
Total	2071.74	0.22	457.24	100.00

Thermal bridges	Area or Length	Avg. Heat conductivity	Total [W/K]
External wall - Internal slab	48.17 m	0.005 W/(K m)	0.241
External wall - Internal wall	83.76 m	0.005 W/(K m)	0.419
External wall - External wall	27.37 m	0.060 W/(K m)	1.642
Window perimeter	601.50 m	0.020 W/(K m)	12.030
External door perimeter	65.90 m	0.020 W/(K m)	1.318
Roof - External wall	176.48 m	0.070 W/(K m)	12.354
External slab - External wall	154.00 m	0.080 W/(K m)	12.320
Balcony floor-External wall	3.59 m	0.100 W/(K m)	0.359
External slab - Internal wall	185.08 m	0.005 W/(K m)	0.925
Roof - Internal wall	206.98 m	0.005 W/(K m)	1.035
External wall - Inner corner	0.00 m	0.000 W/(K m)	0.000
Total envelope	2071.49 m²	0.020 W/(K m²)	40.885
Extra losses	-	-	0.001
Sum	-	-	83.528

Windows	Area [m²]	U Glass [W/(K m²)]	U Frame [W/(K m²)]	U Total [W/(K m²)]	U*A [W/K]	Shading factor g
N	42.64	0.80	2.00	0.92	39.23	0.68
ENE	9.90	0.80	2.00	0.92	9.11	0.68
E	13.96	0.80	2.00	0.92	12.85	0.68

SSE	2.53	0.80	2.00	0.92	2.33	0.68
S	55.08	0.80	2.00	0.92	50.67	0.68
W	28.03	0.80	2.00	0.92	25.79	0.68
NNW	2.88	0.80	2.00	0.92	2.65	0.68
R	15.50	0.80	2.00	0.92	14.26	0.68
Total	170.52	0.80	2.00	0.92	156.88	0.68

Air handling unit	Pressure head supply/exhaust [Pa/Pa]	Fan efficiency supply/exhaust [-/-]	System SFP [kW/(m^3/s)]	Heat exchanger temp. ratio/min exhaust temp. [-/C]
AHU	1122.00/1122.00	0.60/0.60	1.87/1.87	0.85/1.00
Return air only (no supply side)	0.00/1122.00	0.00/0.60	0.00/1.87	0.00/0.00

DHW use	kWh/m2 floor area and year	Total, [l/s]
	10.000	0.004

Occupant schedules in zones (click to expand/contract)

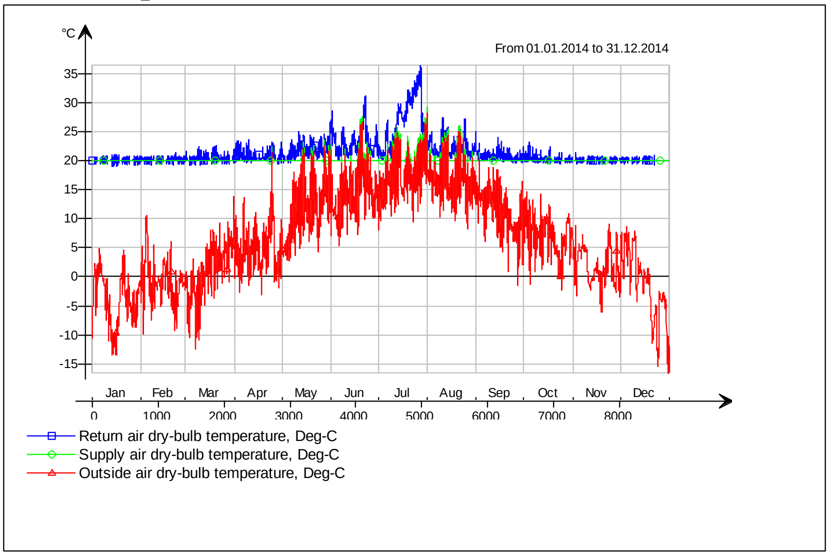
Lighting schedules in zones (click to expand/contract)

Equipment schedules in zones (click to expand/contract)

Controller setpoints in zones (click to expand/contract)

Air Handling Unit

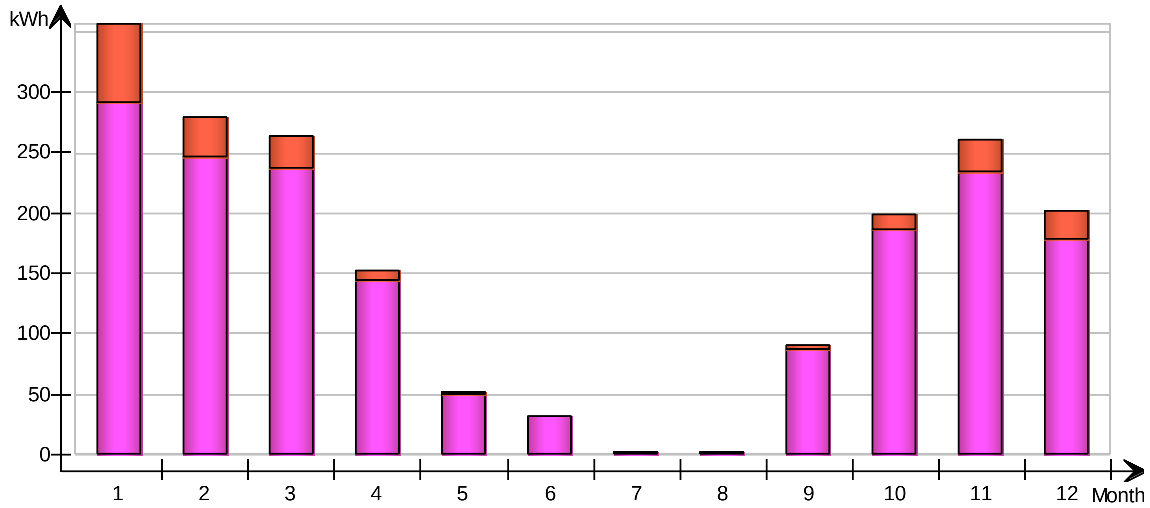
AHU temperatures



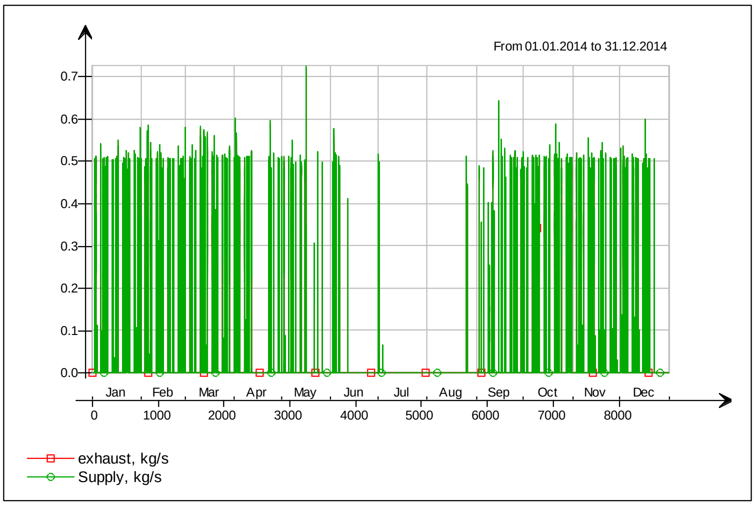
Energy report for "Air Handling Unit"

kWh (sensible and latent)

Month	Heating	Cooling	AHU heat recovery	AHU cold recovery	Humidification	Fans
1	64.4	0.0	291.7	0.0	0.0	0.4
2	32.3	0.0	246.7	0.0	0.0	0.4
3	25.8	0.0	237.2	0.0	0.0	0.4
4	8.0	0.0	144.7	0.0	0.0	0.3
5	1.5	0.0	49.6	0.0	0.0	0.1
6	0.3	0.0	30.6	0.0	0.0	0.1
7	0.2	0.0	2.2	0.0	0.0	0.0
8	0.2	0.0	2.3	0.0	0.0	0.0
9	2.6	0.0	86.6	0.0	0.0	0.2
10	12.6	0.0	186.2	0.0	0.0	0.4
11	26.4	0.0	233.5	0.0	0.0	0.4
12	23.8	0.0	178.6	0.0	0.0	0.3
Total	**198.0**	**0.0**	**1689.8**	**0.0**	**0.0**	**3.1**

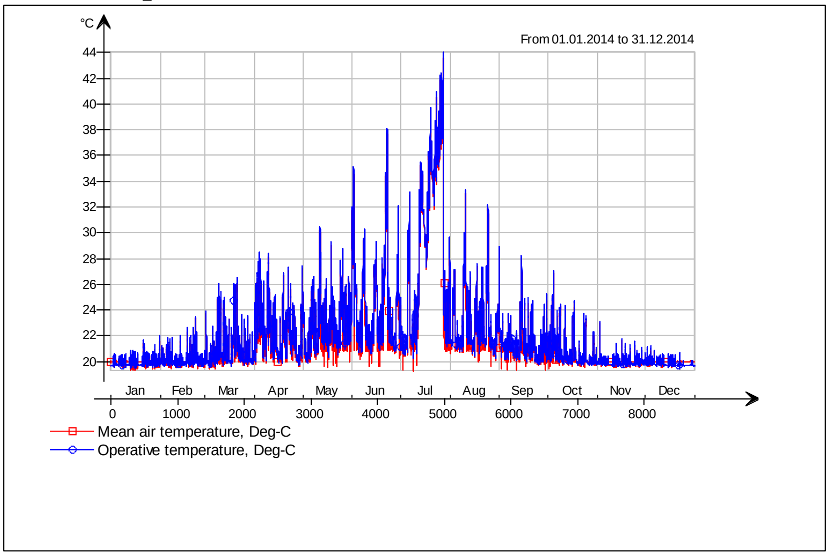


OUTPUT-FILE



Agora

Main temperatures

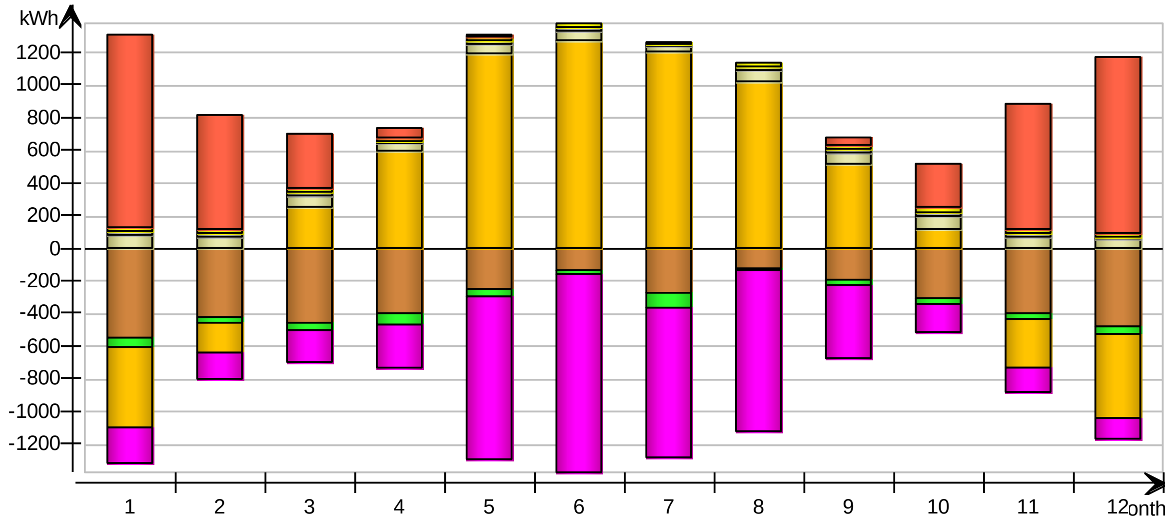


Energy for "Agora"

Energy for "Agora"

kWh (sensible only)

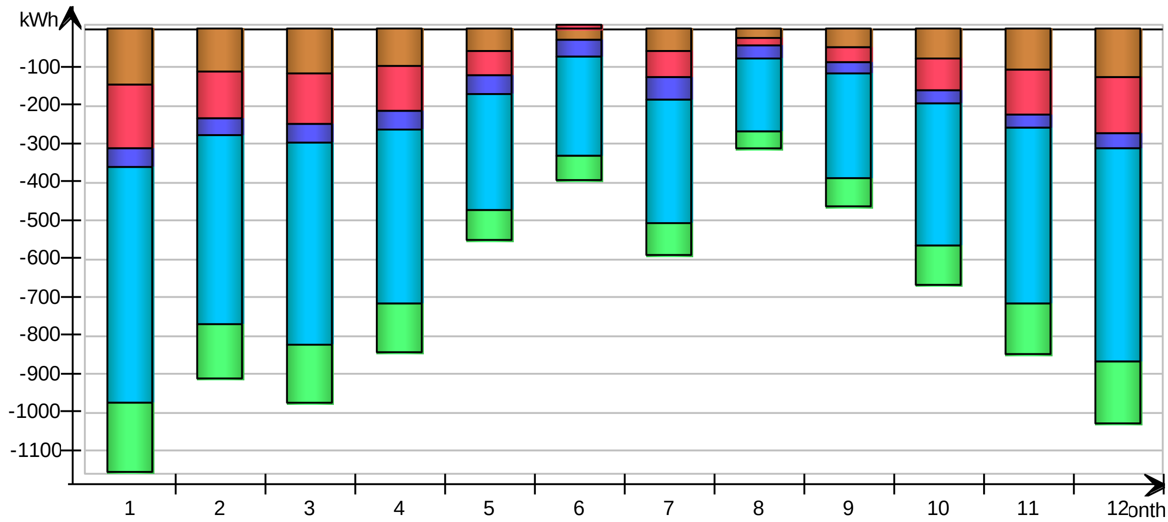
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-547.4	-54.3	-488.7	-0.2	-212.6	76.9	20.8	27.6	1177.0	0.0	0.0
2	-428.1	-34.8	-186.4	-0.3	-162.8	69.2	18.9	25.1	698.2	0.0	0.0
3	-454.4	-43.7	249.5	-2.2	-199.7	66.9	19.8	26.3	337.7	0.0	0.0
4	-397.1	-66.3	592.2	-3.4	-266.8	46.4	15.1	20.1	61.1	0.0	0.0
5	-253.3	-48.1	1189.0	-2.0	-997.7	57.2	18.9	25.1	12.9	0.0	0.0
6	-136.2	-21.7	1269.0	-2.2	-1216.0	60.0	19.9	26.3	0.0	0.0	0.0
7	-272.9	-86.5	1206.0	-0.2	-911.8	37.9	12.3	16.3	0.2	0.0	0.0
8	-129.0	-12.3	1021.0	-0.2	-989.7	64.0	19.9	26.3	0.0	0.0	0.0
9	-196.6	-33.4	510.8	-1.7	-446.9	71.1	20.8	27.6	48.6	0.0	0.0
10	-306.4	-31.3	114.1	-0.9	-168.2	78.2	21.7	28.8	264.0	0.0	0.0
11	-397.8	-34.6	-304.0	-0.2	-148.6	70.3	18.9	25.1	770.6	0.0	0.0
12	-483.0	-50.2	-516.0	-0.1	-124.9	56.7	15.1	20.1	1082.0	0.0	0.0
Total	-4002.2	-517.2	4656.5	-13.6	-5845.7	755.1	222.1	294.6	4452.3	0.0	0.0
During heating (5381.0 h)	-1550.3	80.7	-1714.2	-2.2	-1975.3	416.1	122.8	150.4	4452.8	0.0	0.0
During cooling (1306.0 h)	-1698.1	-419.2	2880.6	-3.2	-815.8	36.3	15.0	18.8	0.0	0.0	0.0
Rest of time	-753.8	-178.7	3490.1	-8.2	-3054.6	302.7	84.3	125.4	-0.5	0.0	0.0



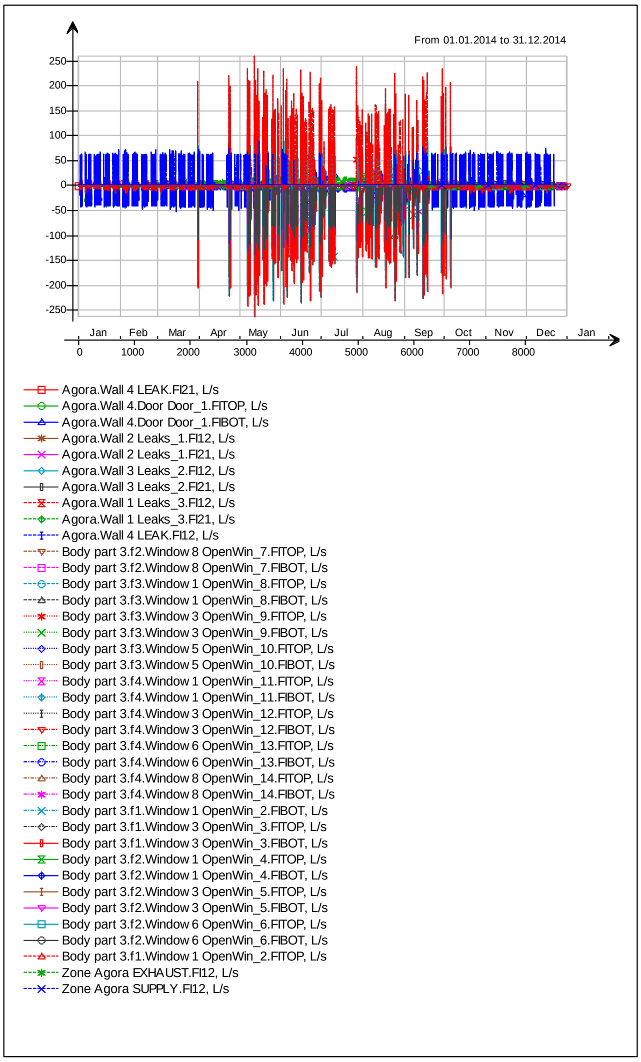
Envelope transmission

kWh

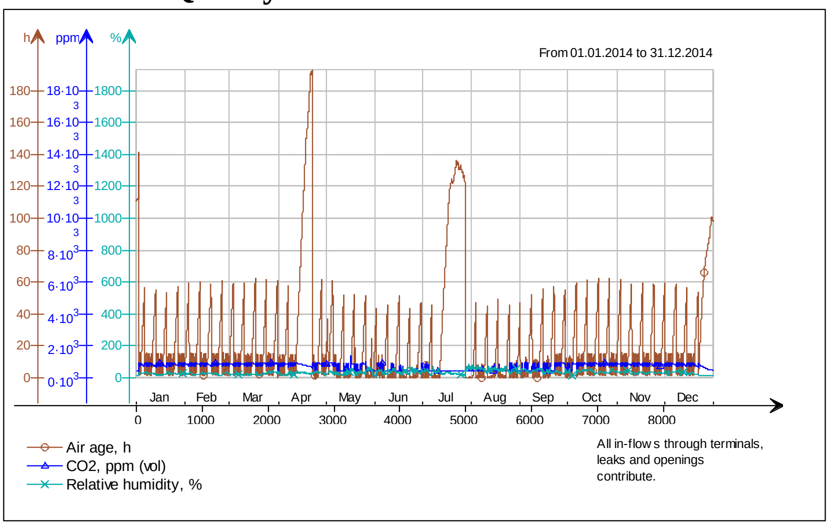
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-146.4	-168.1	-52.3	-615.5	0.0	-180.6
2	-113.3	-126.2	-44.9	-494.9	0.0	-143.8
3	-118.3	-133.2	-51.9	-527.1	0.0	-151.0
4	-99.8	-117.4	-51.1	-457.1	0.0	-128.9
5	-58.5	-63.7	-50.3	-302.0	0.0	-80.9
6	-33.5	8.0	-43.5	-259.9	0.0	-67.2
7	-61.2	-67.7	-58.3	-322.6	0.0	-85.7
8	-27.9	-19.4	-35.0	-189.9	0.0	-46.8
9	-50.4	-41.0	-31.0	-276.1	0.0	-74.2
10	-80.2	-85.6	-35.3	-374.2	0.0	-105.3
11	-106.8	-120.0	-36.9	-462.3	0.0	-134.1
12	-130.4	-147.2	-41.5	-559.0	0.0	-163.9
Total	-1026.6	-1081.5	-531.8	-4840.6	0.0	-1362.3
During heating	-495.0	155.1	-254.0	-3333.3	0.0	-956.4
During cooling	-338.9	-1051.4	-131.6	-647.5	0.0	-176.2
Rest of time	-192.7	-185.2	-146.2	-859.8	0.0	-229.7



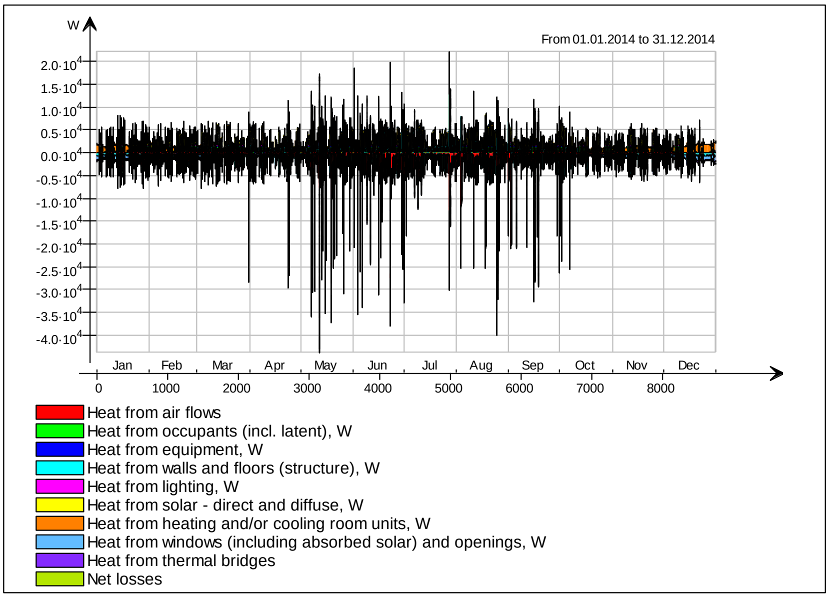
Ventilation air flows



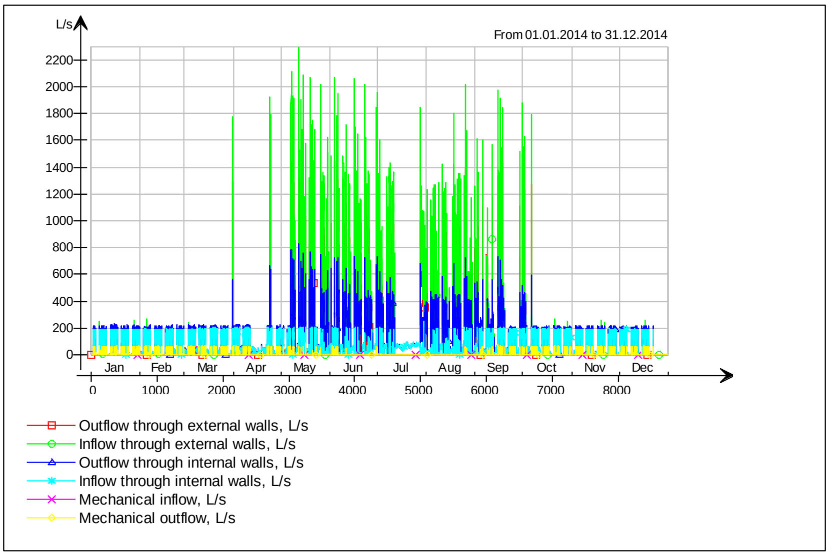
Indoor Air Quality



Heat balance

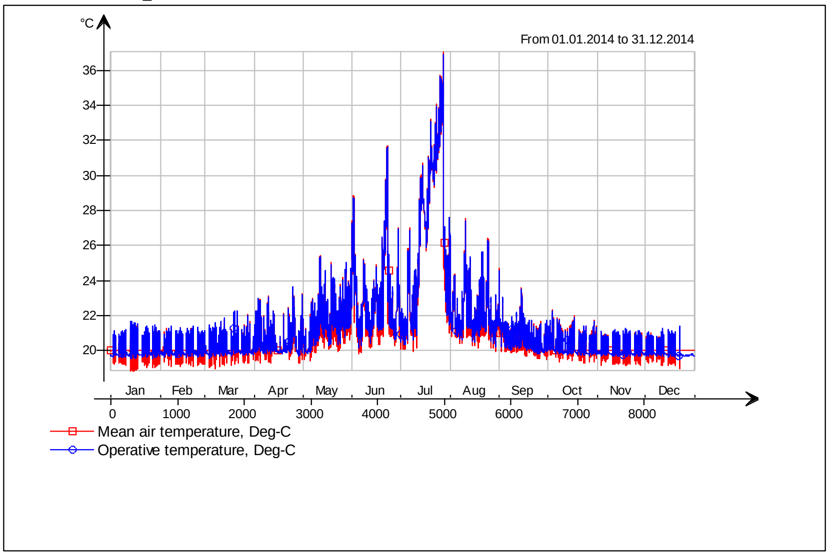


Air flow in zone



Askeladden

Main temperatures

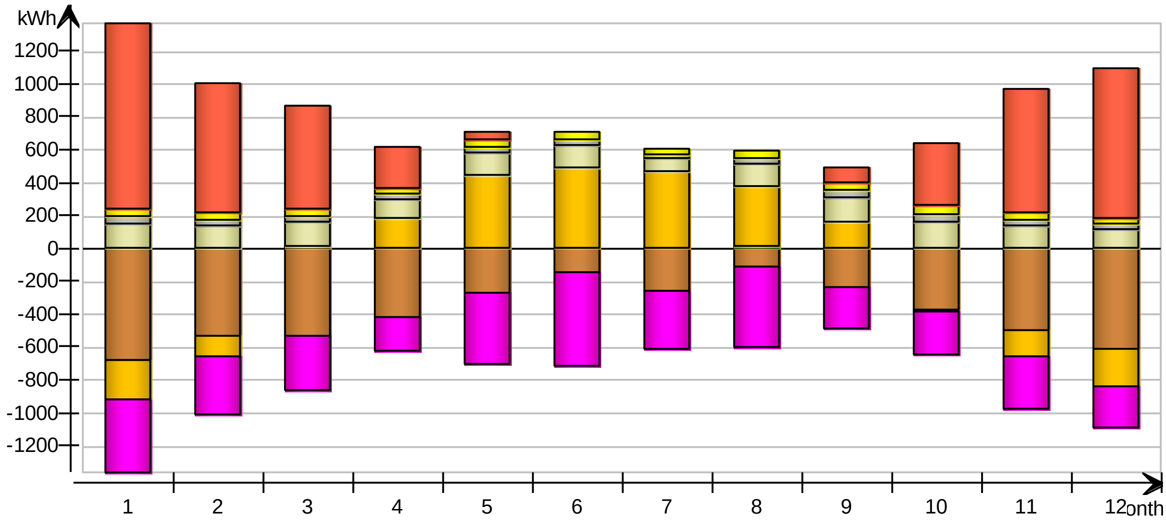


Energy for "Askeladden"

Energy for "Askeladden"

kWh (sensible only)

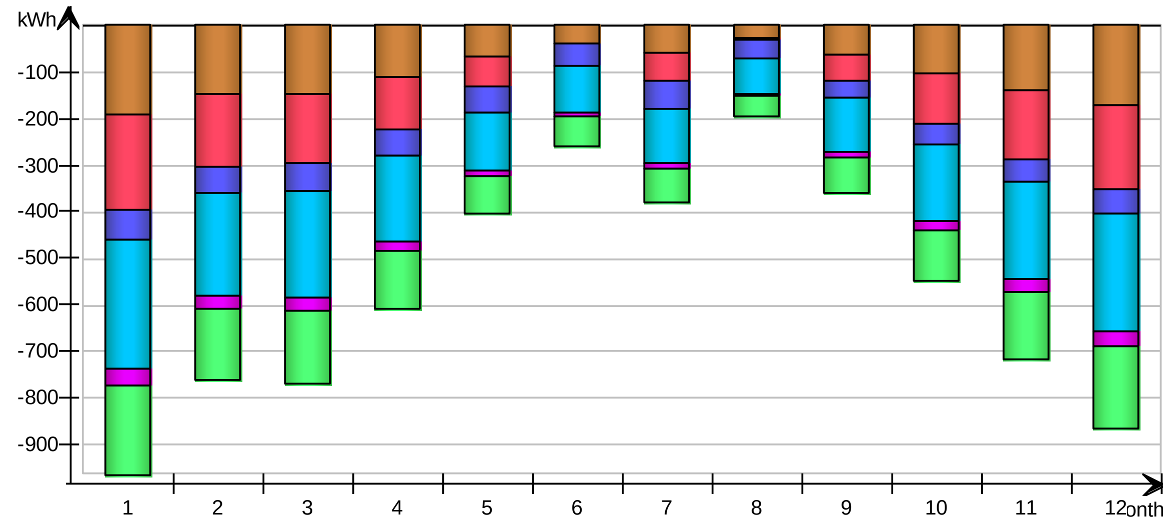
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-686.1	-0.1	-234.5	-0.1	-444.0	151.9	41.6	50.2	1123.0	0.0	0.0
2	-536.2	0.4	-126.9	-0.1	-346.8	139.4	37.8	45.7	788.9	0.0	0.0
3	-533.4	0.9	10.7	-0.3	-334.4	145.5	39.7	48.0	625.4	0.0	0.0
4	-416.6	0.1	185.8	-0.8	-200.8	110.4	30.2	36.5	256.8	0.0	0.0
5	-270.3	-3.6	444.2	-0.9	-430.7	133.3	37.8	45.7	47.0	0.0	0.0
6	-152.0	6.0	492.5	-1.6	-568.5	136.7	39.7	48.0	0.5	0.0	0.0
7	-257.7	-1.9	473.2	-0.1	-350.4	84.1	24.6	29.7	0.0	0.0	0.0
8	-112.9	9.0	361.7	-0.1	-485.6	141.4	39.7	48.0	0.0	0.0	0.0
9	-237.1	-2.6	157.3	-1.0	-253.4	154.6	41.6	50.2	92.2	0.0	0.0
10	-375.0	-0.0	-6.4	-0.6	-255.7	164.5	43.5	52.5	379.4	0.0	0.0
11	-498.3	0.3	-159.3	-0.1	-322.4	140.8	37.8	45.7	757.7	0.0	0.0
12	-609.1	0.3	-230.1	-0.1	-251.7	113.1	30.2	36.5	912.4	0.0	0.0
Total	-4684.7	9.0	1368.2	-5.9	-4244.4	1615.7	444.2	536.7	4983.3	0.0	0.0
During heating (6325.0 h)	-3408.3	63.1	-613.9	-2.6	-2732.2	1072.8	301.7	349.7	4980.6	0.0	0.0
During cooling (727.9 h)	-620.6	-27.4	675.8	-0.5	-71.4	26.0	9.0	10.5	0.0	0.0	0.0
Rest of time	-655.8	-26.7	1306.3	-2.8	-1440.8	516.9	133.4	176.5	2.7	0.0	0.0



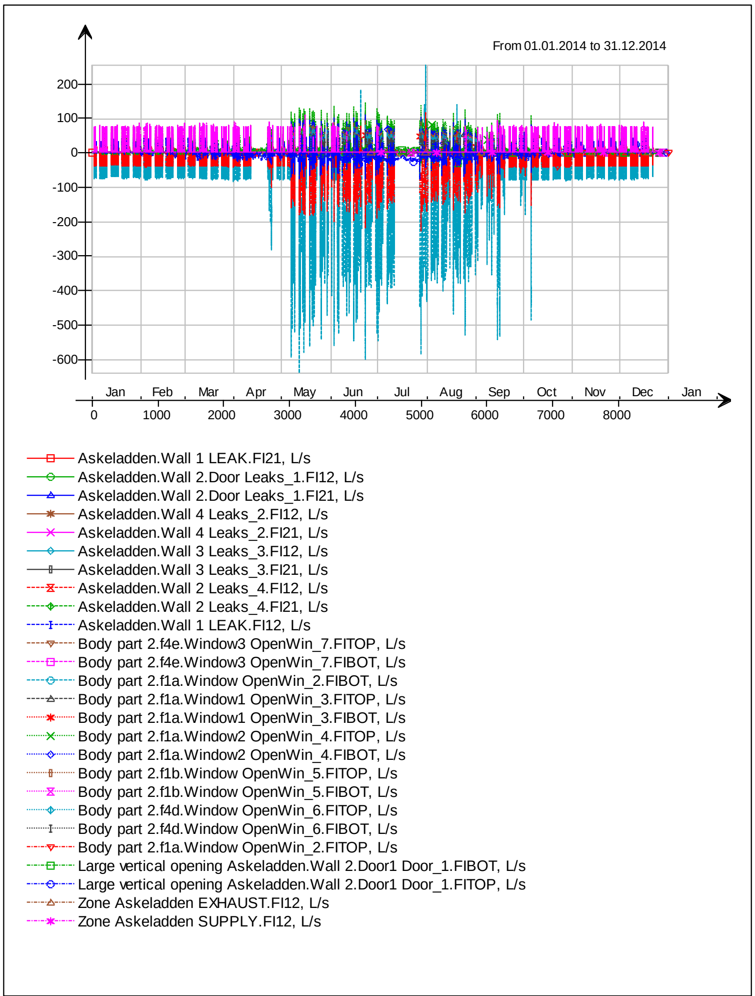
Envelope transmission

kWh

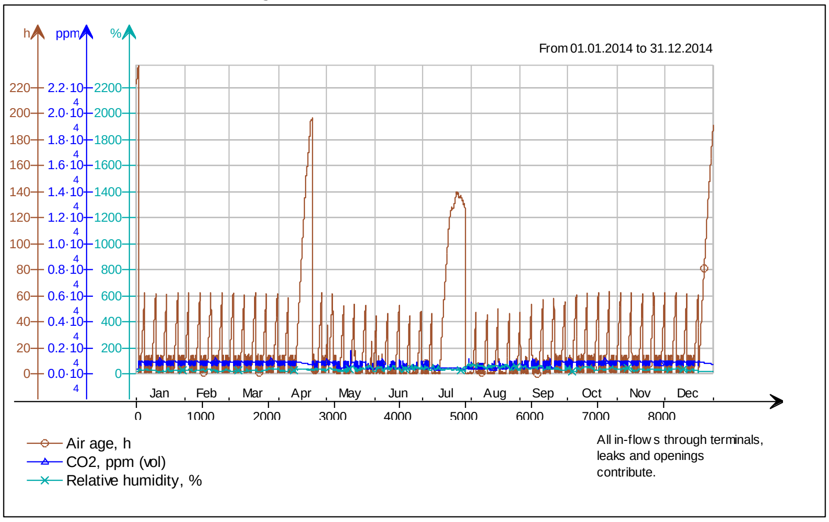
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-191.5	-203.8	-63.5	-277.7	-35.4	-191.9
2	-148.0	-155.2	-53.8	-221.3	-27.3	-151.9
3	-146.1	-148.2	-58.4	-226.6	-26.3	-154.5
4	-111.4	-109.6	-53.3	-183.0	-19.1	-123.1
5	-66.9	-61.5	-55.2	-121.2	-9.4	-77.2
6	-38.2	1.8	-47.5	-100.7	-6.0	-62.0
7	-60.1	-56.8	-60.1	-114.3	-8.5	-72.2
8	-25.8	-2.0	-37.8	-74.0	-4.2	-43.2
9	-63.2	-53.6	-34.8	-115.7	-11.4	-74.2
10	-102.4	-104.9	-40.9	-161.8	-18.7	-108.1
11	-139.2	-146.0	-44.8	-208.0	-26.1	-142.2
12	-171.1	-181.1	-50.6	-251.9	-32.1	-174.2
Total	-1263.8	-1220.8	-600.9	-2056.2	-224.5	-1374.7
During heating	-974.2	-675.8	-394.4	-1727.2	-192.6	-1171.1
During cooling	-130.0	-327.8	-75.0	-117.6	-11.9	-75.7
Rest of time	-159.6	-217.2	-131.5	-211.4	-20.0	-127.8



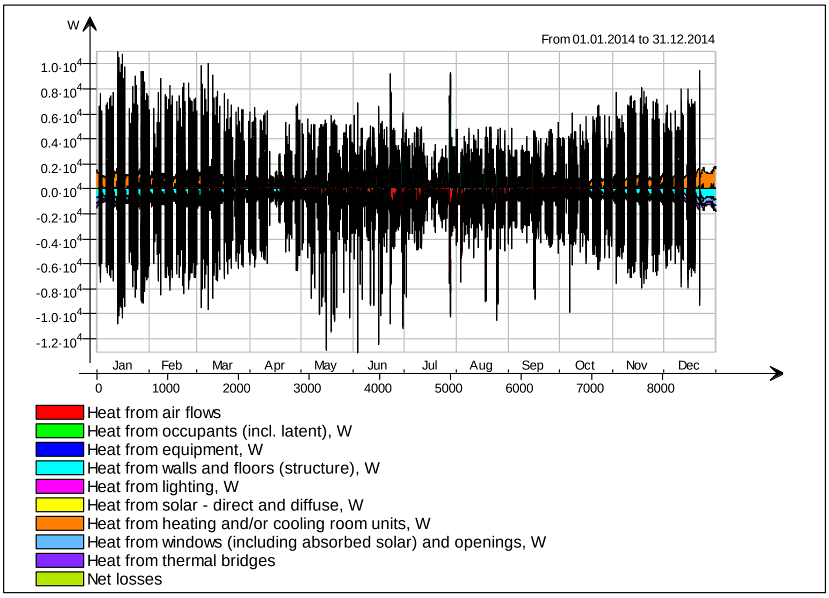
Ventilation air flows



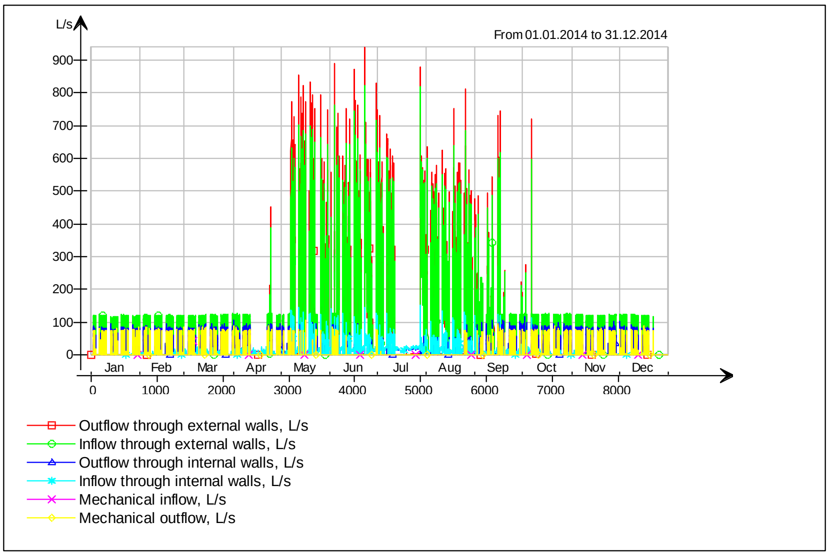
Indoor Air Quality



Heat balance

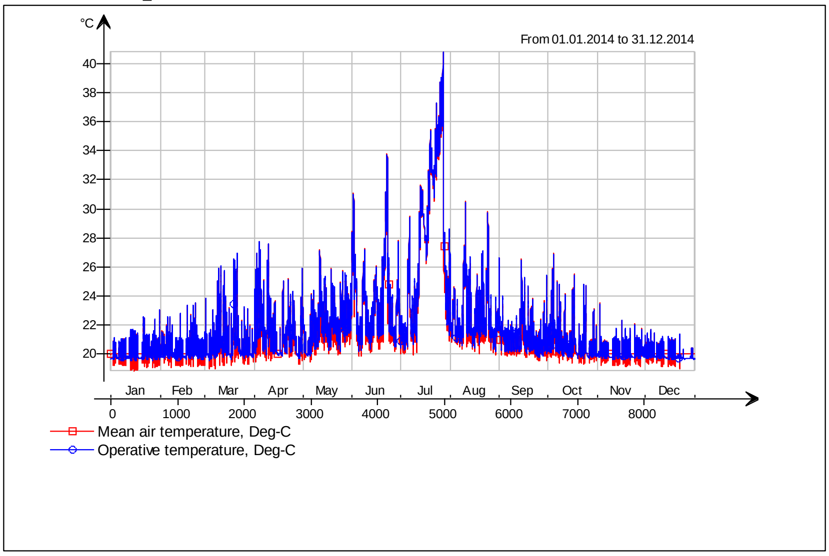


Air flow in zone



Rødhette

Main temperatures

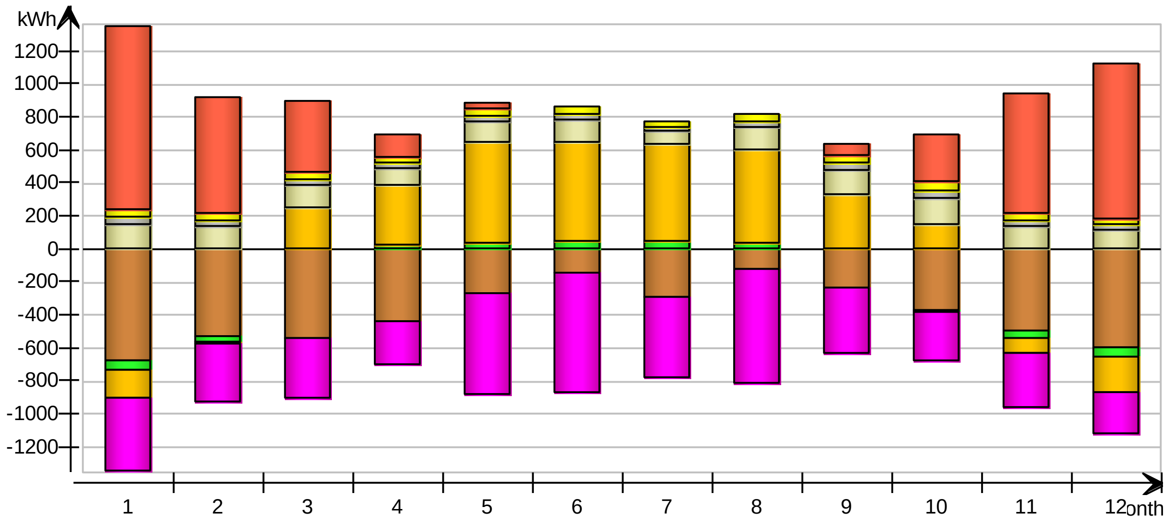


Energy for "Rødhette"

Energy for "Rødhette"

kWh (sensible only)

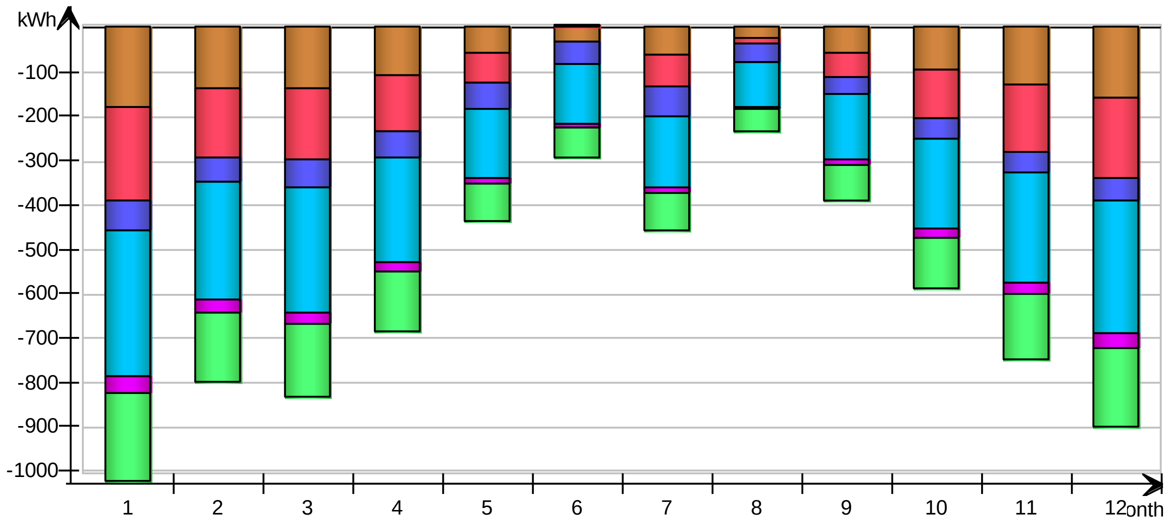
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-678.2	-60.6	-173.8	-0.1	-444.3	151.7	41.6	50.5	1116.0	0.0	0.0
2	-526.2	-32.0	-13.6	-0.3	-348.9	138.3	37.8	45.9	701.2	0.0	0.0
3	-544.5	-3.5	249.1	-2.3	-356.3	138.8	39.7	48.2	433.2	0.0	0.0
4	-440.8	25.8	365.2	-2.6	-253.9	102.5	30.2	36.7	139.0	0.0	0.0
5	-270.4	30.3	607.8	-1.4	-611.4	127.4	37.8	45.9	36.5	0.0	0.0
6	-148.1	43.0	606.7	-2.0	-718.4	131.6	39.7	48.2	0.5	0.0	0.0
7	-287.8	41.4	593.1	-0.2	-480.0	80.8	24.6	29.8	0.0	0.0	0.0
8	-127.3	29.9	567.8	-0.2	-693.1	136.1	39.7	48.2	0.1	0.0	0.0
9	-236.6	3.4	327.5	-1.9	-399.2	150.1	41.6	50.5	66.5	0.0	0.0
10	-375.0	-10.5	143.4	-1.4	-290.4	160.1	43.5	52.8	279.6	0.0	0.0
11	-492.3	-38.5	-92.0	-0.3	-323.7	140.3	37.8	45.9	725.1	0.0	0.0
12	-597.3	-56.0	-217.7	-0.2	-251.9	113.1	30.2	36.7	944.6	0.0	0.0
Total	-4724.5	-27.4	2963.4	-12.9	-5171.5	1570.8	444.2	539.3	4442.3	0.0	0.0
During heating (5638.0 h)	-2478.9	-93.3	-727.5	-3.3	-2665.8	960.3	257.0	316.9	4438.9	0.0	0.0
During cooling (1062.0 h)	-1271.4	35.3	1465.0	-1.5	-325.3	54.0	26.3	24.2	0.0	0.0	0.0
Rest of time	-974.2	30.6	2225.9	-8.1	-2180.4	556.5	160.8	198.2	3.4	0.0	0.0



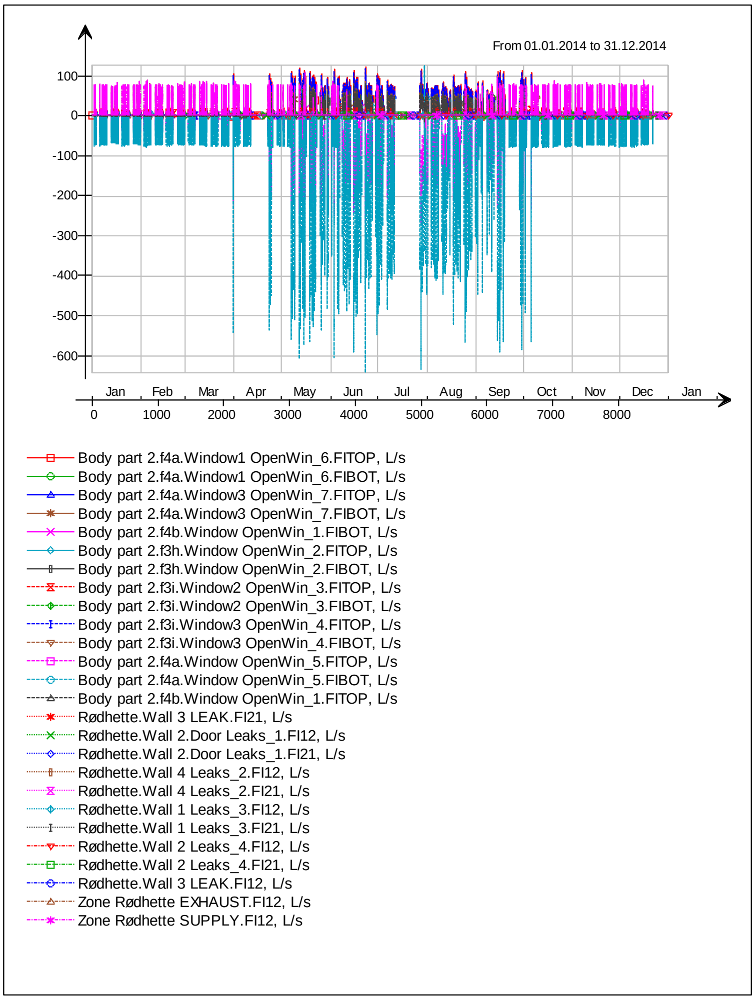
Envelope transmission

kWh

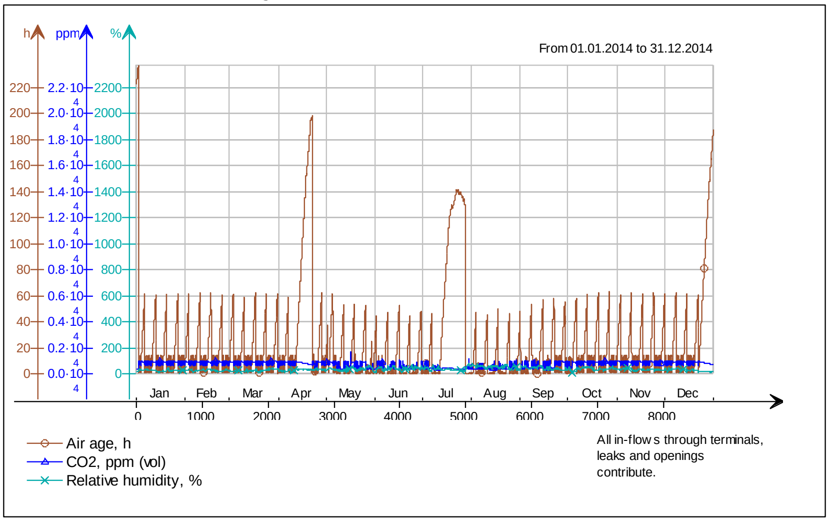
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-177.5	-207.5	-64.1	-328.6	-34.2	-194.9
2	-135.8	-154.7	-54.7	-265.3	-25.9	-155.1
3	-137.4	-159.4	-61.7	-280.0	-24.9	-161.1
4	-107.5	-124.5	-57.4	-234.3	-19.2	-132.2
5	-58.9	-64.2	-56.5	-154.1	-9.3	-81.6
6	-32.1	6.2	-48.9	-131.4	-6.2	-67.1
7	-60.2	-69.9	-64.8	-157.0	-9.9	-83.0
8	-24.1	-11.8	-39.9	-99.6	-3.5	-48.1
9	-57.3	-54.3	-36.4	-146.1	-10.6	-78.0
10	-94.8	-106.5	-42.8	-200.5	-17.8	-113.1
11	-128.9	-148.1	-45.3	-247.6	-25.0	-144.9
12	-158.1	-180.3	-50.7	-297.7	-31.3	-176.9
Total	-1172.5	-1275.0	-623.1	-2542.2	-217.8	-1436.0
During heating	-705.0	-189.1	-339.4	-1866.9	-163.3	-1081.9
During cooling	-246.3	-750.0	-120.4	-247.2	-22.7	-131.9
Rest of time	-221.2	-335.9	-163.3	-428.1	-31.8	-222.2



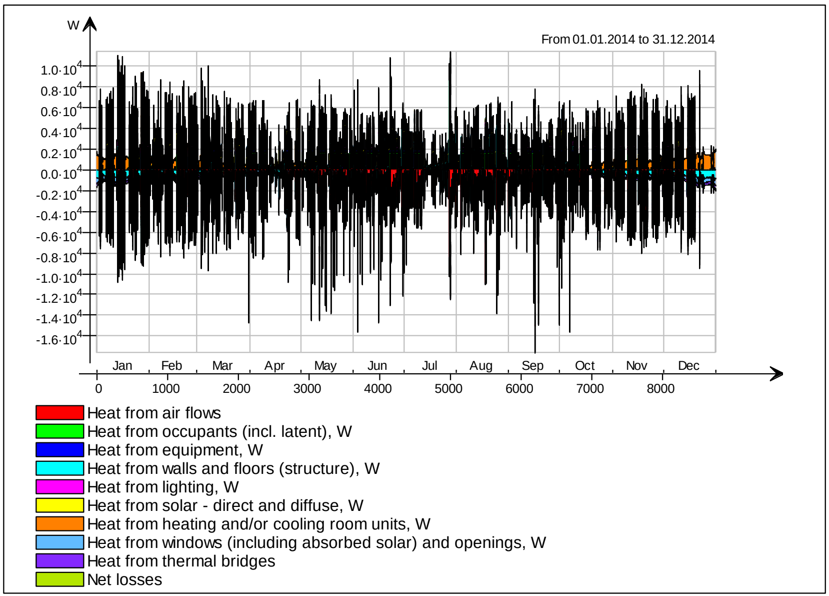
Ventilation air flows



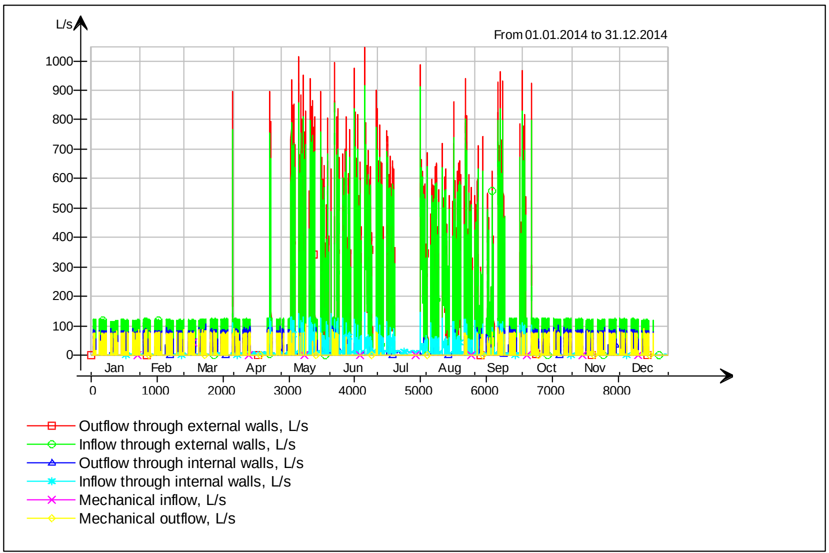
Indoor Air Quality



Heat balance



Air flow in zone



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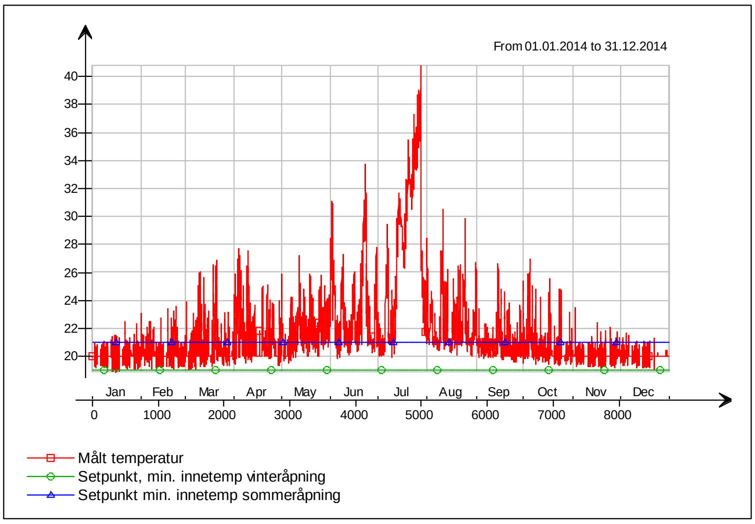

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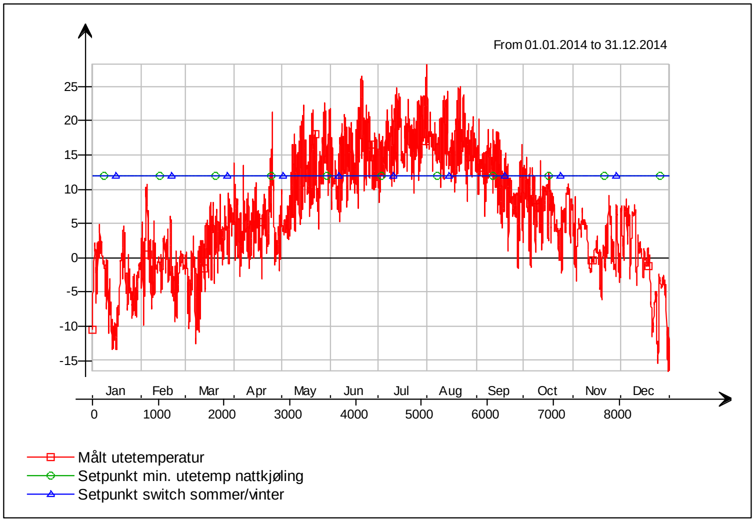

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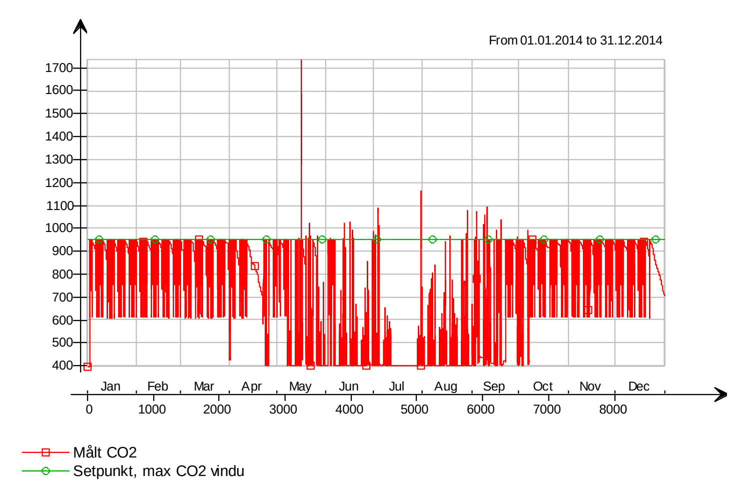

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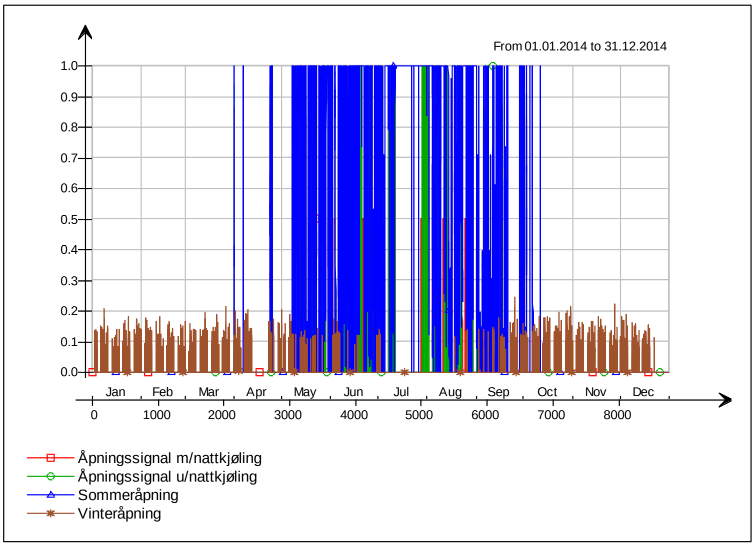
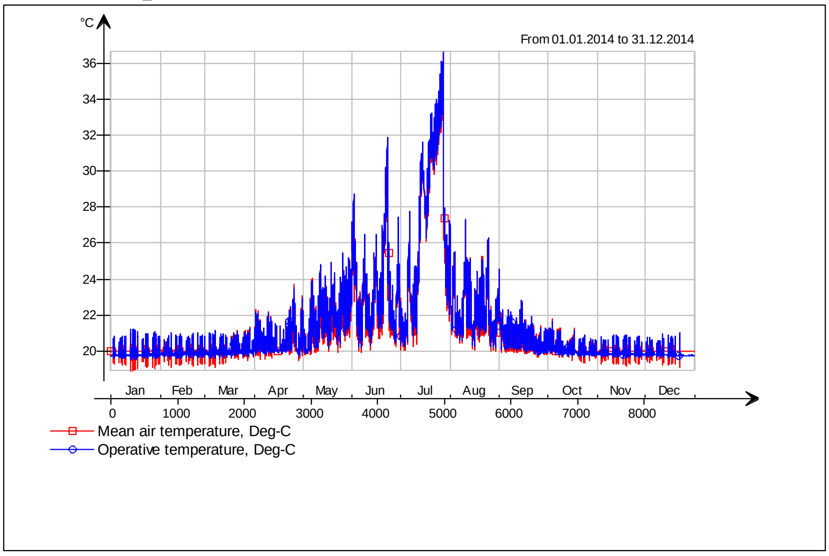


Ateliet

Main temperatures

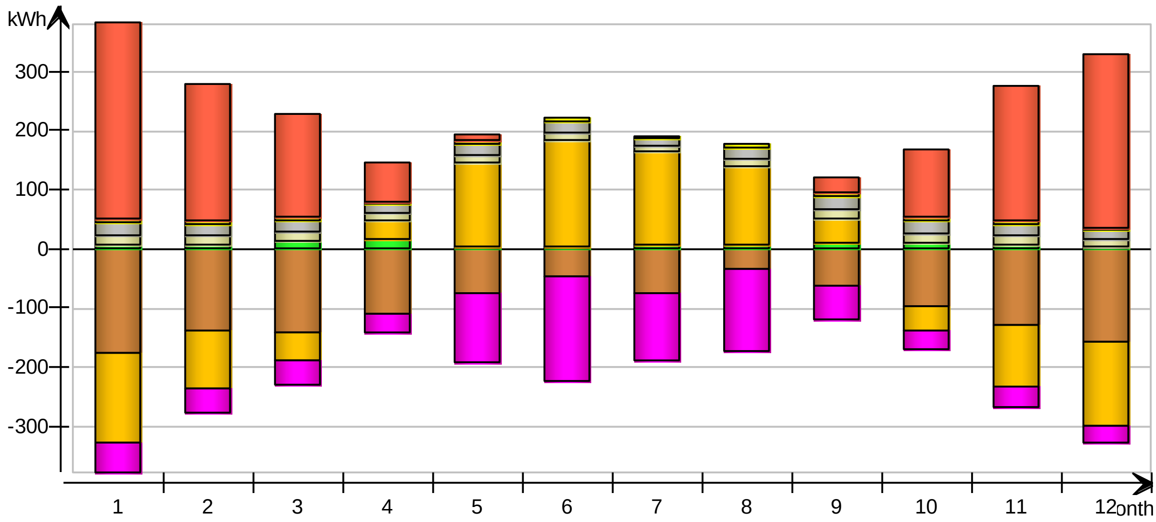


Energy for "Ateliet"

Energy for "Ateliet"

kWh (sensible only)

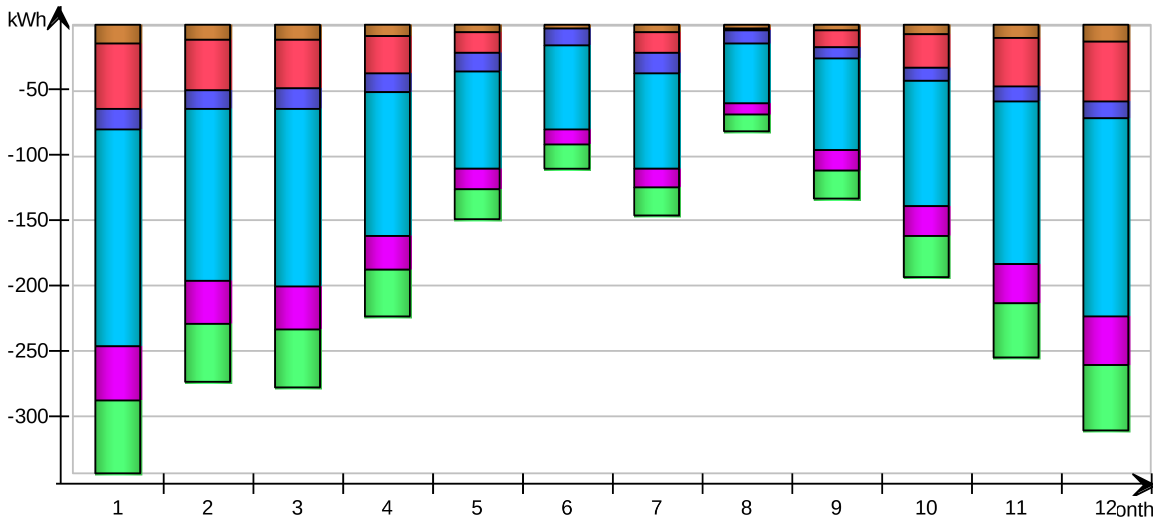
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-178.0	5.4	-150.1	-0.0	-51.0	16.1	20.8	5.3	331.7	0.0	0.0
2	-140.3	6.9	-96.4	-0.1	-39.4	14.7	18.9	4.8	231.1	0.0	0.0
3	-141.4	12.9	-47.2	-0.2	-39.4	15.2	19.8	5.1	175.4	0.0	0.0
4	-111.9	15.5	32.8	-0.4	-31.4	11.3	15.1	3.9	65.2	0.0	0.0
5	-74.7	4.3	141.2	-0.5	-117.0	13.3	18.9	4.8	9.8	0.0	0.0
6	-46.9	4.8	180.5	-0.6	-176.2	13.5	19.9	5.1	0.1	0.0	0.0
7	-74.7	6.3	158.8	-0.1	-113.8	8.3	12.3	3.1	0.0	0.0	0.0
8	-35.6	5.1	131.5	-0.1	-140.2	14.2	19.9	5.1	0.0	0.0	0.0
9	-63.3	8.9	42.3	-0.4	-55.7	15.8	20.8	5.3	26.5	0.0	0.0
10	-98.6	10.2	-39.7	-0.2	-30.0	17.0	21.7	5.6	114.1	0.0	0.0
11	-130.6	5.3	-104.5	-0.0	-36.1	14.8	18.9	4.8	227.6	0.0	0.0
12	-159.1	3.4	-142.2	-0.0	-28.3	11.8	15.1	3.9	295.5	0.0	0.0
Total	-1255.1	89.1	107.0	-2.6	-858.5	166.0	222.1	56.9	1477.1	0.0	0.0
During heating (6093.0 h)	-895.0	109.2	-618.9	-1.0	-356.1	108.8	140.5	36.0	1477.2	0.0	0.0
During cooling (880.8 h)	-181.0	-4.3	234.5	-0.4	-60.3	3.0	7.5	1.3	0.0	0.0	0.0
Rest of time	-179.1	-15.8	491.4	-1.2	-442.1	54.2	74.1	19.6	-0.1	0.0	0.0



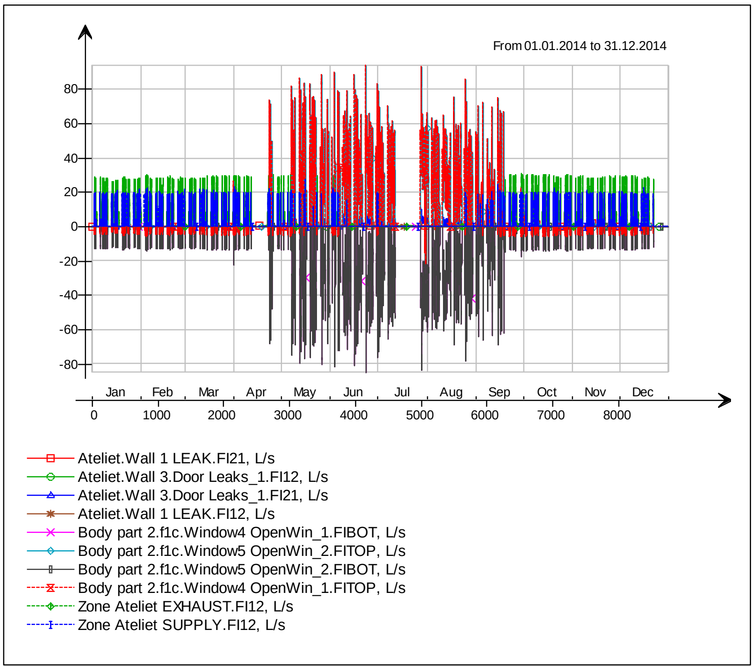
Envelope transmission

kWh

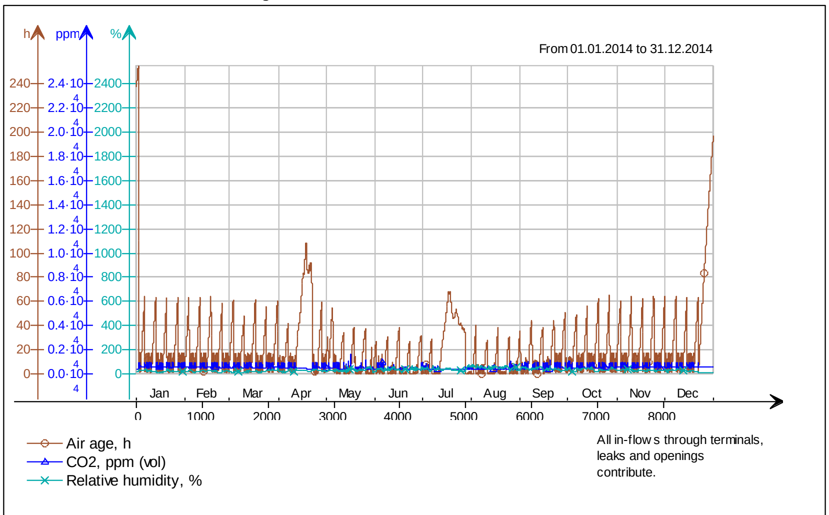
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-13.8	-50.9	-16.4	-166.6	-41.4	-55.5
2	-10.8	-39.1	-13.9	-132.7	-32.5	-44.0
3	-11.0	-38.0	-15.2	-136.1	-32.6	-44.7
4	-8.6	-28.3	-14.0	-111.2	-25.2	-35.9
5	-5.6	-16.2	-14.6	-75.2	-15.4	-23.0
6	-3.5	-0.3	-12.8	-64.1	-11.3	-19.0
7	-5.3	-16.3	-16.3	-73.7	-14.6	-22.2
8	-2.5	-1.6	-10.1	-46.6	-8.2	-13.1
9	-4.8	-12.8	-9.0	-69.8	-15.1	-21.6
10	-7.6	-26.2	-10.6	-96.8	-23.0	-31.3
11	-10.1	-37.2	-11.6	-124.6	-30.6	-41.1
12	-12.4	-45.8	-13.1	-151.6	-37.4	-50.4
Total	-96.0	-312.6	-157.6	-1249.0	-287.1	-402.0
During heating	-70.3	-160.6	-100.3	-1018.3	-230.4	-333.3
During cooling	-12.1	-96.5	-23.1	-88.8	-22.3	-27.0
Rest of time	-13.6	-55.5	-34.2	-141.9	-34.4	-41.7



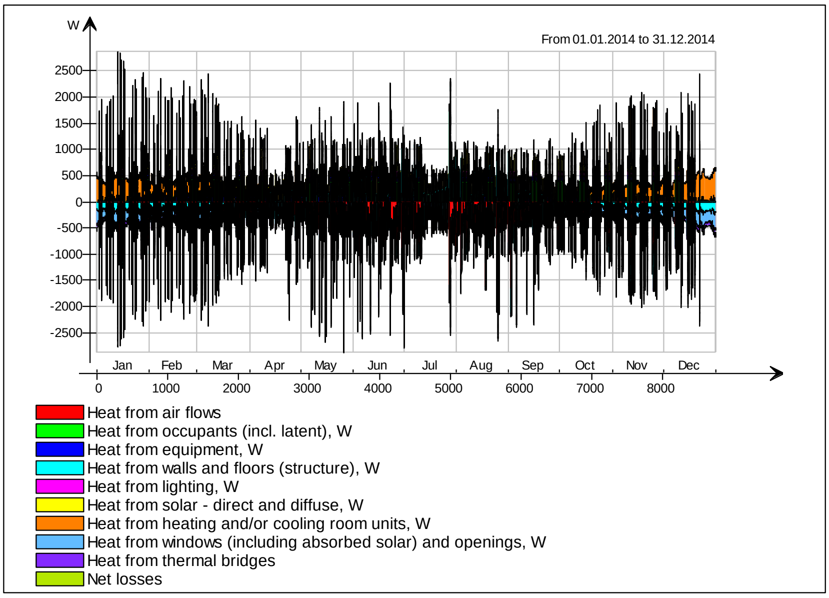
Ventilation air flows



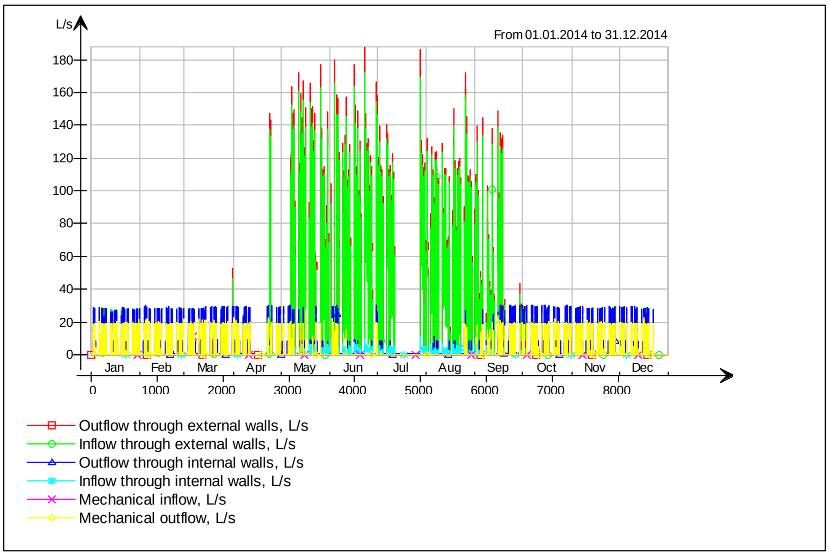
Indoor Air Quality



Heat balance

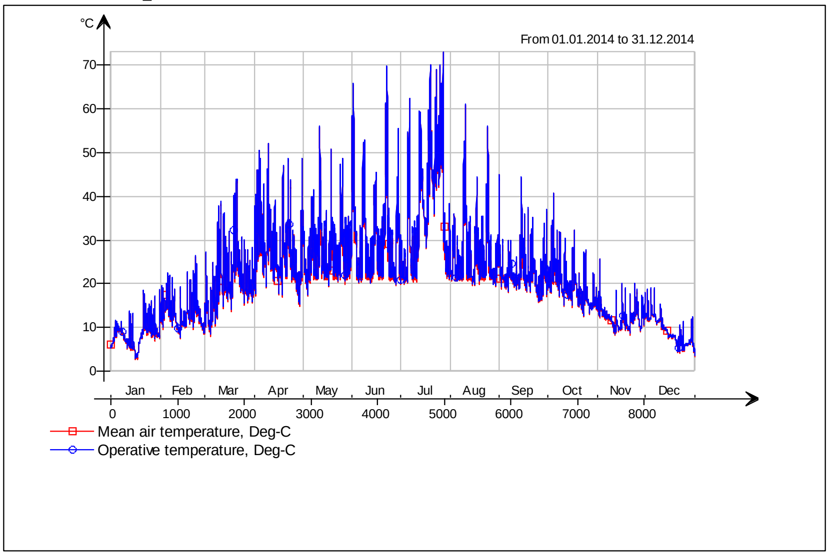


Air flow in zone



Winter garden

Main temperatures

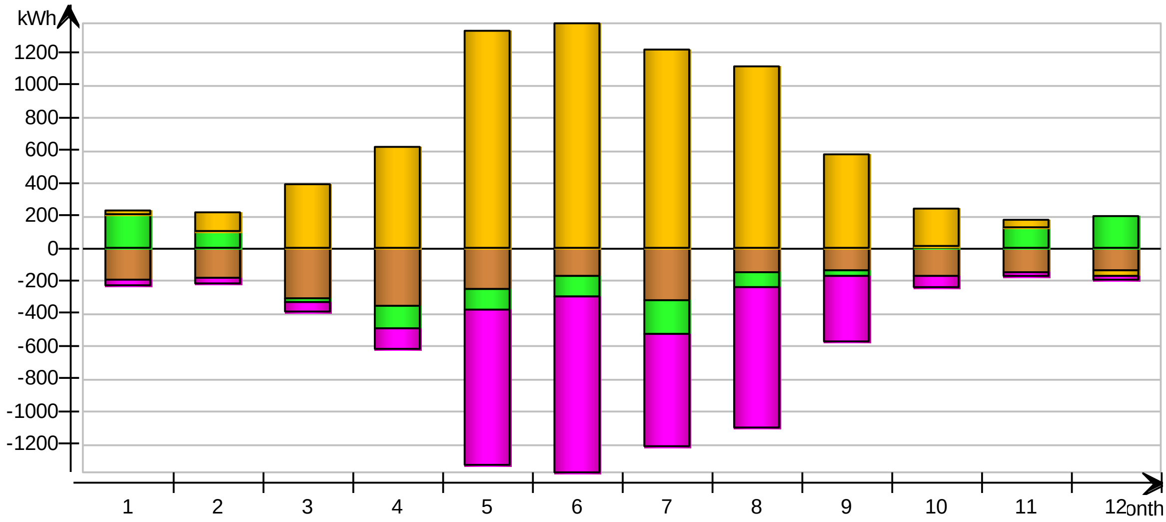


Energy for "Winter garden"

Energy for "Winter garden"

kWh (sensible only)

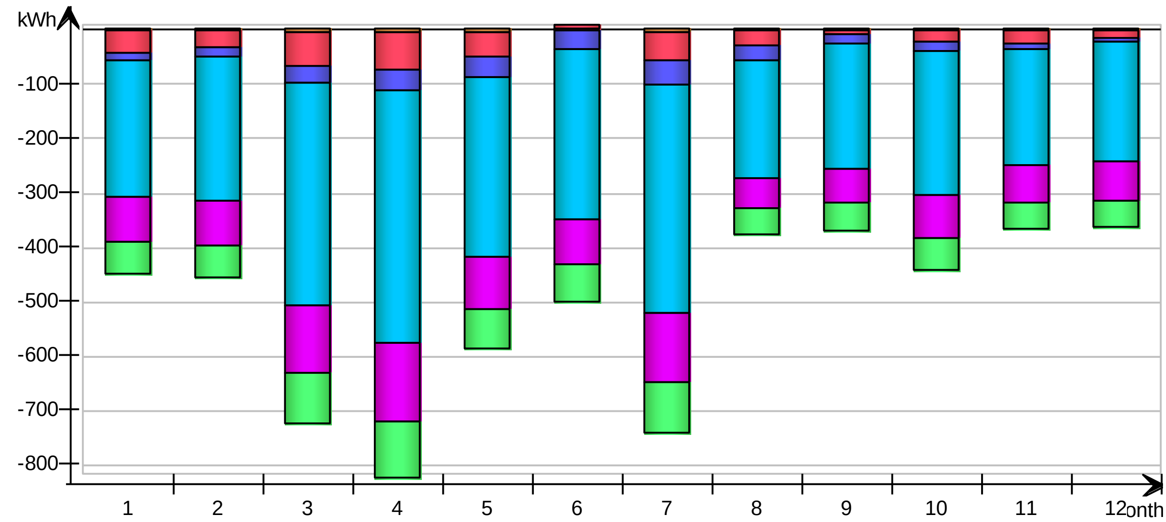
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-191.8	203.1	26.7	0.0	-38.0	0.0	0.0	0.0	0.0	0.0	0.0
2	-185.6	105.2	112.4	0.0	-32.4	0.0	0.0	0.0	0.0	0.0	0.0
3	-307.4	-20.6	386.3	0.0	-58.2	0.0	0.0	0.0	0.0	0.0	0.0
4	-355.7	-136.1	617.5	0.0	-125.4	0.0	0.0	0.0	0.0	0.0	0.0
5	-250.3	-129.0	1330.0	0.0	-949.8	0.0	0.0	0.0	0.0	0.0	0.0
6	-172.8	-130.7	1377.0	0.0	-1074.0	0.0	0.0	0.0	0.0	0.0	0.0
7	-316.8	-206.2	1211.0	0.0	-687.8	0.0	0.0	0.0	0.0	0.0	0.0
8	-152.8	-91.2	1109.0	0.0	-865.4	0.0	0.0	0.0	0.0	0.0	0.0
9	-135.9	-32.5	574.1	0.0	-405.9	0.0	0.0	0.0	0.0	0.0	0.0
10	-171.8	13.8	226.8	0.0	-69.3	0.0	0.0	0.0	0.0	0.0	0.0
11	-143.8	130.2	40.4	0.0	-27.2	0.0	0.0	0.0	0.0	0.0	0.0
12	-138.6	195.7	-32.9	0.0	-24.8	0.0	0.0	0.0	0.0	0.0	0.0
Total	-2523.3	-98.3	6978.3	0.0	-4358.1	0.0	0.0	0.0	0.0	0.0	0.0
During heating (4689.0 h)	-401.1	816.1	-12.8	0.0	-405.8	0.0	0.0	0.0	0.0	0.0	0.0
During cooling (2732.0 h)	-2299.7	-903.6	5930.6	0.0	-2724.2	0.0	0.0	0.0	0.0	0.0	0.0
Rest of time	177.5	-10.8	1060.5	0.0	-1228.1	0.0	0.0	0.0	0.0	0.0	0.0



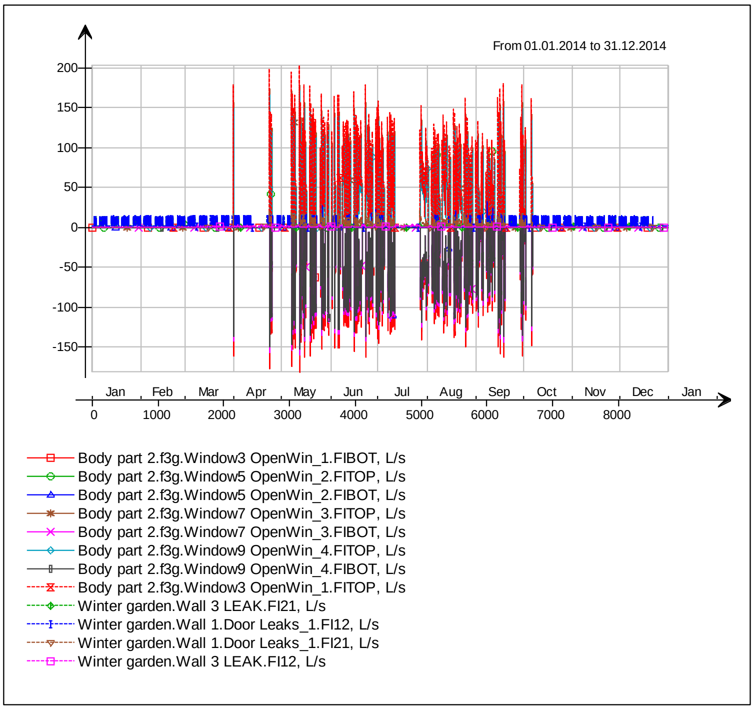
Envelope transmission

kWh

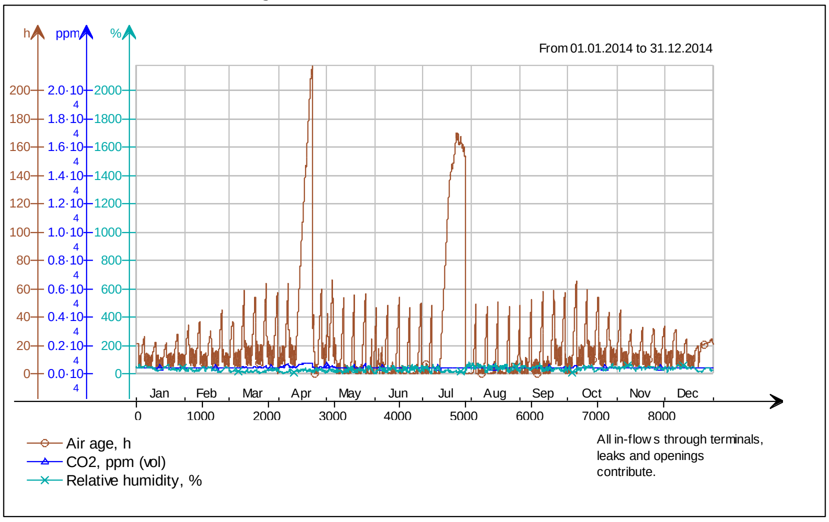
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-3.1	-40.2	-10.7	-249.4	-82.3	-55.5
2	-2.8	-29.6	-14.6	-262.3	-80.5	-58.1
3	-4.7	-59.5	-29.1	-407.4	-124.0	-90.0
4	-5.4	-68.8	-36.8	-462.9	-142.8	-101.8
5	-3.6	-44.3	-36.1	-328.8	-94.9	-71.3
6	-2.1	8.4	-31.3	-310.7	-81.0	-66.8
7	-4.5	-50.4	-44.8	-419.2	-126.3	-90.8
8	-2.1	-25.2	-25.0	-216.1	-55.0	-45.6
9	-1.7	-6.5	-17.0	-229.7	-61.4	-49.3
10	-2.4	-20.3	-15.5	-262.3	-76.3	-57.4
11	-2.2	-21.1	-7.6	-211.7	-66.4	-46.6
12	-2.1	-13.5	-4.5	-218.7	-70.0	-48.4
Total	-36.7	-371.1	-273.0	-3579.2	-1060.9	-781.5
During heating	-0.9	347.5	-49.3	-1557.2	-356.4	-341.9
During cooling	-42.3	-1063.6	-193.6	-1573.9	-656.7	-343.6
Rest of time	6.5	345.0	-30.1	-448.1	-47.8	-96.0



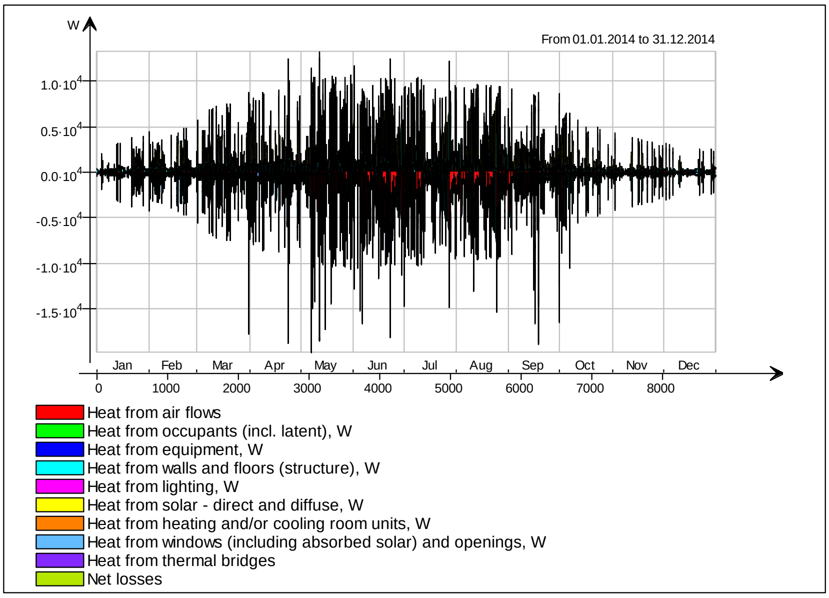
Ventilation air flows



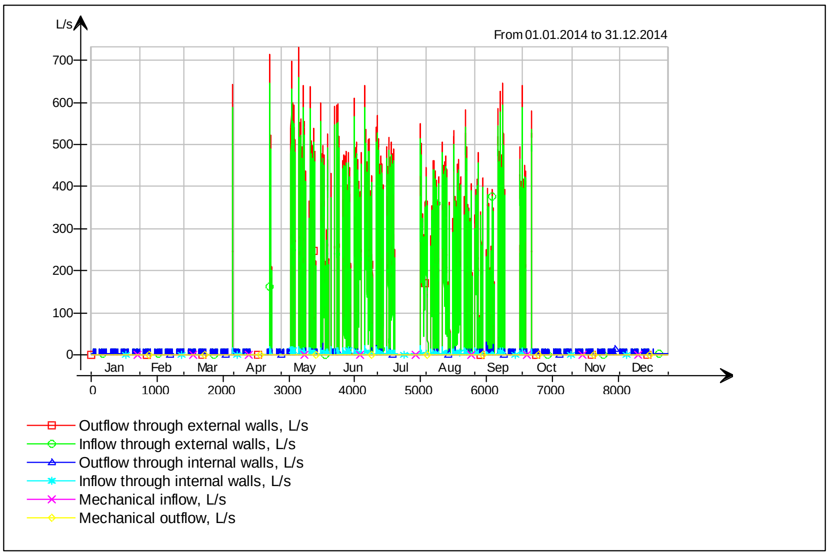
Indoor Air Quality



Heat balance

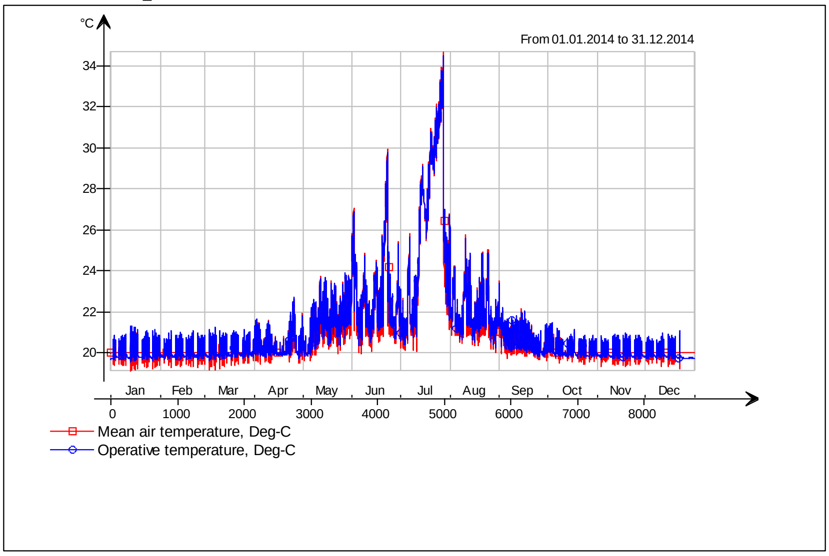


Air flow in zone



Gullhår

Main temperatures

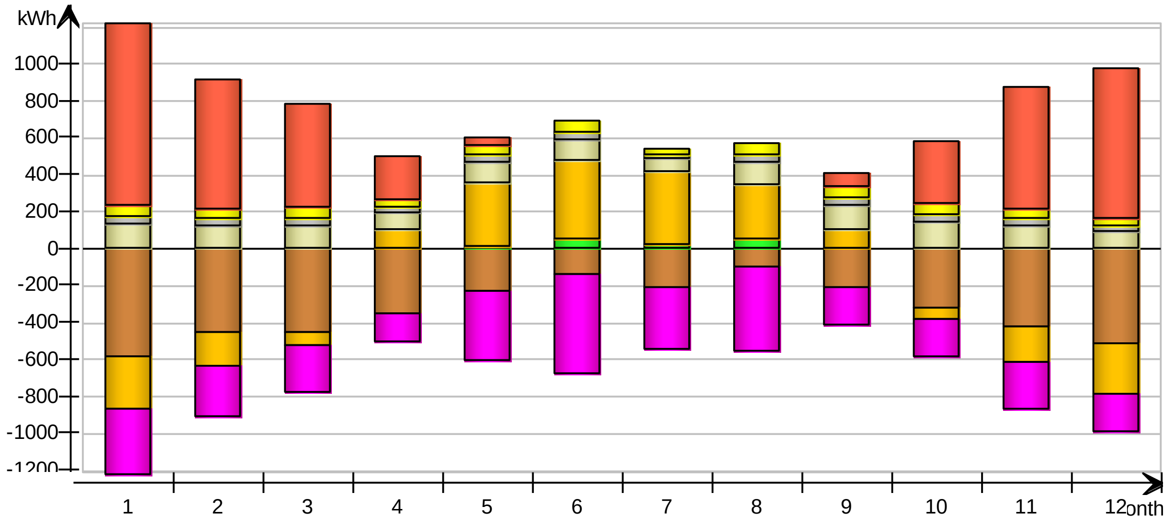


Energy for "Gullhår"

Energy for "Gullhår"

kWh (sensible only)

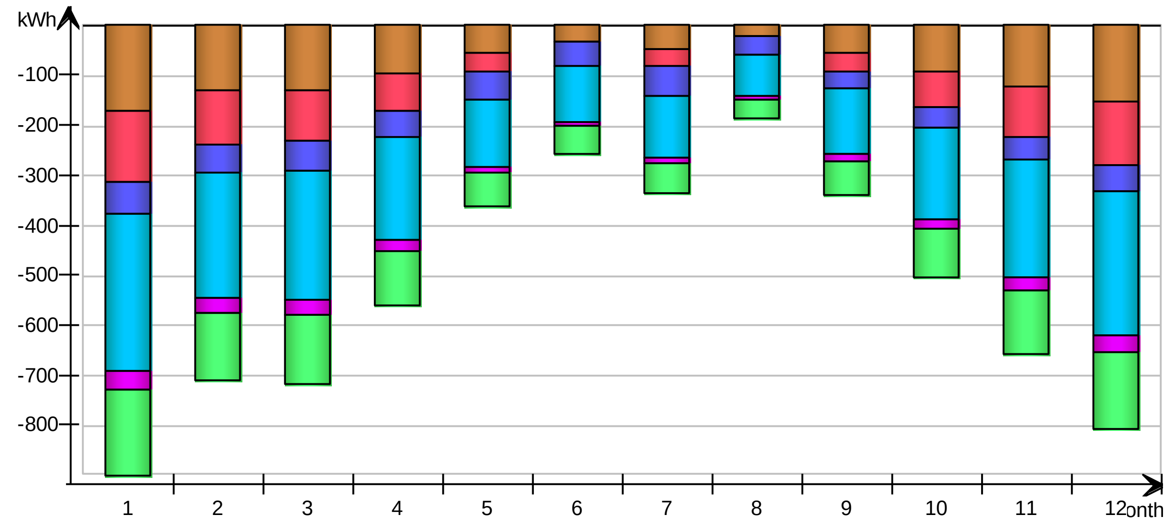
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltration & Openings	Occupants	Equipment	Lighting	Local heating units	Local cooling units	Net losses
1	-582.4	3.6	-282.6	-0.2	-349.9	130.9	41.6	59.6	981.4	0.0	0.0
2	-457.8	3.5	-177.7	-0.3	-272.9	119.7	37.8	54.2	695.3	0.0	0.0
3	-456.8	4.0	-66.1	-1.0	-257.0	124.8	39.7	56.9	557.3	0.0	0.0
4	-353.5	3.1	105.9	-1.7	-149.6	93.8	30.2	43.4	229.8	0.0	0.0
5	-230.7	14.3	348.9	-1.4	-371.9	111.8	37.8	54.2	38.8	0.0	0.0
6	-143.1	49.3	423.2	-1.9	-537.3	114.1	39.7	56.9	0.0	0.0	0.0
7	-213.8	19.8	395.3	-0.2	-329.6	69.8	24.6	35.2	0.0	0.0	0.0
8	-104.2	46.9	299.6	-0.2	-456.3	118.4	39.7	56.9	-0.0	0.0	0.0
9	-207.3	2.2	104.7	-1.5	-204.8	130.3	41.6	59.6	76.5	0.0	0.0
10	-321.5	2.3	-64.8	-1.3	-197.3	139.8	43.5	62.3	338.6	0.0	0.0
11	-424.5	3.8	-196.0	-0.4	-254.5	120.6	37.8	54.2	660.7	0.0	0.0
12	-517.1	3.3	-267.9	-0.3	-199.8	96.7	30.2	43.4	812.9	0.0	0.0
Total	-4012.7	156.0	622.6	-10.4	-3580.9	1370.7	444.2	636.8	4391.4	0.0	0.0
During heating (6433.0 h)	-3111.1	218.8	-909.2	-5.0	-2193.6	908.1	298.9	411.1	4391.7	0.0	0.0
During cooling (669.9 h)	-371.4	-64.4	416.9	-0.5	-29.3	25.7	9.4	14.5	0.0	0.0	0.0
Rest of time	-530.2	1.6	1114.9	-4.9	-1358.0	436.9	135.8	211.2	-0.3	0.0	0.0



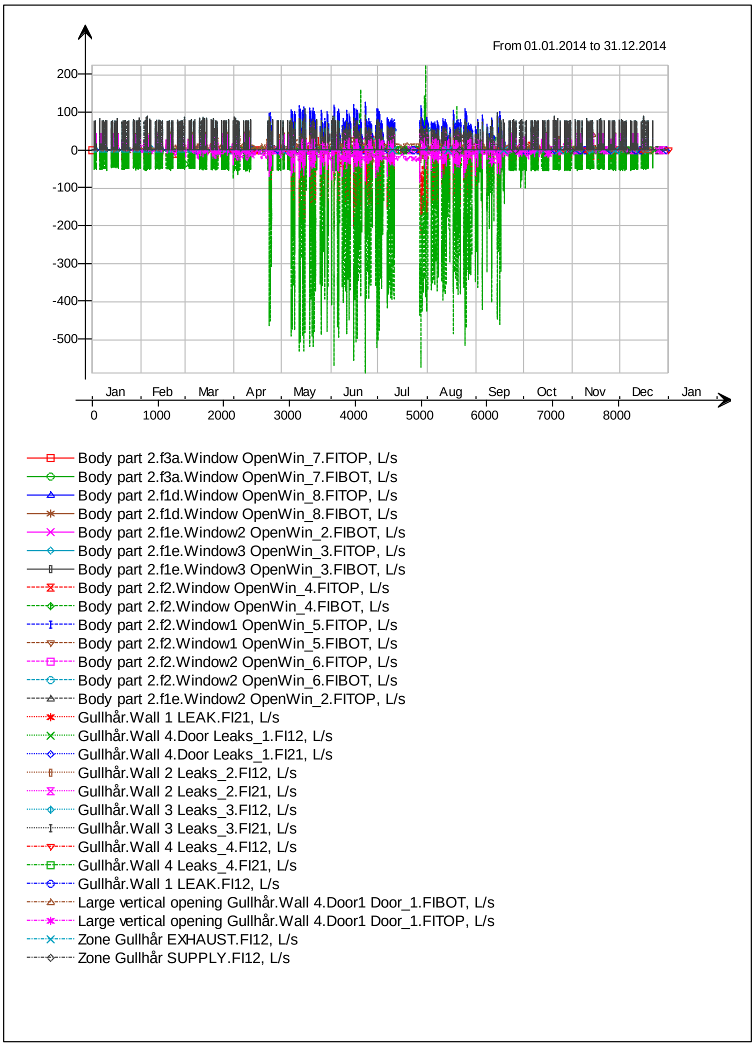
Envelope transmission

kWh

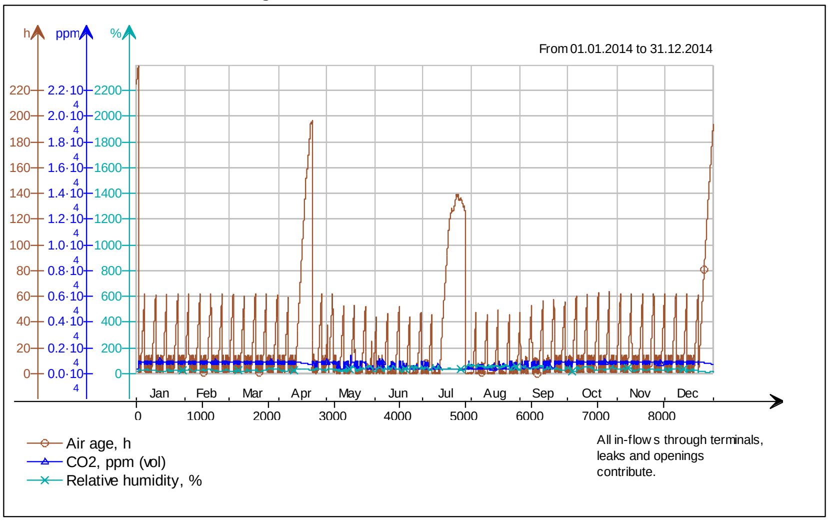
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-170.6	-141.0	-64.5	-315.3	-35.7	-170.6
2	-132.4	-107.6	-54.7	-251.1	-28.0	-135.1
3	-130.4	-102.3	-59.0	-256.4	-28.0	-137.1
4	-97.7	-72.7	-53.1	-206.2	-21.2	-108.8
5	-57.4	-38.6	-54.5	-135.7	-12.4	-67.8
6	-33.1	0.3	-47.4	-112.2	-8.6	-54.3
7	-49.3	-34.3	-58.6	-123.3	-10.7	-61.0
8	-22.3	0.2	-37.8	-82.9	-6.4	-37.9
9	-56.3	-37.2	-35.1	-130.6	-12.9	-65.8
10	-91.7	-72.6	-41.4	-182.9	-19.8	-96.0
11	-124.4	-101.6	-45.7	-236.1	-26.4	-126.4
12	-152.6	-125.9	-51.5	-286.4	-32.2	-154.9
Total	-1118.2	-833.3	-603.4	-2319.1	-242.2	-1215.7
During heating	-901.7	-535.0	-415.3	-1981.9	-205.6	-1052.8
During cooling	-85.2	-151.5	-63.0	-117.3	-12.5	-59.3
Rest of time	-131.3	-146.8	-125.1	-219.9	-24.1	-103.6



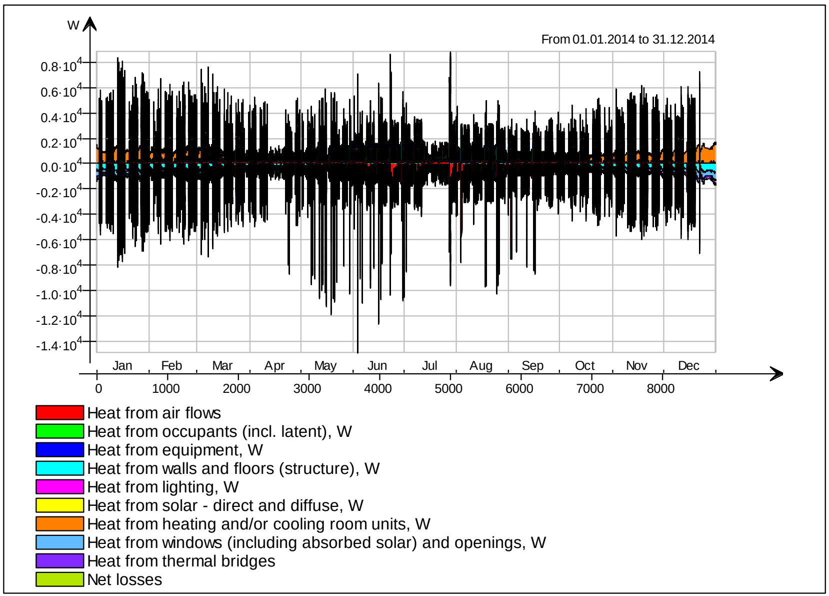
Ventilation air flows



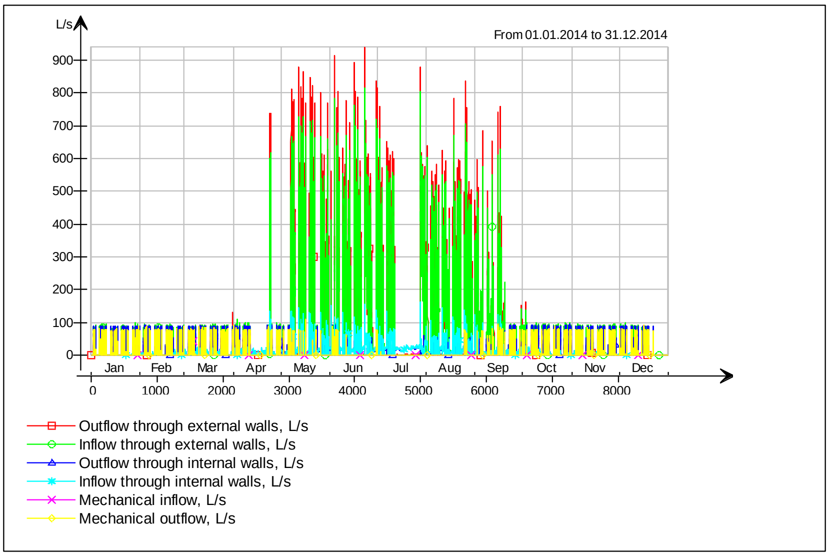
Indoor Air Quality



Heat balance

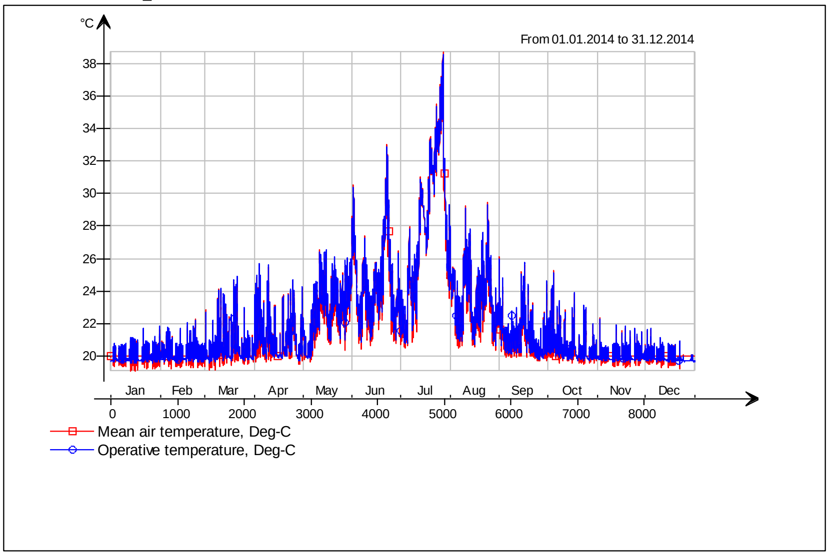


Air flow in zone



Tyrihans

Main temperatures

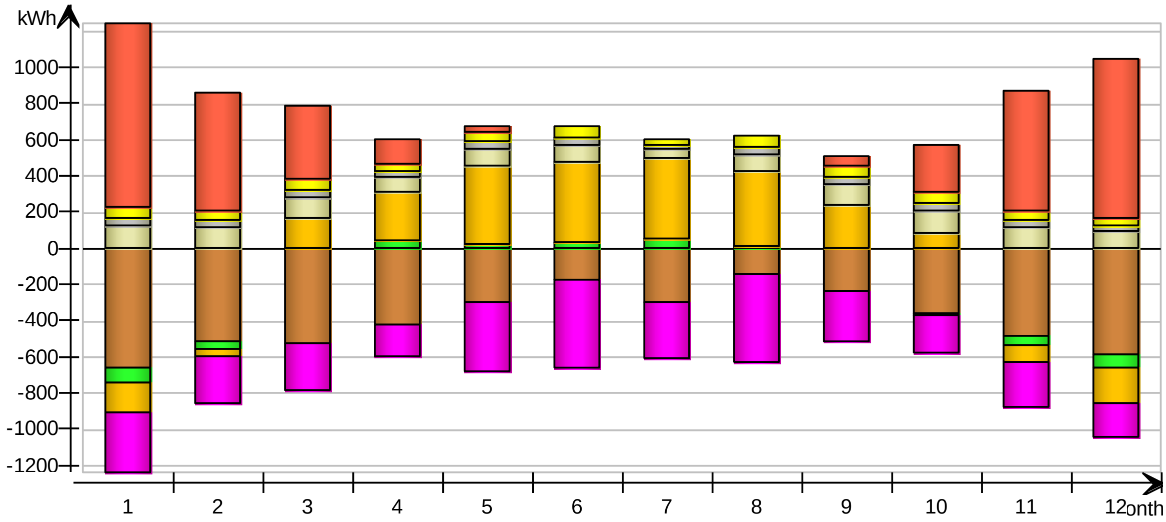


Energy for "Tyrihans"

Energy for "Tyrihans"

kWh (sensible only)

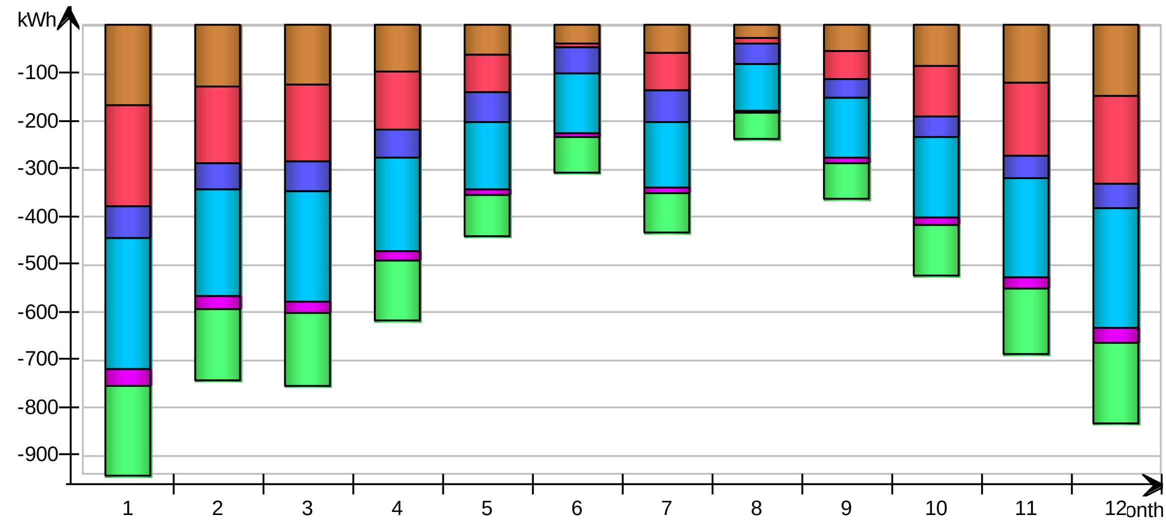
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-664.7	-76.7	-165.9	-0.3	-332.8	122.9	41.6	61.0	1017.0	0.0	0.0
2	-517.2	-37.5	-39.9	-0.6	-260.6	111.7	37.8	55.4	652.6	0.0	0.0
3	-528.0	5.5	165.9	-2.9	-258.3	112.4	39.7	58.2	409.3	0.0	0.0
4	-419.7	44.8	266.0	-3.4	-173.3	81.8	30.2	44.3	130.6	0.0	0.0
5	-300.9	23.2	440.0	-2.2	-377.5	92.8	37.8	55.4	33.7	0.0	0.0
6	-179.6	33.5	446.7	-2.9	-487.1	92.8	39.7	58.2	0.0	0.0	0.0
7	-297.9	50.8	442.0	-0.2	-307.1	53.6	24.6	36.0	0.0	0.0	0.0
8	-144.8	16.5	415.6	-0.3	-482.1	98.2	39.7	58.2	0.0	0.0	0.0
9	-236.7	5.5	235.7	-2.6	-274.0	116.6	41.6	61.0	54.2	0.0	0.0
10	-361.8	-5.7	82.3	-1.9	-209.9	127.8	43.5	63.7	263.7	0.0	0.0
11	-483.7	-47.6	-94.5	-0.6	-242.5	112.8	37.8	55.4	664.7	0.0	0.0
12	-589.0	-72.7	-193.5	-0.3	-190.0	90.8	30.2	44.3	881.5	0.0	0.0
Total	-4724.0	-60.3	2000.4	-18.3	-3595.2	1214.1	444.2	651.3	4107.3	0.0	0.0
During heating (5230.0 h)	-2925.0	-171.9	-678.1	-3.8	-1627.5	712.2	243.7	351.9	4108.3	0.0	0.0
During cooling (1407.0 h)	-1009.7	75.8	1270.8	-3.4	-593.6	120.1	58.3	86.0	0.0	0.0	0.0
Rest of time	-789.3	35.8	1407.7	-11.1	-1374.1	381.8	142.2	213.4	-1.0	0.0	0.0



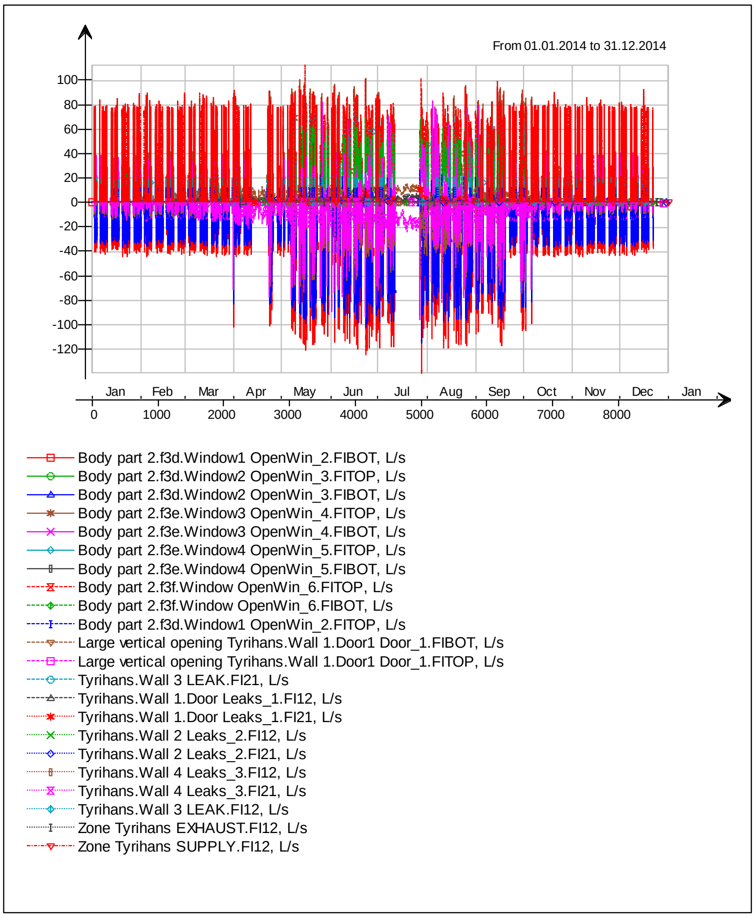
Envelope transmission

kWh

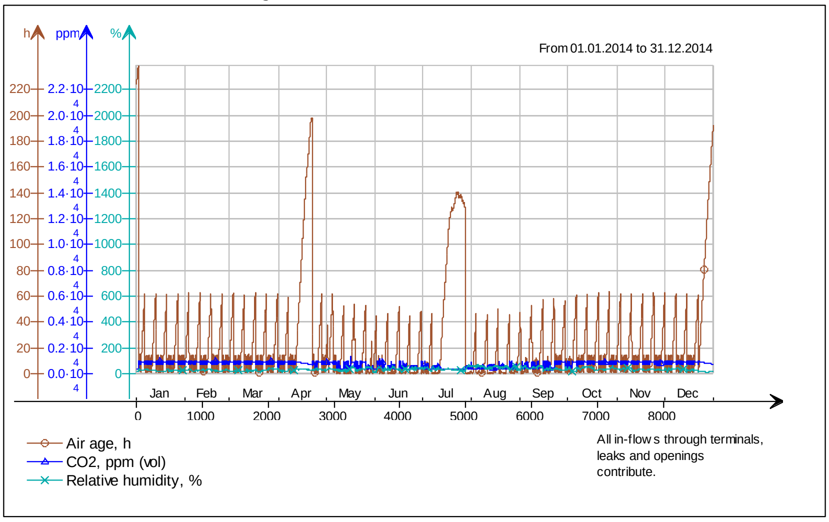
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-167.1	-210.7	-66.0	-276.1	-34.0	-187.0
2	-127.9	-158.9	-56.2	-222.1	-25.8	-148.4
3	-127.3	-160.5	-62.5	-232.7	-24.6	-153.1
4	-98.1	-120.3	-57.6	-194.5	-18.8	-125.0
5	-63.0	-80.3	-61.7	-140.5	-10.5	-85.4
6	-37.9	-6.3	-54.5	-124.2	-7.8	-73.1
7	-59.9	-77.4	-67.9	-136.6	-10.3	-82.4
8	-27.3	-13.2	-44.7	-96.9	-5.0	-54.5
9	-54.7	-57.7	-37.4	-124.7	-10.8	-76.1
10	-88.0	-105.4	-43.3	-166.7	-17.6	-107.5
11	-121.5	-151.7	-46.7	-207.8	-24.9	-138.9
12	-149.7	-185.9	-52.4	-250.5	-31.2	-169.8
Total	-1122.4	-1328.3	-650.8	-2173.3	-221.3	-1401.1
During heating	-761.9	-617.2	-355.6	-1533.3	-169.4	-1020.6
During cooling	-184.7	-524.7	-136.7	-242.2	-20.8	-142.6
Rest of time	-175.8	-186.4	-158.5	-397.8	-31.1	-237.9



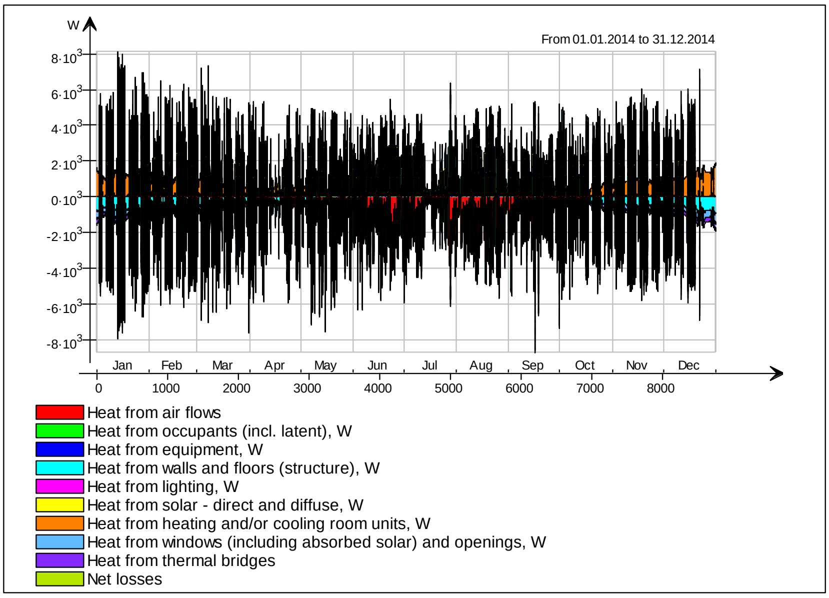
Ventilation air flows



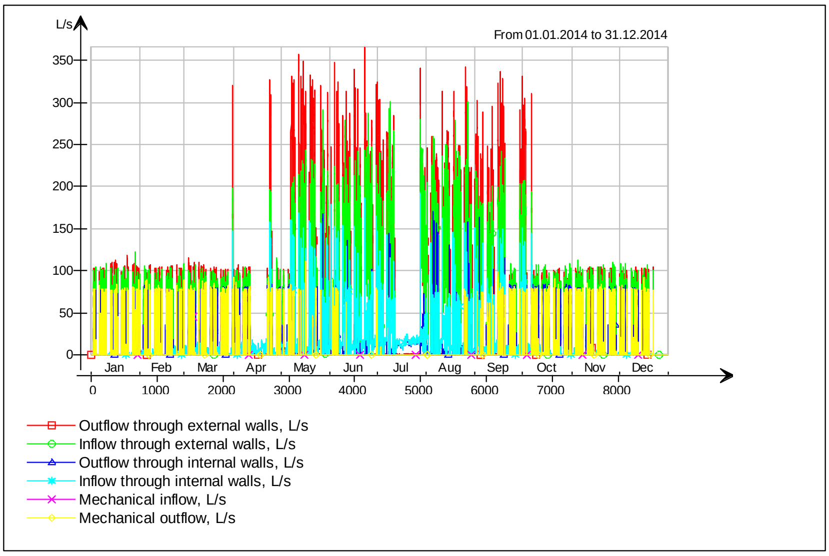
Indoor Air Quality



Heat balance

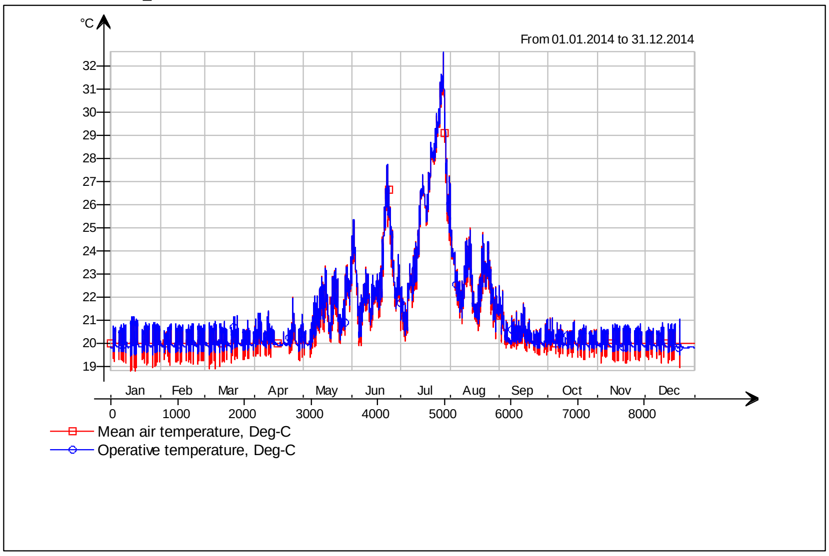


Air flow in zone



Locker rooms, west

Main temperatures

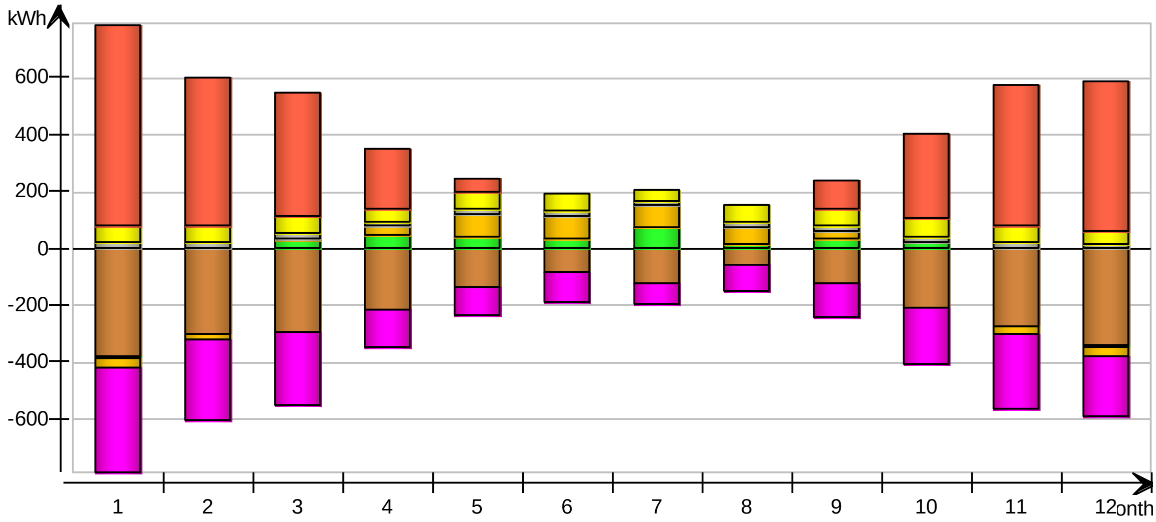


Energy for "Locker rooms, west"

Energy for "Locker rooms, west"

kWh (sensible only)

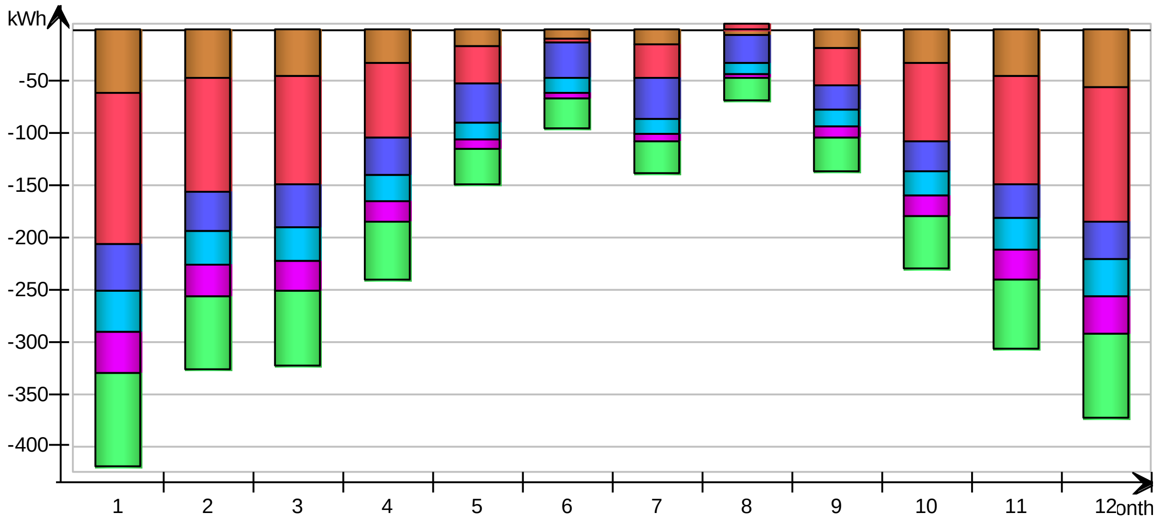
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-384.7	-3.7	-34.4	0.0	-367.1	0.0	20.8	62.5	706.6	0.0	0.0
2	-300.2	3.3	-17.6	0.0	-283.2	0.0	18.9	56.9	522.0	0.0	0.0
3	-293.8	24.1	6.4	0.0	-253.7	0.0	19.8	59.7	437.6	0.0	0.0
4	-220.0	48.7	33.9	0.0	-131.8	0.0	15.1	45.5	208.7	0.0	0.0
5	-136.3	37.7	76.3	0.0	-98.0	0.0	18.9	56.9	44.8	0.0	0.0
6	-84.8	32.8	78.8	0.0	-107.2	0.0	19.9	59.7	0.7	0.0	0.0
7	-128.3	74.9	79.1	0.0	-74.7	0.0	12.3	37.0	0.0	0.0	0.0
8	-56.6	12.8	57.3	0.0	-93.5	0.0	19.9	59.7	0.0	0.0	0.0
9	-124.6	32.7	26.6	0.0	-117.4	0.0	20.8	62.5	99.2	0.0	0.0
10	-209.3	18.1	2.1	0.0	-195.9	0.0	21.7	65.4	297.9	0.0	0.0
11	-279.6	-0.2	-23.6	0.0	-265.0	0.0	18.9	56.9	492.6	0.0	0.0
12	-341.0	-3.6	-34.0	0.0	-208.7	0.0	15.1	45.5	526.8	0.0	0.0
Total	-2559.2	277.5	251.1	0.0	-2196.2	0.0	222.1	668.0	3336.9	0.0	0.0
During heating (6225.0 h)	-2184.4	143.2	-40.5	0.0	-1913.3	0.0	164.3	494.2	3336.1	0.0	0.0
During cooling (717.3 h)	-148.1	77.9	95.5	0.0	-57.9	0.0	8.1	24.5	0.0	0.0	0.0
Rest of time	-226.7	56.4	196.1	0.0	-224.9	0.0	49.7	149.3	0.8	0.0	0.0



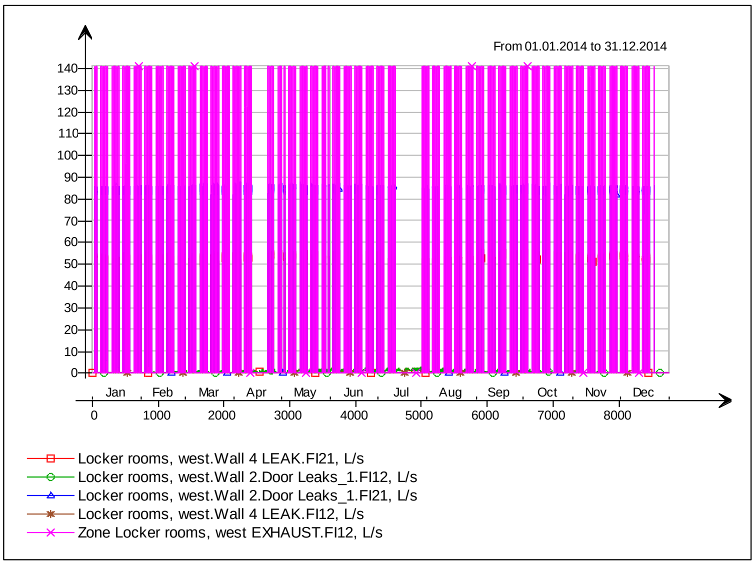
Envelope transmission

kWh

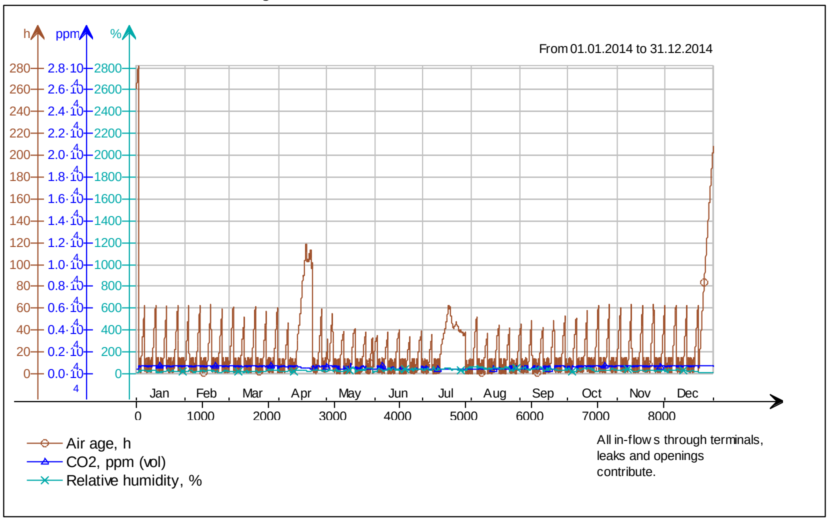
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-61.9	-145.8	-46.2	-40.6	-40.5	-90.4
2	-47.5	-110.9	-39.1	-32.3	-31.2	-71.5
3	-45.7	-103.8	-41.9	-33.0	-29.8	-72.6
4	-32.6	-72.1	-37.1	-26.2	-21.1	-57.0
5	-16.7	-36.6	-37.9	-17.0	-9.7	-35.5
6	-9.7	-4.8	-34.0	-14.6	-6.5	-29.7
7	-14.4	-33.8	-40.8	-15.3	-8.1	-31.2
8	-6.0	4.6	-27.7	-11.5	-5.1	-22.5
9	-18.1	-36.6	-23.8	-16.2	-12.2	-33.8
10	-32.2	-75.8	-29.5	-23.5	-21.1	-50.6
11	-45.0	-105.0	-32.7	-30.4	-29.8	-67.0
12	-55.5	-129.8	-36.9	-36.8	-36.7	-82.0
Total	-385.4	-850.5	-427.6	-297.5	-251.7	-643.9
During heating	-345.6	-754.4	-305.0	-250.8	-230.0	-549.7
During cooling	-15.8	-51.6	-42.5	-14.9	-7.6	-30.5
Rest of time	-24.0	-44.5	-80.1	-31.8	-14.1	-63.7



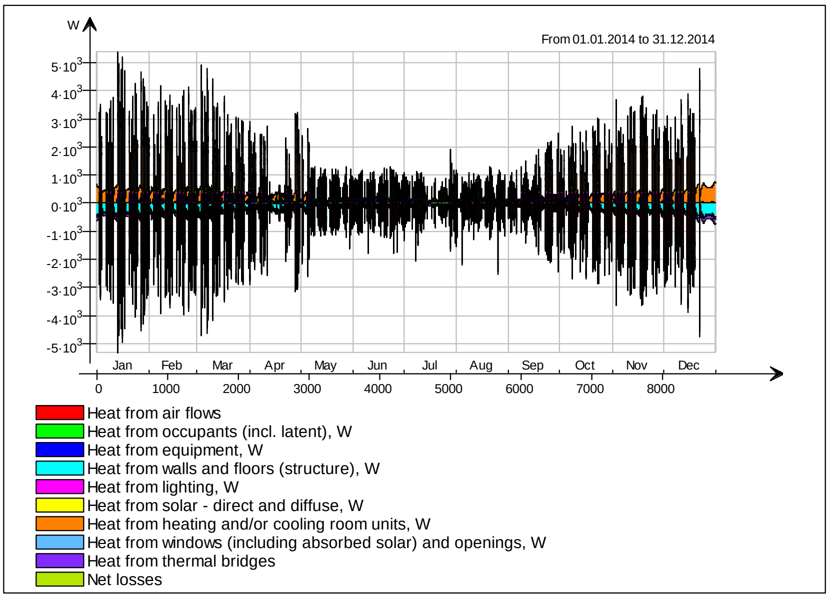
Ventilation air flows



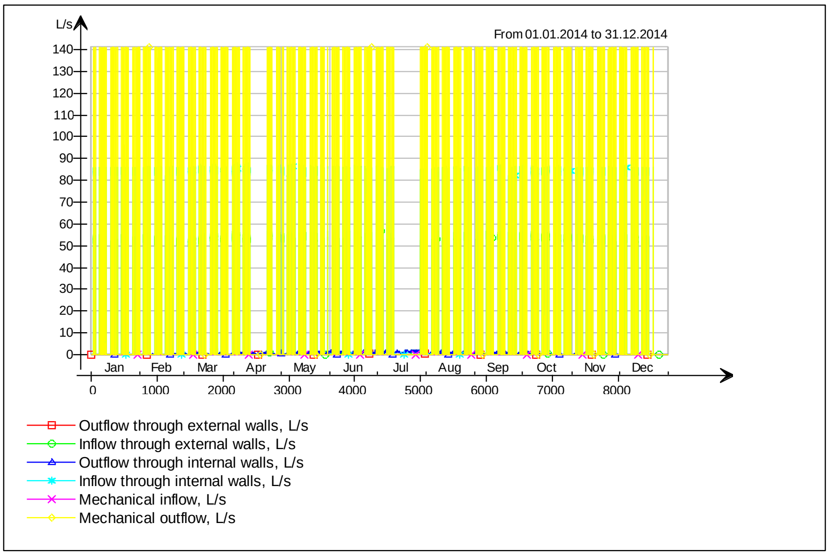
Indoor Air Quality



Heat balance

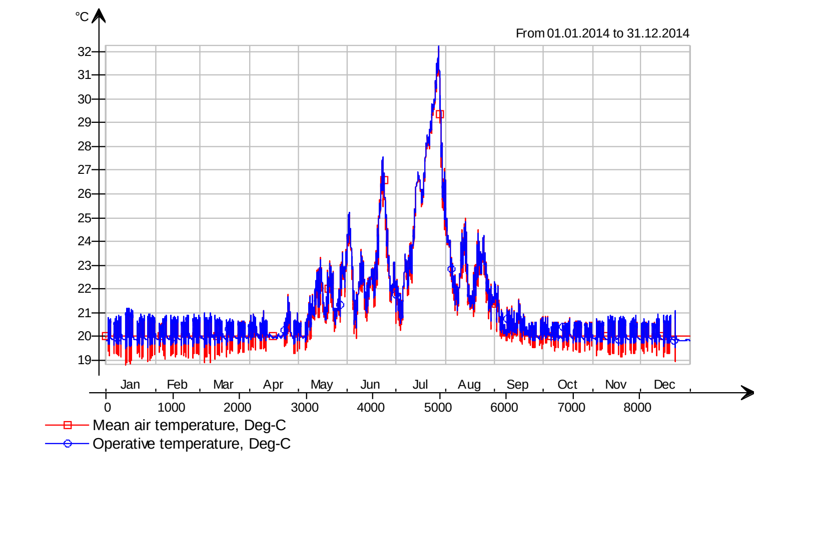


Air flow in zone



Locker rooms, east

Main temperatures

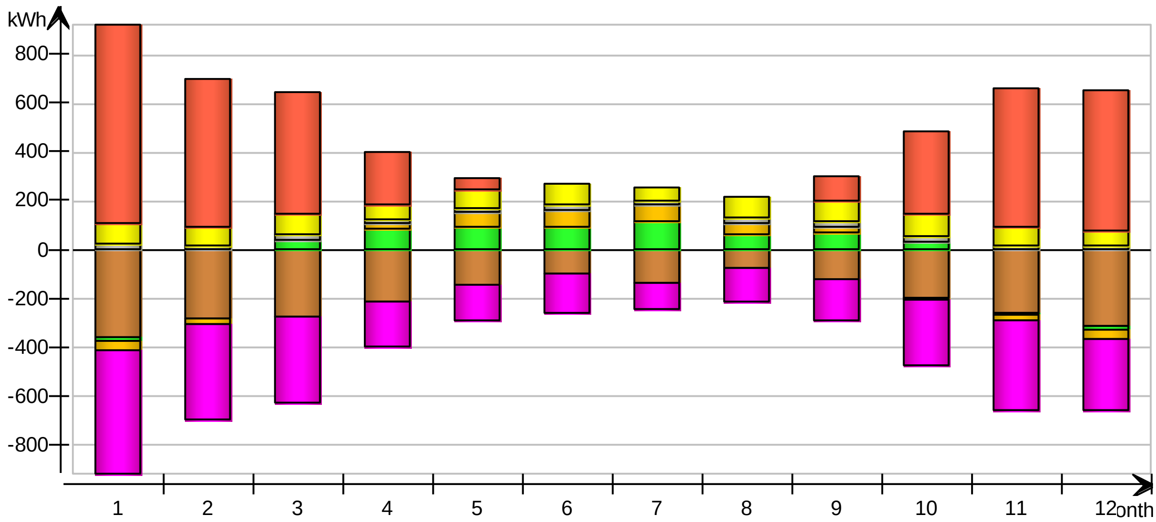


Energy for "Locker rooms, east"

Energy for "Locker rooms, east"

kWh (sensible only)

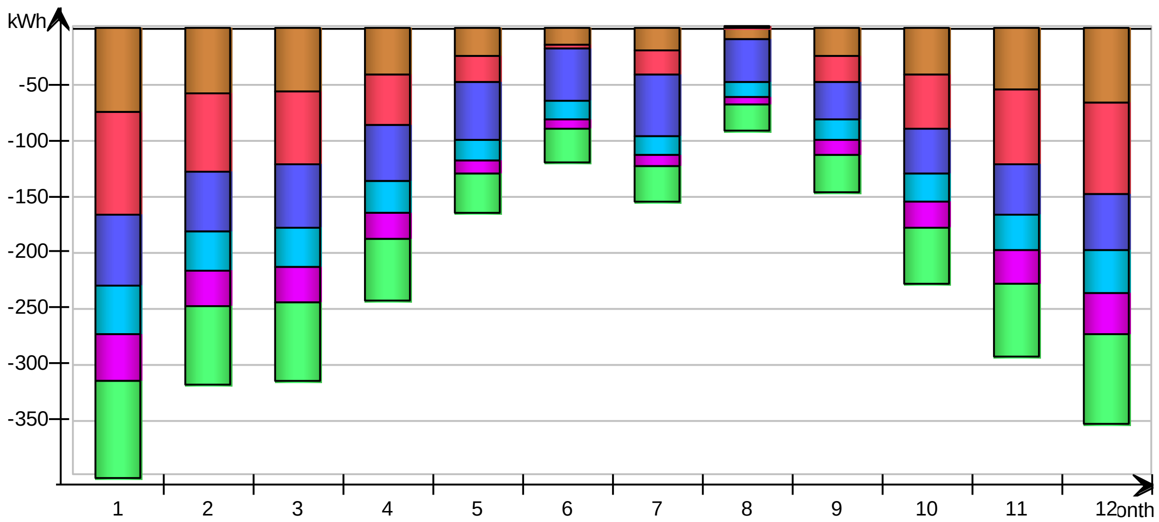
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-356.6	-17.0	-38.5	0.0	-507.2	0.0	20.8	84.3	814.2	0.0	0.0
2	-281.3	-1.3	-23.8	0.0	-391.4	0.0	18.9	76.6	602.2	0.0	0.0
3	-279.0	36.1	-3.4	0.0	-351.0	0.0	19.8	80.5	497.2	0.0	0.0
4	-212.7	81.4	23.1	0.0	-183.6	0.0	15.1	61.3	215.3	0.0	0.0
5	-144.9	89.9	60.2	0.0	-147.3	0.0	18.9	76.6	46.8	0.0	0.0
6	-101.0	94.1	65.5	0.0	-159.5	0.0	19.9	80.5	0.1	0.0	0.0
7	-136.2	114.9	65.3	0.0	-105.8	0.0	12.3	49.8	0.0	0.0	0.0
8	-73.9	60.4	47.5	0.0	-134.9	0.0	19.9	80.5	0.0	0.0	0.0
9	-125.1	70.8	19.5	0.0	-167.3	0.0	20.8	84.3	96.8	0.0	0.0
10	-198.8	27.5	-7.1	0.0	-271.3	0.0	21.7	88.1	339.9	0.0	0.0
11	-259.5	-6.8	-26.6	0.0	-366.3	0.0	18.9	76.6	563.6	0.0	0.0
12	-313.8	-14.4	-36.3	0.0	-288.5	0.0	15.1	61.3	576.6	0.0	0.0
Total	-2482.8	535.6	145.4	0.0	-3074.1	0.0	222.1	900.4	3752.7	0.0	0.0
During heating (6108.0 h)	-2083.9	220.5	-72.6	0.0	-2626.9	0.0	160.3	650.0	3752.8	0.0	0.0
During cooling (738.9 h)	-143.8	123.5	57.8	0.0	-81.5	0.0	8.7	35.2	0.0	0.0	0.0
Rest of time	-255.1	191.6	160.2	0.0	-365.7	0.0	53.1	215.2	-0.1	0.0	0.0



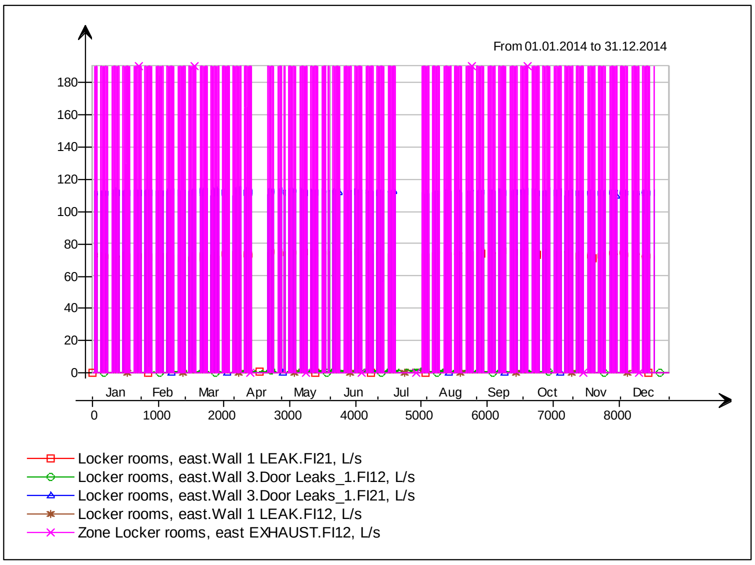
Envelope transmission

kWh

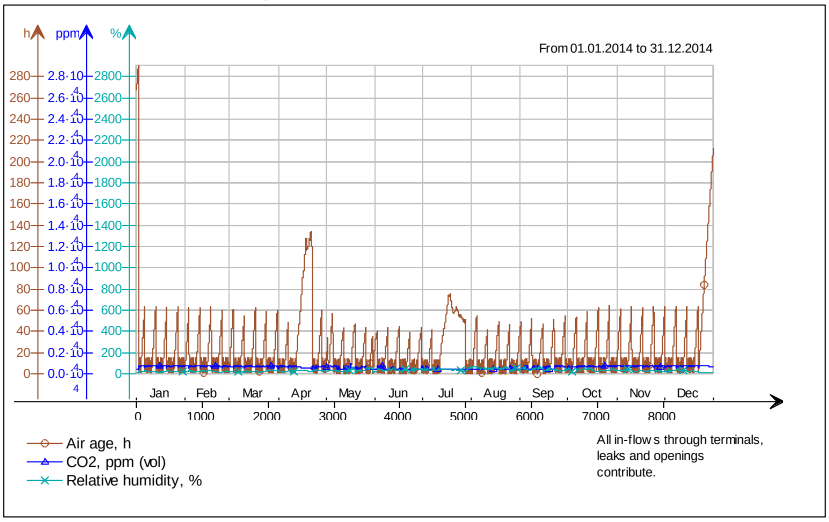
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-75.2	-91.1	-62.2	-42.6	-40.9	-87.3
2	-58.4	-69.3	-52.6	-33.9	-31.9	-69.1
3	-57.0	-64.7	-56.4	-34.6	-31.0	-70.0
4	-41.3	-44.3	-49.7	-27.4	-22.4	-55.0
5	-23.7	-23.5	-51.0	-18.1	-11.8	-34.8
6	-14.6	-2.9	-45.9	-15.6	-8.3	-29.3
7	-20.2	-20.9	-54.8	-16.2	-9.7	-30.6
8	-10.1	2.2	-37.3	-12.2	-6.6	-22.1
9	-23.8	-22.8	-32.3	-17.1	-13.4	-32.9
10	-40.6	-47.4	-39.7	-24.6	-22.2	-48.8
11	-54.8	-65.7	-44.1	-31.9	-30.2	-64.7
12	-67.0	-81.1	-49.8	-38.7	-36.8	-79.2
Total	-486.6	-531.4	-575.9	-313.1	-265.2	-623.7
During heating	-429.2	-485.8	-406.1	-260.9	-236.2	-526.7
During cooling	-20.9	-24.5	-57.7	-16.4	-9.8	-31.0
Rest of time	-36.5	-21.1	-112.1	-35.8	-19.2	-66.0



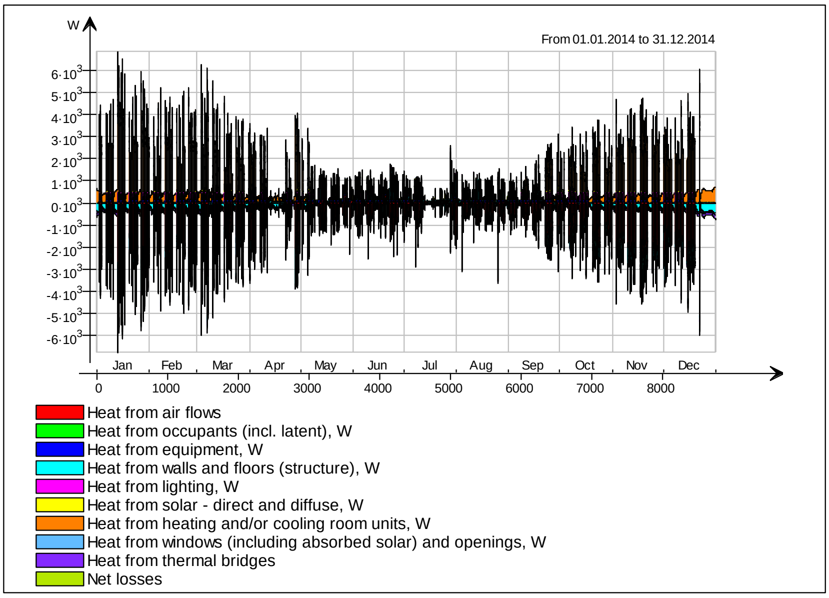
Ventilation air flows



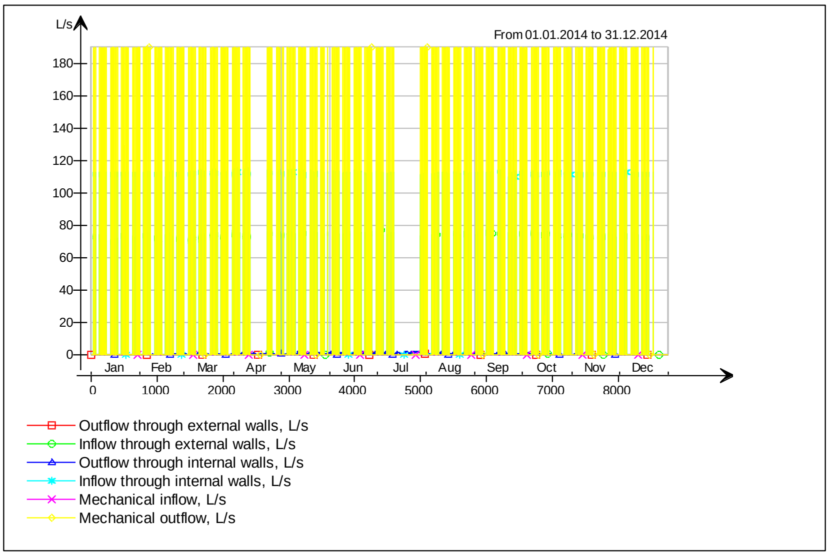
Indoor Air Quality



Heat balance

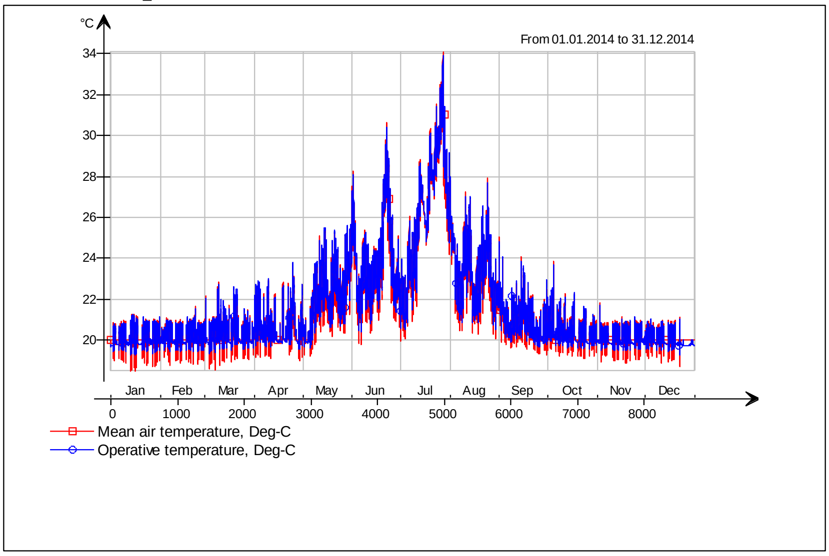


Air flow in zone



Office, management

Main temperatures

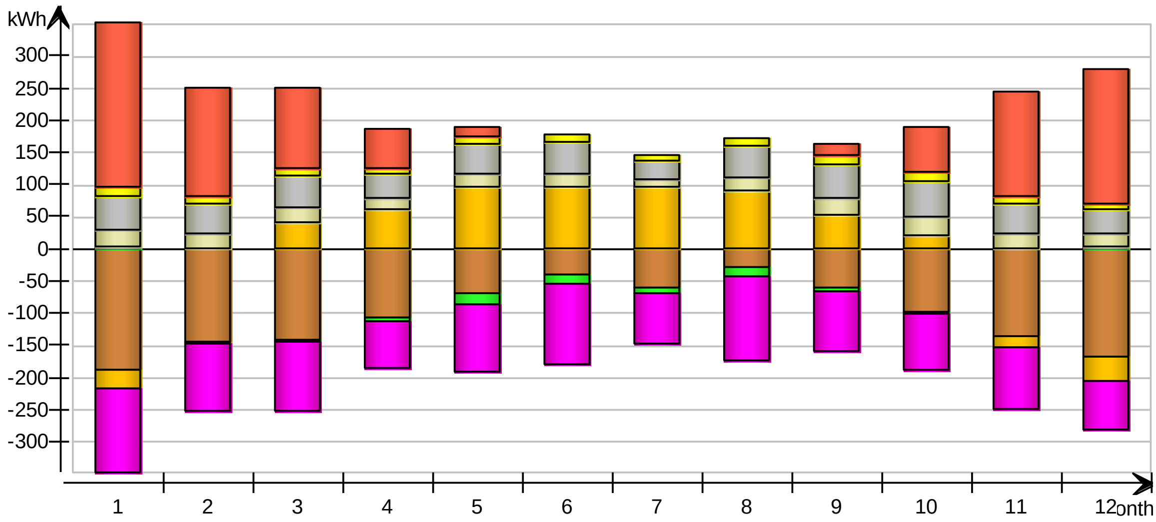


Energy for "Office, management"

Energy for "Office, management"

kWh (sensible only)

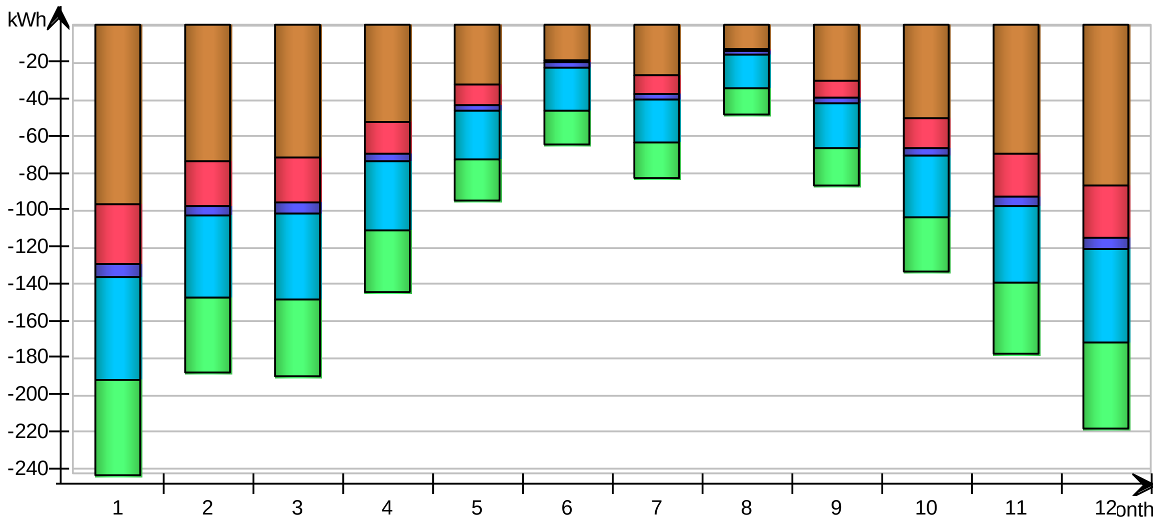
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-187.2	1.7	-29.7	-0.0	-131.5	26.2	52.0	13.6	255.3	0.0	0.0
2	-144.6	0.4	-3.8	-0.0	-103.3	24.0	47.3	12.4	168.0	0.0	0.0
3	-143.2	-3.3	40.4	-0.1	-106.0	24.7	49.6	13.0	125.4	0.0	0.0
4	-107.6	-5.5	60.0	-0.2	-72.9	18.4	37.8	9.9	60.5	0.0	0.0
5	-68.7	-16.1	96.1	-0.2	-104.6	21.2	47.3	12.4	13.4	0.0	0.0
6	-40.9	-13.4	95.9	-0.3	-124.3	21.0	49.6	13.0	0.1	0.0	0.0
7	-59.4	-9.0	97.1	-0.1	-78.4	11.9	30.7	8.1	0.0	0.0	0.0
8	-29.7	-15.2	90.5	-0.1	-129.4	21.8	49.6	13.0	0.0	0.0	0.0
9	-61.9	-6.9	53.0	-0.2	-92.4	25.8	52.0	13.6	17.4	0.0	0.0
10	-99.9	-2.8	21.5	-0.1	-85.6	27.9	54.3	14.3	70.7	0.0	0.0
11	-136.7	1.3	-16.0	-0.0	-95.8	24.3	47.3	12.4	163.6	0.0	0.0
12	-168.0	2.2	-36.1	-0.0	-75.0	19.5	37.8	9.9	210.0	0.0	0.0
Total	-1247.7	-66.6	469.0	-1.3	-1199.1	266.7	555.2	145.7	1084.5	0.0	0.0
During heating (5645.0 h)	-929.4	24.4	-70.0	-0.3	-686.1	166.9	327.2	85.9	1084.4	0.0	0.0
During cooling (1149.0 h)	-156.6	-45.3	235.5	-0.2	-131.5	22.5	61.2	16.1	0.0	0.0	0.0
Rest of time	-161.7	-45.7	303.5	-0.8	-381.5	77.3	166.8	43.7	0.1	0.0	0.0



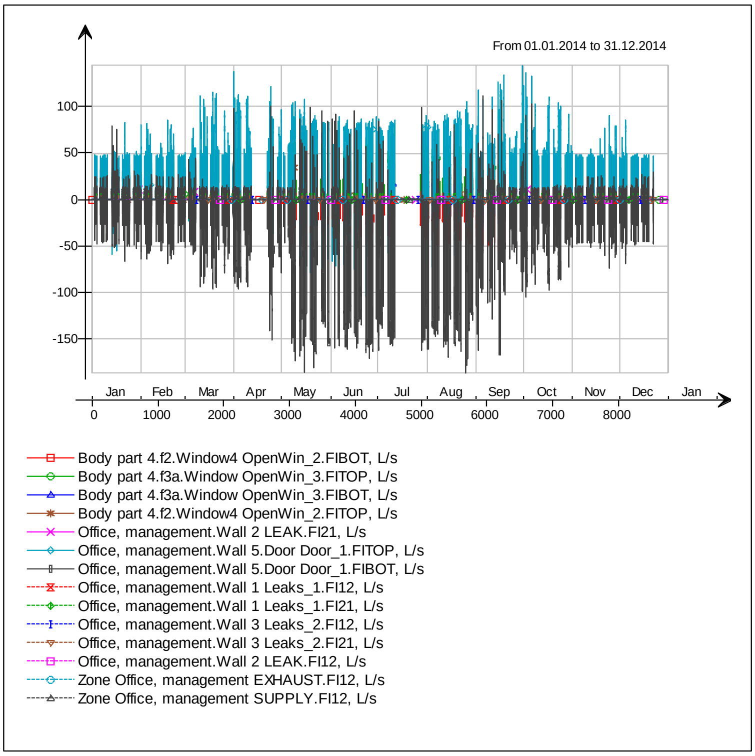
Envelope transmission

kWh

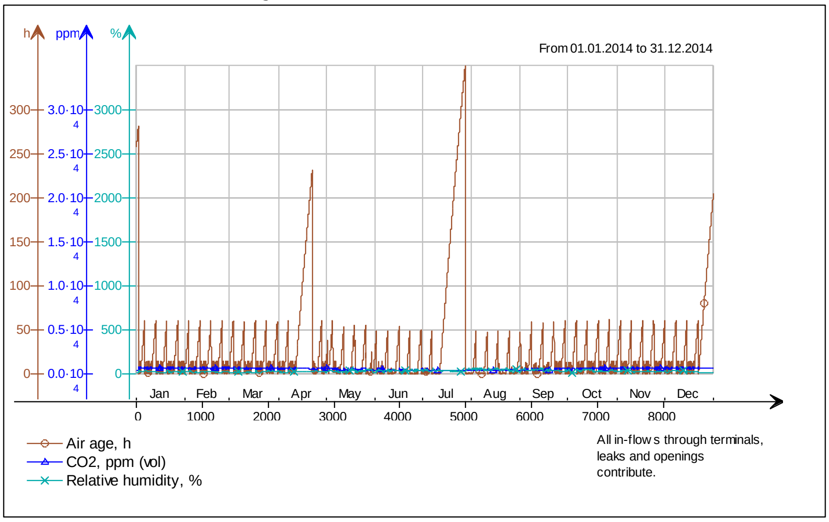
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-96.9	-32.1	-6.9	-55.7	0.0	-51.4
2	-74.0	-24.4	-5.5	-44.8	0.0	-40.8
3	-71.9	-24.0	-5.7	-46.3	0.0	-41.6
4	-53.0	-17.0	-4.5	-37.7	0.0	-33.1
5	-32.4	-10.9	-3.2	-26.3	0.0	-22.1
6	-18.7	-0.9	-2.6	-22.9	0.0	-18.7
7	-27.5	-10.2	-2.8	-23.2	0.0	-18.9
8	-12.8	-0.6	-1.9	-18.3	0.0	-14.4
9	-30.1	-8.8	-2.7	-24.2	0.0	-20.3
10	-50.3	-16.5	-3.9	-33.1	0.0	-29.2
11	-70.4	-23.1	-5.0	-41.9	0.0	-38.1
12	-86.8	-28.4	-6.1	-50.5	0.0	-46.7
Total	-624.8	-196.8	-50.8	-425.0	0.0	-375.3
During heating	-479.7	-114.5	-38.2	-328.1	0.0	-296.9
During cooling	-68.5	-56.6	-4.8	-33.4	0.0	-26.8
Rest of time	-76.6	-25.7	-7.8	-63.5	0.0	-51.6



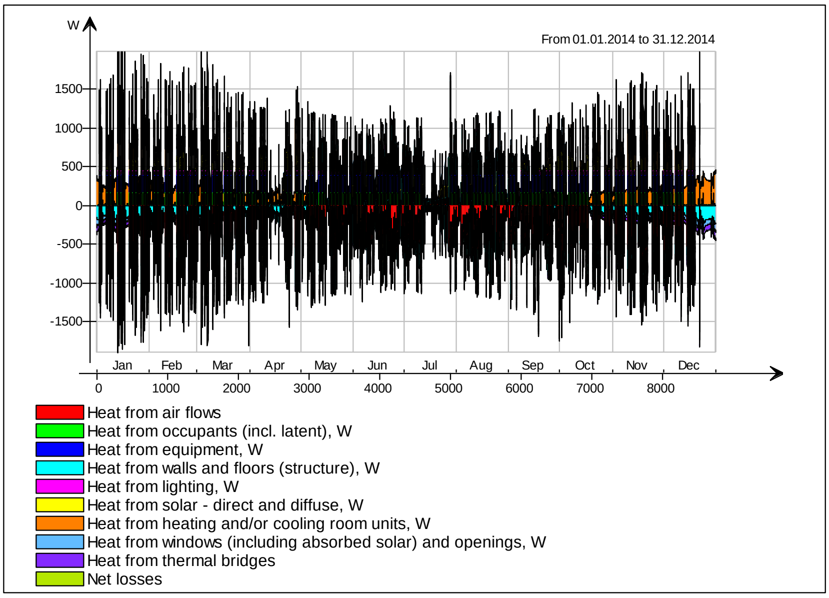
Ventilation air flows



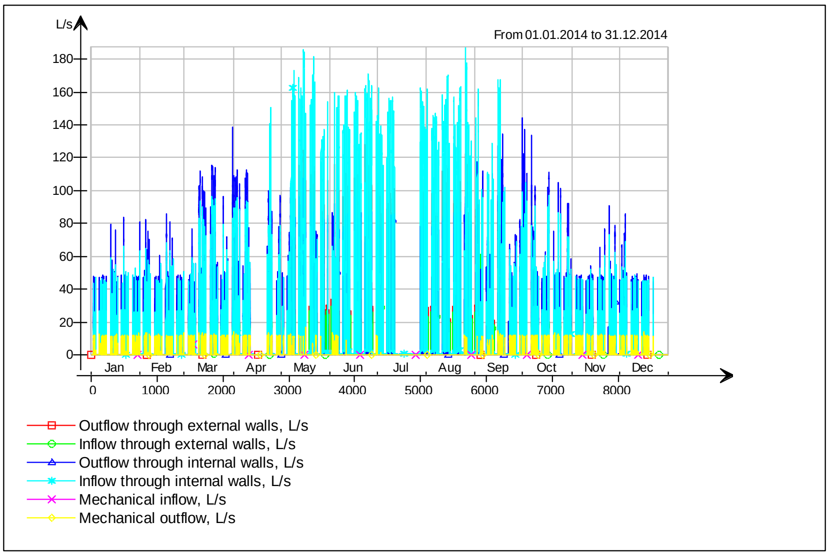
Indoor Air Quality



Heat balance



Air flow in zone



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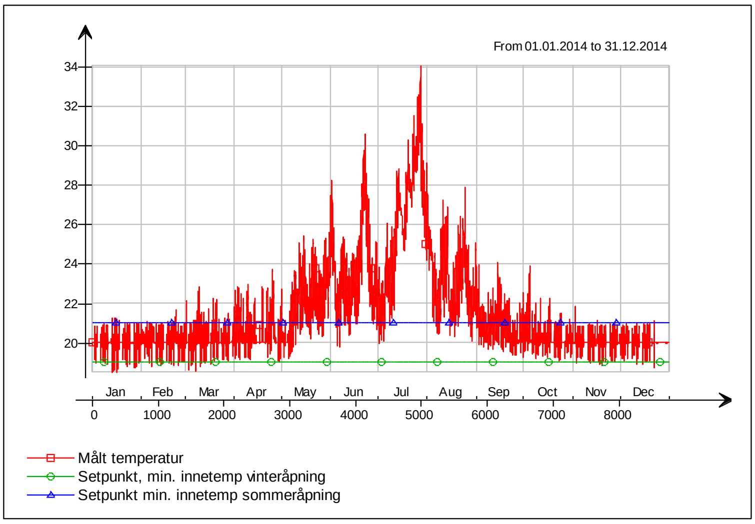

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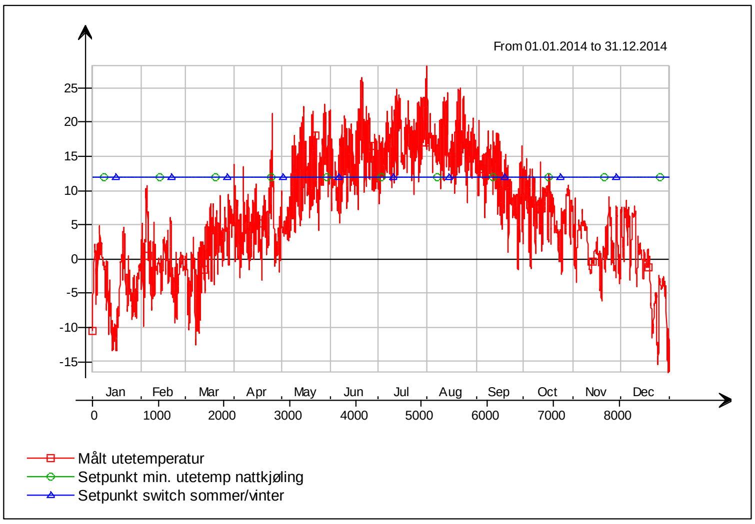

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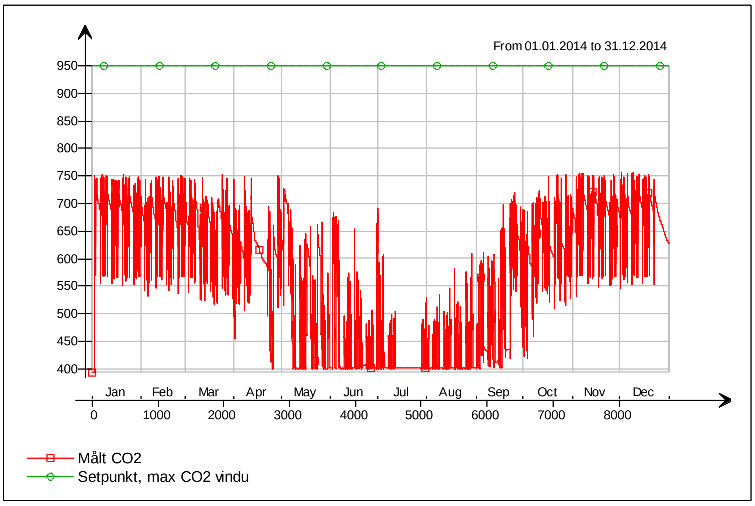

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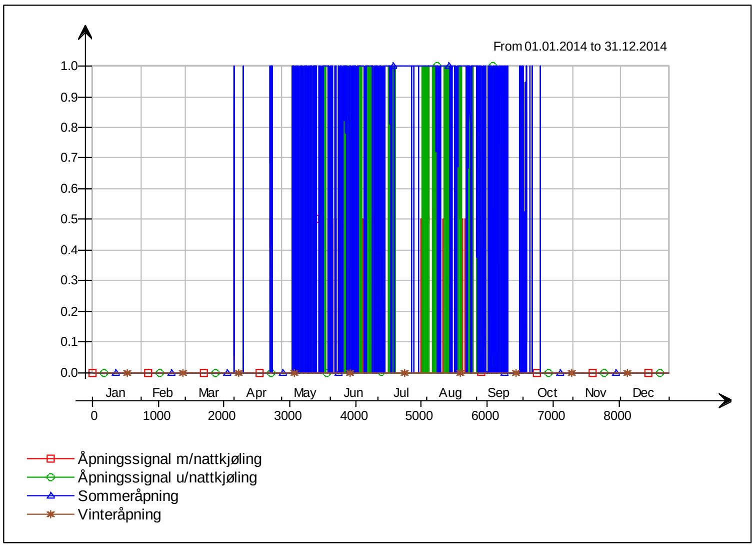
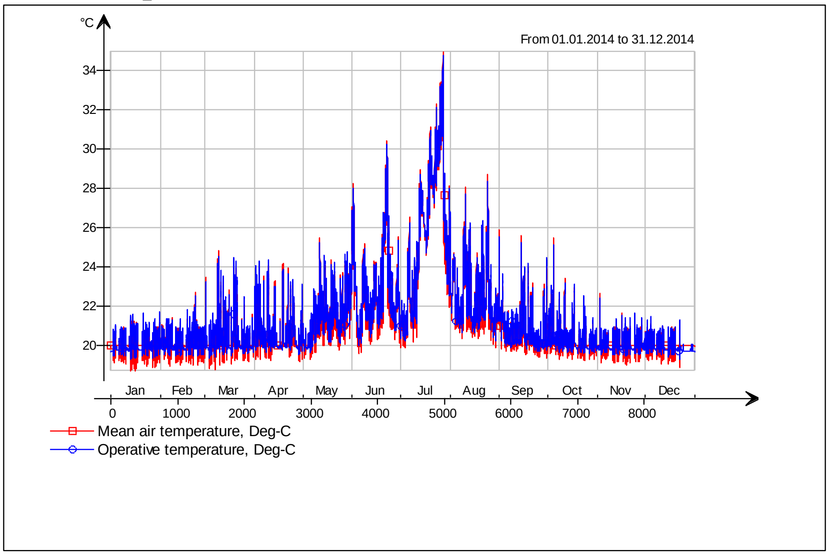


Lunch room

Main temperatures

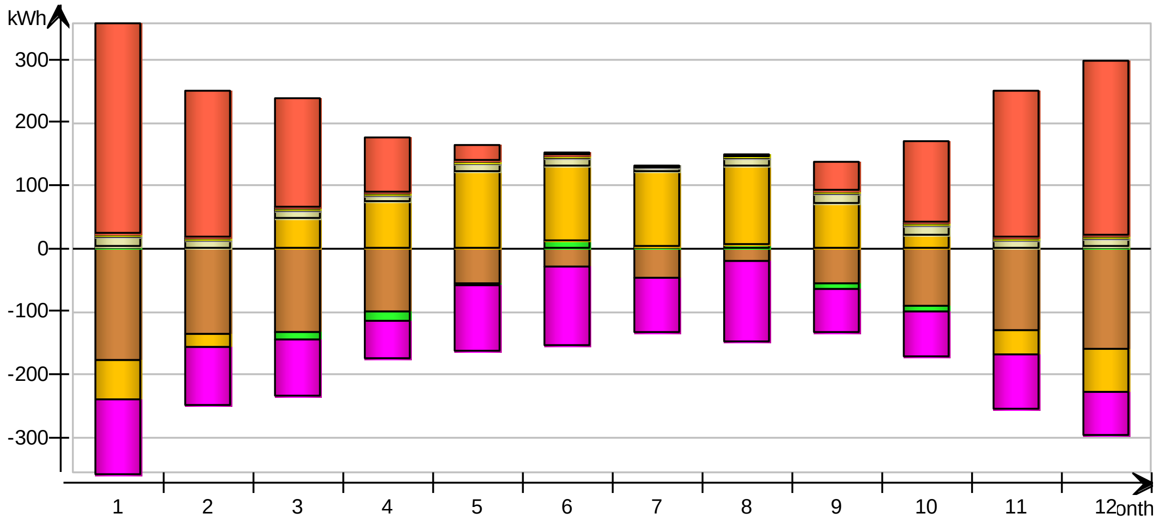


Energy for "Lunch room"

Energy for "Lunch room"

kWh (sensible only)

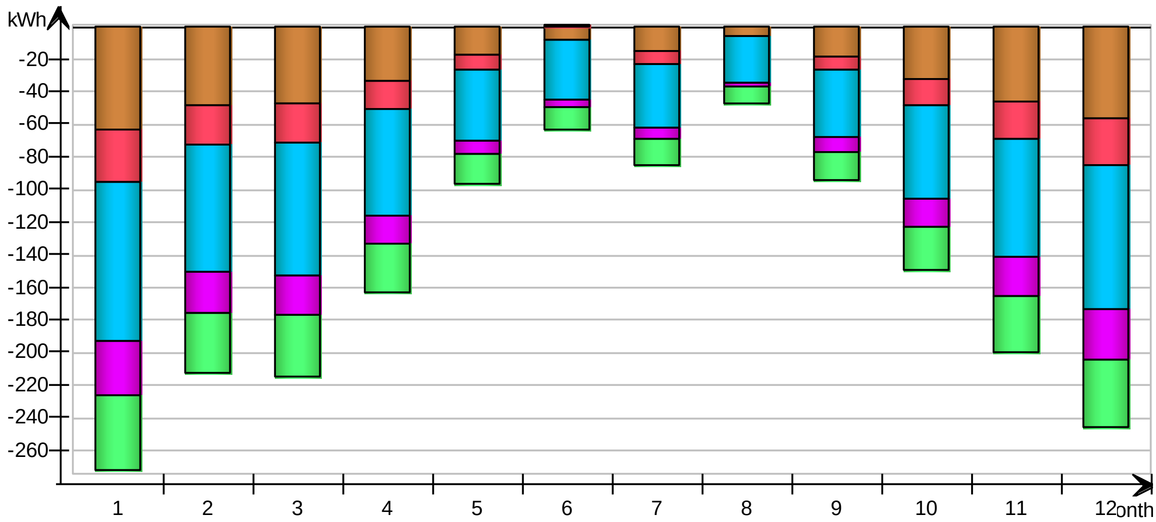
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-177.1	2.1	-61.7	0.0	-117.5	14.5	4.0	2.7	333.4	0.0	0.0
2	-136.1	-1.2	-20.5	-0.0	-91.6	13.2	3.6	2.4	230.6	0.0	0.0
3	-134.3	-12.6	46.5	-0.2	-90.1	13.4	3.8	2.5	171.2	0.0	0.0
4	-99.8	-15.6	73.4	-0.2	-59.6	9.9	2.9	1.9	87.2	0.0	0.0
5	-54.9	-4.2	121.5	-0.1	-104.5	12.2	3.6	2.4	24.2	0.0	0.0
6	-28.1	13.2	119.3	-0.2	-124.6	12.6	3.8	2.5	1.7	0.0	0.0
7	-46.9	2.1	120.0	-0.0	-86.6	7.4	2.3	1.6	0.2	0.0	0.0
8	-21.8	5.4	124.1	-0.0	-126.6	12.6	3.8	2.5	0.1	0.0	0.0
9	-56.3	-9.7	70.1	-0.1	-68.3	14.3	4.0	2.7	43.6	0.0	0.0
10	-93.0	-7.5	21.1	-0.1	-70.8	15.4	4.1	2.8	128.3	0.0	0.0
11	-129.4	1.1	-37.9	-0.0	-85.2	13.4	3.6	2.4	232.2	0.0	0.0
12	-159.6	3.6	-69.2	-0.0	-67.1	10.8	2.9	1.9	276.8	0.0	0.0
Total	-1137.4	-23.4	506.7	-0.9	-1092.6	149.8	42.3	28.4	1529.5	0.0	0.0
During heating (6249.0 h)	-834.2	79.3	-204.8	-0.2	-691.9	85.0	22.9	15.4	1529.2	0.0	0.0
During cooling (811.7 h)	-136.4	-56.5	230.6	-0.1	-45.9	5.5	1.9	1.3	0.0	0.0	0.0
Rest of time	-166.8	-46.2	480.9	-0.6	-354.8	59.3	17.5	11.7	0.3	0.0	0.0



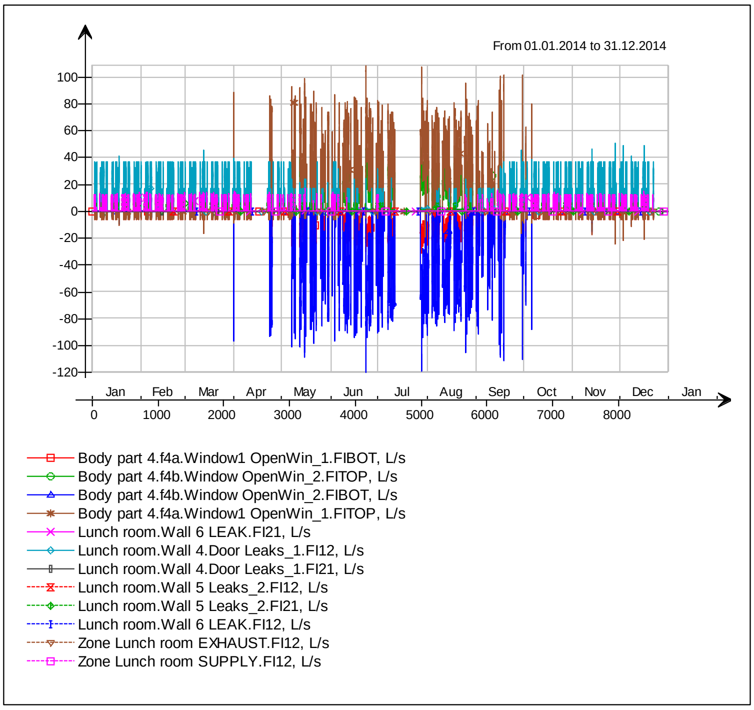
Envelope transmission

kWh

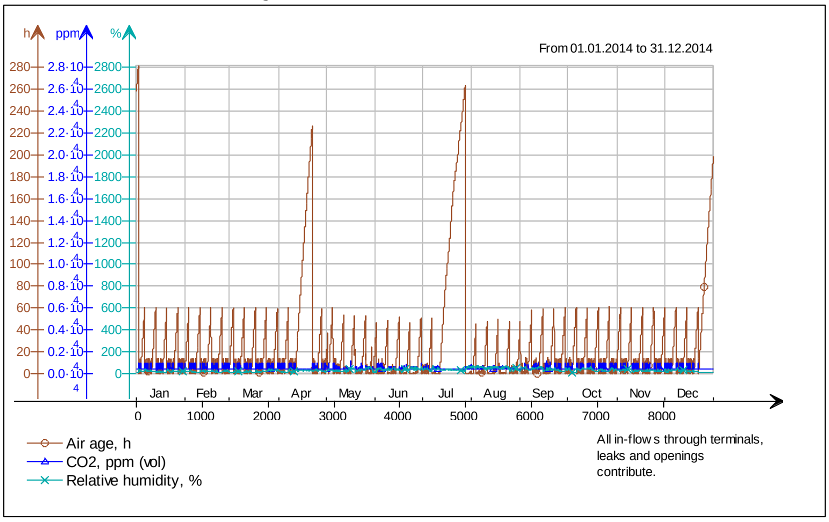
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-63.7	-32.6	0.0	-97.6	-34.2	-46.6
2	-48.5	-24.8	0.0	-78.5	-25.9	-37.0
3	-47.3	-24.6	0.0	-81.7	-24.4	-37.9
4	-34.4	-17.3	0.0	-66.5	-17.9	-30.2
5	-18.2	-9.8	0.0	-43.9	-8.4	-18.6
6	-8.7	0.6	0.0	-36.8	-5.2	-14.9
7	-15.1	-8.8	0.0	-39.0	-6.9	-16.1
8	-6.4	-0.9	0.0	-29.4	-3.2	-11.3
9	-19.1	-8.9	0.0	-42.1	-10.2	-18.1
10	-32.6	-16.6	0.0	-58.1	-17.4	-26.5
11	-46.3	-23.6	0.0	-73.4	-25.0	-34.6
12	-57.1	-28.8	0.0	-88.5	-31.3	-42.4
Total	-397.2	-196.1	0.0	-735.4	-209.9	-334.1
During heating	-296.4	-77.9	0.0	-602.5	-179.0	-280.8
During cooling	-44.4	-62.7	0.0	-44.0	-11.2	-18.1
Rest of time	-56.4	-55.5	0.0	-88.9	-19.7	-35.2



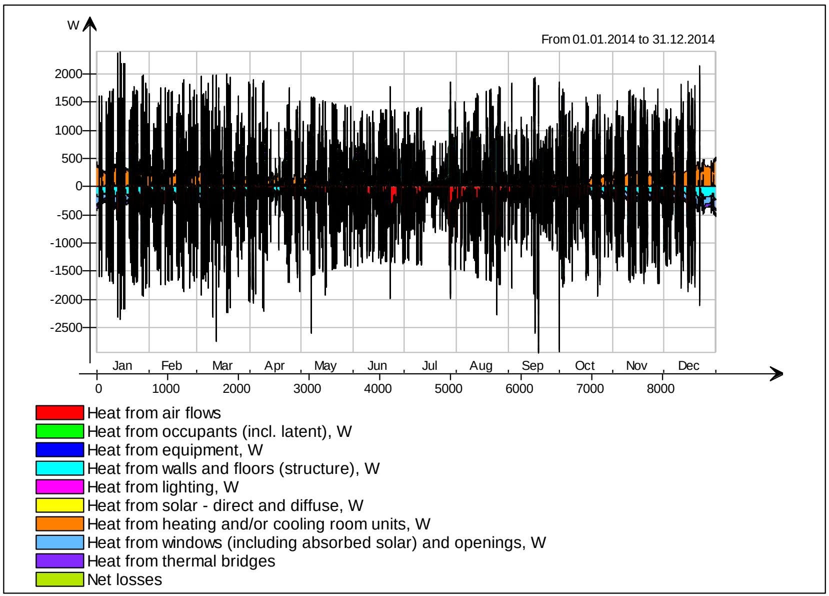
Ventilation air flows



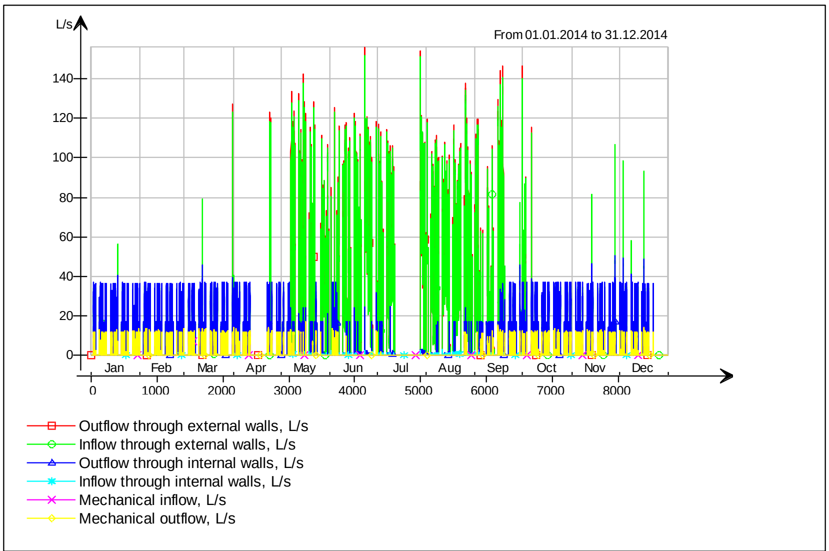
Indoor Air Quality



Heat balance

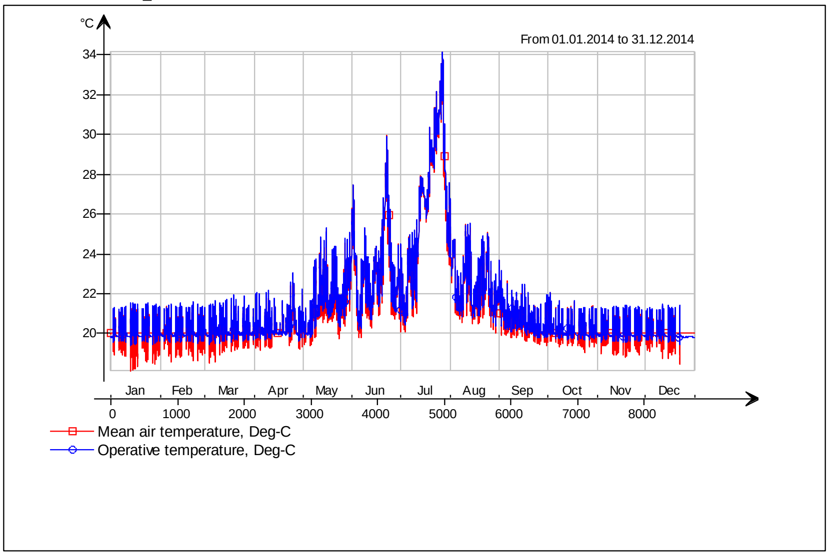


Air flow in zone



Meeting room

Main temperatures

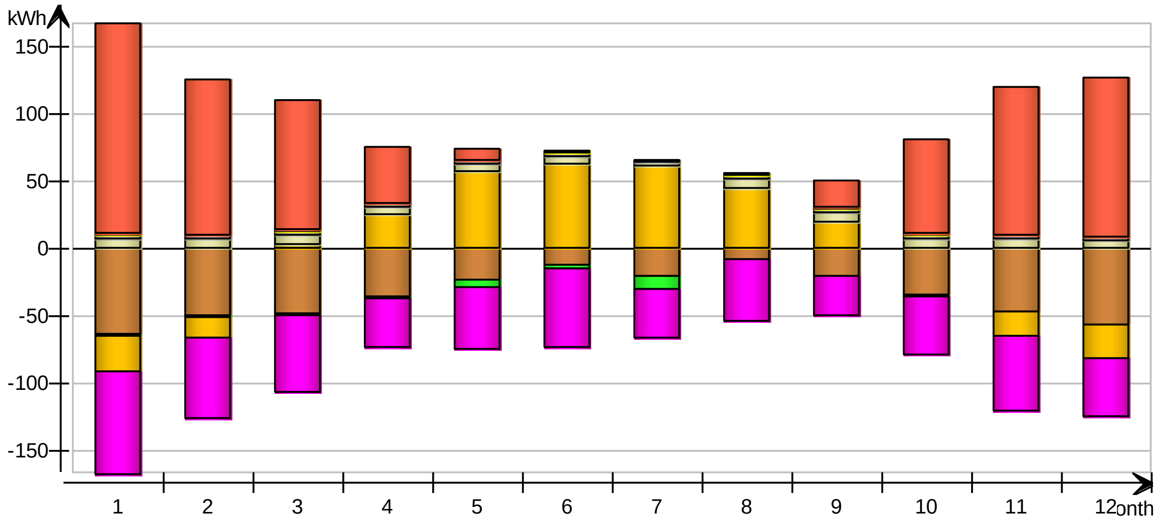


Energy for "Meeting room"

Energy for "Meeting room"

kWh (sensible only)

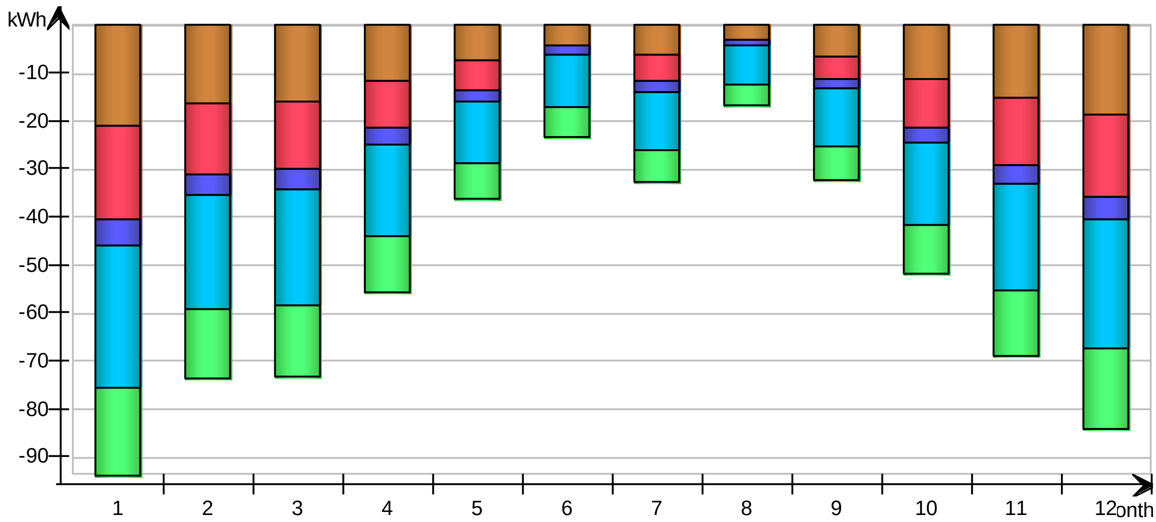
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-64.0	-0.9	-25.9	-0.0	-75.7	7.0	3.3	0.8	155.5	0.0	0.0
2	-49.9	-0.9	-14.7	-0.0	-59.5	6.4	3.0	0.7	115.1	0.0	0.0
3	-49.1	-1.8	2.6	-0.0	-57.4	6.7	3.1	0.8	95.2	0.0	0.0
4	-36.6	-2.0	24.3	-0.0	-35.5	5.1	2.4	0.6	41.9	0.0	0.0
5	-23.2	-5.1	56.5	-0.1	-45.8	5.9	3.0	0.7	8.2	0.0	0.0
6	-12.2	-2.3	62.8	-0.1	-58.3	6.0	3.1	0.8	0.3	0.0	0.0
7	-20.8	-9.5	60.9	-0.1	-36.2	3.4	2.0	0.5	-0.0	0.0	0.0
8	-8.7	0.2	44.1	-0.0	-45.8	6.4	3.1	0.8	-0.0	0.0	0.0
9	-20.7	-0.6	19.4	-0.0	-28.6	7.2	3.3	0.8	19.4	0.0	0.0
10	-34.8	-0.6	-2.0	-0.0	-43.3	7.6	3.5	0.8	68.8	0.0	0.0
11	-46.8	-0.6	-17.5	-0.0	-55.3	6.4	3.0	0.7	110.2	0.0	0.0
12	-57.4	-0.5	-24.8	-0.0	-43.3	5.2	2.4	0.6	117.9	0.0	0.0
Total	-424.3	-24.7	185.7	-0.4	-584.8	73.4	35.3	8.4	732.4	0.0	0.0
During heating (6227.0 h)	-346.4	12.4	-44.3	-0.1	-420.8	43.4	20.3	4.9	731.1	0.0	0.0
During cooling (801.4 h)	-37.7	-22.1	77.4	-0.1	-26.8	5.5	3.2	0.8	0.0	0.0	0.0
Rest of time	-40.2	-15.0	152.6	-0.2	-137.2	24.5	11.8	2.7	1.3	0.0	0.0



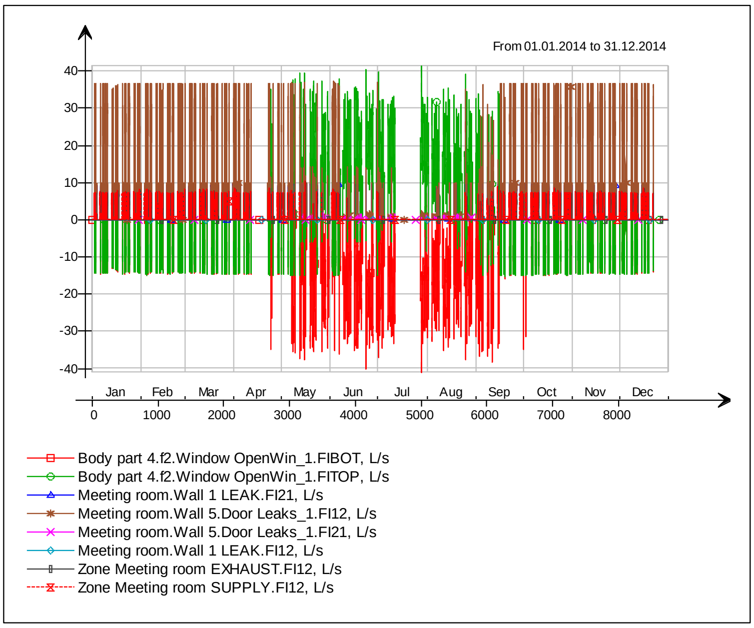
Envelope transmission

kWh

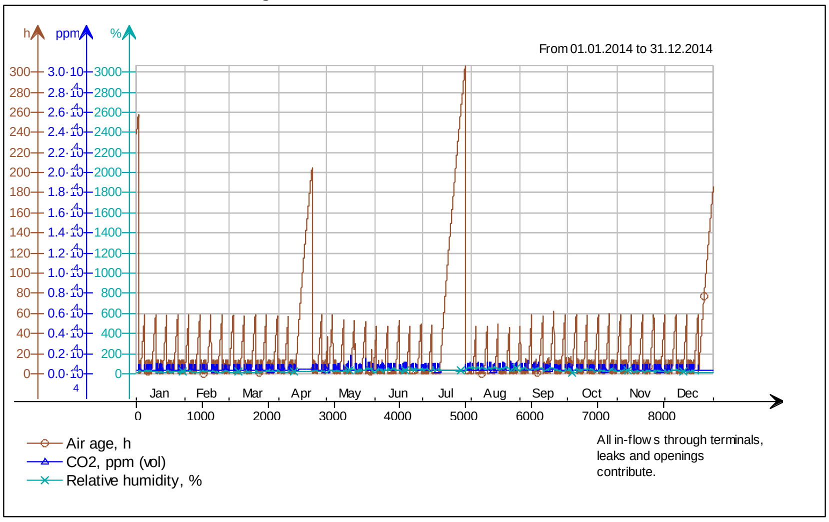
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-21.0	-19.4	-5.3	-29.7	0.0	-18.3
2	-16.4	-14.8	-4.2	-23.6	0.0	-14.5
3	-16.0	-14.0	-4.4	-24.1	0.0	-14.7
4	-11.8	-9.8	-3.4	-19.3	0.0	-11.6
5	-7.2	-6.2	-2.4	-13.0	0.0	-7.4
6	-4.1	-0.1	-1.9	-11.1	0.0	-6.1
7	-6.3	-5.6	-2.2	-12.0	0.0	-6.7
8	-2.9	-0.1	-1.3	-8.3	0.0	-4.4
9	-6.8	-4.9	-2.1	-12.2	0.0	-7.0
10	-11.4	-10.2	-3.0	-17.2	0.0	-10.2
11	-15.4	-14.0	-3.9	-22.3	0.0	-13.5
12	-18.7	-17.3	-4.8	-26.9	0.0	-16.6
Total	-138.1	-116.2	-38.9	-219.7	0.0	-131.0
During heating	-115.5	-88.0	-31.7	-183.9	0.0	-111.3
During cooling	-10.1	-17.8	-2.6	-12.9	0.0	-7.3
Rest of time	-12.5	-10.4	-4.6	-22.9	0.0	-12.4



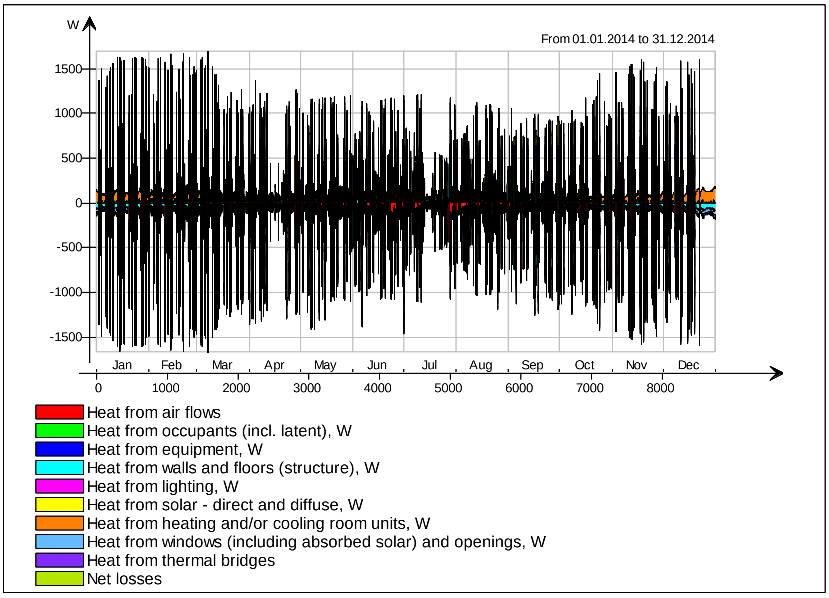
Ventilation air flows



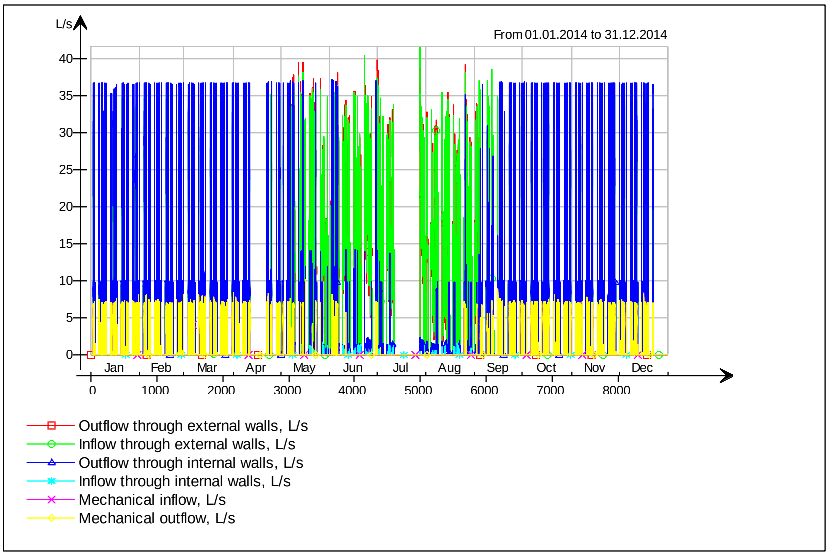
Indoor Air Quality



Heat balance

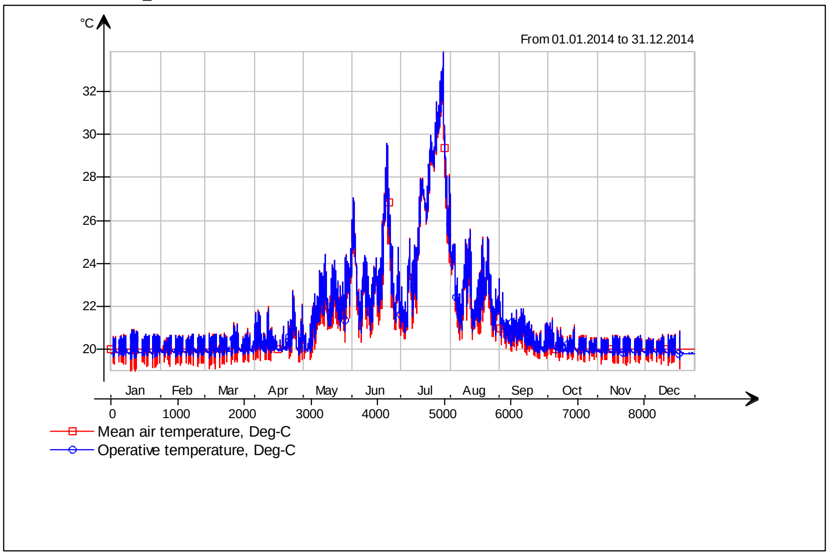


Air flow in zone



Hallway

Main temperatures

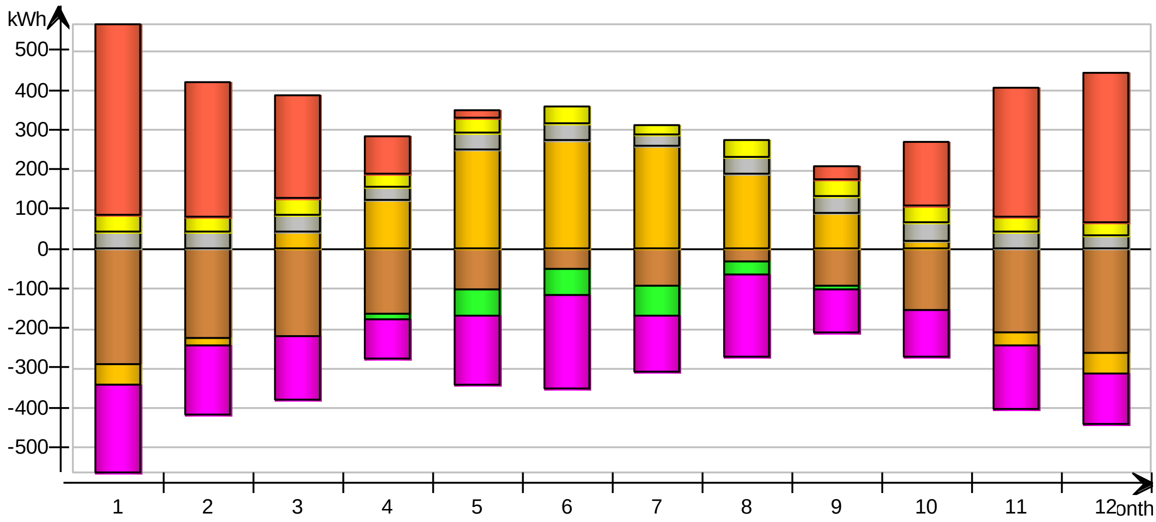


Energy for "Hallway"

Energy for "Hallway"

kWh (sensible only)

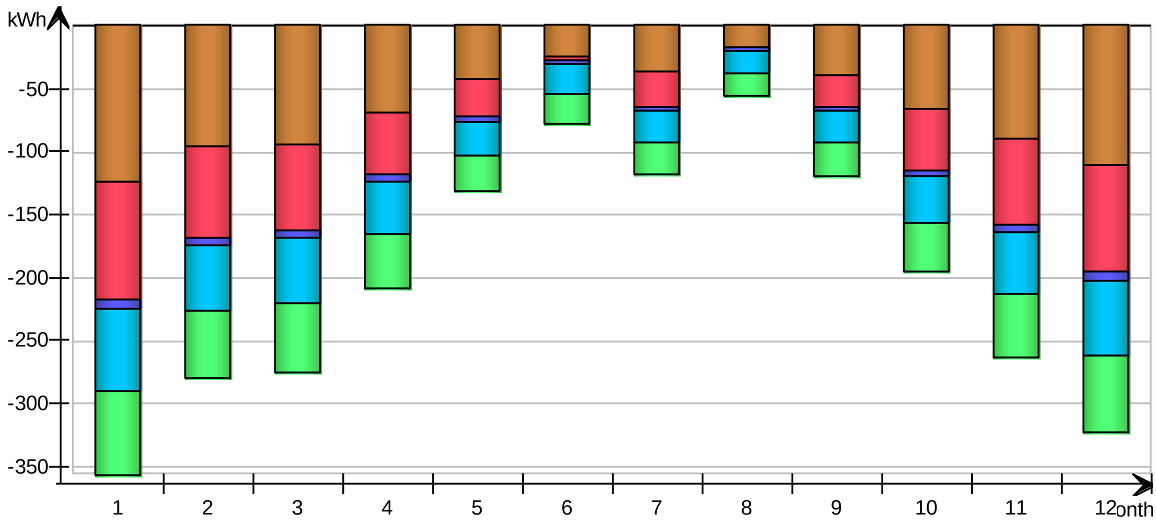
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-291.5	-0.1	-49.9	0.0	-223.0	0.0	44.4	42.6	477.7	0.0	0.0
2	-226.1	0.9	-17.9	0.0	-172.9	0.0	40.3	38.7	336.8	0.0	0.0
3	-221.9	-0.1	42.5	0.0	-160.6	0.0	42.3	40.6	257.0	0.0	0.0
4	-165.3	-15.2	122.3	0.0	-98.1	0.0	32.3	31.0	92.9	0.0	0.0
5	-103.6	-65.2	248.2	0.0	-174.8	0.0	40.3	38.7	17.0	0.0	0.0
6	-53.8	-66.9	271.4	0.0	-234.5	0.0	42.3	40.6	0.0	0.0	0.0
7	-92.4	-73.9	258.3	0.0	-142.9	0.0	26.2	25.2	0.0	0.0	0.0
8	-34.5	-32.8	188.9	0.0	-205.7	0.0	42.3	40.6	0.0	0.0	0.0
9	-93.3	-8.6	88.7	0.0	-108.0	0.0	44.4	42.6	33.8	0.0	0.0
10	-155.6	2.4	19.5	0.0	-119.2	0.0	46.4	44.5	161.9	0.0	0.0
11	-213.0	2.1	-30.6	0.0	-161.0	0.0	40.3	38.7	323.4	0.0	0.0
12	-261.6	1.0	-50.3	0.0	-126.5	0.0	32.3	31.0	374.1	0.0	0.0
Total	-1912.6	-256.5	1091.0	0.0	-1927.2	0.0	473.8	454.8	2074.6	0.0	0.0
During heating (5832.0 h)	-1577.8	18.5	50.3	0.0	-1175.8	0.0	309.2	296.9	2074.7	0.0	0.0
During cooling (881.4 h)	-159.5	-125.1	353.1	0.0	-112.3	0.0	23.4	22.4	0.0	0.0	0.0
Rest of time	-175.3	-149.9	687.6	0.0	-639.1	0.0	141.2	135.4	-0.1	0.0	0.0



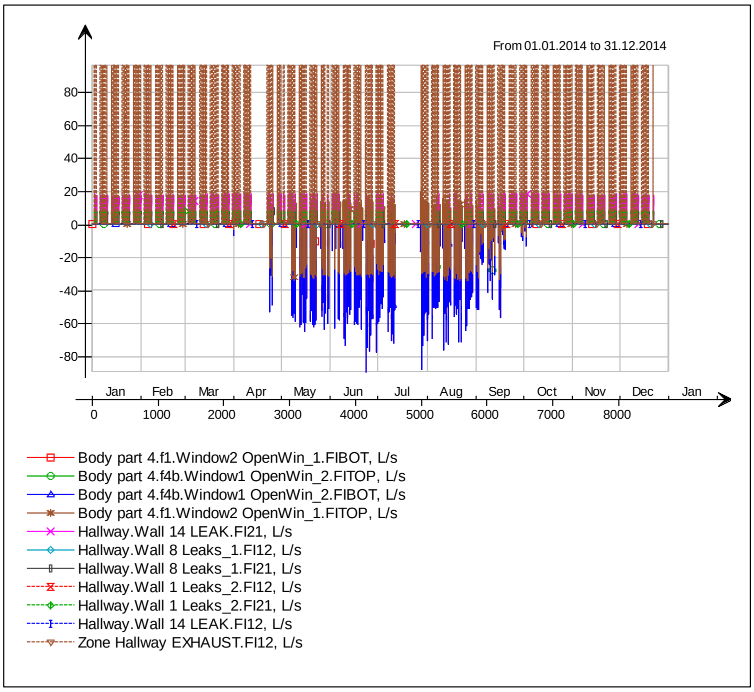
Envelope transmission

kWh

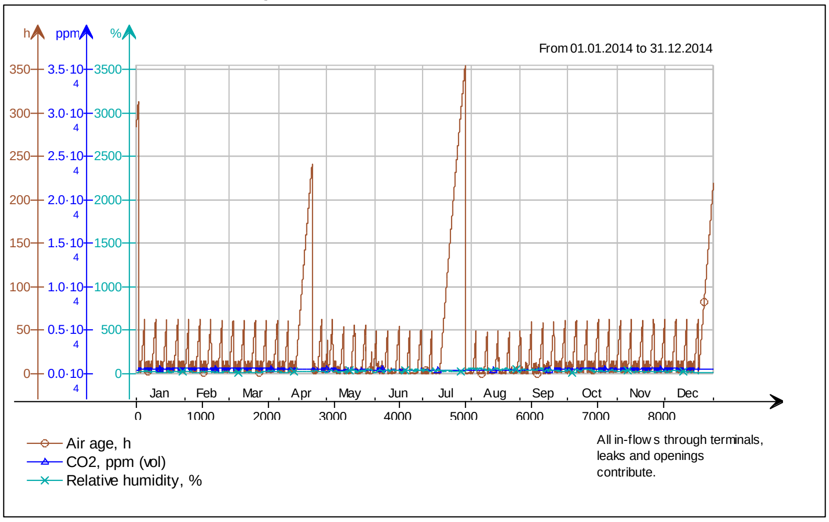
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-124.3	-93.4	-7.1	-64.6	0.0	-66.8
2	-96.1	-71.5	-5.6	-51.1	0.0	-52.9
3	-94.0	-68.5	-5.8	-51.7	0.0	-53.6
4	-69.6	-48.6	-4.6	-41.1	0.0	-42.6
5	-42.7	-29.7	-3.2	-26.8	0.0	-27.9
6	-25.4	-2.5	-2.5	-22.8	0.0	-23.4
7	-37.0	-27.6	-2.9	-24.5	0.0	-24.9
8	-16.5	0.7	-1.8	-16.6	0.0	-16.9
9	-39.8	-24.8	-2.8	-25.3	0.0	-25.9
10	-65.9	-48.3	-4.0	-36.4	0.0	-37.5
11	-90.7	-67.7	-5.2	-48.0	0.0	-49.5
12	-111.3	-83.3	-6.3	-58.4	0.0	-60.6
Total	-813.2	-565.2	-51.6	-467.3	0.0	-482.5
During heating	-680.6	-461.7	-41.1	-381.9	0.0	-394.7
During cooling	-56.0	-71.4	-3.5	-28.3	0.0	-28.6
Rest of time	-76.6	-32.1	-7.0	-57.1	0.0	-59.2



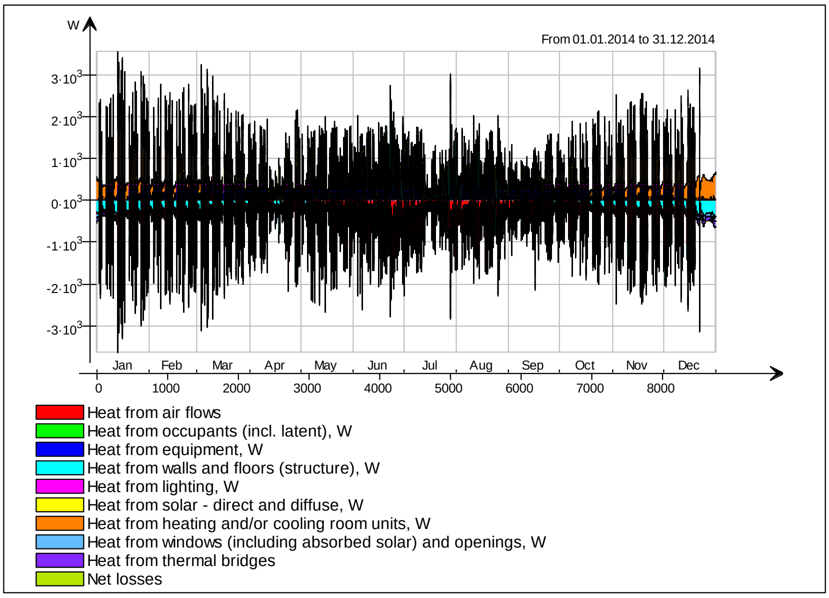
Ventilation air flows



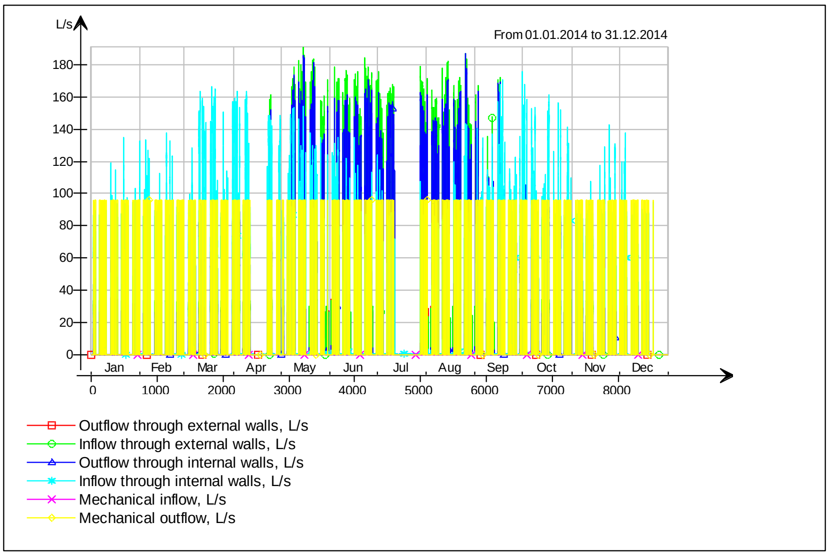
Indoor Air Quality



Heat balance

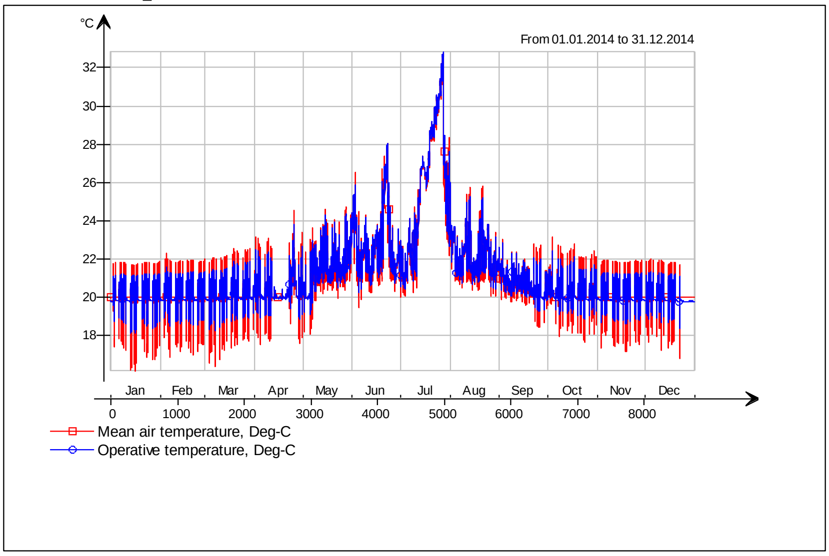


Air flow in zone



Office, shared

Main temperatures

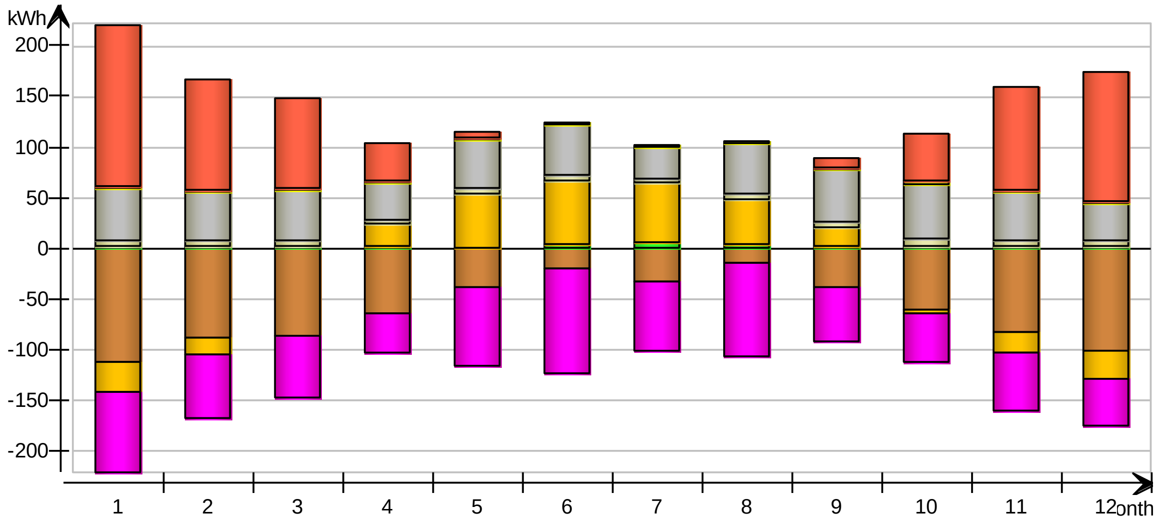


Energy for "Office, shared"

Energy for "Office, shared"

kWh (sensible only)

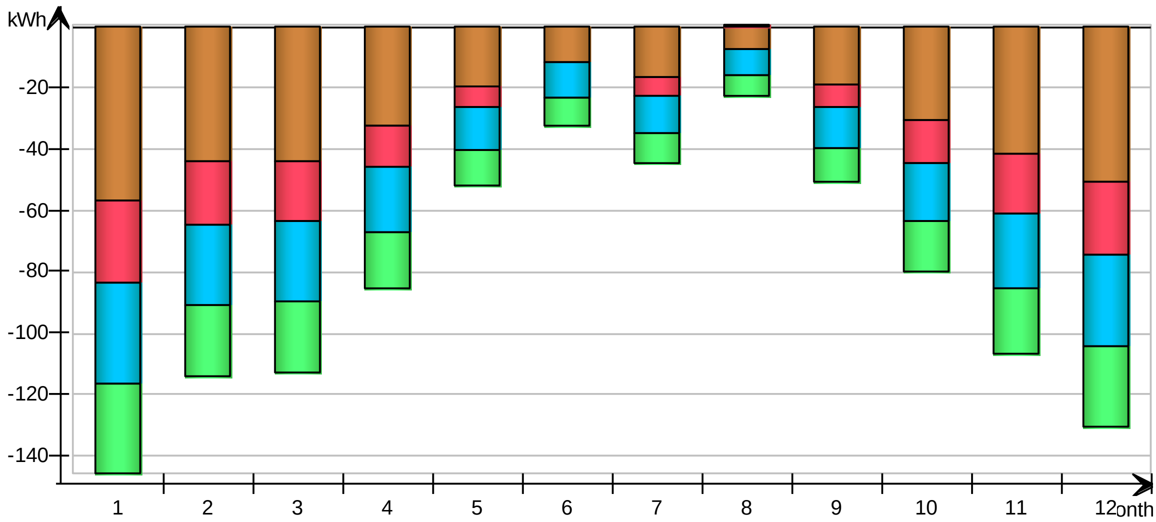
Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-113.1	2.0	-28.8	-0.0	-79.9	6.5	52.0	2.8	158.7	0.0	0.0
2	-88.3	2.1	-16.7	-0.0	-62.4	5.9	47.3	2.5	109.8	0.0	0.0
3	-87.3	2.1	-0.2	-0.0	-60.8	6.2	49.6	2.6	88.0	0.0	0.0
4	-65.5	1.9	21.8	-0.1	-39.6	4.6	37.8	2.0	37.1	0.0	0.0
5	-38.4	0.2	54.1	-0.2	-76.8	5.4	47.3	2.5	6.1	0.0	0.0
6	-21.2	4.6	62.1	-0.3	-103.1	5.5	49.6	2.6	0.0	0.0	0.0
7	-33.1	5.6	59.6	-0.1	-67.7	3.3	30.7	1.6	0.0	0.0	0.0
8	-14.1	4.2	43.8	-0.0	-91.9	5.7	49.6	2.6	0.0	0.0	0.0
9	-38.0	2.7	18.3	-0.1	-53.0	6.3	52.0	2.8	9.1	0.0	0.0
10	-61.7	2.2	-3.4	-0.0	-47.6	6.8	54.3	2.9	46.6	0.0	0.0
11	-83.0	2.6	-19.5	-0.0	-58.0	5.9	47.3	2.5	102.2	0.0	0.0
12	-101.6	2.0	-27.6	-0.0	-45.4	4.8	37.8	2.0	128.1	0.0	0.0
Total	-745.3	32.3	163.6	-0.8	-786.1	66.7	555.2	29.6	685.7	0.0	0.0
During heating (6181.0 h)	-590.6	53.3	-68.3	-0.2	-470.3	34.6	341.1	14.8	685.6	0.0	0.0
During cooling (631.9 h)	-47.8	-0.5	54.1	-0.1	-30.5	3.0	20.3	1.6	0.0	0.0	0.0
Rest of time	-106.9	-20.5	177.8	-0.5	-285.3	29.1	193.8	13.2	0.1	0.0	0.0



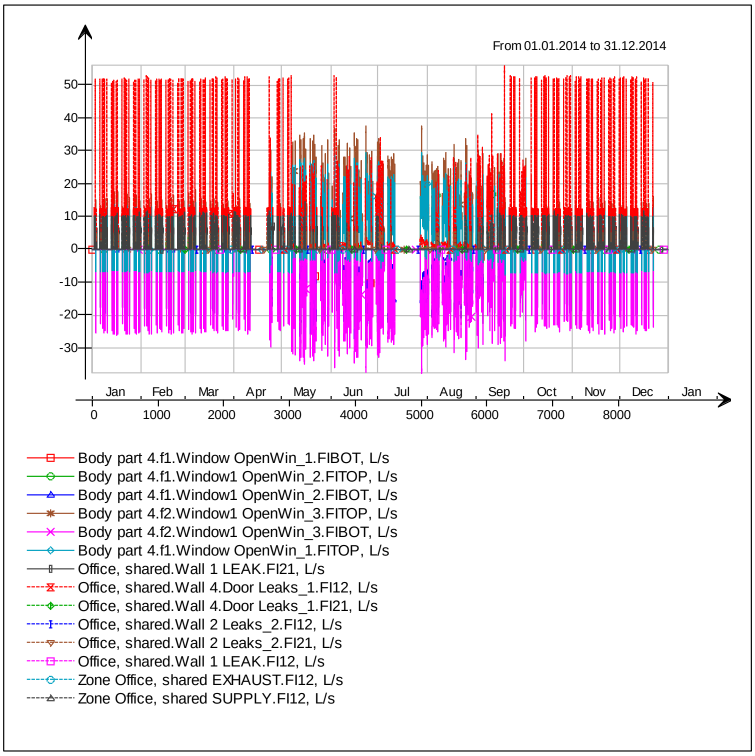
Envelope transmission

kWh

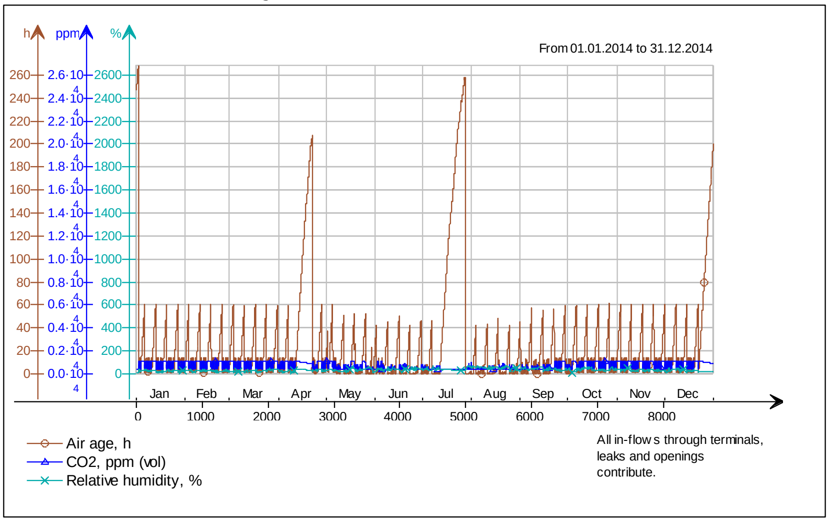
Month	Walls	Roof	Floor	Windows	Doors	Thermal bridges
1	-56.7	-27.0	0.0	-32.9	0.0	-29.5
2	-44.3	-20.7	0.0	-26.2	0.0	-23.3
3	-43.9	-19.7	0.0	-26.7	0.0	-23.7
4	-32.9	-13.9	0.0	-21.4	0.0	-18.8
5	-19.6	-7.1	0.0	-14.1	0.0	-11.8
6	-11.6	-0.2	0.0	-11.6	0.0	-9.4
7	-16.5	-6.4	0.0	-12.4	0.0	-10.1
8	-7.8	0.4	0.0	-8.6	0.0	-6.6
9	-19.2	-7.3	0.0	-13.6	0.0	-11.4
10	-30.9	-14.1	0.0	-19.1	0.0	-16.6
11	-41.5	-19.6	0.0	-24.6	0.0	-21.9
12	-50.7	-24.2	0.0	-29.9	0.0	-26.8
Total	-375.6	-159.9	0.0	-241.1	0.0	-209.8
During heating	-303.3	-109.4	0.0	-201.5	0.0	-177.7
During cooling	-21.1	-17.7	0.0	-11.0	0.0	-9.1
Rest of time	-51.2	-32.8	0.0	-28.6	0.0	-23.0



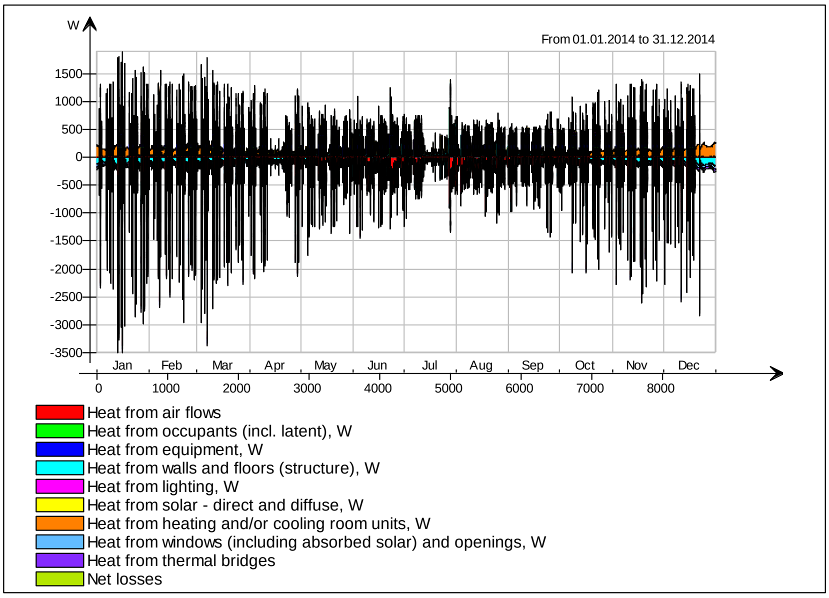
Ventilation air flows



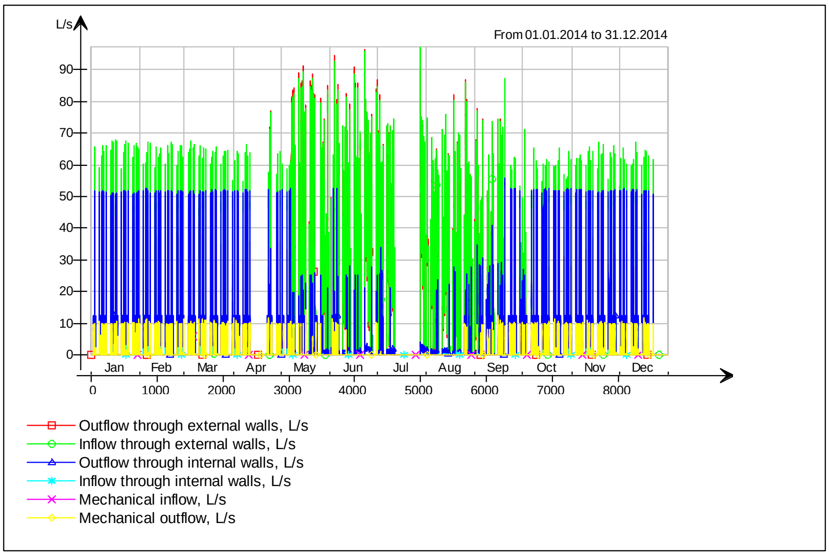
Indoor Air Quality



Heat balance

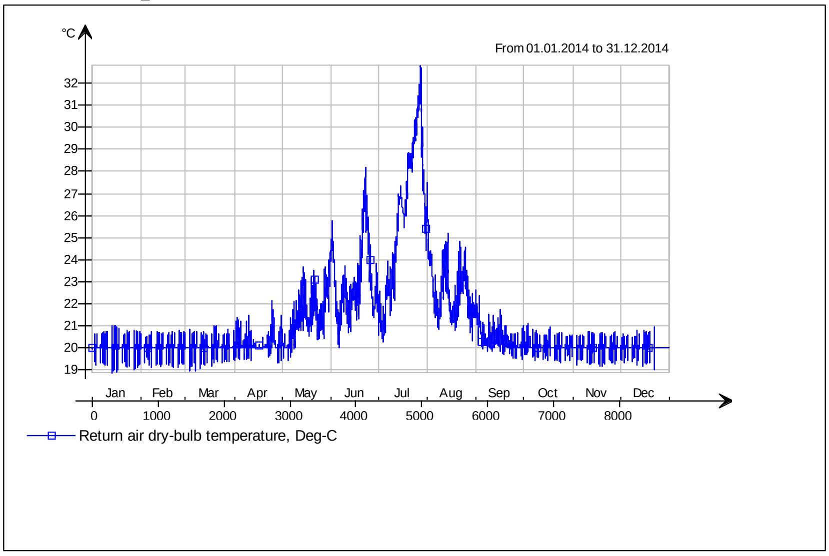


Air flow in zone



Return air only (no supply side)

AHU temperatures



Energy report for "Return air only (no supply side)"

kWh (sensible and latent)

Month	Heating	Cooling	AHU heat recovery	AHU cold recovery	Humidification	Fans
1	0.0	0.0	0.0	0.0	0.0	184.1
2	0.0	0.0	0.0	0.0	0.0	167.4
3	0.0	0.0	0.0	0.0	0.0	175.7
4	0.0	0.0	0.0	0.0	0.0	133.9
5	0.0	0.0	0.0	0.0	0.0	167.3
6	0.0	0.0	0.0	0.0	0.0	175.7
7	0.0	0.0	0.0	0.0	0.0	108.8
8	0.0	0.0	0.0	0.0	0.0	175.7
9	0.0	0.0	0.0	0.0	0.0	184.1
10	0.0	0.0	0.0	0.0	0.0	192.5
11	0.0	0.0	0.0	0.0	0.0	167.4
12	0.0	0.0	0.0	0.0	0.0	133.9
Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1966.5**