Delft University of Technology

Exchanging and Storing Energy

Reducing Energy Demand through Heat Exchange between Functions and Temporary Storage

ing. Edward Sillem

Project Report

MSc in Architecture and Building Technology

Tutors:

ir. L. de Ruijsscher

Prof. dr. ir. A. van den Dobbelsteen

Department of Climate Design

Lab Coordinator:

ir. F.R. Schnater

Rotterdam, June 2011

Acknowledgments

First of all I would like to thank Leo de Ruijsscher my main tutor during this research for the many inspiring consultations. Many assumptions would not have been realistic without the help of a professional and he has also been a great help with a wide range of technical possibilities.

Many thanks to Andy van den Dobbelsteen for the consults and for sharing his broad experience about the subject.

Many thanks to Frank Schnater for checking the process and building technology aspects.

Thanks to John van der Vliet (installation advisor) for giving a critical review on the calculations.

Thanks to Eric van den Ham for providing the calculation software ORCA and for his help in interpreting the data.

I would also like to acknowledge Ruud Reinders (project manager/advisor) from Volantis for sharing his experience about energy roofs.

Thanks to Sílvia Botelho for moral support and help in Microsoft Excel.

Summary

As typical office buildings from the nineties have large heating and cooling installations to provide heat or cold wherever and whenever needed, more recent office buildings have almost no demand for heating due to high internal heat loads caused by people, lighting and office appliances and because of the great thermal qualities of the contemporary building envelope. However, these buildings still have vast cooling units to cool down servers and other energy consuming installations. At the same time other functions such as dwellings, swimming pools, sporting facilities, archives and museums still need to be heated most of the year.

In the current building market there is an increasing demand for mixed-use buildings or so called hybrid buildings. The Science Business Centre, which was conceptualized during the MSc03 period, is no different and houses a conference centre, offices, a museum, archives, an exhibition space and a restaurant. From the initial program brief it seemed that the building will simultaneously house functions that need cooling most of the year and functions that will need to be heated the majority of the year. Can this building be equipped with a ‘micro heating and cooling network’ and where necessary temporarily store energy? With this idea a research proposal was formulated.

How can the demand for heating and cooling of the Science Business Centre be reduced by using energy exchange between different kinds of functions and by temporarily storing energy?

Building “a sustainable building” cannot by itself be the primary objective. An energy neutral building which does not function properly is useless. The same goes for a building that is not healthy or comfortable. Therefore functionality, health and comfort are to be set as constraints when the objective is to build an energy efficient building. A *functional terms of reference* was created to in which the requirements for the indoor climate are set like: internal heat loads, type of use, etc.

Energy calculations are complex, in real practice the energy demands calculated usually turn out to be quite different from the actual values. To calculate the energy demand for

the various functions, manual (or static) calculations are plotted with dynamic calculations on one sheet in order to give a proper comparison. For the dynamic calculations the computer software ORCA was used. Some building elements or aspects are simulated, like thermal energy storage, by applying additional concrete or heat recovery by re-circulating indoor air. This requires extra attention during the interpretation of the data.

The four installation concepts are being researched, derived from the preliminary design of the Science Business Centre, namely: pavilion concept, museum concept, archive concept and auditorium concept. These concepts are calculated and optimized by adjusting: thermal properties, heat loads, sun shading, thermal storage capacity, heat recovery etc. Here, short term energy storage is determined. A major intervention is that the archive will be placed underground to utilize the stable ground temperature of 12°C and to avoid exposure to the elements. Another important discovery is that the museum will need special attention because it is exposed in the open and requires a rather stable indoor climate. Afterwards, three other sources of energy are considered in the building: the server space, restaurant and energy roof. All the concepts as well as the other energy sources are calculated to be compared.

By plotting the energy consumption patterns on one page (see annex 13) relations between the patterns can be seen. Unfortunately exchanging energy between these four functions is not feasible for two main reasons. First the consumption pattern is too much alike (they require heat or cold at the same time) and second because within the functions there is not enough temperature difference to create an energy flow. However, it is possible to use the waste energy from the server space and the restaurant as well as the energy roof. The server space waste heat will be used in the winter season through a heat exchanger with a 90% efficiency. This can reduce the heating energy for the whole 1000m² office floor by 1,8%. The archive has a low heating demand throughout almost the whole year and can be largely heated by the waste heat of the cooling and freezing units from the restaurant. The total energy reduction for heating and cooling of the archive is 34,5% on the total archive surface of 1000m². The annual heat gains, collected from the energy roof, are 21,1kWh per square meter (SenterNovem) + 120 kWh per square meter for the PV-cells. The heat will be used to recharge the aquifer in summer, which would otherwise be exhausted, and the electrical energy can be used to power all installations for the climate design.

In conclusion the research led to:

- four optimized installation concepts
- short term energy storage in pavilion concept and museum
- energy exchange between the restaurant and archives
- energy exchange between the server space and the offices,
- the majority of heat and cold will be extracted from the soil (long term energy storage)
- the access heat will be generated by the energy roof.
- PV cells from the energy roof power all climate installations
- a total energy plan for the Science Business Centre
- a systematic approach for exchanging and temporary storing energy

Samenvatting (Nederlands)

Een typisch kantoorgebouw uit de jaren negentig heeft vaak enorme koel- en verwarmingtoestellen om warmte of koude te leveren op iedere gewenste plek en op ieder gewenst tijdstip. Hedendaags zijn er kantoren die bijna geen verwarming meer nodig hebben maar die nog wel een grote koellast hebben door de hoge interne warmtebronnen zoals personen, verlichting, computers en andere apparatuur en door de goede eigenschappen van de hedendaagse gevels. Deze gebouwen hebben vaak grote airconditioning units om server ruimtes en kantoorvloeren te koelen terwijl er misschien andere functies zijn die juist verwarmt moeten worden zoals woningbouw, zwembaden, sport faciliteiten, archieven en musea.

In de huidige bouwmarkt is er en groeiende behoefte aan multifunctionele gebouwen of zogezegd hybride gebouwen. Het betreffende bouwproject, het Science Business Centre, is geen uitzondering en behuisd een conferentie centrum, kantoren, een museum, archieven, expositie ruimtes en een restaurant. Vanuit het programma van eisen lijkt er een gelijktijdige behoefte te bestaan tussen functies die een warmtebehoefte hebben en functies die een koudebehoefte hebben. Zou het Science Business Centre uitgerust kunnen worden met een '*micro heating and cooling network*' en waar mogelijk energie tijdelijk opslaan? Met dit in gedacht was een onderzoeksvraag opgesteld.

Hoe kan de vraag naar warmte en koude voor het Science Business Centre worden gereduceerd door gebruik te maken van energie uitwisseling en tijdelijke energie opslag?

Een duurzaam gebouw op zichzelf zou niet het ultieme doel moeten zijn. Een energieneutraal gebouw dat niet goed functioneert, niet gezond is of niet comfortabel is, is waardeloos. Daarom moeten er eerst begrenzingen opgesteld worden die deze kwaliteiten waarborgen. Tijdens de eerste fase van het onderzoek in een functiematrix

opgesteld waarin alle uitgangspunten voor: binnenklimaat, interne warmte lasten, gebruikstype, etc. zijn vastgelegd.

Energieberekeningen zijn complex. In werkelijkheid wijken de berekende waarde sterk af van de gemeten waarde. Om een goed overzicht in het energieverbruik te krijgen is een handmatige (statische) berekening geplot in dezelfde grafiek als een dynamische berekening. Om de dynamische berekeningen te kunnen maken is er gebruik gemaakt van computer software ORCA. Sommige gebouw element of aspecten zijn naar werkelijkheid gesimuleerd omdat ze niet in de software zijn opgenomen zoals de warmte opslagcapaciteit welke is gesimuleerd door extra beton toe te voegen of het gebruik van warmte terugwinning welke is gesimuleerd door luchtrecirculatie aan te zetten. Dit vereist extra aandacht bij de interpretatie van de data.

De vier installatie concepten die in deze thesis worden onderzocht zijn afgeleid van het voorlopig ontwerp van het Science Business Centre. Het zijn paviljoen concept, museum concept, archief concept en auditorium concept. Deze concepten zijn doorgerekend en qua energieverbruik geoptimaliseerd door het aanpassen van: thermische eigenschappen, warmte lasten, zonwering, thermische opslagcapaciteit, warmte terugwinning, etc. Hier wordt onder andere de korte termijn warmteopslag capaciteit bepaald. Een van de grootste ingrepen is dat het archief, dat voorheen boven de terp zweefde, onder de grond is verplaatst om zo gebruik te kunnen maken van de constante bodemtemperatuur van 12 °C en dat het niet blootgesteld hoeft te worden aan de elementen van de natuur. Een andere belangrijke ontdekking is dat het museum een complex vraagstuk is doordat het in de lucht zweeft en binnen vrij strenge comforttemperatuur eisen gelden. Naderhand zijn er nog drie andere energiebronnen beschouwd: de server ruimtes, het restaurant en een energiedak. Alle installatie concept alsmede de andere energiebronnen zijn berekend om te kunnen vergelijken en bekritiseren.

Door de verschillende consumptiepatronen in één grafiek te tekenen zouden relaties opgemerkt kunnen worden tussen verschillende programma onderdelen. Helaas is energie uitwisseling tussen de desbetreffende gebruiksfuncties in de huidige context niet mogelijk om twee redenen. Ten eerste vertonen de consumptiepatronen te veel overeenkomsten (ze hebben gelijktijdig een warmte of koude vraag) om het aannemelijk te maken en ten tweede omdat er binnen de gebruiksfuncties te weinig temperatuur verschil aanwezig mag zijn om een warmtestroom te creëren. Wel is het mogelijk om de restwarmte van de serverruimte, het restaurant en het energiedak te gebruiken. De restwarmte uit de serverruimte zal in de winter worden gebruikt om de kantoorfunctie te verwarmen door gebruik te maken van een warmte wisselaar met een efficiency van 90%. Hiermee kan een reductie van de warmtevraag voor de gehele 1000 m² kantoorruimte worden gerealiseerd van 1,8%. The restwarmte van de koelcellen uit het restaurant zal worden gebruikt om de archieven te verwarmen. Het archief heeft al een beperkte warmte- /koudevraag omdat het ondergronds is gesitueerd. De totale reductie van warmte- en koudevraag voor de 1000 m² archiefruimte bedraagt 34,5%. Het energiedak produceert zowel warmte als elektriciteit. De geproduceerde warmte per m² dakoppervlak bedraagt 21,1 kWh (SenterNovem) en de elektriciteit 120 kWh. De warmte zal worden gebruikt om in de zomer de aquifer op te laden zodat deze warmte in de winter benut kan worden. Zonder deze toevoeging zou de aquifer in een beperkt tijdsbestek uitgeput raken. The elektrische energie zal gebruikt worden om alle installaties voor het klimaatontwerp van stroom te voorzien.

Tot slot heft het onderzoek geleid tot:

- vier geoptimaliseerde installatieconcepten
- korte termijn energie opslag in het paviljoen concept en het museum concept
- energie uitwisseling tussen het restaurant en de archieven
- energie uitwisseling tussen de serveruimte en de kantoren
- de meerderheid van de benodigde warmte- / koudevraag zal uit de aquifer komen
- de resterende warmte om de input / output van de aquifer in balans te brengen wordt opgewekt op het energiedak.
- PV- cellen voorzien alle klimaat installaties van energie en hebben een overschot van 120.000 kWh
- een totaal energie concept voor het Science Business Centre
- een aanbeveling: een systematische aanpak voor het uitwisselen en tijdelijk opslaan van energie.

Foreword

In the current sustainable building scene there are the designers on the one hand, who think of energy solutions in idealistic schemes in perfect situations, and on the other hand, there are the engineers with a more practical approach for whom it is difficult to think outside the box. It is therefore most crucial that an integrated design is being developed in a design team of architects, engineers and constructors. The aim in this thesis is to operate on the interface of architecture and building technology.

This thesis is part of the SADD graduation track which is divided as follows:

Scheme of graduation track

In this 4th semester the architectural design is in its preliminary stage. The building technological research is being conducted to further improve the design. In this research the role of the design is twofold. Firstly it serves as a test building to generate different installation concepts which will be used for analysis. Secondly the design is used as a case study to which the developed methodology is applied.

Glossary

Comfort temperature

When the majority of the users have no direct desire for more or less heat.

Energy concept

The sum of all installations and all building technical elements which co-operate to create together a desirable indoor climate. Apart from heating, cooling, ventilation, filtering, (de)- humidifying this also contains cantilevers, facades, roofs insulation, etc.

Energy consumption

The total of consumed energy by all climate installations: heating and cooling, ventilation, water pump, heat exchangers air treatment etc.

Energy-neutral

When, with sustainable means, an equal or greater amount of energy is generated on site than the sum of energy consumed by the entire building including all technical installations and all energy consumption by the users.

Installation concept

When referred to ‘installation concept’ the author means the sum of all installations which co-operate to create a desirable indoor climate. consisting of heating, cooling, ventilation, filtering, (de)- humidifying

Overall installation concept

When referred to ‘overall installation concept’ the author means the installation concept for the building as a whole. The division in climate zones, all technical spaces, the relations between the zones and the zone by themselves (the installation concepts)

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1 Introduction

In this chapter the scope of the project is framed. The incentive for research is given and the context of the problem is explained. From these topics the research question is formulated and the research boundaries are defined.

1.1 Motive

That buildings need to be more energy efficient is evident. The Rotterdam Climate Initiative aims to reduce CO2 emissions in its city by 50%[1] and the Dutch building codes are getting stricter every year[2]. With this research I anticipate to make a contribution in creating a sustainable built environment. In the current sustainable building scene there are the designers on the one hand who think of energy solutions in idealistic schemes in perfect situations. On the other hand there are the engineers with a more practical approach for whom it is difficult to think outside the box. This led to the idea to formulate a research topic which lies on the interface of these two professions.

1.2 Problem's context

A typical office building from the nineties has huge heating and cooling installation to provide heat or cold wherever and whenever needed. In the last decades, office buildings that were developed had almost no demand for heating due to high internal heat loads caused by people, lighting and office appliances and because of the great thermal qualities of the contemporary building envelope[3]. Instead these buildings still have vast cooling units to cool down servers and other energy consuming installations. At the same time other functions such as dwellings, swimming pools, sporting facilities, archives and museums still need to be heated most of the year.

A new trend is on the rise. Currently projects of several buildings are being developed in a district to form a cooling and heating network. Access heat or cold is being transported over the district to other buildings to provide other functions with heat or

[1] Rotterdam Climate Initiative: www.rotterdamclimateinitiative.nl
[2] Bouwbesluit online: http://www.bouwbesluitonline.nl
[3] Watts, A; Modern Construction Envelopes; SpringerWienNewYork, Vienna, 2011

cold. In this thesis I attempt to investigate the possibility to apply the concept of exchanging and temporary storing energy to a single building.

In the current building market there is an increasing demand for mixed use buildings or so called hybrid buildings. The Science Business Centre, which was conceptualized during the MSc03 period, is no different and houses a conference centre, offices, a museum, archives, an exhibition space and a restaurant. From the initial program brief it seems that the building will simultaneously house functions that need cooling most of the year and functions that will need to be heated also the majority of the year. Can this building be equipped with a 'micro heating and cooling network' and where necessary temporarily store energy? With this idea a research proposal was formulated.

1.3 Research questions

In relation to the prior topic the research question is formulated as follows:

How can the demand for heating and cooling of the Science Business Centre be reduced by using energy exchange between different kinds of functions and by the temporary storing of energy?

From this main research question the following sub-questions arise:

-What are the preconditions for functionality, health and comfort for the functions of the SBC?
-How much energy is lost when heating / cooling a building, and per function?
-What are the energy consuming patterns like in a time scheme for each function?
-What is the energy potential of different kinds of functions?
-What are efficient ways to transport "waste" energy from one function to another?
-What are efficient ways to temporarily store energy?
-Which functions will gain advantage when linked together to form an energy network?
-What is the optimal energy concept for the Science Business Centre?

The aim of this research is to answer all these questions. However, several research boundaries still need to be defined which will function as a guideline in order to stay on topic throughout the research.

1.4 Scope of research

The Science Business Centre to which this research is applied serves as a “case study”. It is within the course of the SADD program that this research is conducted and needs therefore to be applied to the related design project. Not every inch of the SBC will be fully calculated neither will it provide exact data for the entire building. The program of the SBC is merely generalized into four ‘installation concepts’ which represent the larger program in the actual building. In this way the research will provide us with generic data that can be applied to other projects with the same functions and that deal with the same climate conditions.

Furthermore it can be said that:

- The project is primarily focused on heating, cooling and ventilation so initially no electricity will be calculated.
- The project is restricted to the Dutch climate.
- Various ways for transporting energy will be researched
- Various ways for temporary storing energy will be researched

1.5 Methodology

In this thesis, a distinction can be made between five important phases. Introduction, Preparation phase, Calculation phase, Implementation phase and Evaluation phase. The Introduction phase is to put the research on track, to formulate the research questions, the scope of the research and to sketch a brief plan of attack. The body of the thesis lies in the preparation, calculation and implementation phase. In the preparation phase assumptions are made, subsequently they will be calculated and implemented. When the result is not desirable the assumptions of the preparation phase have to be adjusted and the sequence starts from there. The thesis ends with the evaluation phase and a recommendation in the form of a roadmap for exchanging and storing energy. See figure 01for the thesis structure.

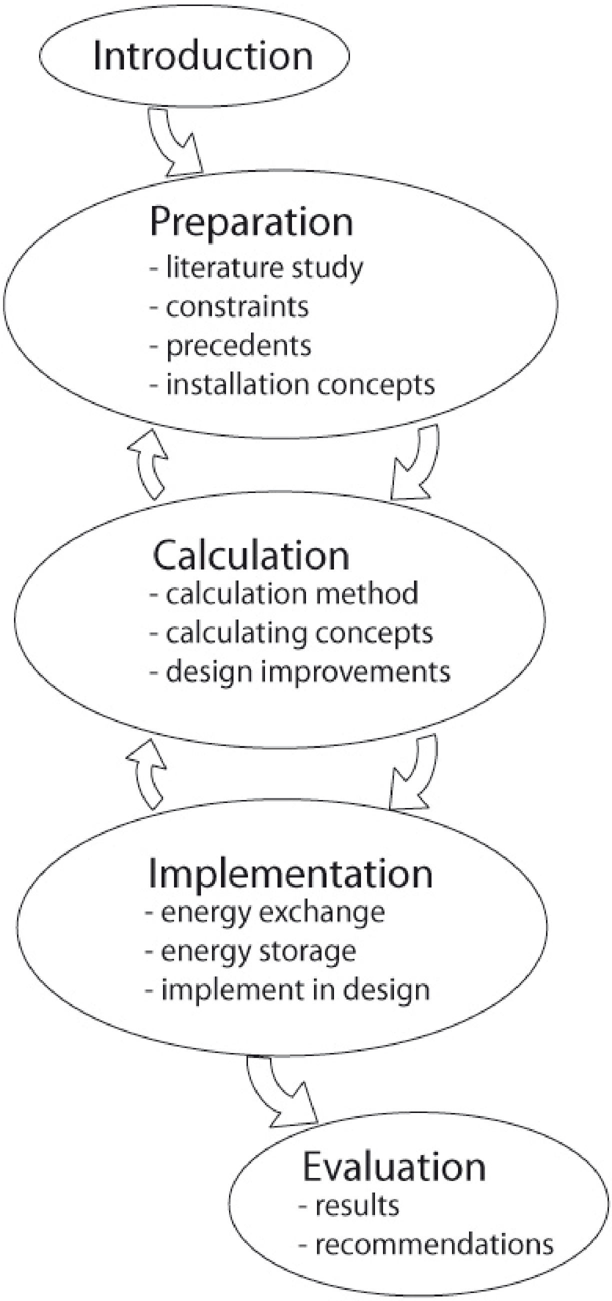

Figure 01 thesis structure

Throughout the research the preliminary design for the Science Business Centre will be used as a case study. At the same time a more general methodology is developed to minimize energy consumption through energy exchange and temporary storage. In chapter 8 recommendations are given to reduce the energy demand by exchanging and the temporary storing of energy.

2 Theoretical review

That buildings need to be more energy efficient is evident. But building “a sustainable building” cannot by itself be the primary objective. An energy neutral building which does not function properly is worthless. The same goes for a building that is not healthy or comfortable. Therefore functionality, health and comfort are to be set as constraints when the objective is to build an energy efficient building. This chapter presents the result of a literature research covering these several aspects as well as the theory of energy exchange and the theory of energy storing.

2.1 Functional constraints

The functional constraints are primarily determined in the architectural design. These are the architectural qualities as well as functional qualities of the design. Above all, the goal is that the building should fulfill its function as a Science Business Centre.

2.1.1 Energy consumption

In terms of energy consumption the architectural or functional qualities can be justified as follows. When one wants to know the impact that a product (in this case a building) has on the planet, energy usage alone is not enough, one needs to look at the *Life-cycle analysis*[4]. See in figure 02 the life cycle sketched.

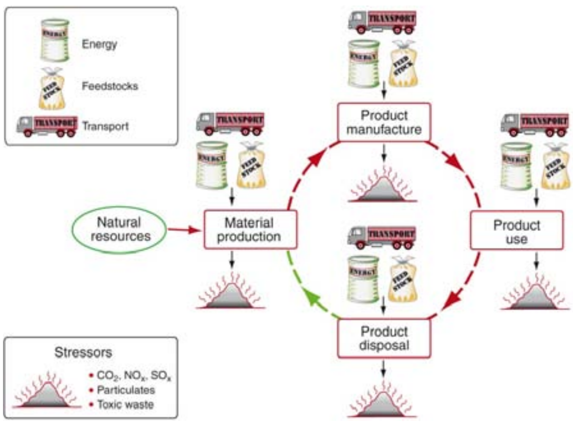

Figure 02 the Life-cycle analysis

[4] Ashby, M.; Shercliff, H; Cebon, D.; Materials Engineering, Science, Processing and Design, Elsevier, Oxford, 2008

Ashby et al. also mention that ore and feedstock are mined and processed to yield a material. This is manufactured into a product that is used and, at the end of its life, discarded or recycled. Energy and materials are consumed in each phase, generating waste heat and solid, liquid and gaseous emissions. This LCA is just for a single product. A building consists of many elements that in turn are composed of several products.

Figure 03 below shows the approximate values for the energy consumed at each phase of figure 02 for a range of products.[5] The columns show the approximate embodied energy (‘Mat.’), energy to manufacture (‘Manu.’), use energy over design life (‘Use’) and energy for disposal (‘Displ.’).

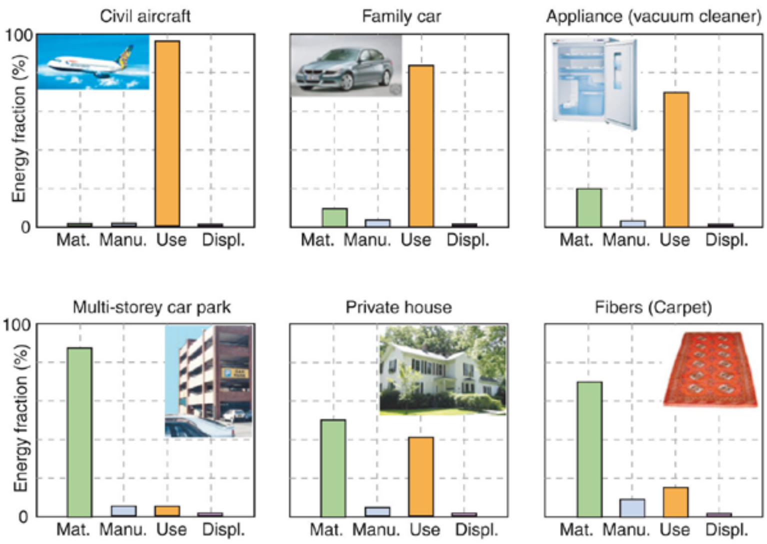

Figure 03 Approximate values for energy consumed at each phase.

From the figure can be read that to construct a building costs a major part of the total energy of the LCA. There are no exact numbers because these values vary between different climates, functions, users, etc. The point is that buildings need to have a certain lifespan for them to become ecologically profitable and thus acquire the right to exist. For this reason the first restraint is functionality.

[5] idem

2.1.2 Architectural and functional qualities

Sustainability is usually measured by limiting the flows of materials, energy, water and mobility as in the principle of Cradle to Cradle[6]. This technical sustainability is focused on the measurability: Greencalq, BREEAM and the LCA are examples. “A technically perfect sustainable building with a great score on all the measurable instruments does not prevent the building to fail architectonically”[7]. Architectural quality is an aspect that is not often included in the measuring instruments. A building with great architectural quality which is 1800 years old is in this sense 36 times more durable than a building that lasts only 50 years. The last one would have been broken down and built up again 36 times over the course of 1800 years of which the required energy can be read in the table of figure 02. The architectural value is primarily measured by how much the building is appreciated. An example of such a building that does survive century after century is the Pantheon in Rome which is nearly 1900 years old. It leaves an impression to the visitor because of its great sense of space.

Not only the architectural but also the functional qualities determine the lifespan of a building. The building should be suited for many different institutions and businesses. Abundance of daylight, extra high ceilings and over dimensioned spaces makes the building flexible in use. When the needs of the users or the organization changes the building should be able to cope with these changes, remaining a functional building. These architectural and functional aspects are already set in the preliminary design stage but will be further developed throughout this research.

2.1.3 User friendly interface between building and users

With user friendly interface is meant the extent to which users have the possibility to control their environment. The options to open a window, close sunshades, change the lighting and adjust the temperature are some of these possibilities. These buildings are called Alpha buildings. People accept a wider range of comfort temperature in these buildings. A building with a centrally controlled heating and cooling system or a Bèta building does not provide the individual users with the possibility to control their own

[6] William McDonough and Michael Braungart, Cradle to Cradle: afval = voedsel, Scriptum, 2007
[7] Translated from: Ruurd Roorda and Bas Kegge, Great Spaces een architectonische visie op duurzaamheid, de Architect, 2009

environment. Furthermore the preference is for low-tech solutions so that in case of an error the users can see the problem and not be dependent on a service desk to fix the problem. 'Low tech solutions with high tech effect' is the motto of Rau Architecten[8].

2.1.4 Flexibility in design

Changes in organization, expansion / reduction and new users in a building can be the provocation for reorganizing the floor plan lay-out. On the building scale, the floor plan should provide the possibility for rooms to be rearranged to meet the new demands of the clients. On a smaller scale individual rooms should be in their turn flexible to allow different kinds of activity.

2.2 Health and comfort constraints

In general this chapter is concerned with creating a healthy and comfortable building for its users. This involves several physical aspects like heating, cooling, (de)humidification, natural and artificial lighting and undesired odors as well as psychological aspects like the possibility to control your environment (Sick Building Syndrome) and views. For most of these aspects the requirements for comfort are stricter than for health and will therefore be discussed under thermal comfort.

2.2.1 Thermal comfort

The performance and condition of office workers is for a major part dependant on a healthy and comfortable indoor climate. Bad luminance causes drowsiness. High indoor temperatures will lead to a loss in concentration and performance. A high humidity levels in the indoor climate can induce undesired odors. Low humidity can cause irritation of the mucosa through dust. The requirements for thermal comfort are ever getting stricter due to legislations and the clients' awareness of these effects on performance and health.

One of the first to succeed in conducting a scientific research about the relation between thermal comfort and the users is P. Ole Fanger[9]. His model assumes the energy balance of a human being in a stationary situation. The heat produced in the human body

[8] Rau Architecten: www.rau.nl
[9] Linden, A.C. van der et al; Bouwfysica, ThiemeMeulenhoff, Utrecht/Zutphen, 2000

through metabolism is equivalent to the extracted energy. When this is in equilibrium, one is at comfort. Because Fanger's research is mainly about the relation between the indoor climate and the appreciation by its users, it is limited to thermal aspects which influence the thermal experience of a space.

Recent studies by *Brager en De Bear*[10] show that not only thermal aspects but also psychological aspects determine the comfort temperature. In buildings with openable windows and where the individual users can influence the indoor climate, people accept a higher comfort temperature in case of a high outdoor temperature and they accept a lower comfort temperature in case of low outdoor temperatures. In naturally ventilated buildings the comfort temperature shows more correspondence to the outdoor temperature than the static model of Fanger displays. This is first of all caused by the fact that the choice for clothing is determined by the daily weather. And second because people psychologically adjust themselves to the indoor climate which has a stronger correspondence to the outdoor climate than in a fully climate controlled buildings. This means that, in buildings where the users have influence on the indoor climate, the energy consumption is lower in the summer because there is a lower demand for cooling and lower in the winter because there is a lower demand for heating. On top of that energy is saved because less mechanical installations are used for ventilation. The majority of the building will be equipped with openable windows just for this reason.

2.2.2 Thermal comfort in the winter

Concerning thermal comfort we first assume that the indoor climate will remain within the acceptable limits throughout the year.[11] In the case that people can influence their environment the comfort temperature (which is the average air temperature and the average radiation temperature) in winter is between 20 and 24 °C. The temperature gradient (which is the vertical temperature difference in a room) cannot vary more than 1°C per meter so that the temperature difference from head to toe does not deviate more than ≈ 2°C. The human body is sensitive to large cold surfaces such as single glass surfaces and cold bridges and warm surfaces like floor and ceiling heating. To keep the

[10] Linden, A.C. van der; Boerstra, A.C. et al.; Adaptive Temperature Limits: A new Guideline in the Netherlands, in Energy and Buildings no. 38, 2006, (p8-17)
[11] Vandaele, L. et al; Moderne kantoren meer comfort met minder energie; Van Muysenwinkel, Enschede, 2001

temperature deviation in acceptable limits it is advisable to have a surface temperature between 19 and 26 °C for light or sitting activities in winter. The air velocity indoors should be less than 0,15m/s and the relative humidity should be between 30 and 70%.

For average climate conditions (such as office space) the standard for criticizing thermal comfort is the method of the NBN EN ISO 7730. With this method the human perception of the climate is expressed in a numerical value, the PMV (Predicted Mean Vote) on a scale from +3 to -3. A PMV of 0 means an optimal thermal climate for most of the people. A negative PMV means that it is too cold and a positive PMV means that it is too warm. The closer to the optimum of PMV=0, the less people complain. Obviously, the PMV has a close relation to the percentage of people that is unsatisfied with the indoor climate, (the PPD: Predicted Percentage of Dissatisfied).

Energy usage during the winter period is dependent on heat loss through transmission loss (through building and construction) and ventilation loss and on heat gain by sun, people, office equipment and lighting. In winter the goal is to limit transmission loss, limit ventilation loss and maximize the use of sun energy. Sun energy can be temporarily stored in the mass if available. This prevents quick overheating and the energy can be saved later on.

2.2.3 Thermal comfort in the summer

In summer the comfort temperature is between 23 and 26 °C max air velocity 0,18 m/s. In Holland it is a custom to calculate with the amount of hours that the climate is unacceptable, the GTO (gewogen temperatuur overschrijdingsuren) in which the PPD and the time the climate limits are exceeded are important parameters. For extreme weather conditions during the summer it is not required to remain within the temperature limits without the use of active cooling. A certain small period of the year the temperature limits may be exceeded, these are the GTO.

The strategy for thermal comfort in the summer consists of three steps. First of all, limit the heat gains by reducing the direct and indirect sun gain and reduce the internal heat load caused by office equipment etc. Second use the temporary energy storage such as night time ventilation and the use of thermal mass. And last if needed use active cooling.

The total summations of constraints are given in an overview in annex 01and annex 02 *Functional terms of reference.* The internal heat loads caused by people and appliances are provided by Senternovem[12] and are categorized in five groups. These groups are equal to the values used for EPN calculations.

2.3 Theory: exchanging energy

Heat transfer, also known as heat flow, heat exchange, or simply heat, is the transfer of thermal energy from one region of matter or a physical system to another. When an object is at a different temperature from its surroundings, heat transfer occurs so that the body and the surroundings reach the same temperature at thermal equilibrium.[13]

2.3.1 Energy exchange between two user functions

A spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature as required by the second law of thermodynamics[14]. Therefore when we want energy exchange between two different functions to occur these functions should, first of all, have a different indoor temperature. The temperature fluctuations within one function are limited from 2 to 4 °C depending on the type of function and the individual user influence. See in annex 01-02 (Functional Terms of Reference) the desired indoor temperature per function.

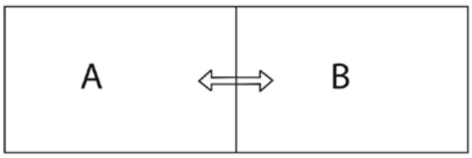

Figure 04 scheme for heat exchange

In a direct energy exchange between two functions (shown in figure 04) without any secondary medium the power (W) to heat or cool a space is dependent on the temperature difference ΔT, the heat transfer coefficient α and the surface A. In formula it is expressed as follows:

$$P\ (W) = \alpha\ (W/m^2K) \cdot A\ (m^2) \cdot \Delta T \text{ in } (°C)$$

[12] Senternovem: www.senternovem.nl/EPN/
[13] Linden, A.C. van der et al; Bouwfysica, ThiemeMeulenhoff, Utrecht/Zutphen, 2000
[14] Idem

When two spaces are connected in an ideal situation with water tubes, the water inside the tubes will be the average temperature between the two spaces. Thus, when two spaces with a temperature difference of 4 °C are connected, the water in the tubes will differ only 2 °C from each space. The heat transfer coefficient α is a constant in this equation depending on which surface subtracts or releases the heat or cold. See table 01

Table 1: Heat transfer coefficients according to NEN-EN 15377		
Floor heating and ceiling cooling	$\Phi_{c;sp} = \alpha\ \Delta\theta = 8.92\ \Delta\theta^{1.1}$	W/m²
Floor cooling	$\Phi_{c;sp} = \alpha\ \Delta\theta = 7.00\ \Delta\theta$	W/m²
Ceiling heating	$\Phi_{c;sp} = \alpha\ \Delta\theta = 6.00\ \Delta\theta$	W/m²
Wall heating and wall cooling	$\Phi_{c;sp} = \alpha\ \Delta\theta = 8.00\ \Delta\theta$	W/m²

Table 01 Heat transfer coefficients[15]

When heat is transported from one space to another with water as a carrier, water is simultaneously heating one space and cooling another. The heat flow is dependent on the lower value for α, which would be for a ceiling: 6.

According to the previous assumptions the total heating and cooling capacity per m² ceiling surface is limited to:

$$P = \alpha \cdot A \cdot \Delta T = 6 \cdot 1 \cdot 2 = 12 \text{ W/m2}$$

2.3.2 Energy exchange between a heat source and a user function

Where for the heat exchange between two functions the restraint was the temperature difference (ΔT), for energy exchange between a heat source and a user function the main limitation will be the surface (A) of exchange. The reason for that is that a relatively small area, like a server room or cold storage unit, has to heat a large area. More precisely the effect can be seen in the chapters 6.3.2 and 6.3.3.

[15] Engel, P.,Bokel, R., Ruijsscher, L. de; I-431 Concrete core activation, Kennisbank Bouwfysica, August 2009

Exergy

The exergy is a way of measuring the quality of the energy. The exergy indicates how much labor can be obtained from an energy or material flow.[16] It can be described as the labor potential, which is the maximum amount of labor, and which can be obtained by a certain amount of energy. Even in an ideal situation not all the energy out of heat can be recovered and used for labor. The part of energy that can be used for labor in the ideal situation is the energy potential or exergy. The fact that not all energy out of heat can be used for labor is because when the energy out of heat is in equilibrium with the surrounding, it still contains a waste heat which cannot be used. The zero point used is zero degree Kelvin. See figure 05 for the ideal labor process.

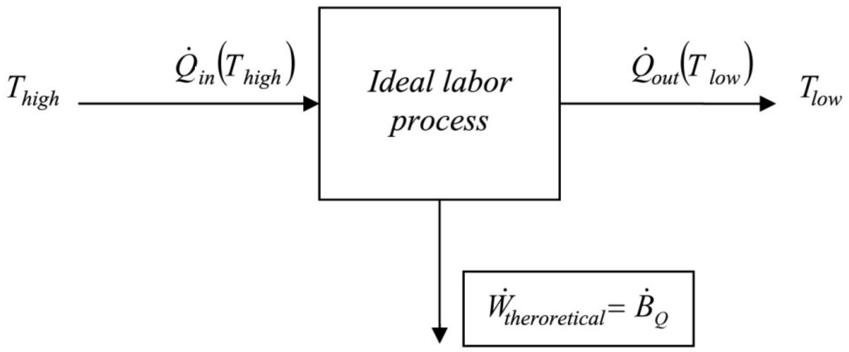

Figure 05 Schematic overview of an ideal labor process

In energy exchange between a heat source and a user function the heat will be transported from a high energy level to a lower energy level and thus loose labor potential. However, since the energy would otherwise be disregarded, this exchange can be seen as 100% profit.

2.3.3 Heat exchangers

Heat exchangers can exchange heat between gasses, water and/or air. In this research only water-water and air-water heat exchangers will be considered. For both these types there are several different heat exchangers on the market with efficiencies till 95%. This

[16] Cornelissen, R.L., Rens, G.L.M.A. van; Vermijden van verliezen bij het gebruik van industriële restwarmte Het ontwikkelen van een rankingcriterium voor warmte-uitwisseling op basis van exergie. Agentschap NL Divisie NL Energie en Klimaat: www.senternovem.nl

efficiency can be achieved by countercurrent flow as opposed to concurrent flow. In concurrent flow two streams come together 100 % and 0 % and the result lies in the middle at 50%. In countercurrent flow much great efficiencies can be achieved, approaching 100% (see figure 6). For the calculations in this thesis a heat exchanger with an efficiency of 90% is assumed.

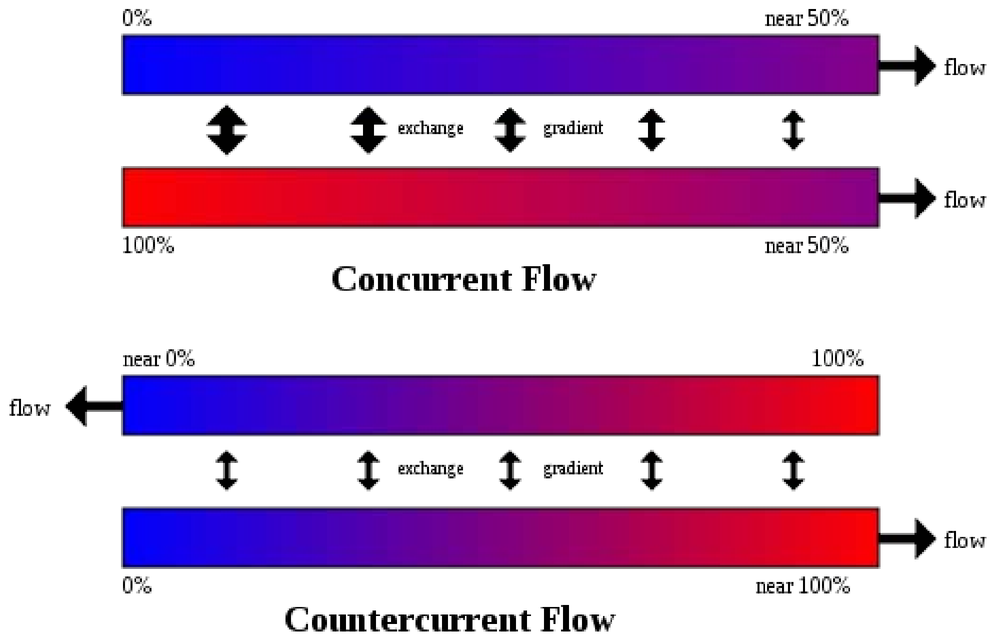

Figure 06 Energy exchange principles

2.4 Theory: storing energy

Short term energy storage is used to cope with short term temperature fluctuations like day and night but also with the temperature differences over a couple of days. Thermal storage can either take the form of sensible heat storage (SHS) or latent heat storage (LHS)[17]. Latent heat storage is accomplished by changing a material's physical state, whereas SHS is accomplished by increasing a material's temperature. Short term energy storage is since antiquity mainly realized by sensible heat storage e.g. by the thermal mass of the construction. The inertia of the mass keeps the building relatively cool during a hot summer day and relatively warm during a cold night. This is for example the reason why old churches are always cool in summer.

[17] Ip, K.C.W, and Gates, J.R. Thermal storage for sustainable dwellings, University of Brighton School of Environment, Brighton, 2000

2.4.1 Storage capacity of thermal mass (SHS)

The sensible heat storage capacity (J/m³) is dependent on the volumetric mass ρ (kg/m³), the specific heat of the material c in (J/kgK) and the temperature difference ΔT in (K). It is shown in the following equation:

$$Q = \rho \cdot c \cdot \Delta T$$

Where: Q = energy storage capacity of the floor J/m³, ρ = volumetric mass of the floor kg/ m³, c = specific heat of the floor J/kgK, ΔT = temperature difference K

When a light floor of 0,07m¹ concrete (ρ = 2.400 kg/ m³, c = 840 J/kgK) increases or decreases 1 K in temperature, the stored energy according to the equation is 141.120 J/m² or 141 kJ/m². The temperature within one user space can deviate max. 3 °C to remain within the temperature limits of the comfort zone. The maximum stored energy is than 3 ·141 = 423 kJ/m² with a floor weight of 168 kg/m²

2.4.2 Phase change materials (LHS)

When the thermal mass is absent or not sufficiently exposed latent heat storage with PCM materials can be used instead. A phase change material (PCM) is a substance with a high heat or fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa (changing from one phase to another). This is latent heat storage.

The latent heat for a different mass of the substance can be calculated using the equation:

$$Q = m \cdot L$$

where: Q is the amount of energy released or absorbed during the change of phase of the substance in (kJ), m is the mass of the substance in (kg), and L is the specific latent heat for a particular substance ($kJ\text{-}kg_m^{-1}$)*; substituted as* L_f *to represent as the specific latent heat of fusion,* L_v *as specific latent heat of vaporization.*

A frequently used PCM is Paraffin wax. The latent heat storage capacity of the wax is 200 – 220 kJ/kg. When we compare this to the previous example of sensible heat storage we can see that the required amount of material is considerably less. The concrete floor of 0,07 m thick has a storage capacity of 423 kJ/m² per 3 K and a weight of 168 kg/m² The same storage capacity with PCM can be achieved with only:

423 kJ/m² / 200 kJ/kg = 2,12 kg

In building products the storage capacity of PCM is influenced by additives which are required to customize the product for construction. Also phase change materials need some form of containerization in order for them to be used for thermal storage in buildings. A number of proposed systems encapsulate the PCM in building materials such as plasterboard, building blocks and concrete.[18] Another system uses induction units.

The same Paraffin wax is mixed with a copolymer and encapsulated in aluminium laminated panels.[19] The panels have a thickness of 5,26 mm, the Paraffin loading is 60%, the latent heat storage capacity is > 70 kJ/kg and the weight of the panels is 4,5 kg/m². The total latent heat storage capacity is: 4,5 · 70 = 315 kJ/m². The actual heat storage capacity is still a little higher because sensible heat storage occurs as well.
So the 5,26 mm laminated panels have a storage capacity nearly the same as a 70 mm concrete floor. Another advantage is that the release rates with PCM materials are more constant than with heat storage in thermal mass.

2.4.3 Seasonal energy storage

Long term or seasonal energy storage can be utilized with aquifers or PCM bulk storage. Latent heat storage can be utilized by using vast quantities of PCM in storage tanks. As they rely on bulk storage, large amounts of PCM are stored in tanks or

[18] Ip, K. PhD MSc, Gates, J. BSc; Thermal storage for sustainable dwellings, University of Brighton, School of Environment, 2000
[19] DuPont Energain, Duport energain energy-saving thermal mass systems installation guidelines, 2006: www.energain.dupont.com retrieved: November 2010

cylinders. In these systems a secondary medium is required to transport the heat. Also the PCM should remain on the right temperature for them only to change phase when needed. In the near future bulk storage with PCM can play an important role in the building scene but for now it is too underdeveloped to further discuss this topic.

Seasonal thermal energy storage with aquifers requires one to obtain a permit from the local municipalities, which usually implies that one needs to find equilibrium between the annual input and output of heat and cold. This aquifer balance can be seen in annex 17. The cold extracted from the cold source can be directly utilized for cooling. This only requires a standard water pump for the water circulation and a heat exchanger to keep the two water circuits separately. However the heat from the heat source is usually not warm enough for heating. The additional temperature increment can be realized with a heat pump with a high COP of 7 since the temperature difference is very limited.

3 Precedential review of technologies

This chapter provides a review of a number of relevant precedential projects and techniques varying on different technologies and different scales. These examples can help to put some of the later proposed operations or schemes into a realistic perspective.

3.1 Heating and cooling networks in districts

Heating and cooling pipes are used to link buildings together to form a district energy network to distribute the thermal energy from a decentralized energy generation station. An early form of a heating network is district heating (stadsverwarming). The first city in the Netherlands that utilized district heating is Utrecht. The heat for city heating is typically extracted from power plants but geothermal energy or heat from waste burners can also be used.

3.1.1 Technologies

Heating networks typically fall into two categories, low temperature (a flow temperature of circa 80°C) and high temperature (a flow temperature of circa 100 to 120°). If at all possible the use of a lower temperature network is recommended as this significantly reduces heat losses, increases the energy that can be used for lower temperature sustainable energy sources, and lower cost piping systems can be utilized.[20] Figure 07 shows the heat source (left) transporting the heat to the heat transfer station (middle) form which it is further distributed to the houses (right).

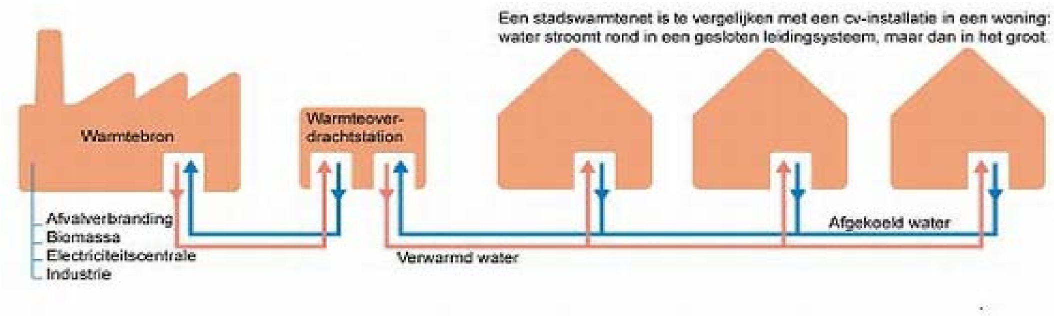

Figure 07 district heating scheme.[21]

[20] Decentralised Energy Knowledge Base; www.dekb.co.uk
[21] P. van der Wilt, Stadswarmte uit Diemen voor Almere, Technisch Weekblad, http://www.technischweekblad.nl, published: June 2008

Figure 08 shows an example of the pipes used. In the houses the heat from the district heating is extracted by a heat exchanger to warm the tap water.

Figure 08 district heating pipes for the Harnaschpolder in Delft.[22]

3.2 The Energy-roof of the Christiaan Huygens College

The Christiaan Huygens college design by Rau Architects is the first CO_2 - neutral school in the Netherlands (see figure 9). The building produces its own energy using an Energy-roof and roofing with PV-foil. On sunny days the abundant energy will be transported to a local ‘energy internet’ and will be available for the nearby dwellings and sport facility. The total annual saving for the three buildings is €130.000.[23]

Figure 09 Christiaan Huygens college with nearby dwellings and sport facility[24]

[22] J.P. de Wit, Ambitieus restwarmtebedrijf is totaal mislukt, http://www.jpdewit.nl, published February 2008
[23] Scholen en Bouwen aan de toekomst special energie en milieu, 2009: www.rau.nl
[24] Idem.

The Energy-roof is developed by Schiebroek Dakbedekkingen in collaboration with Volantis and the TU Eindhoven. It is a thermal system in which sun collectors consisting of a piping system with heat exchanger are included in the insulation layer of the roof construction.(see figure 10) This insulation layer is covered by polymer roofing with integrated PV-cells to produce electricity.

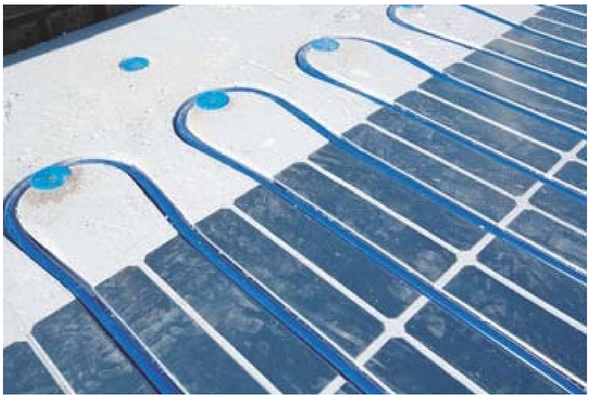

Figure 10 Energy roof of the Christiaan Huygens college[25]

The Energy-roof or Climate-roof has several great advantages. The two functions of the roof enhance each other. The sun collector constantly cools the roof; reducing internal heat loads, enhance the lifetime of the PV-cells and collect warm water. The PV-cells produce electricity for the pumps and other appliances in the building. During summer nights the climate roof can be connected to the climate ceiling so it could be utilized as a radiator for night time cooling[26]. The water flow between the internal heating/cooling system and the roof ensures the release of heat stored within the building during the day.

Critical comments for the energy roof are:
Can the produced heat be utilized?
Can the produced heat be stored?
Can the produced heat be used for seasonal storage?

[25] Nederlandse Dakbedekkers Associatie NDA B.V., http://www.energiedak.nl, retrieved: Nov 2010
[26] Schiebroek Dakbedekkingen: www.schiebroek.nl , retrieved Nov 2010

3.3 Passive House

The term Passive House (Passivhaus in German) refers to the rigorous, voluntary, Passivhaus standard for energy efficiency in a building, reducing its ecological footprint.[27] It results in ultra-low energy buildings that require little energy for space heating or cooling.[28] A similar standard, MINERGIE-P, is used in Switzerland.[29] The standard is not confined only to residential properties; several office buildings, schools, kindergartens and a supermarket have also been constructed to the standard.

The Passivhaus standard for central Europe requires that the building fulfills the following requirements:[30]

- The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year (4746 btu/ft² per year) in heating and 15 kWh/m² per year cooling energy OR to be designed with a peak heat load of 10W/m²
- Total primary energy (source energy for electricity and etc.) consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m² per year (3.79×10^4 btu/ft² per year)
- The building must not leak more air than 0.6 times the house volume per hour ($n_{50} \leq 0.6$ / hour) at 50 Pa (N/m²) as tested by a blower door,

In conclusion the Passivehaus concept consists of a set of very strict rules, which have a great impact on the execution phase e.g. air tightness and insulation thickness. To meet the strict requirement one has to pay a great deal of attention to small details which is less realistic for a large and fictitious project because the project will not be developed until this level. However the standard can be used as a reference for splendid design.

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[27] Zeller, Jr, T.; Beyond Fossil Fuels; Can we Build a Brighter Shade of Green?, New York Times, September 26, 2010, p.BU 1.

[28] Gröndahl, Mika & Gates, Guilbert. The Secrets of a Passive House, New York Times website, September 25, 2010. Retrieved November 11, 2010.

[29] Minergie; The Minergie – Standard for Buildings, Minergie website; www.minergie.ch retrieved November 11, 2010

[30] Nieminen, J., Holopainen, R. Lylykangas, K. Concepts and market acceptance of a cold climate passive house, Helsinki University of Technology; www.passivhusnorden.no retrieved November 11, 2010

3.4 Aquifers

When we speak about geothermal energy storage there are “open systems” and “closed systems”. Closed systems use a set of pipes or channels running under or around the building to utilize the more constant temperature of the soil. Closed systems are usually small and usually for one building only. An aquifer is considered an “open system” e.g. a system that utilizes the open ground water. Storing heat and cold in aquifers requires one to obtain a permit. An important condition to obtain a permit is that the total of input and output of heat and cold (in Joules) should be in equilibrium throughout the year.

4 Calculation methods

4.1 Theory for heat and cold calculations

The heat / cold load calculations are the basis for establishing connections between different functions. In this chapter, two types of calculations are described and example calculations are made. Within the calculations the place and time are indicated where energy exchange or storage can be feasible. The calculations can be seen in annex 04 to annex 16.

4.1.1 The Dutch climate

The project is situated in Delft which has a typical Dutch climate. The Netherlands have a moderate maritime climate which is influenced by the North Sea. The closer you get to the sea the smaller are the temperature differences between summer and winter. Wind rates increase when you get closer to the sea and generally the wind comes from the south-west.[31] In annex 03 an overview is given of the average Dutch minimal, mean and maximum temperatures per 10 days over the course of a year. The average temperatures are used for the static calculations. For the more accurate dynamic calculations ORCA uses the reference year of 1964-1965.

4.1.2 Static calculation

The static calculation can be used to make an approximation for the heating and cooling demand. The need for cooling and heating can be divided into two elements. The internal heat loads and the external heat/cold loads. In formula it is expressed as follows:

ϕ cooling = ϕ internal + ϕ external (W)

in which: ϕ internal = the internal heat load, ϕ external = the external heat load

the internal heat load is calculated as follows:

ϕ internal = ϕ people + ϕ lighting + ϕ appliances (W)

[31] Stichting Deltawerken Online 2004: www.deltawerken.com

in which: ϕ people = heat load caused by people (W), ϕ lighting = heat load caused by artificial lighting (W), ϕ appliances = heat load caused by appliances (W)

the external heat load is calculated as follows:

ϕ external = ϕ s,gl + ϕ tr,gl + ϕ s,cl +ϕ inf,vent (W)

in which : ϕ s,gl = heat load caused by the sun through the glazing (W), ϕ tr,gl = heat load caused by transmission through the glazing and walls (W),ϕs,cl = heat load caused by sun through closed facades and roof, ϕ inf,vent = heat load caused by infiltration and ventilation (W)

ϕ s,gl = z * Awindow * ZTA * qconv * fd (W)

in which : z = ratio of sun prevention, Awindow = glass surface (m2), ZTA = sun emittence ratio sunscreen/glass, qconv = correction factor for the intensity for the moment of the day; 1 is at 13:00 hour when the intensity is the greatest

ϕ tr,gl = Uwind * Awind * Δti,o (W)

in which : Uwind = heat transmittance coefficient (W/m2K), Awindow = glass surface (m2), Δti,o = temperature difference inside - outside (Ti-To) (K)

ϕ s,cl = a * Acl * qw (W)

in which : a = absorption coefficient of sun radiation, internal surface of closed parts (m2), heat flow of closed parts (W/m2)

ϕ inf,vent = qair * ρ * c * Δti,o (W)

*in which: qair = airflow = 0,2 to 0,3 * (volume/3600) (m3/s), ρ = air density = 1,2 (kg/m3), c = specific heat of air = 1000 (J/kg*K), Δti,o = temperature difference inside - outside (Ti-To) (K)*

For these formulas the ‘Globale koelbehoefte berekening’ was used provided by ‘Kennisbank Bouwfysica’[32]. The static calculations are made on calculation sheets in MS Excel (see annex 04). On the top in the 6 black rectangular all the specific data for the function is inserted like: the geometry, internal heat loads, external heat loads, required indoor climate and the heat load by transmission and ventilation and

[32] Engel, P. v.d.; Verhoeven,M.; Ruijsscher, L. de; Vliet, J. van de; Kennisbank Bouwfysica I380 Klimaatontwerp globale koelberekening

infiltration losses. The whole calculation is expressed on one line so that we can compare the 12 calculations per 2 hours in one column. The first part of the line; the internal heat loads are shown multiplied by a ratio so that the heat loads differ between day and night. Also the sun load through glass, the heat load through transmission and the ventilation losses are dynamic in a way that they can deviate between day and night. Finally the result is the average required power in W/m2 during 2 hours. Average in the way that during that day and that time this will be the average required power. The graphic shows the required power over the course of one day made out of twelve calculations (the last column). In the same way calculations are made with the average month consumption.

4.1.2.1 Night time cooling

Night time cooling can be utilized by cooling the building during the night time with ventilation air (night time ventilation) or with the use of water. In case of night time ventilation the building mass needs to be accessible for the ventilation air to pass through and reach the mass. In the case of night time cooling with water the building mass does not need to be directly accessible but can be reached with water tubes. An average value for night time cooling is 20 W/m2 which will be applied in the static calculations.[33]

4.1.3 Dynamic calculation

Dynamic calculations have to be made with computers because they consist of many different variables. For this purpose the computer software ORCA is used which is a shell of the more extended version of VA114 (both from VABI). VA114 requires excellent knowledge about building physics and regular practice in using the program. In ORCA, which uses the same calculation basis, all the concept properties, as given in the chapter five, can be inserted and an output can be generated more easily. The program provides us with detailed information about indoor temperatures, comfort temperatures, weighted temperature exceeding hours (GTO) and many more. However,

[33] Engel, P. v.d.; Verhoeven,M.;Ruijsscher, L. de; Vliet, J. van de; Kennisbank Bouwfysica I380 Klimaatontwerp globale koelberekening

it provides less detailed information about energy consumption except for the power needed for the entire period for heating, cooling and the sum of those. To obtain more accurate information an extension of the program was created in excel. In the OorcaW folder an input file is located called VA114UIT.QQ1. This file contains for the whole summer or winter period one energy calculation per hour. This vast amount of data is transformed by formulas in excel to create energy consumption graphs per year, month, week or even day (see annex 5). The output file contains calculations for every hour for the entire winter or summer season. The values can be reduced to one value per day to create a seasonal graphic or the data can be used directly to create a week or daily graphic. Two seasonal graphics have been plotted together with the manual calculation to give a comparison. (see annex 6). The ORCA calculations are more dynamic because all the input deviates. The desired comfort temperature fluctuates as the sun comes out or the outdoor temperature changes.

N.B.

The values for energy consumption in the dynamic calculations differ from the statistic calculations due to several issues:

- In the dynamic calculations some extreme values are included instead of a summation of only averages.
- In the dynamic calculation there is a distinction between heating and cooling with radiation and the heating and cooling of the air. In the calculations it can be seen that in certain moments in time there is a simultaneous need for heating with radiation and cooling of the air and vice versa. This is primarily caused by the heat recovery which is simulated with air re-circulation.
- The comfort temperature in the static calculation has one value in summer and one in winter. In the dynamic calculation this differs per day per hour.
- In the static calc. the temperature meets the comfort requirements during a weekday and in the weekend during day and during night. In the dynamic calc. this is limited to the time the building is in use so during night and weekends energy can be saved.

Furthermore, it can be said that the energy calculations are complex because it is extremely difficult to predict the future climate and context conditions and how the building will react to these conditions. Also the calculated energy demand and the real energy demand are often quite different. As an example figure 11 shows the actually measured energy consumption per square meter floor area of 73 office buildings (plotted on the vertical axis) compared to the calculated energy performance according to the Dutch code NEN 2916 (plotted on the horizontal axis).[34] Construction has a major impact on the buildings performance. But also presumptions are made which can turn out to be quiet different in reality.

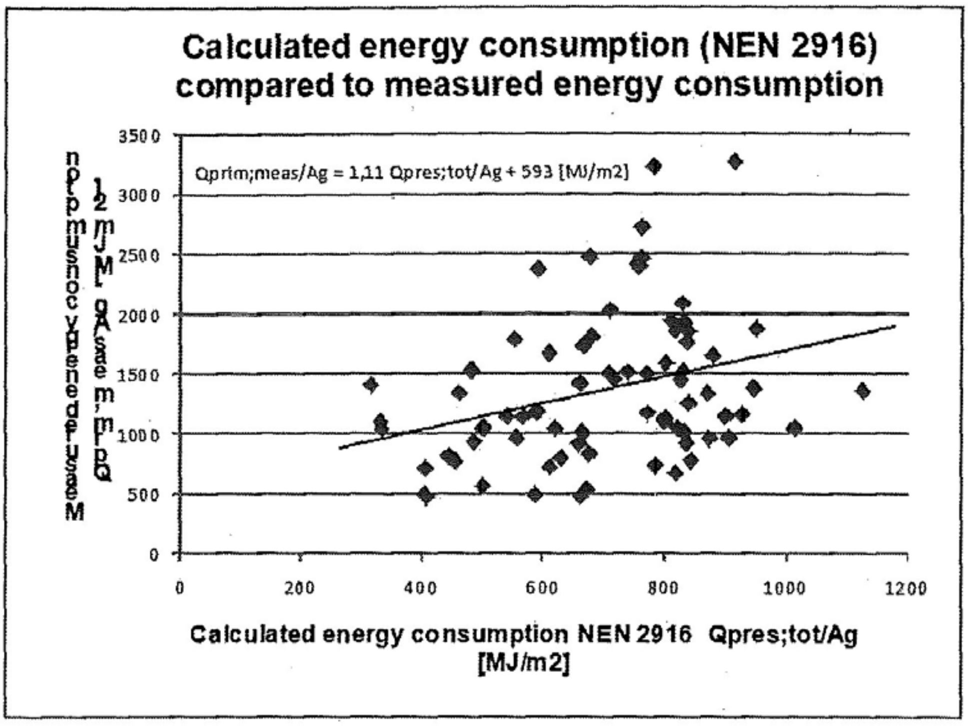


Figure 11 Calculated energy performance compared to actual consumption

The results achieved by ORCA calculations should therefore not be seen as the absolute truth but they should be considered in comparison to previous results which were calculated in the same way. Design improvements can be made.

[34] Kurvers, S.; Ham, E. van den; Leijten, J.; Robust climate design as a concept for energy efficient, comfortable and healthy buildings, Rumoer, Nov. 2010, Delft

5 Installation concepts

In this chapter different installation concepts are described which, derive from the preliminary design of the SBC and will be used as a case study for further analysis. Each concept will be considered on its own. First the initial idea will be explained as was intended in the preliminary design, then design improvements resulted from this research will be explained and last a figure is given showing the implications on the architectural design. Also, three alternative sources of energy will be considered.

5.1 From functions to installation concepts

The Science Business Centre is at this stage in its preliminary design. The main architectural gesture is the museum which hovers above a mound. The other functions are largely placed underneath an elevated public park landscape. For every function some points of departure are set which are further developed in the following sub-chapters. The Science Business Centre has a wide variety in functions which are all housed in four different energy concepts (see figure 12). In order to maintain flexibility within the building several functions are housed in one installation concept. The museum, the archive and the conference centre need their own tailored installation concept for them to function properly. The museum is a hovering volume which needs special attention due to its exposure to the outdoor temperatures. The archive needs to have a constant temperature and requires well treated air. The auditorium needs a lot of ventilation air for all the spectators and has very high but short internal heat loads (when lectures are given). Most of the other functions can be brought together in the “pavilion concept” which is flexible to the extent that each of the other function can be located within this concept. The name pavilion does not relate to a pavilion per se but is given because the program is situated around courtyards with a strong interaction with outside. The four concepts are generalized and prescribed in the following sub-chapters. They are the basis for further research.

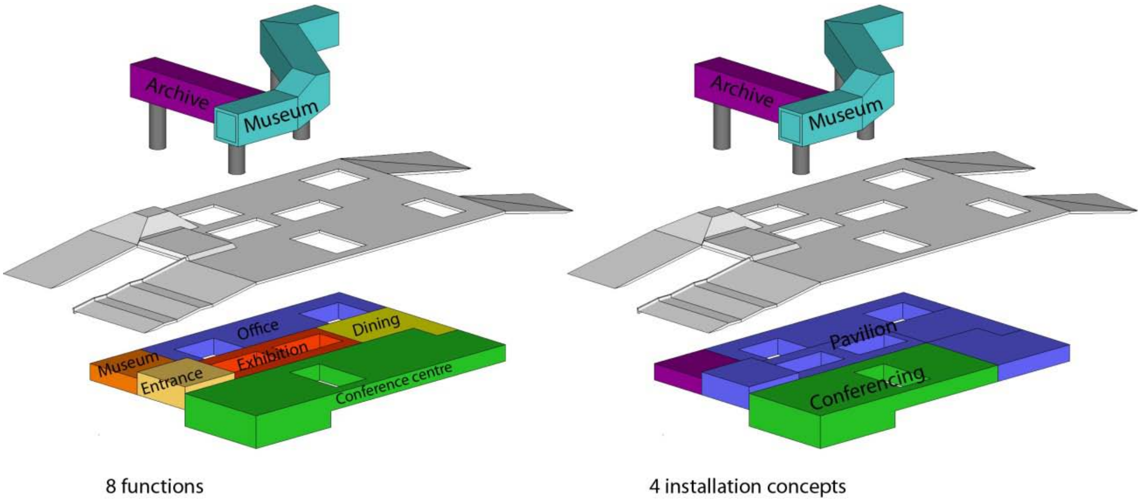


Figure 12; 8 functions in 4 installation concepts

5.2 Pavilion concept

Preliminary Design Idea

A large part of the Science Business Centre consists of the pavilion concept. Flexibility is an important topic as it houses offices, common space, a restaurant and meeting rooms. A point of departure is that the users are to a certain extend in control of their own environment; turn on/off light, open a window and they are free to go somewhere else. This allows the indoor comfort temperature to be set more flexible and thus energy is saved. The idea from the preliminary design was a relatively high space with large glass surfaces to maximize the relation from inside to outside. The installation consists of LTH (Low Temperature Heating) and HTC (High Temperature Cooling) with concrete core activation. The concrete is exposed. The ventilation is mainly natural but mechanical if needed. Lights and appliances are largely in plain sight and can be disguised in each space separately. (An impression is shown in figure 13)

Figure 13 pavilion concept

For every installation concept some assumptions have been made on which the calculations are based. Some information is based on the preliminary design and other information on precedential studies or assumptions.

General properties for "pavilion concept":

Orientation	: east - west
Walls	: insulated roof, floor Rc: 5 m² K/W, U-value: 0,2 W/m²K
Glass	: Hr++ glass U-value: 1,2 W/m²K
Openable windows	: night time ventilation
Ventilation	: natural if possible, mech. if needed, heat recovery 90%
Heating and cooling	: Low Temp. Heating, High Temp. Cooling, with concrete core activation

In the calculations it was made a distinction within this concept because the internal heat loads vary due the different functions. In the calculations one is referred to as the "office concept" and the other as the "common concept" (as in common space). The 'office concept' has greater internal heat loads caused by appliances and people 24 W/m² as opposed to the 16 W/m² of the 'common concept'. The 'common concept' however is also used in the weekend so it has a more steady consumption pattern. Both the manual and dynamic calculations are shown on one sheet for a comparison of the consumption patterns. (See annex 06 and annex 07 for the office concept and the common concept)

Design Development

Windows

In the pavilion concept, openable windows are not yet included. However in the preliminary design openable windows are a point of departure so that the conditions of the comfort temperature can be set more flexible.

Ventilation

The ventilation is largely natural but in the winter period a mechanical ventilation is necessary to remain within the limits of the comfort zone and to seriously reduce the energy demand. (calculated with ORCA) In the mechanical ventilation heat recovery can be applied with an efficiency of 90%.

Thermal storage capacity

In ORCA several different floors and ceilings have been calculated to see the influence of the thermal storage capacity on the energy consumption. An ideal storage capacity is 300 mm concrete in the floor and 300 mm in ceiling. The energy consumption in the summer period is calculated for three different floors / ceilings thickness. After 300mm there is no more improvement in for the storage capacity. See the results below

Thermal cap. Thickness concrete	250 mm	300 mm	350 mm
Consumption in summer period	10,54 kWh/m2	10,48 kWh/m2	10,48 kWh/m2

ORCA calculation results

Critical comment: The optimum of 300 mm concrete floors and ceilings can be applied in this manner or can be realized by applying a lighter (wood or steel) floor and then additionally add PCM materials.

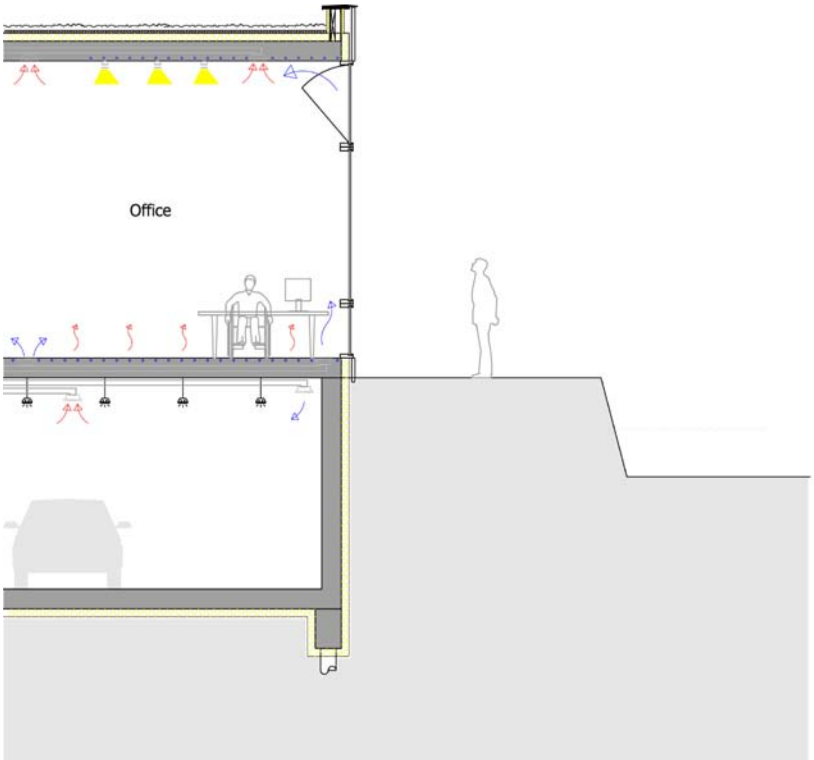
Draft in front of window

Usually radiators are placed directly under windows to compensate the cold draft coming down with a warm upward air flow from the radiator. Because the glass surface for the pavilion concept is large and the floor has limited floor heating capacity, a cold draft in front of the window can be expected. A heating pipe below the window could compensate the draft but the higher temperature required for such a pipe is not desired because it requires a separate heating mechanism for a higher temperature. A small windowsill can compensate the cold draft by both reducing the glass surface and containing more heating surface within the sill itself. The sill will be set at the height of a standard office desk of approximately 700mm.

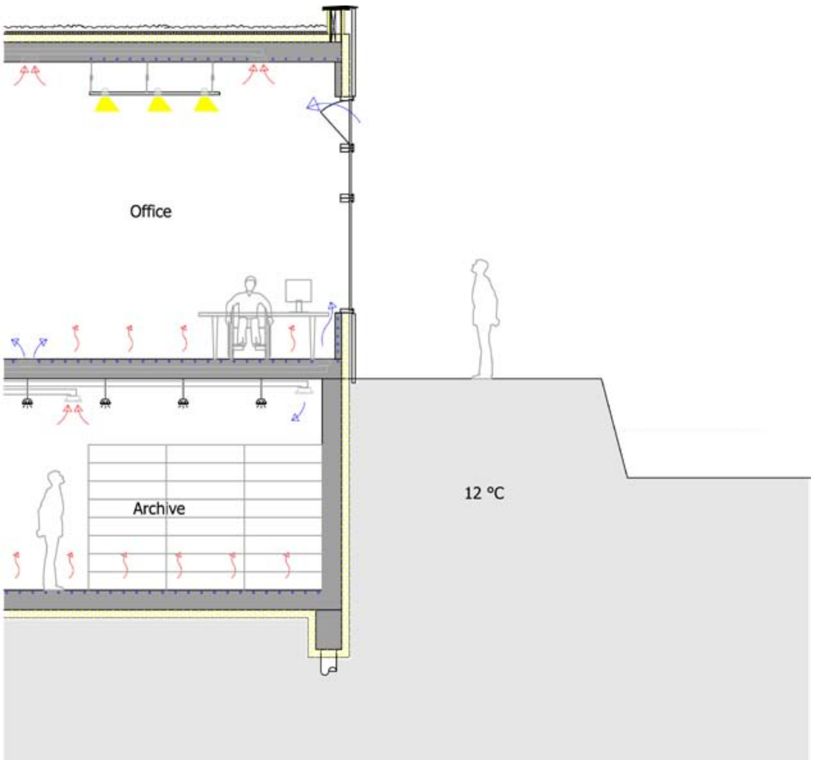
Server space

The server space has a constant heat supply (see chapter 5.6.3). The server space will be used as a heat source in winter so here energy will be exchanged. At the same time the server should release the heat to the outdoor in summer to prevent overheating.

All changes can be seen in figure 14



Old situation



New situation

Figure 14 design development in the pavilion concept

5.3 Museum concept

Preliminary Design Idea

The museum consists of a volume hovering above the mound and is therefore to the utmost exposed to the outdoor climate. Sensitively it would be logical for a museum to have a proper mass in order to retain a stable indoor temperature but for architectural reasons the museum will be a light weight structure. The volume will span great distances to provide an optimal visual continuity between the Mekelpark and the polders. The architectural concept from the preliminary design is a light weight structure that spans great distances. The volume is a two storey (10m high) space in which an in between floor can be installed. The mezzanine and all interior walls are flexible and can be easily removed for different expositional compositions. See figure 15

Figure 15 museum concept

The envelope has to deal with major changes in temperature. The first presumption for this installation concept was a standard glass façade with a low ZTA factor and a standard sun shading system. The calculations of the annual energy balance show that with this concept, despite high performance façade elements, the museum will have the largest need for heating in winter and substantial need for cooling in summer. See table 02.

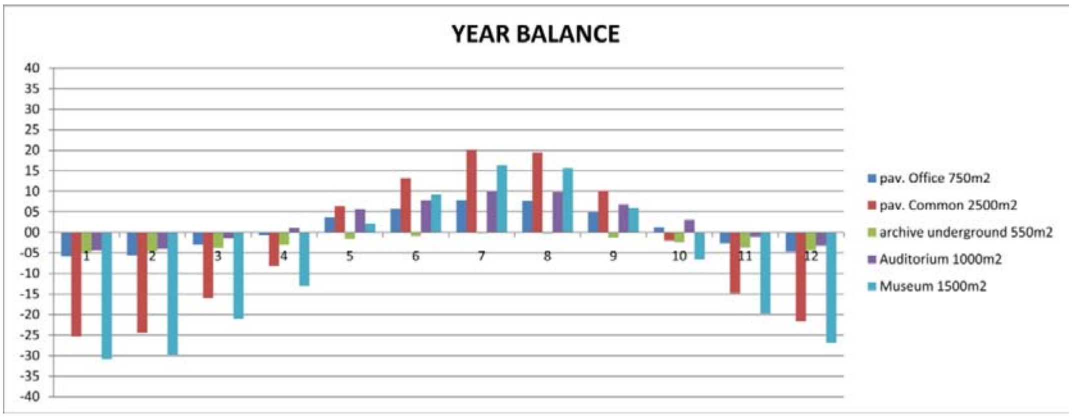


Table 02 Manual calculation year balance in kW per function

For this reason there has to be found an alternative energy concept which adapts more to seasonal changes. In summer the majority of the sunlight needs to be blocked and in winter the insulation value of the façade has to be improved. The new design idea is to use sun shading louvers which can be used in winter to provide the façade with an extra insulation layer. One requirement is that the louvers have to be hermetically sealed when closed. In the new energy concept the museum has a traditional glass façade with insulating / sun shading louvers on both sides. See figure 16.

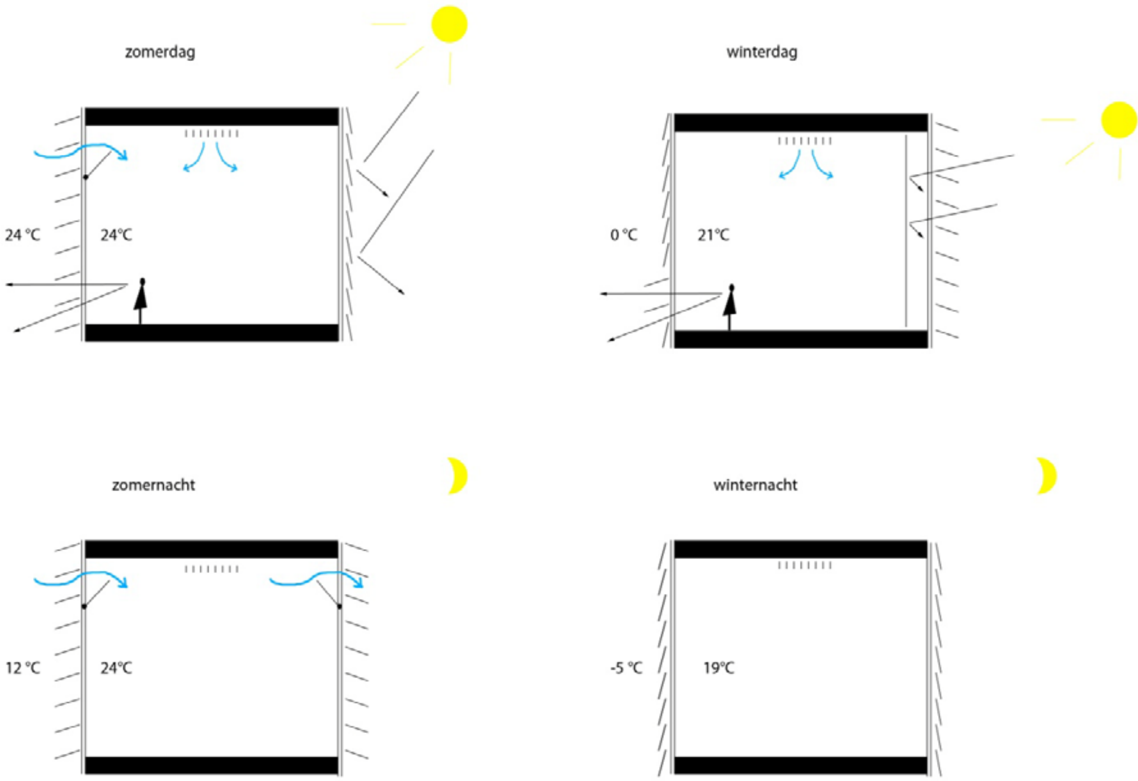


Figure 16 museum concept with louvers on the outside

On a warm summer day, the sun on the sunny side is blocked by the louvers, and the shaded side is used for natural ventilation as far as possible. In the night both sides are open to make night time ventilation possible. In the winter the sun radiation is permitted through the thermal skin and blocked by a second sun blind to prevent dazzle. In the night all the louvers are shut and the ventilation is ceased. With this energy concept maximum profit can be gained from the sun and minimal heat is lost through transmission through the glass. This dynamic concept is simulated by calculating the two extreme situations (façade open and façade closed). The two calculations are superimposed and at any given moment in time the best performance is selected for the output (see annex 8 for the results).

General properties for “museum concept”:

Orientation	: east - west
Walls	: insulated roof, floor Rc: 5 m² K/W, U-value: 0,2 W/m²K
Glass	: Hr++ glass U-value: 1,2 W/m²K
Openable windows	: night time ventilation
Ventilation	: natural if possible, mech. if needed, heat recovery 90%
Heating and cooling	: Low Temp. Heating, High Temp. Cooling, with concrete core activation

Design Development

Energy concept

The initial energy concept was not suited for the function and/or place. As explained above it required too much energy and has therefore been exchanged for a more developed dynamic concept which adapts more easily to weather changes.

Louvers

The louvers have besides the usual function of sun shading also an insulating capacity. On cold days or nights the louvers can be shut to have an extra insulation layer.

Ventilation system partially mechanical to fully mechanical

The first assumed ventilation concept was a natural ventilation system supported by mechanical ventilation when needed and the idea was to use night time cooling. For two reasons the possibility to ventilate natural has be skipped. First the visitors cannot have a real influence on the indoor climate sine they are constantly walking around. Second the night time cooling by means of natural ventilation can cause condensation on the cooling ceiling in summer. In the new concept all ventilation is supplied by the air handling units.

Displacement ventilation

The architectural idea is that a double high space can function as a whole or can be split up in two stories. The ventilation system should be suited for all situations. The first idea for ventilation was inlets in the floor and extraction in the ceiling but the in between floor would interrupt this air flow. Displacement ventilation from left to right or vice versa could be better suited for this concept.

Cold draft

The primary heating and cooling system are *low temperature heating* and *high temperature cooling*. In a traditional central heating system the heat from the radiators compensates the cold draft air in front of the windows. In the museum concept the floor heating has a limited capacity and cannot compensate the enormous draft created by the 10 m high glass façade. As an additional measure heating pipes (with 60°C water) will be installed on the inside of the glass façade to reduce the cold draft.

Thermal storage capacity

The ideal storage capacity for the museum is, like the pavilion concept, 300 mm concrete in the floor and 300mm in the ceiling according to the ORCA calculations. Because the calculation consist of two parts, one with the façade closed and one with the façade open, the comparison has been made for both. In both case the 300 mm floor and ceiling scores the best. This storage capacity will primarily be achieved by PCM materials. (See chapter 6.4.1)

Thermal cap. Thickness concrete	250 mm	300 mm	350 mm
Consumption summer closed	15,7 kWh/m2	15,5 kWh/m2	15,8 kWh/m2
Consumption summer open	48,9 kWh/m2	48,8 kWh/m2	49,1 kWh/m2

ORCA calculation results

The development can be seen in figure 17

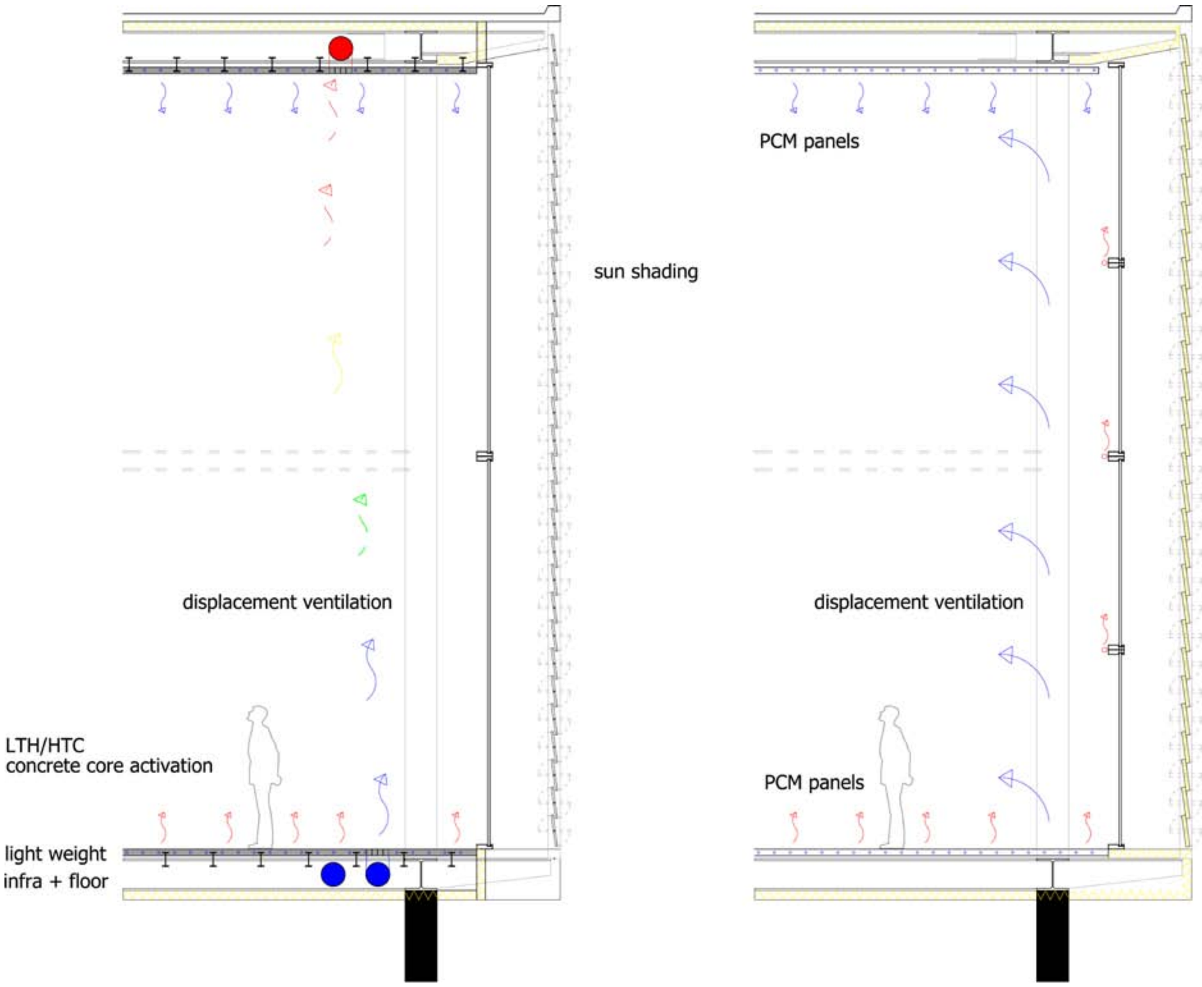


Figure 17 design development in the museum concept

5.4 Archive concept

Preliminary Design Idea

Initially the archive was located above the mound directly connected to the museum. The idea was a solid volume with few windows to conserve the treasure of the TU Delft. The archive is a function that requires throughout the year a stable indoor temperature. The designed section which derived from the preliminary design and is two floors high. See figure 18 for the concept setup.

Figure 18 archive concept

The first approach has been made with a static calculation. The energy demand is typical; high demand for cooling in the summer period and a high demand for heating in the winter period. There is limited space for temperature fluctuations due to the strict indoor temperature requirement of 20 – 22 °C. An alternative idea, to minimize the energy demand, is to locate the archive (partially) underground to make use of the stable ground temperature of 12°C. The cold ground temperature is slightly compensated by some internal heat loads so the overall energy demand is very low. A comparison of energy consumption made with a static calculation can be seen in annex 11 and annex 12. Based on this comparison it was decided to relocate the archive underground so it requires an almost evenly energy supply throughout the year.

General properties for "archive concept":

Orientation	: n.a.
Walls	: insulated walls Rc: 5 m² K/W, U-value: 0,2 W/m²K
Glass	: n.a.
Openable windows	: n.a.
Ventilation	: minimal ventilation, mechanical with heat recovery 90%
(De)-Humidification + filter	: yes
Heating and cooling	: Low Temp. Heating, High Temp. Cooling, with concrete core activation

Design Development

LTH and HTC

The museum requires very limited heating and theoretically no cooling. Because the ventilation air is relatively expensive through humidification and filtering the ventilation air is minimized. The archive is heated with radiant heating (and cooling).

Infiltration losses

Because the program is located underground there are no windows and almost no door so the heat losses through infiltration are almost zero.

Heat exchanger with restaurant

Because of the stable ground temperature the museum needs heating most of the year with the exception of July and August. The excess heat from the cold storage units (see chapter 5.6.2) is also constant so here energy can be exchanged.

The design development can be seen in figure 19

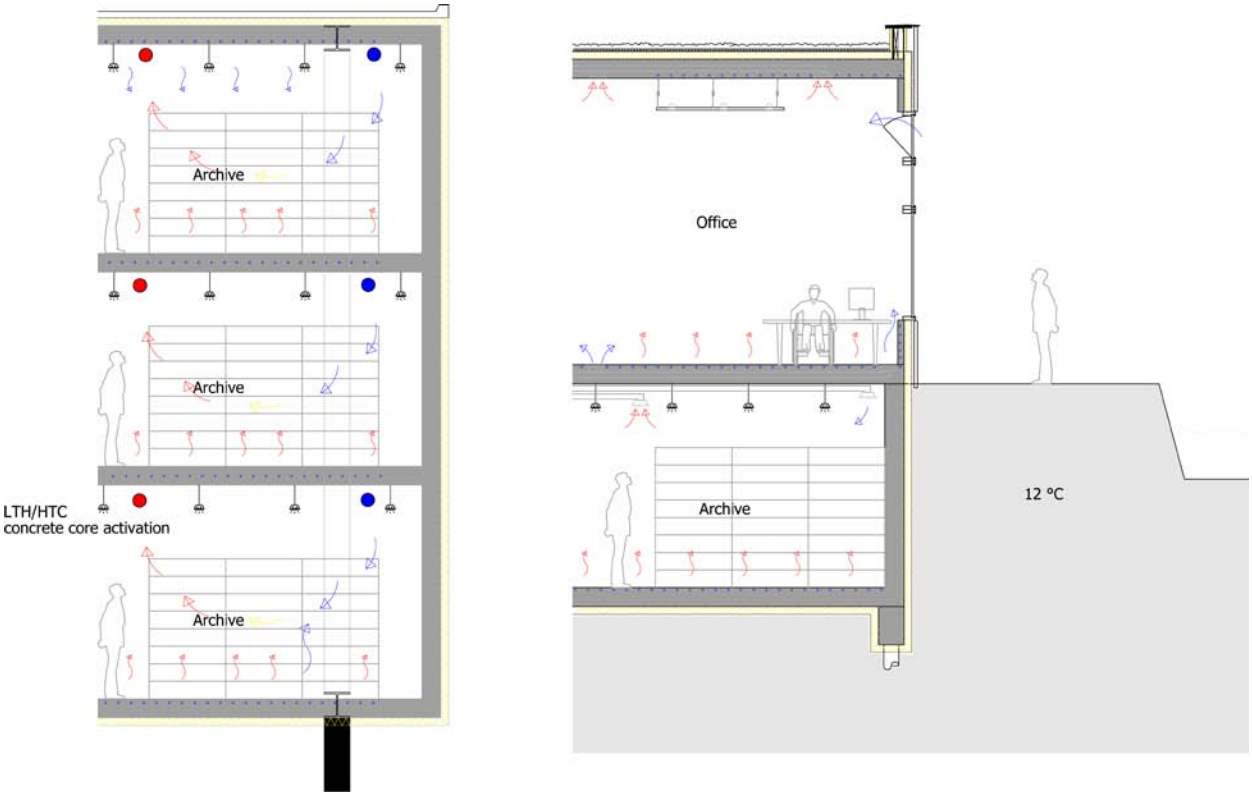


Figure 19 design development in the archive concept

5.5 Auditorium concept

Preliminary Design Idea

A point of departure for the auditorium is that it will be used more by businesspeople than by students higher comfort standards for business people should apply. This resulted in slightly wider seats and more leg space. The ventilation air will enter the auditorium from underneath the seats to directly divert undesired odors. The idea for the auditorium was an all-air installation concept and like the other concepts LTH and HTC. Because vast amounts of air are required for ventilation purpose, this air can simultaneously be used for heating and cooling. The "auditorium concept" distinguishes itself from the other concepts by the fact that it requires vast amounts of ventilation air and that there are high peak loads at the time a lecture is given. An impression is given in figure 20.

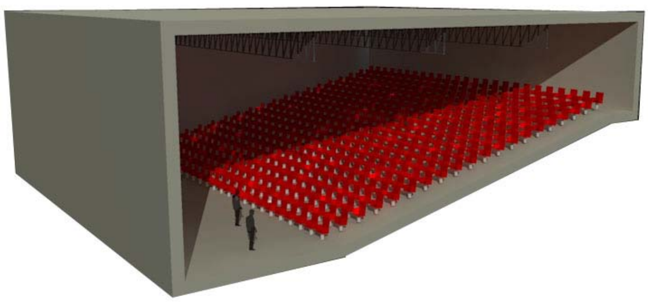


Figure 20 auditorium concept

General properties for "auditorium concept":

Orientation	: west
Walls	: insulated roof, floor Rc: 5 m² K/W, U-value: 0,2 W/m²K
Glass	: n.a.
Openable windows	: n.a
Ventilation	: mechanical with heat recovery 90%
Heating and cooling	: primarily with cooling ceiling and secondary with ventilation air

The energy consumption for the auditoria is not the highest because the spaces are only used a couple of hours a day. However the auditoria do have the highest cooling load due to the enormous amount of people in one space. (See annex 10)

Design Development

Radiant heating and cooling

In the ORCA calculation a comparison was made between All-Air heating and cooling or Radiant heating and cooling. The radiant heating and cooling turned out to be more profitable in summer as well as in winter.

Heating and cooling with LTH and HTC

The auditoria do not require a perfect indoor climate all the time but only during the two hours a lecture is given. The Low Temperature Heating and High Temperature Cooling in combination with some thermal mass requires a relatively large amount of energy to keep the spaces warm in winter. As soon as a lecture starts the auditorium needs to be cooled again due through high internal heat loads caused by people. The LTH and HTC are too slow to start cooling right away. During the time a lecture is given the concrete core activation would still be heating the space with overheating as a result. As an alternative concrete surface activation has been investigated but this still has some delays due through its mass. The final result is a cooling ceiling made of aluminium or steel perforated cassettes which can almost instantly heat or cool from the ceiling. A secondary advantage is that the cassettes have a good acoustical performance.

Thermal storage

As explained above the thermal storage capacity slows down the heating and cooling system and is therefore, for the auditorium not suited. The walls will have some storage capacity but these will not include heating or cooling devices

Ventilation

The auditorium needs large amounts of fresh air. A widely applied efficient way of ventilating an auditorium or theatre is displacement ventilation. The fresh air inlets are placed under the seats of the spectators and the air is extracted centrally in the ceiling.

This way any undesired odors are directly discharged. The auditoria have their own air handling units.

Energy exchange

Sharing the heat recovery with the foyer (common concept)

A comparison between four different energy concepts shows the auditorium needs heating at the same time that the common space needs to be cooled. (See annex 13). This will be discussed later.

The final result after developing the concept can be seen in figure 21

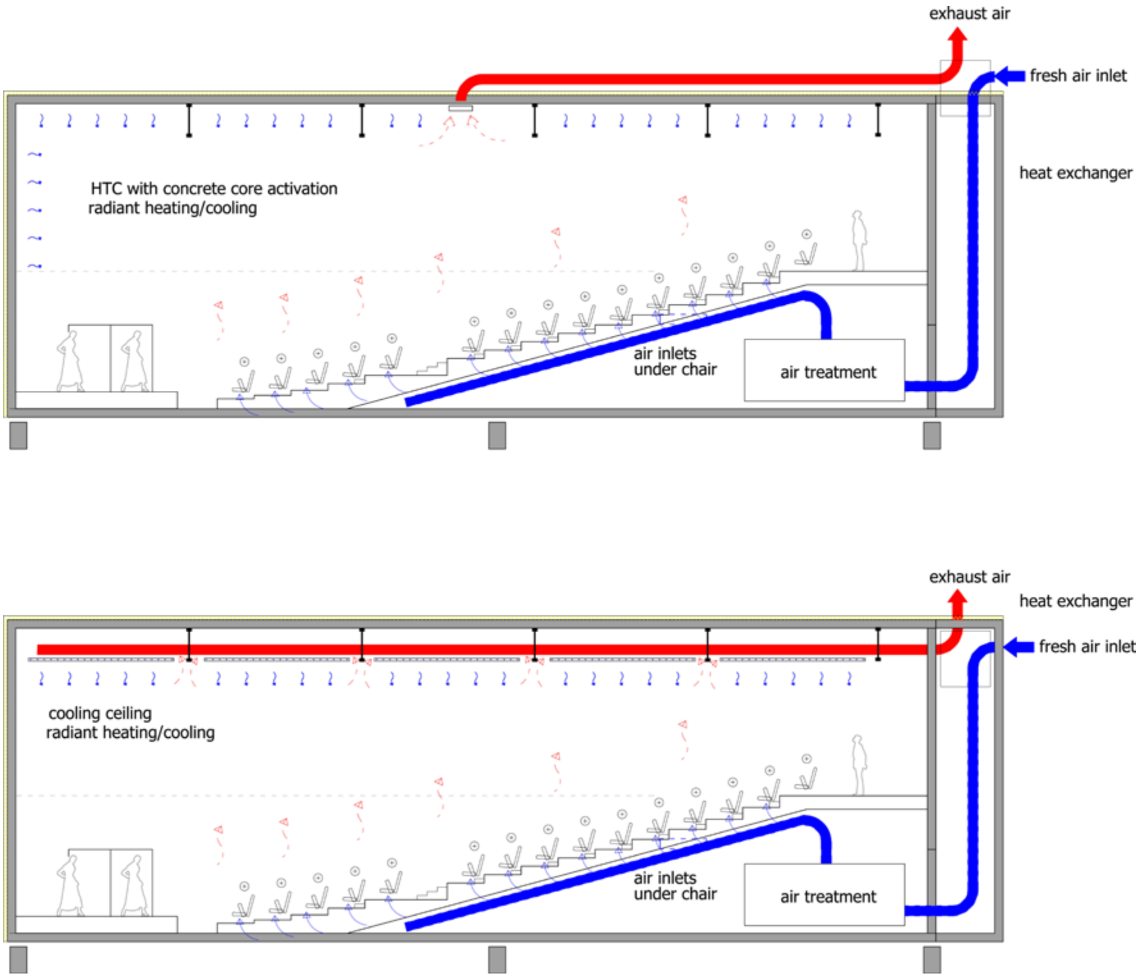


Figure 21 design development in the museum concept

5.6 Other energy sources within the building

Several other elements or functions provide a feasible energy source as well. These are described in this sub-chapter

5.6.1 Climate roof

By applying a climate roof to the museum, as was realized in the Christiaan Huygens college, a substantial percentage of energy required for heating drinking water can be saved. At the same time the heat load on the roof of the museum will be reduced to a minimum. But the most important reason for applying a climate roof is that the energy balance for the aquifer can be made in equilibrium. In a cold year when too much heat is extracted from the earth, the heat can be obtained from the roof in the summer and put back into the soil to create an equilibrium. This roof, when covering the entire museum will generate a large amount of access heat which can be either: used directly, exchanged to another function where needed or temporary stored till needed later.

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Commissioned by SenterNovem a practical experiment was conducted to see the amount of energy which can be obtained by a sun collector.[35] Presuming there are 1623 sun hours per year (source KNMI) than the amount of collected energy can be read in table 03.

	Energie [GJ/jaar]	Zonne-uren [Uren]	Energie per oppervlakte [GJ/m²]	Gem. vermogen per oppervlakte [W/m²]
Benodigde Opbrengst t.b.v. Regeneratie	291	1623	-	-
Werkelijke opbrengst zonne-energiedak	5	1623	0,076	13,11

Table 03 income sun-energy roof

Based on the Dutch 1623 sun hours the profit is 0,076 GJ/m² or 21,1 kWh/m². The roof surface of the climate roof is 1850 m² so the total profit could be 39.000 kWh per annum.

35 Boven, J. van, Oerlemans, B.J.G.M.; Eindrapportage praktijkexperiment Zonne-energiedak Toepassingsgebied: Regeneratie en warmtelevering; Dubotechniek B.V., 2005, Zaltbommel

5.6.2 Restaurant

The restaurant generates a large amount of waste heat throughout the year. In the winter period this heat can directly be used to heat the building. In the summer it can possibly be used to charge the aquifer. The heat supply from the kitchen consists of two separate flows. First there is a heat supply directly generated by the cold storage rooms from the kitchen and the refrigerated units from the buffet. And second there is a heat supply created by the exhaust air from the kitchen. Both these streams of waste energy have potential to be utilized.

Provided that there is no internal heat load and no infiltration losses, the access heat created by cold storage and freezing units can be calculated with the following equation:

ϕ,cooling = U,wall (W/m²K) · A,wall (m²) · ΔT (K)

Properties of the refrigeration unit:

-Geometry: length 6m, width 4m, height 4m; total A,walls = 128m²
-Insulation 70mm U-value = 0,6 W/m²K
- ΔT = (Ti – To) = 23 – 6 = 17 K
-Efficiency heat pump COP 4

The required cooling is: ϕ,cooling = 0,6 · 128 · 17 = 1306 Watt

The refrigeration unit uses a heat pump, transporting the heat from the cold storage unit to the warmer restaurant (or other) area. The efficiency of the pump depends largely on the temperature difference ΔT. For the refrigeration unit a reasonable COP (Coefficient Of Performance) is four which equals a efficiency of 400%. The heat pump works as follows (See figure 22):

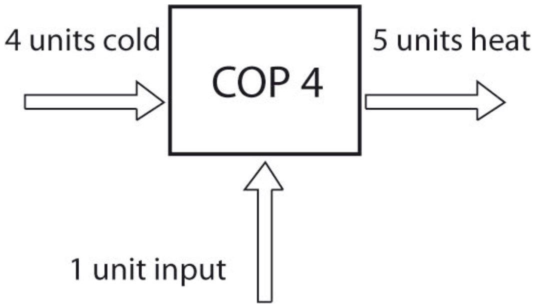

Figure 22 heat pump with a COP 4

With a heat pump COP 4, the (electrical) energy put into the machine is multiplied four times to transport heat from the cold side to the warm. The access heat on the warm side equals the transported heat plus the added initial input heat.

With a required cooling capacity of 1306 Watt, the input is ¼ · 1306 = 327 W, and the access heat is 5/4 · 1306 = 1633 W

The consumption (in electricity or gas) is 327/1000 · 24 · 365 = 2.865 kWh/year
The access heat is 1633/1000 · 24 · 365 = 14.305 kWh/year

Properties of the freezer unit:
-Geometry: length 4m, width 4m, height 3m; total A,walls = 80m²
-Insulation 100mm U-value = 0,4 W/m²K
- ΔT = (Ti – To) = 23 – – 20 = 43 K
-Efficiency heat pump COP 2

The required cooling for the whole freezer: ϕ,cooling = 0,4 · 80 · 43 = 1376 Watt

Due to a large temperature difference the heat pump for the freezer has a COP of just 2 so the investment energy is significantly higher. The input is 1/2 · 1376 = 688 W, and the access heat is 3/2 · 1376 = 2055 W
The total access heat from the refrigeration and freezers unit is 1633 + 2055 = 3688 Watt.

5.6.3 Server room

The energy consumption in server spaces is high due to the servers themselves and because of the cooling needed. One square meter of server space is equivalent to an average household about 3.000 kWh per year.[36]

Several different functions need a server room. Usually the archive has its own server space in which large amounts of data are stored in a database. Several computers in the archive can be connected to the server and have access to this data. The offices need a server room in which several different companies can have their own small server so privacy is secured. And also the conference centre, the museum and auditoria need to be connected to the server in which data can easily be exchanged between different meeting rooms, lecture rooms or seminar rooms. The server space should provide for 120 computers for the flex workspaces and 80 computers for the rest of the building.
A total is needed for about 200 pc's.

Per 100 computers a server space is needed with about 24 racks which is a space of 3 by 4m. The total server space can be 24m2 with a total of 48 racks with 19 inch servers. A typical Rackmount is powered by 200 till 250 Watts[37] so the total capacity is 48*225= 10,8kW. The consumed energy is 225/1000*48*10*5*52= 28.080 kWh/year.

Typically server spaces are cooled down with air. In the server room there should remain a constant temperature of ideally 21°C. However some appliances also function properly with temperatures of around 30 to 40 °C. By creating different climate zone not the whole server space has to remain on the 21°C. To keep the server space on the right temperature often implies that the room should be cooled with temperatures much lower than 21°C to have the desired temperature throughout the whole room. Often it is more efficient to cool a server room not per room but per row or per rack. See image 23.

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[36] Kenniscentrum Duurzaam MKB: www.duurzaammkb.nl
[37] Made-in-China.com: http://szeton.en.made-in-china.com, retrieved December 6th 2010

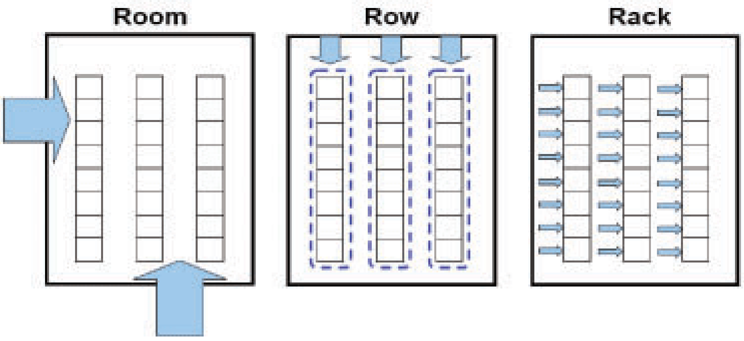

Figure 23 different ways of cooling the server space

The Co efficiency of Performance for server cooling is about 3 (COP3). For example the air conditioning unit **Panasonic WA-21HP/I/WR 6,3kW**[38] takes 2,21 kW power. Two of these units would have sufficient cooling capacity for the server space. The access heat will be 6,3+2,2=8,5 kW heat per unit or 17kW for the total.

[38] Airco-Superstore.nl: http://www.airco-superstore.nl/5-panasonic-wa-21hp-i-wr-6-3kw.html, retrieved December 6th 2010

6 Exchanging and storing energy

In this chapter the feasibility for energy exchange and temporarily store energy in examined. There will be further elaborated on how energy exchange and storage can be applied between the different installation concepts and energy sources.

6.1 Feasibility energy exchange

6.1.1 Exchange between user functions

An overview of the annual consumption patterns for each energy concept is shown in annex 13. The graphs show the energy consumption in kWh/m² per day for the reference year of 27th April 1964 till 27th April 1965. The dynamic calculation consists of two separate plots; the summer period which is followed by the winter period. The manual calculations are plotted in the background for a comparison.
Although the different functions have different peak loads the consumption pattern in time are quiet similar. From the graph can be read that energy exchange between these functions can only occur in the spring and autumn and only between the auditoria and the common /office concept as was already addressed in chapter 5.5.5. The result is not optimal since the energy consumption during these times is already low. The energy with the potential to be exchanged is, in comparison with the total energy consumption relatively small but the best chance for energy exchange will be from April 27th till May 11th. A closer look at the exact energy consumption is needed to check the feasibility.

A thorough analysis of the consumption patterns from the auditorium concept and the common concept for the weeks from April 27th till May 11th show that the energy patters are still quite similar (see annex 14). Both concepts demand cold air inlet but at the same time the auditorium concept has a high heating demand for surface heating.

These contradictory results of the auditorium, which requires cooling and heating at the same time, are due to the simulation of the heat recovery, which can only be set for the entire period. Although this is the summer period there are still some cold days when heat recovery is feasible. According to the ORCA calculations a heat recovery of 40 % is most profitable and the seasonal energy consumption is the lowest. In ORCA the amount of re-circulated air can only be set for the entire period as for reality the heat exchanger would constantly adapt to the current situation. Due to this limitation the cold air demand for both installation concepts is false because the heat exchanger would simply cease to operate and fresh air would come in.

6.1.2 Exchange between restaurant and archive

The archive (see consumption pattern in annex 9) is planned underground and has therefore a very low energy demand. The constant ground temperature of 12 °C and the internal heat load slightly compensate each other. However overall the archive needs to be heated most of the year. Only in July and August there is a demand for cooling of 1 W/m². The restaurant has a constant heat (energy) surplus of about 3688 Watt which can provide the 1000 m² archive with a constant heat of 3,69 W/m². The energy losses through heat transfer are estimated to be 10%. So the total energy reduction is 3,32 W/m² which is only for the months that there is a heat demand. (See energy reduction in annex 15.)

In mid-summer months when there is a cold demand according to the graph this access heat from the restaurant has to be disposed outside. To realize this a heat pump with a valve is required to switch between the two circuits. In one circuit the waste heat is brought to the archive and in the another the waste heat is disposed outside. See exchanging scheme in figure 24. Because the two circuits of the refrigeration unit and the archive heating system require different liquids. The two are separated and the heat will be transferred by a heat exchanger. In this case a water to water heat exchanger with an efficiency of 90% can be applied.

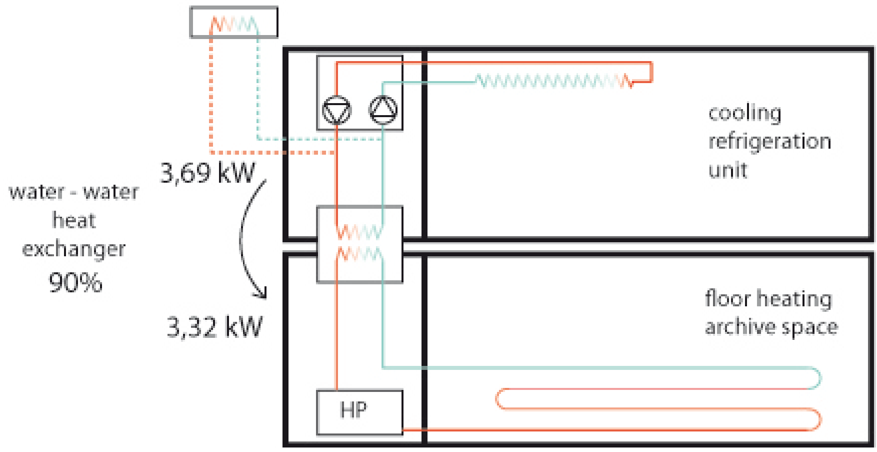

Figure 24 Energy exchange scheme between restaurant and archive

6.1.3 Exchange between server spaces and offices

The server spaces that are required in several functions produce despite their limited size a great amount of access heat which can be utilized elsewhere in the building.

Re-using waste flow

Cooling down servers is efficient with air because one can cool in between the racks. During the summer period this waste heat is directly disposed outside but in winter season the heat can be extracted. In order for the energy exchange to work, there needs to be a heat exchanger right after the air outlet where the air is most warm. In the winter season the heat is extracted and put into the heating system for the offices. The heating system in the offices uses the waste heat as pre-heating and the water can additionally be heated by the heat pump. With a valve can be swapped between using the heat exchanger or not, or between summer and winter period. See figure 25.

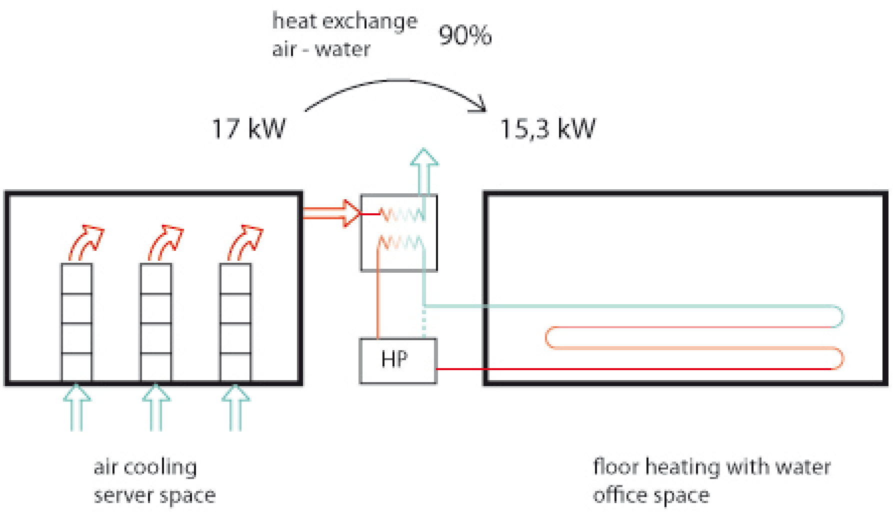

Figure 25 Energy exchange scheme between server space and office

The obtained power from the server space is 17kW. Very efficient heat exchangers can have a efficiency of 95 % so that 90 % efficiency is a feasible assumption. The power for left for the offices is 15,3 kW. The offices are 1000 m² so the heating capacity per m² is; 15.300W / 1000 = 15,3 W/m². The total reduction on heating is only 1,8% and can be seen in a graph in annex 16. The deducted area is shown in green which can be observed along the red line.

6.1.4 Exchanging between roof and functions

The climate roof partially functions as a solar collector which generates a great amount of warm water during the day and especially in summer. This warm water can be used for several appliances. First to pre-heat the warm water supply, second to pre-heat the LTH *(low temperature heating)* of the museum and third it can be used to charge the warm aquifer in summer to prepare it for the winter and to come to the required annual thermal equilibrium. During summer nights the climate roof can be connected to the climate ceiling so it could be utilized as a radiator. The water flow between ceiling and roof ensures the release of heat which was stored in the PCM material during the day.

6.2 Feasibility energy storing

6.2.1 Short term energy storage

Short term energy storage to achieve thermal equilibrium between day and night is usually realized by thermal mass of the construction. For all installation concepts this aspect is different. The “archive concept” requires to be heated throughout the entire year so the need for any heat storage is superfluous. Thermal mass would require an additional amount of energy to keep the mass up to a temperature of 20 °C so it is not profitable. The auditoria in the “auditorium concept” are used on average only three times a day. These spaces have therefore three extremely high peak loads on a time cycles of 24-hours. Short term storage is here not profitable because the reaction time of thermal mass is very slow. The mass would literary have to heat the space until the instant that the people walk into the room, and then it would need to cool the space. So for auditoria short term energy storage is also not profitable. The “office concept” however is more suited for short term energy storage. The need for heating and cooling is more dependent on the outdoor temperatures. The (solar) heat gained during the summer day can be gradually released in the night. In the winter the building is kept on a stable temperature at night without too many fluctuations so that in the morning the building does not need to be pre-heated more than 1 or 2 °C. The optimum amount of concrete for thermal mass storage is 300 mm/m² according to ORCA calculations presuming that at least 60% of the mass is exposed to the space to absorb and release heat. The “museum concept” is most exposed to the outdoor temperatures. For the same reasons as the “office concept” thermal mass should be applied. The optimal amount of concrete according to ORCA calculations is also 300 mm/m². For architectural reasons the museum construction spans great distances and should therefore be as light as possible. A 300 mm concrete floor + 300mm concrete ceiling would give an unnecessary additional weight to the structure. Here it would be wise to use latent heat storage with a PCM material instead sensible heat storage which is dependent on a greater amount of mass. The objective is to achieve the same required storage capacity and additionally minimize the weight.

According to the equation in chapter 2.4.1., the 300 mm concrete floor has a sensible heat storage capacity of:

Heat storage capacity: 0,3 · 2400 · 840 = 604 kJ/m² per K The energy stored within the boundaries of the comfort temperature is (max. 3 K) 3 · 604 = 1812 kJ/m², The weight is: 0,3 · 2400 = 720 kg/m²

The equivalent in latent heat storage would require:

1812 kJ/m² / 70 kJ/kg = 26 kg/m² of material or 26 / 4,5 (panel weight) = 5,7 = 6 layers of PCM panels The thickness is 5,26 mm so the total PCM layer will be 6 · 5,26 mm = 26,3 mm

Note: the sensible heat storage capacity of the PCM is not included so the actual values of required amount of material are even lower.

The museum will require a 26,3 mm layer of PCM material on floor and ceiling. Another option would be to use PCM material in concrete. The concrete layer would have a double role of functioning as a structural element and as a heat storing material. The Departament d'Informàtica I Eng. Industrial Universitat de Lleida performed several tests comparing two identical houses; one with PCM in the concrete and one without.[39] These tests show that concrete with PCM perform considerably better than normal concrete (see figure 26).

[39] Castellón,C., Nogués, M., Roca, J., Medrano, M., Cabeza, L. F.; Microencapsulated Phase Change Materials (PCM) for building applications, Departament d'Informàtica i Eng. Industrial, Universitat de Lleida, 2005, Lleida

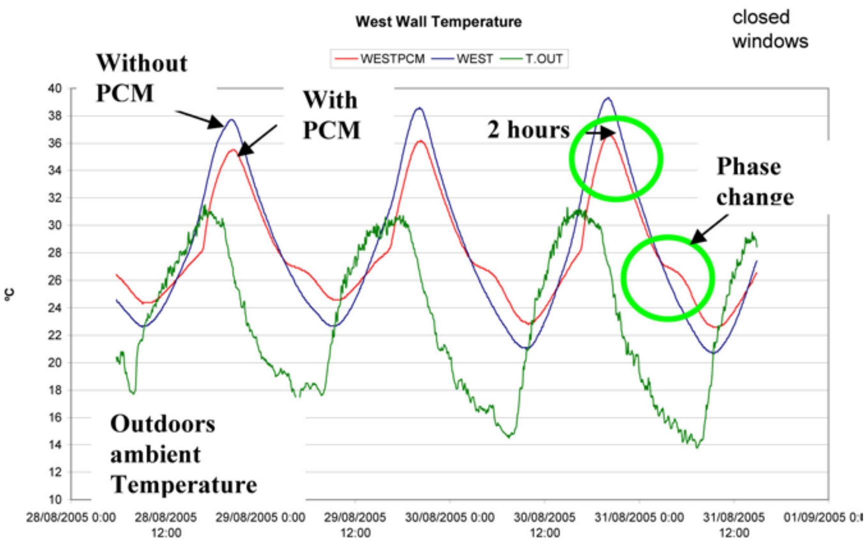

Figure 26 Detail of the west wall temperatures and ambient temperature with closed windows, test in August 2005

The performance of concrete with PCM is better than without but clearly not enough better to reduce the concrete by at least half in mass in order to reduce weight. The best option is to use PCM panels.

6.2.2 Long term energy storage

Long term energy storage will be applied using aquifers. The most predominant factor for seasonal storage is that the heat or cold extracted from the aquifers should be the equivalent to the stored heat or cold so that over one annum the energy balance of the soil is zero. Suppose a majority of heat or cold would be extracted from the soil, then due to changes in ground temperature, the energy source will be depleted in just a couple of years.

Annex 17 shows the total energy consumption of the building. Clearly there is a greater need for heat than for cold. In the table the aquifer balance shows 207.000 kWh for heat and 172.000 kWh for cold. This 35.000 kWh can be compensated by the climate roof.

6.3 Implementation

In this sub chapter the overall energy plans for the Science Business Centre are shown. From top to bottom. The hovering volume now solely consists of the museum with a large technical space in the middle to reach all the wings with treated air. See figure 27

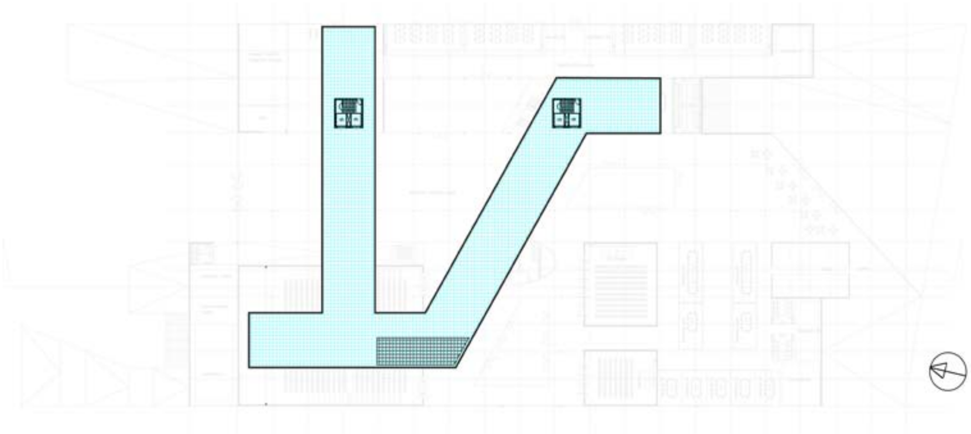

Figure 27 Museum floor with technical space in the middle

The ground floor houses most of the functions as can be seen in figure 28. In purple are shown the offices and in the centre the server space in yellow which will be coupled to a technical space. The common space in shown in pink. On the right side is shown the restaurant in yellow from which the access heat will be distributed to the basement. The auditoria are shown in green. Their installations are situated in the basement.

\

Figure 28 Ground floor: in green auditoria, in pink common space and purple office

The basement houses the large auditorium and the archives. The technical installations for the auditorium and partially the common space are located underneath and around the large auditorium. The archives are located under the offices See figure 29

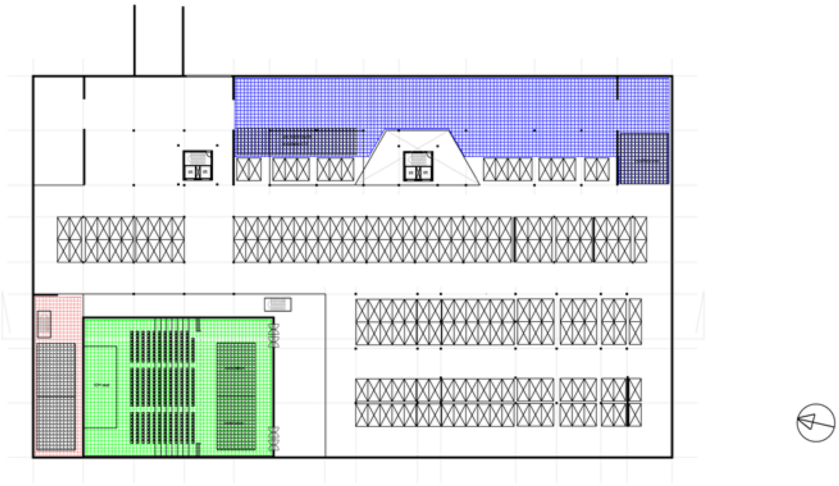

Figure 29 Basement floor: in green auditoria, in blue the archives

7 Consumption

In this chapter the energy consumption for the different installation concept and for the building as a whole are presented and discussed. Also, the aquifer balance is presented.

7.1 Energy consumption Science Business Centre

The energy consumption for the Science Business Centre can be seen in annex 17. Briefly the consumption for the different installation concepts can be seen in table 04.

Electrical energy for Heating Cooling Ventilation and Air treatment

Function	m2	heat pump	water pump	ventilation	total
Office	1000	3125	5	4200	7330
Common	6100	23640	31	25600	49271
Museum	1850	6700	9	7800	14509
Auditorium	1400	3150	7	5900	9057
Archive	1000	600	5	2100	2705
Total					82872

Heat pump

The heat pumps will bring temperature of the pre-heating water extracted from the aquifers to an operable level. The energy required for the heat pump derived from the co-efficiency of performance which is for all functions (COP7).

Water pump

During the summer period the water from the aquifers is cold enough for cooling. The building can be cooled using 16 °C water from the aquifers. The only required energy for cooling is the pump mechanisms to pump water from the cold aquifer to the warm aquifer and the water pumps to distribute the water through the building.

Ventilation

A proper way to determine the yearly energy consumption of ventilation units is by handling the NEN 5128.[40] In order to determine the energy requirement for ventilation for EPN (Energy Performance Norms) calculations, the NEN 5128 provides a table with standard values. (See table 05)

ventilatiesysteem	uitvoering ventilator	elektriciteitsverbruik kWh/m²
mechanische afzuiging	wisselstroom	3,5
	gelijkstroom	2,4
warmtepomp met ventilatieretourlucht als bron, indien schakelbaar	wisselstroom	4,0
	gelijkstroom	2,8
gebalanceerde ventilatie (niet voor luchtverwarming, indien schakelbaar)	wisselstroom	6,6
	gelijkstroom	4,2
luchtverwarming	zonder ventilatorregeling	10,3
	met ventilatorregeling	7,4

Table 05 determination method for consumption of air handling units

Air treatment

The museum and the archive space need air treatment. The archive needs to be kept on the right humidity and needs air to be filtered from dust. The museum needs only filtering because it does not have any historical pieces. The amount of treated air can be calculated as follows:

The museum space is 1850m² * 10m¹ (height) the ventilation rate is 2. So the required air is 39.000 m³/h or 10 m³/s. This requires no additional electrical power only maintenance.

The archive is 1000 m² * 4m¹ (height) the ventilation rate is 0,1. So the required air is 400 m³/h or 0,11 m³/s. This requires additional electrical power for (de)-humidifying the air.

[40] SenterNovem: http://www.senternovem.nl/epn/maatregelen/ventilatie/ventilatoren.asp retrieved: december 12th 2010

Humidifying calculation

The air mass flow can be calculated as follows:

$M = Q * pL = 400\ m^3/h\ * 1{,}2\ kg/\ m^3 = 480\ kg/h$

The humidity addition $\Delta x = 5{,}2$ g/kg[41]

Determining the humidifying unit: F humidifying = M * Δx = 480 kg/h *5,2 g/kg = 2 kg/h (which equals 2 l / h)

The efficiency is usually around 80% so that the pump capacity should be Fpump = B/0,8 = 2,5 l / h

Several small humidifiers meet the requirements. Most have a power of around 1,5 kW. The humidifying does not need to operate at full capacity the whole day. The annual consumption is 1,5 * 2 (hours) * 365 = 1095 → 1100 kWh will be used for the balance.

7.2 Aquifer balance

Seasonal thermal energy storage with aquifers requires one to obtain a permit from the local municipalities, which implies that one needs to find an equilibrium between the annual input and output of heat and cold. This aquifer balance can be seen in annex 17. A greater amount of heat is extracted from the soil:

The demand for cold is	17.2070	kWh
The demand for heat is	20.7460	kWh
Heat shortage	35.390	kWh

The excess heat (35.390 kWh) that will be extracted too much from the soil in winter has to be put back in summer. Here, the heat obtained by the energy roof can be used to compensate the shortage. The energy roof produces an equal amount of heat as a heat collector. The total roof generates 39.000 kWh of heat per annum (see chapter 5.6.1. for the details). In this way, the access heat from the aquifer can be compensated and there is an additional 3.610 kWh surplus.

[41] Danfoss Nessie, Luchtbevochtiging en adiabatische koeling met Danfoss Nessie, www.nessie.danfoss.com retrieved: Jan 2011

8 Conclusions and recommendations

In this chapter, first the conclusions from the research are represented, than the conclusions from the process and finally recommendations are given for future research.

8.1 Calculation results conclusions

During the research the following was concluded:

- Energy exchange between the given user functions in this context is not possible.
- Energy exchange is strongly dependent on temperature differences between functions and is therefore more profitable between different types of functions with a greaterΔT. In this case study the heat from the refrigeration units, the server space and the energy roof could be utilized for transportation due to their high temperature.
- Optimizing energy concepts could have a negative effect on possibility to exchange energy between functions because the primary need is reduced to a minimum. However in exchanging energy there is always a certain loss due to heat transfer. Therefore it is always more profitable to first reduce the primary need to a minimum.
- Energy storage could be utilized per day or per season. Logically first the daily storage is optimized to reduce the energy need in both summer and winter. Then there could be searched for an equilibrium in energy demand between the two seasons.
- Daily energy storage is mainly realized by the thermal mass of the construction. The inertia of the mass keeps the building relatively cool during a hot summer day and relatively warm during a cold night. When the thermal mass is absent or not sufficiently exposed, PCM materials can be used instead which are light, recyclable and non-toxic.
- Long term or seasonal energy storage can be utilized with aquifers. This requires permits from the local municipalities, which usually require that there is equilibrium between the input and output of heat and cold in the ground.

For the building it implies:

- The archive space are re-located underground to use the stable ground temperature of 12 °C.
- All installation concepts are optimized using a proper thermal storage capacity, optimizing the thermal properties of the façade and the finding the right installations.
- The museum concept was redeveloped because the initial design was not suited for context. An alternative façade concept was created.
- Energy exchange was established between the restaurant and the archives.
- Energy exchange was established between the server spaces and the offices.
- The access heat from the energy roof will be used to recharge the aquifer during the summer period.
- The main heat and cold demand will be extracted from the aquifers.
- PV-cells on the roof will power all climate installation.

8.2 Process conclusions

- Energy calculations can solely be used for optimization or development of building elements and installations. The results cannot be seen as the absolute truth because the calculated results are always unreliable as was pointed out in chapter 4.1.3. by showing the difference between the calculated and measured energy consumption.
- During the research many assumptions are made. Assumptions have to be clearly stated in the beginning of the research so that in later stages the initial assumptions are clear. The assumptions should strictly remain the same when making different calculations and in various phases of the research to make a right comparison. In this thesis a *functional terms of reference* was created which was consulted during all phases of the research.
- Also with assumptions extra care should be taken during the interpretation of the data, taking these assumptions into consideration.

- There is no direct option for heat recovery in ORCA. It can be simulated by mixing used air with fresh air 0-100%. When simulating heat recovery the total seasonal consumption can be reduced. A limitation of the program is that it can only be either turned on or off. So this in fact gave false result in the annual energy consumption graphic because heat recovery is always applied only when it is useful. It can be said that when an energy potential is observed, it should first be double checked and closer examined because the graph could show false results as happened in this research.
- Thermal storage capacity cannot be included in the ORCA calculations. Instead additional concrete can be applied to simulate this storage capacity and the consequences can be observed.

8.3 Recommendations

Especially when the different functions differ in heat / cold demand, energy exchange can be feasible. An important aspect for heat exchange is the comfort temperature as was pointed out in chapter 2.3. It is easier to use waste heat from an industrial plant, super market or computer server station than from another function which has an almost equal comfort temperature.

Figure 30 shows a scheme for exchanging and temporary storing energy. It always starts with a design idea. The first thing to do is to set the constraints for functionality, health and comfort as was done in chapter 2. Then the building(s) should be divided into installation or climate zones. These installation zones should first be considered individually and an energy consumption pattern should be generated. Only afterwards the possibilities for energy exchange and storage capacity could simultaneously be studied so that one will gain more insight in the relation between the two. Thermal storage capacity influences energy consumption and thus the consumption pattern. Vice versa exchanging energy could make energy storage superfluous. Next the feasibility and the corresponding installations should be studied. If it turns out to be profitable the functions could be rearranged to minimize the energy transport and enhance the efficiency. Afterwards, in the implementation phase, we could rearrange the floor plan in definite and determine the technical installation spaces. And last it should be evaluated and preferable monitored.

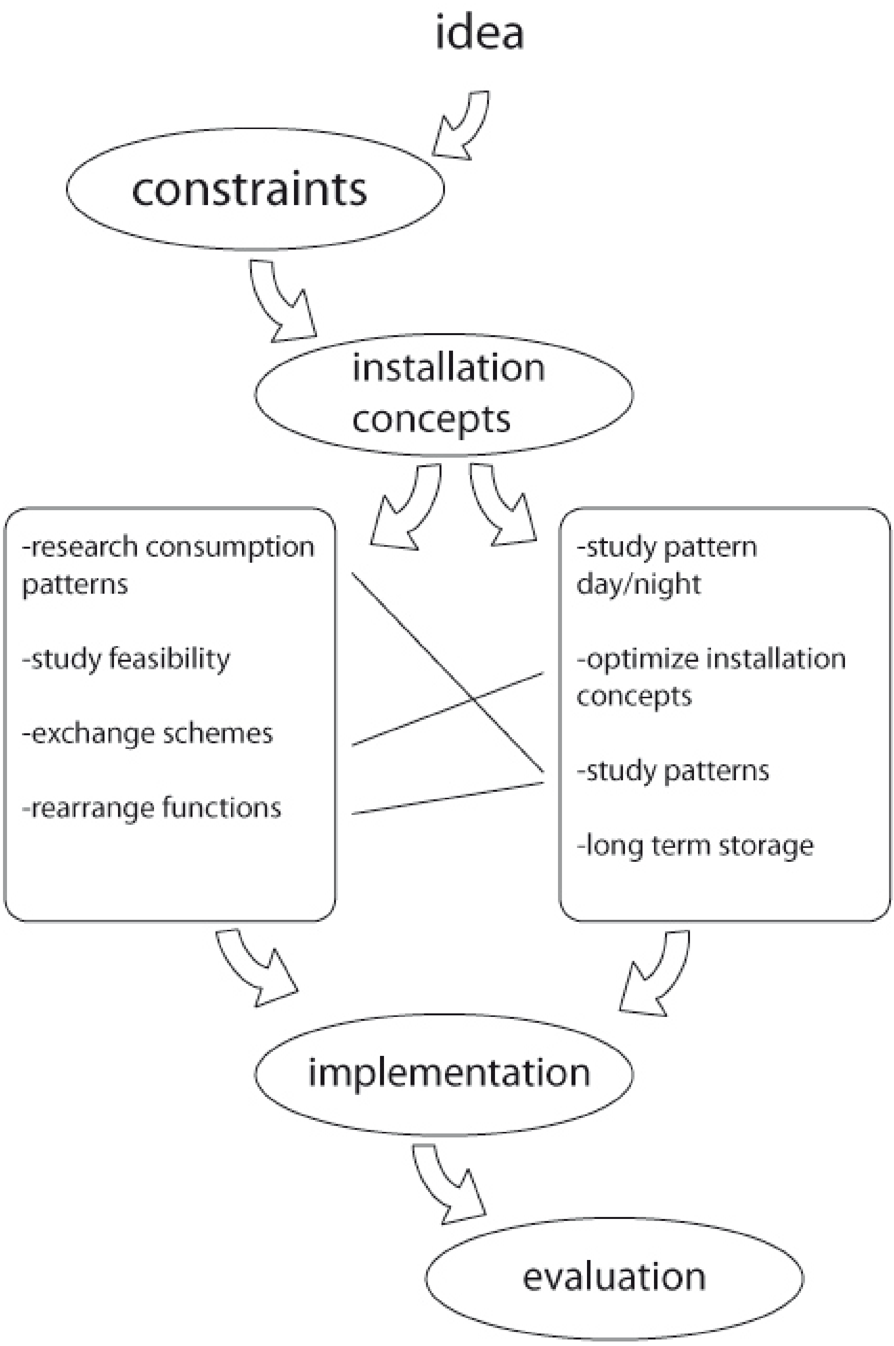

Figure 30 Roadmap for energy exchange and temporary storage

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Annex 01: Functional terms of Reference (part 1/2)

functions	amount	m2	height m1	volume m3	max. ocupancy	average occupancy	ventilation rate 1/h	min. Ventilation m3	metabolism	00 tot 8	8 tot 12	12 tot 18	18 tot 24	temp. Summer	temp. Winter	humidity	ocupancy rate	heatload people W/m2	heatload art. light W/m2	heatload appliences W/m2	total int. heatload W/m2
	space measurements				ventilation				activity	occupancy in time								heatloads			
auditoria																					
large auditorium 634 seats		1020	5 - 9.1	7140	650	400	2,2759	32500	1		XXX	XXX	XX	23-26	21-24	30-70	I	17	15	1	33
large lecture room 153 seats		233	5	1165	170	100	3,6481	8500	1		XXX	XXX	XX	23-26	21-24	30-70	I	16	15	1	32
small lecture room 77 seats		152	5	760	90	50	2,9605	4500	1		XXX	XXX	XX	23-26	21-24	30-70	I	17	15	1	33
foyer space		413	5	2065	600	50	7,2639	30000	1,4 - 2		XX	XX	X	23-26	21-24	30-70	I	13	12	1	26
distribution		68	5	340			0	0	2	X	X	X		23-26	21-24	30-70	III	5	12	0	17
toilets		94	4	376			0	0	1 - 1,4		XXX	XXX	XX	23-26	21-24	30-70	II	20	9	0	29
lecture support and facility		111	5	555	n.a.	n.a.			1,4 - 2		X	X	X	23-26	21-24	30-70	V	2	1	1	4
conference																					
meeting room 24 seats	2	58	5	290	26		2,2414	1300	1		XXX	XXX	XX	23-26	20-24	30-70	II	20	9	3	32
meeting room 16 seats	2	41	5	205	18		2,1951	900	1		XXX	XXX	XX	23-26	20-24	30-70	II	20	9	3	
meeting room 12 seats	3	38	5	190	14		1,8421	700	1		XXX	XXX	XX	23-26	20-24	30-70	II	20	9	3	
learning room		62	5	310	26		2,0968	1300	1		XX	XXX	XXX	23-26	20-24	30-70	II	20	9	3	
distribution		150	5	750			0		2		X	X	X	23-26	20-24	30-70	III	5	9	0	
toilets		35	4	140			0		1 - 1,4		XXX	XXX	X	23-26	20-24	30-70	II	20	9	0	
restaurant																					
storage		43	5	215	2			100	1,4 - 2					23-26	21-24	30-70	V	2	9	1	12
cold kitchen		66	5	330	10			500	1,4 - 2					23-26	21-24	30-70	III	5	9	3	17
warm kitchen		66	5	330	10			500	1,4 - 2					n.a.	n.a.	30-70	III	5	9	3	17
buffet		70	5	350	20			1000	1,4 - 2		XXX	XXX	XXX	23-26	21-24	30-70	II	20	9	3	32
restaurant 2,5m2/person		358	5	1790	144		2,0112	7200	1		XXX	XXX	XXX	23-26	21-24	30-70	II	20	9	1	30
commen space																					
entrance hall		534	6	3204	500		3,9014	25000	1,4 - 2	X	XXX	XXX	XXX	23-26	20-24	30-70	I	15	9	1	25
wardraobe / locker		75	5	375	2		0,1333	100	1,4 - 2					23-26	20-24	30-70	V	2	9	1	12
toilets		31	4	124				0	1 - 1,4		XXX	XXX	XXX	23-26	20-24	30-70	II	20	9	0	29
shop		50	5	250	10		1	500	1,4 - 2		X	X	X	23-26	20-24	30-70	III	5	9	3	17
science services		171	5	855	70		2,0468	3500	1		X	X	X	23-26	21-24	30-70	II	20	9	1	30
reading room		116	5	580	60		2,5862	3000	1		X	X	X	23-26	21-24	30-70	II	20	9	1	30
temporary exhibition space		817	5	4085	400		2,448	20000	1,4 - 2		XX	XX	X	23-26	20-24	30-70	II	20	9	1	30

Annex 02: Functional terms of Reference (part 2/2)

functions	amount	m2	height m1	volume m3	max. ocupancy	average occupancy	ventilation rate 1/h	min. Ventilation m3	metabolism	00 tot 8	8 tot 12	12 tot 18	18 tot 24	temp. Summer	temp. Winter	humidity	ocupancy rate	heatload people W/m2	heatload art. light W/m2	heatload appliences W/m2	total int. heatload W/m2
	space measurements				ventilation				activity	occupancy in time								heatloads			
office																					
flexible office space 24 seats	4	101	5	505	30		1,4851	1500	1		XXX	XXX	X	23-26	20-24	30-70	III	5	9	3	17
flexible office space 18 seats	4	90	5	450	23		1,2778	1150	1		XXX	XXX	X	23-26	20-24	30-70	III	5	9	3	17
toilets		31	4	124				0	1 - 1,4		XXX	XXX	X	23-26	20-24	30-70	III	5	9	0	14
museum																					
museum lobby		108	5	540	60		2,7778	3000	1,4 - 2		XXX	XXX		23-26	21-24	30-70	I	18	9	5	32
archive spaces public		565	3,5	1977,5	250			12500	1,4 - 2		XXX	XXX		20-22	20-22	30-50	IV	3	9	3	15
archive spaces private		1130	3	3390	10			500	1,4 - 2		X	X		20-22	20-22	30-50	V	2	4	3	9
museum floor high		677	10	6770	150			7500	1,4 - 2		XXX	XXX		23-26	21-24	30-70	IV	3	9	5	17
museum floor med. High	2	392	5	1960	80			4000	1,4 - 2		XXX	XXX		23-26	21-24	30-70	IV	3	9	5	17
garage																					
		7710	5	38550										n.a.	n.a.						
stair / elevator shaft																					
	4	34	30	1020																	

- The ventilation rates derived from the maximum expected amount of visitors multiplied by 50m³/h which is sufficient.[42]
- The internal heat loads for people and appliances derive from the EPN (*Energy Performance Standard*) calculation.[43]

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[42] Engel, P.,Bokel, R., Ruijsscher, L. de; I-431 Concrete core activation, Kennisbank Bouwfysica, August 2009
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Annex 03: Climate Data for manual calculations

gemiddelde temperaturen

zomermaanden				
gem.				16,6
max.				21,4
min.				14,5
juni	1	11	21	gem.
% zon	37	40	36	37,7
gem.	14,8	14,9	15,9	15,2
max.	19,6	19,5	20,4	19,8
min.	9,8	9,9	11	10,2
juli	1	11	21	gem.
% zon	41	37	39	39
gem.	17,3	17,2	17,7	17,4
max.	22,1	21,8	22,4	22,1
min.	12,3	12,3	12,7	12,4
aug	1	11	21	gem.
% zon	43	43	41	42,3
gem.	18	17,5	16,2	17,2
max.	23,1	22,7	21,2	22,3
min.	12,6	12,3	11,2	12

herfst				
gem.				10,3
max.				14
min.				6,44
sept	1	11	21	gem.
% zon	37	34	33	34,7
gem.	15,2	14,1	13,3	14,2
max.	20	18,5	17,7	18,7
min.	10,4	9,5	9	9,63
okt	1	11	21	gem.
% zon	32	33	31	32
gem.	12	10,1	8,9	10,3
max.	16,1	14,2	12,6	14,3
min.	7,9	6,1	5,5	6,5
nov	1	11	21	gem.
% zon	24	24	19	22,3
gem.	7,7	6,1	4,9	6,23
max.	10,8	9	7,5	9,1
min.	4,4	3	2,2	3,2

winter				
gem.				3,28
max.				5,89
min.				0,28
dec	1	11	21	gem.
% zon	21	17	18	18,7
gem.	4,3	4,1	3,6	4
max.	6,4	6,5	5,9	6,27
min.	0,1	1,5	1,1	0,9
jan	1	11	21	gem.
% zon	17	23	21	20,3
gem.	2,6	2,8	2,9	2,77
max.	5	5,2	5,5	5,23
min.	-0,2	0,1	0,2	0,03
feb	1	11	21	gem.
% zon	24	31	30	28,3
gem.	3,1	2,5	3,6	3,07
max.	5,8	5,6	7,1	6,17
min.	0,2	-0,7	0,2	-0,1

lente				
gem.				8,92
max.				13,4
min.				4,34
mrt	1	11	21	gem.
% zon	30	30	32	30,7
gem.	4,9	5,8	6,6	5,77
max.	8,5	9,7	10,6	9,6
min.	1,4	2,1	2,5	2
apr	1	11	21	gem.
% zon	34	38	41	37,7
gem.	7,3	8	9,7	8,33
max.	11,6	12,7	14,6	13
min.	2,9	3,2	4,6	3,57
mei	1	11	21	gem.
% zon	40	45	41	42
gem.	11,4	13,1	13,5	12,7
max.	16,3	18,2	18,3	17,6
min.	6,3	7,7	8,4	7,47

The averages derive from data recorded in de Bilt provided by de KNMI. [44]

[44] KNMI: http://www.knmi.nl

Annex 04: Manual calculation for the pavilion concept

Geometrie			
surface (m2)	50	A,win (m2)	26,6
volume (m3)	235	A,wall (m2)	0
orientation	east	A,floor (m2)	50
		A,roof (m2)	50

Indoor climate	
T,min Winter (°C)	20
T,max Winter (°C)	24
T,min Summer (°C)	23
T,max Summer (°C)	26

ϕ Internal heat loads (W)	
people	5
light	9
appliences	3

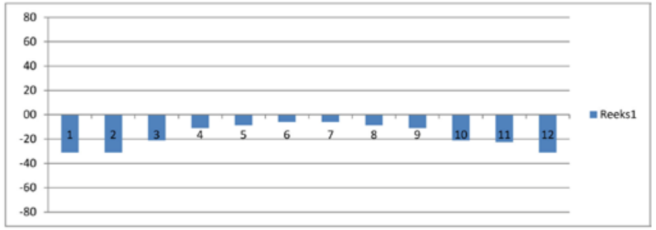
ϕ heat load transmission	
absorptioncoefficient; a	0,95
int. Surface of wall or roof (m2)	50
heat flow qw (see table)	1,6

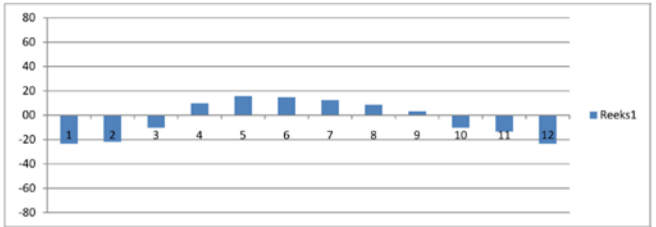
ϕ External heat loads (W)				
ZTA, glass	0,15		U,win (W/m2K)	1,2
sun blinds factor; z	0,8		U,wall (W/m2K)	0,3
q,conv max.	350		U,floor (W/m2K)	0,3
sun intensity; fd	0,5	1	U,roof (W/m2K)	0,3

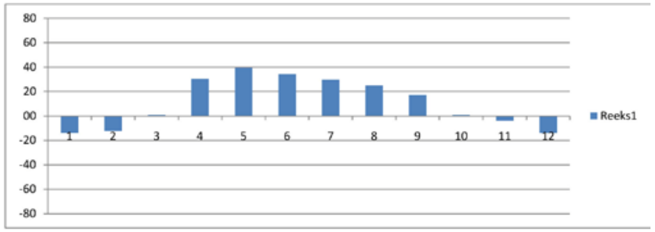
ϕ inf,vent = qair * ρ * c * Δti,o	
qair = 0,2-0,3*(volume/3600 (m3/	0,013
ρ	1,2
c	1000

	Internal heat load		Sun heat load		Transmission Infiltration losses			Output (per50m2)	W/m2	
TIME	ϕ Int.	X ratio	+ ϕ s,gl X	qconv	ϕ tr+ven X	Δt	ϕ s,cl			
JANUARI								W	W/m2	
2	850	0	1,596	0	77,52	-20	0	-1550,4	-31,0	
4	850	0	1,596	0	77,52	-20	0	-1550,4	-31,0	
6	850	0,5	1,596	0	77,52	-19	0	-1047,88	-21,0	
8	850	1	1,596	0	77,52	-18	0	-545,36	-10,9	
10	850	1	1,596	0	77,52	-16,5	0	-429,08	-8,6	
12	850	1	1,596	0	77,52	-14,8	0	-297,296	-5,9	
14	850	1	1,596	0	77,52	-14,8	0	-297,296	-5,9	
16	850	1	1,596	0	77,52	-16,5	0	-429,08	-8,6	
18	850	1	1,596	0	77,52	-18	0	-545,36	-10,9	
20	850	0,5	1,596	0	77,52	-19	0	-1047,88	-21,0	
22	850	0,5	1,596	0	77,52	-20	0	-1125,4	-22,5	
24	850	0	1,596	0	77,52	-20	0	-1550,4	-31,0	
APRIL / OCTOBER										
2	850	0	1,596	0	77,52	-15	0	-1162,8	-23,3	23,3
4	850	0	1,596	0	77,52	-14	0	-1085,28	-21,7	21,7
6	850	0,5	1,596	0	77,52	-12	0	-505,24	-10,1	10,1
8	850	1	1,596	260	77,52	-10	0	489,76	9,8	9,8
10	850	1	1,596	350	77,52	-8	0	788,44	15,8	15,8
12	850	1	1,596	245	77,52	-6,5	0	737,14	14,7	14,7
14	850	1	1,596	175	77,52	-6,5	0	625,42	12,5	12,5
16	850	1	1,596	125	77,52	-8	0	429,34	8,6	8,6
18	850	1	1,596	50	77,52	-10	0	154,6	3,1	3,1
20	850	0,5	1,596	0	77,52	-12	0	-505,24	-10,1	10,1
22	850	0,5	1,596	0	77,52	-14	0	-660,28	-13,2	13,2
24	850	0	1,596	0	77,52	-15	0	-1162,8	-23,3	23,3
									-3	13,8
JULY										
2	850	0	3,192	0	77,52	-10	76	-699,2	-14,0	14,0
4	850	0	3,192	0	77,52	-9	76	-621,68	-12,4	12,4
6	850	0,5	3,192	0	77,52	-6	76	35,88	0,7	0,7
8	850	1	3,192	260	77,52	-3	76	1523,36	30,5	30,5
10	850	1	3,192	350	77,52	-1	76	1965,68	39,3	39,3
12	850	1	3,192	245	77,52	0	76	1708,04	34,2	34,2
14	850	1	3,192	175	77,52	0	76	1484,6	29,7	29,7
16	850	1	3,192	125	77,52	-1	76	1247,48	24,9	24,9
18	850	1	3,192	50	77,52	-3	76	853,04	17,1	17,1
20	850	0,5	3,192	0	77,52	-6	76	35,88	0,7	0,7
22	850	0,5	3,192	0	77,52	-9	76	-196,68	-3,9	3,9
24	850	0	3,192	0	77,52	-10	76	-699,2	-14,0	14,0
									11,1	18,5

TABLE required average power in W/m2 over 1 day per 2 hours

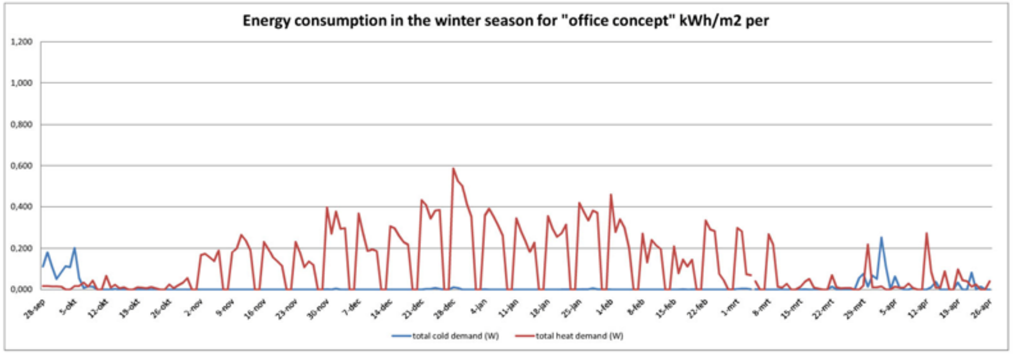




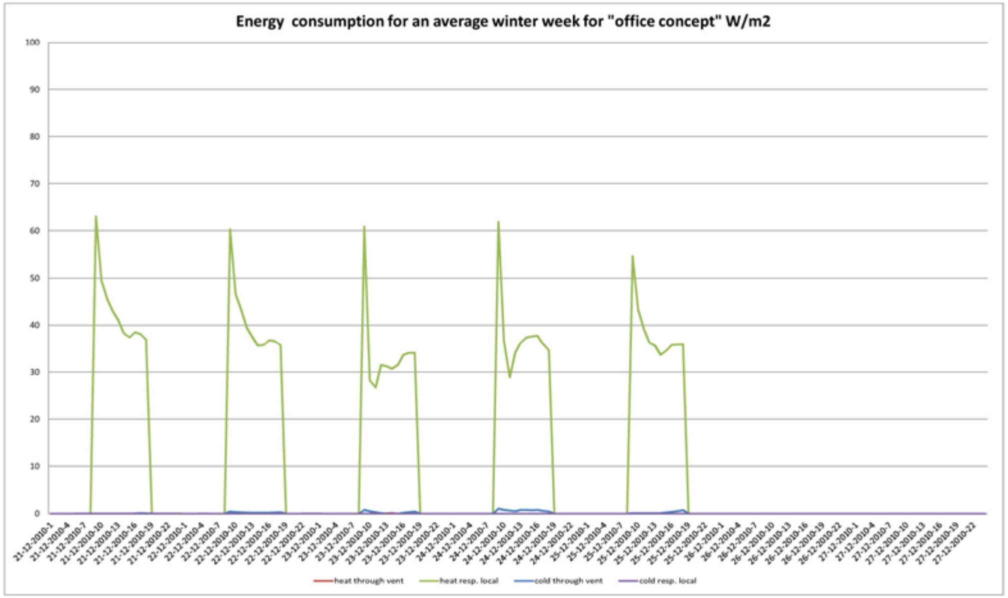


Annex 05: Dynamic calculation for the pavilion concept in the winter season

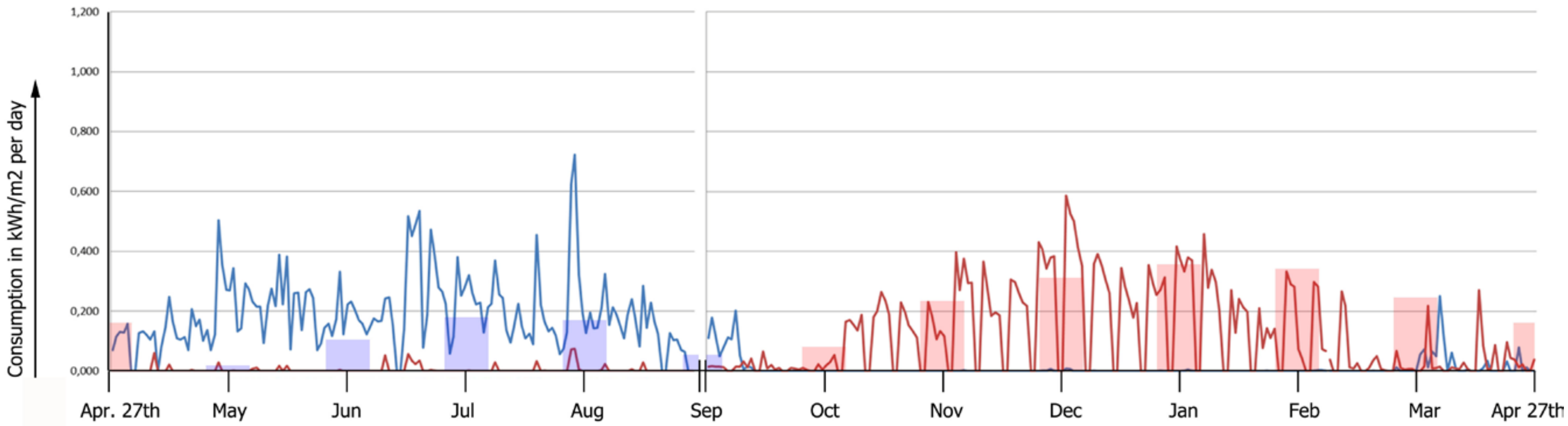
vertrek	dag	maand	jaar	uur	zon hor,vl	Tbuiten	Tlucht	Tcomf	Tinblaas	Warmt Inb (Watt)	resp, lok (Watt)	Koud Inbl (Watt)	resp, lok (Watt)	zoninstra	int last		tot warm (Watt)	tot koude (Watt)
1	28	9	1964	1	0	6,1	23	23,1	0	0	0	0	0	0	0	28-sep	0,017	0,111
1	28	9	1964	2	0	5,8	22,9	23	0	0	0	0	0	0	0			
1	28	9	1964	3	0	5,8	22,8	23	0	0	0	0	0	0	0			
1	28	9	1964	4	0	6,2	22,7	22,9	0	0	0	0	0	0	0			
1	28	9	1964	5	0	5,9	22,7	22,8	0	0	0	0	0	0	0			
1	28	9	1964	6	0	6,3	22,6	22,8	0	0	0	0	0	0	0			
1	28	9	1964	7	47	7,9	23	23,1	0	0	0	0	0	891	0			
1	28	9	1964	8	174	10,1	24,1	24,1	0	0	0	0	0	3586	0			
1	28	9	1964	9	278	13	24	24,6	24,8	60	0	0	-1224	7443	1199			
1	28	9	1964	10	338	15,8	24	24,7	25,1	81	0	0	-1812	6910	1199			
1	28	9	1964	11	205	16,2	24	24,2	25,1	84	0	0	-644	1929	1199			
1	28	9	1964	12	389	17,2	24	24,3	25,2	92	0	0	-450	1877	1199			
1	28	9	1964	13	192	17	24	24,2	25,2	90	0	0	-292	1300	1199			
1	28	9	1964	14	371	18	24	24,2	25,3	98	0	0	-351	1859	1199			
1	28	9	1964	15	423	17,5	24	24,2	25,3	94	0	0	-274	1798	1199			
1	28	9	1964	16	242	17,2	24	24,2	25,2	92	0	0	-352	1284	1199			
1	28	9	1964	17	103	15,5	24	24,1	25	79	0	0	-85	741	1199			
1	28	9	1964	18	11	12	23,4	23,6	24,1	58	0	0	0	106	1199			
1	28	9	1964	19	0	9,4	23,4	23,6	0	0	0	0	0	0	0			
1	28	9	1964	20	0	7,7	23,3	23,4	0	0	0	0	0	0	0			
1	28	9	1964	21	0	6,4	23,1	23,3	0	0	0	0	0	0	0			
1	28	9	1964	22	0	6	23	23,2	0	0	0	0	0	0	0			
1	28	9	1964	23	0	5,8	22,9	23,1	0	0	0	0	0	0	0			
1	28	9	1964	24	0	5	22,8	23	0	0	0	0	0	0	0			
1	29	9	1964	1	0	4,7	22,7	22,9	0	0	0	0	0	0	0	29-sep	0,017	0,179
1	29	9	1964	2	0	4	22,6	22,8	0	0	0	0	0	0	0			
1	29	9	1964	3	0	3,5	22,5	22,6	0	0	0	0	0	0	0			
1	29	9	1964	4	0	3,6	22,4	22,6	0	0	0	0	0	0	0			
1	29	9	1964	5	0	3,2	22,3	22,5	0	0	0	0	0	0	0			
1	29	9	1964	6	0	3,3	22,2	22,4	0	0	0	0	0	0	0			
1	29	9	1964	7	47	4,6	22,6	22,7	0	0	0	0	0	1006	0			
1	29	9	1964	8	160	7,1	24,6	24,5	0	0	0	0	0	6004	0			
1	29	9	1964	9	292	10,6	24	24,7	24,6	42	0	0	-1142	8959	1199			
1	29	9	1964	10	409	14,2	24	24,9	24,9	69	0	0	-1584	8308	1199			
1	29	9	1964	11	482	16,9	24	24,6	25,2	90	0	0	-1402	4782	1199			
1	29	9	1964	12	526	18,4	24	24,4	25,3	101	0	0	-1068	2200	1199			
1	29	9	1964	13	541	18,4	24	24,3	25,3	101	0	0	-824	2115	1199			
1	29	9	1964	14	389	18,8	24	24,3	25,4	104	0	0	-881	1816	1199			
1	29	9	1964	15	259	18,6	24	24,2	25,4	102	0	0	-853	1328	1199			
1	29	9	1964	16	169	17,4	24	24,2	25,2	93	0	0	-618	1167	1199			
1	29	9	1964	17	81	16	24	24,2	25,1	83	0	0	-410	762	1199			
1	29	9	1964	18	11	13	24	24	24,8	60	0	0	-105	106	1199			
1	29	9	1964	19	0	10,1	23,6	23,7	0	0	0	0	0	0	0			
1	29	9	1964	20	0	8,3	23,4	23,5	0	0	0	0	0	0	0			
1	29	9	1964	21	0	8,1	23,3	23,4	0	0	0	0	0	0	0			
1	29	9	1964	22	0	7,2	23,2	23,3	0	0	0	0	0	0	0			
1	29	9	1964	23	0	9,1	23,2	23,3	0	0	0	0	0	0	0			
1	29	9	1964	24	0	8,7	23,1	23,2	0	0	0	0	0	0	0			
1	30	9	1964	1	0	7,3	22,9	23,1	0	0	0	0	0	0	0	30-sep	0,016	0,110
1	30	9	1964	2	0	6,6	22,8	23	0	0	0	0	0	0	0			
1	30	9	1964	3	0	6,5	22,7	22,9	0	0	0	0	0	0	0			
1	30	9	1964	4	0	8,1	22,7	22,9	0	0	0	0	0	0	0			
1	30	9	1964	5	0	9	22,7	22,9	0	0	0	0	0	0	0			
1	30	9	1964	6	0	9	22,7	22,8	0	0	0	0	0	0	0			
1	30	9	1964	7	51	9,4	23,2	23,3	0	0	0	0	0	1549	0			
1	30	9	1964	8	174	11,4	26,3	26,1	0	0	0	0	0	9560	0			
1	30	9	1964	9	316	13,2	24	25,1	24,8	62	0	0	-1108	10846	1199			
1	30	9	1964	10	428	14,5	24	25,1	25	72	0	0	-320	8715	1199			
1	30	9	1964	11	507	15,2	24	24,8	25	77	0	0	-119	5000	1199			
1	30	9	1964	12	552	15,7	23,4	24,1	24,5	85	0	0	0	2292	1199			
1	30	9	1964	13	541	15,9	23	23,8	24,2	90	0	0	0	2107	1199			
1	30	9	1964	14	482	16	24	24,4	25,1	83	0	0	-1656	1949	1199			
1	30	9	1964	15	384	15,8	22,7	23,5	23,9	91	0	0	0	1664	1199			
1	30	9	1964	16	259	15,1	24	24,3	25	76	0	0	-1388	1264	1199			
1	30	9	1964	17	116	14,8	22,4	23,2	23,6	86	0	0	0	722	1199			
1	30	9	1964	18	11	12	24	24,1	24,7	53	0	0	-875	106	1199			
1	30	9	1964	19	0	10,8	23,8	23,9	0	0	0	0	0	0	0			
1	30	9	1964	20	0	9,9	23,6	23,7	0	0	0	0	0	0	0			
1	30	9	1964	21	0	9,2	23,5	23,6	0	0	0	0	0	0	0			
1	30	9	1964	22	0	8,9	23,4	23,5	0	0	0	0	0	0	0			
1	30	9	1964	23	0	8,3	23,3	23,4	0	0	0	0	0	0	0			
1	30	9	1964	24	0	7,9	23,2	23,3	0	0	0	0	0	0	0			
1	1	10	1964	1	0	7,5	23,1	23,2	0	0	0	0	0	0	0	1-okt	0,015	0,051
1	1	10	1964	2	0	7,4	23	23,2	0	0	0	0	0	0	0			
1	1	10	1964	3	0	7,3	22,9	23,1	0	0	0	0	0	0	0			
1	1	10	1964	4	0	6,6	22,8	23	0	0	0	0	0	0	0			
1	1	10	1964	5	0	5,6	22,7	22,9	0	0	0	0	0	0	0			
1	1	10	1964	6	0	5,2	22,6	22,8	0	0	0	0	0	0	0			
1	1	10	1964	7	47	6,2	23,1	23,2	0	0	0	0	0	1267	0			
1	1	10	1964	8	165	8,5	26,1	26	0	0	0	0	0	9183	0			
1	1	10	1964	9	281	10,7	24	25	24,6	43	0	0	-476	9792	1199			
1	1	10	1964	10	384	12,9	24	25	24,8	59	0	0	-631	7907	1199			
1	1	10	1964	11	482	14,5	24	24,8	25	72	0	0	-249	4772	1199			



Total energy consumption	kWh/49,6m2	kWh/m2
heating	1221	25
cooling	74	1
total	1183	24



Annex 06: Energy consumption for the “office concept” kWh/m2 per day



Total kWh/m2/year	Summer	Winter	Total
Heat	0	25	25
Cold	10	1	11

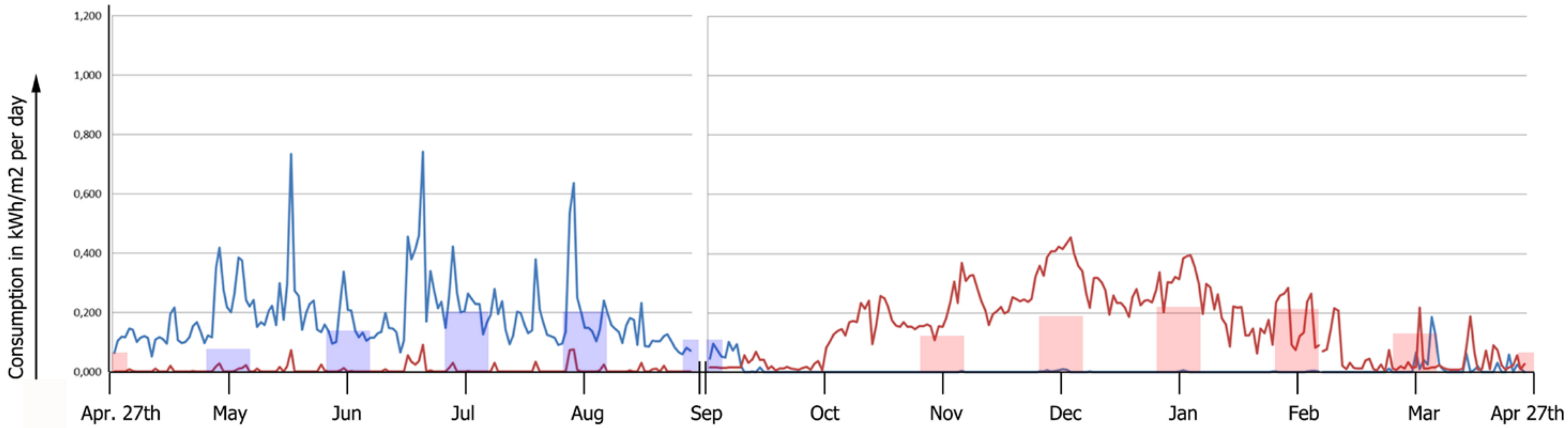
ORCA calculation
- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Manual calculation
- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Office concept properties

Total surface area	1.000 m²
Total Heating energy	25.000 kWh/year
Total cooling energy	11.000 kWh/year
Heating/cooling system	floor and ceiling LTH / HTC with heat pump
Passive system	automatic operated windows with night time ventilation, automatic operated sunblinds
Heat storage	thermal mass 300mm concrete in floor, 300mm concrete in ceiling
Ventilation system	natural if possible, mechanical if needed, heat recovery 90%

Annex 07: Energy consumption for the “common concept” kWh/m2 per day



Total kWh/m2/year	Summer	Winter	Total
Heat	0	31	31
Cold	10	1	11

ORCA calculation

- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Manual calculation

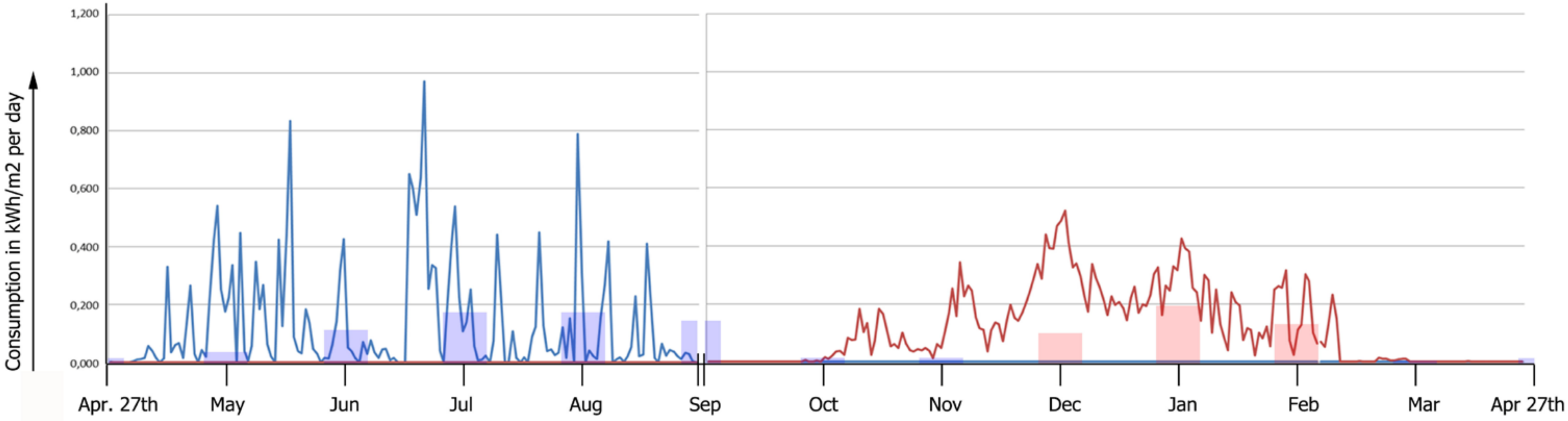
- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Common concept properties

Total surface area: 2.500 m2
Total heating energy: 77.500 kWh/year
Total cooling energy : 27.500 kWh/year

Heating, cooling system: floor and ceiling; LTH / HTC with heat pump
Passive system: -automatic operated windows with night time ventilation
-automatic operated sun blind system
Heat storage: Thermall mass: 100mm floor, 100mm ceiling, 60% accessible, heat stor-
age capacity 0,2m3/m2
Ventilation system: natural when possible, mechanical if needed, heat recovery 90%

Annex 8: Energy consumption for the “museum concept” kWh/m2 per day



Total kWh/m2/year	Summer	Winter	Total
Heat	0	24	24
Cold	22	0	22

ORCA calculation

- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

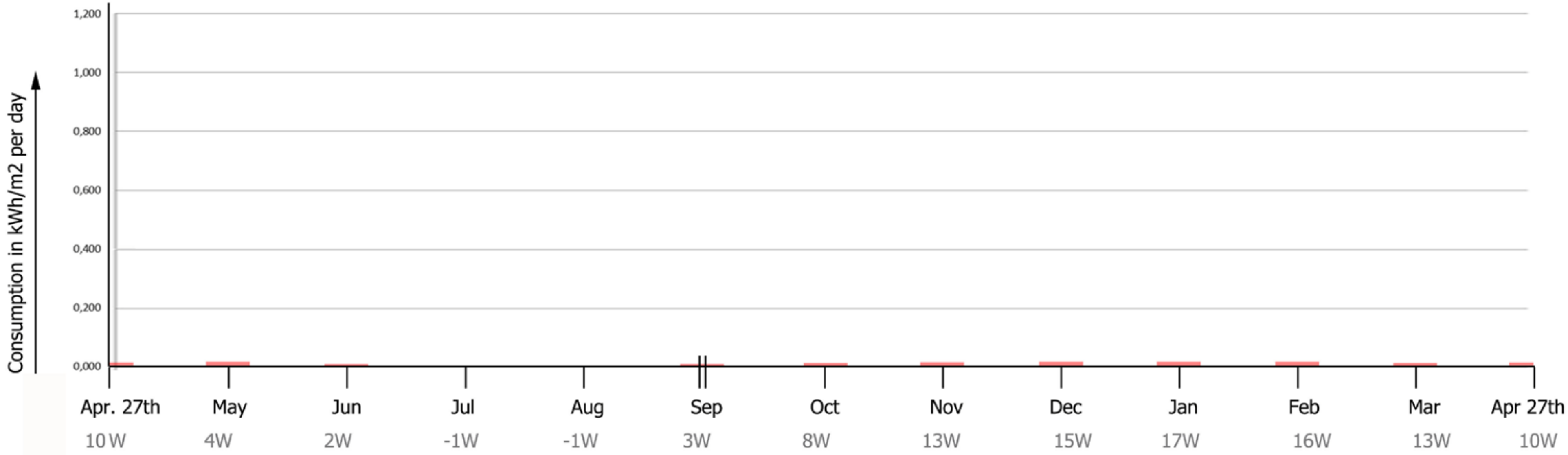
Manual calculation

- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Museum properties

Total surface area:	1500 m2
Total heating energy:	36.000 kWh/year
Total cooling energy :	33.000 kWh/year
Heating, cooling system:	floor and ceiling; LTH / HTC with heat pump
Passive system:	-adjustable louvers with thermal qualities -climate roof; PV cells, sun collector to keep roof cool and charge aquifer
Heat storage:	PCM board(87m), Latend heat storage capacity 2721 kJ/m2
Ventilation system:	natural, mechanical with heat recovery 90%

Annex 9: Energy consumption for the "archive concept" kWh/m2 per day



Total kWh/m2/year	Summer	Winter	Total
Heat	--	--	3
Cold	--	--	0

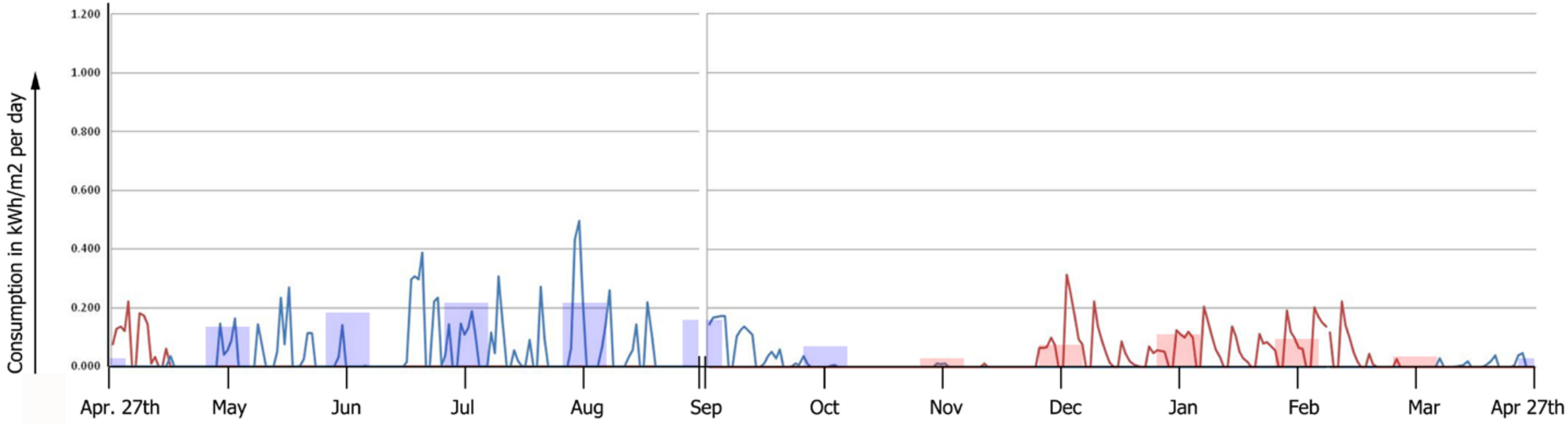
Manual calculation

- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Office concept properties

Total surface area:	550 m2
Total heating energy:	1.650 kWh/year
Total cooling energy :	0 kWh/year
Heating, cooling system:	floor LTH with heat exchanger and heat pump
Passive system:	-heat exchange with kitchen and cold storage units from restaurant
Heat storage:	none actively deployed
Ventilation system:	mechanical with heat recovery 90%, filtering, (de)humidification

Annex 10: Energy consumption for the “auditorium concept” kWh/m2 per day



Total kWh/m2/year	Summer	Winter	Total
Heat	6	12	18
Cold	22	3	25

ORCA calculation
- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Manual calculation
- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Auditorium concept properties

Total surface area	1.400 m²
Total Heating energy	25.200 kWh/year
Total cooling energy	35.000 kWh/year
Heating/cooling system	cooling/heating ceiling, secondary with air
Ventilation system	mechanical displacement ventilation, heat recovery 90%
Passive system, Heat storage	XXXXXXX

Annex 11: Manual calculation for the “archive concept” exposed to outdoor

Geometrie			
surface (m2)	50	A,win (m2)	0
volume (m3)	500	A,wall (m2)	100
orientation	south	A,floor (m2)	50
		A,roof (m2)	50

Indoor climate	
T,min Winter (°C)	20
T,max Winter (°C)	22
T,min Summer (°C)	20
T,max Summer (°C)	22

ϕ Internal heat loads (W)	
people	2
light	4
appliences	3

ϕ heat load transmission	
absorptioncoefficient; a	0,95
int. Surface of wall or roof (m2)	100
heat flow qw (see table)	1,6

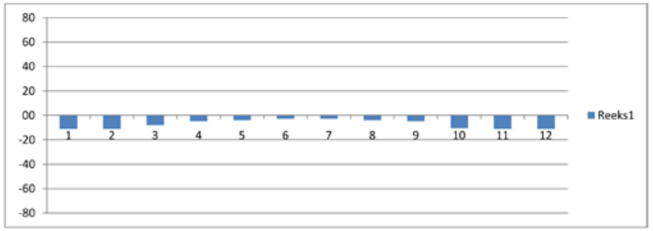
ϕ External heat loads (W)			
ZTA, glass	0,15	U,win (W/m2K)	1
sun blinds factor; z	0,8	U,wall (W/m2K)	0,2
q,conv max.	350	U,floor (W/m2K)	0,2
sun intensity; fd	0,5	U,roof (W/m2K)	0,2

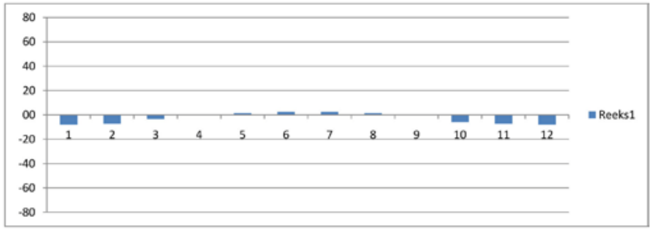
ϕ inf,vent = qair * ρ * c * Δti,o	
qair = 0,2-0,3*(volume/3600 (m3/	0,015
ρ	1,2
c	1000

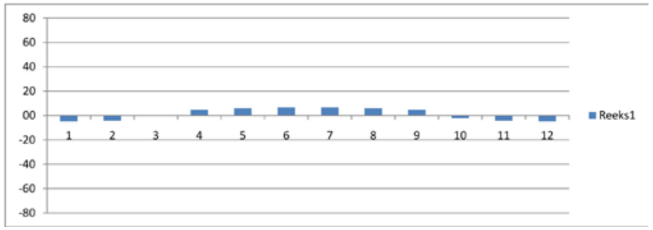
INPUT — OUTPUT (per50m2) 550M2

TIME	ϕ Int.	X ratio	+	ϕ sun,gl X qconv		ϕ tr+ven X Δt		ϕ sun,cl	W	kW	W / m2
JANUARI											
2	450	0		0	0	58	-20	152	-1008	-11,1	-20,16
4	450	0		0	0	58	-20	152	-1008	-11,1	-20,16
6	450	0,5		0	0	58	-19	152	-725	-8,0	-14,5
8	450	1		0	260	58	-18	152	-442	-4,9	-8,84
10	450	1		0	350	58	-16,5	152	-355	-3,9	-7,1
12	450	1		0	245	58	-14,8	152	-256,4	-2,8	-5,128
14	450	1		0	175	58	-14,8	152	-256,4	-2,8	-5,128
16	450	1		0	125	58	-16,5	152	-355	-3,9	-7,1
18	450	1		0	50	58	-18	152	-442	-4,9	-8,84
20	450	0		0	0	58	-19	152	-950	-10,5	-19
22	450	0		0	0	58	-20	152	-1008	-11,1	-20,16
24	450	0		0	0	58	-20	152	-1008	-11,1	-20,16
APRIL / OCTOBER											
2	450	0		0	0	58	-15	152	-718	-7,9	-14,36
4	450	0		0	0	58	-14	152	-660	-7,3	-13,2
6	450	0,5		0	0	58	-12	152	-319	-3,5	-6,38
8	450	1		0	260	58	-10	152	22	0,2	0,44
10	450	1		0	350	58	-8	152	138	1,5	2,76
12	450	1		0	245	58	-6,5	152	225	2,5	4,5
14	450	1		0	175	58	-6,5	152	225	2,5	4,5
16	450	1		0	125	58	-8	152	138	1,5	2,76
18	450	1		0	50	58	-10	152	22	0,2	0,44
20	450	0		0	0	58	-12	152	-544	-6,0	-10,88
22	450	0		0	0	58	-14	152	-660	-7,3	-13,2
24	450	0		0	0	58	-15	152	-718	-7,9	-14,36
JULY											
2	450	0		0	0	58	-10	152	-428	-4,7	-8,56
4	450	0		0	0	58	-9	152	-370	-4,1	-7,4
6	450	0,5		0	0	58	-6	152	29	0,3	0,58
8	450	1		0	260	58	-3	152	428	4,7	8,56
10	450	1		0	350	58	-1	152	544	6,0	10,88
12	450	1		0	245	58	0	152	602	6,6	12,04
14	450	1		0	175	58	0	152	602	6,6	12,04
16	450	1		0	125	58	-1	152	544	6,0	10,88
18	450	1		0	50	58	-3	152	428	4,7	8,56
20	450	0		0	0	58	-6	152	-196	-2,2	-3,92
22	450	0		0	0	58	-9	152	-370	-4,1	-7,4
24	450	0		0	0	58	-10	152	-428	-4,7	-8,56

REQUIRED POWER PER DAY W/m2







Annex 12: Manual calculation for the "archive concept" largely underground

Geometrie			
surface (m2)	50	A,win (m2)	0
volume (m3)	500	A,wall (m2)	50
orientation	south	A,floor (m2)	50
		A,roof (m2)	50

Indoor climate	
T,min Winter (°C)	20
T,max Winter (°C)	22
T,min Summer (°C)	20
T,max Summer (°C)	22

ϕ Internal heat loads (W)	
people	2
light	4
appliences	3

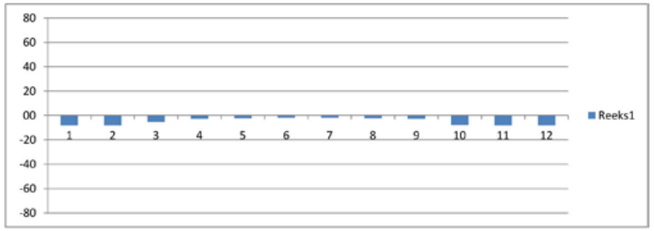
ϕ heat load transmission	
absorptioncoefficient; a	0,95
int. Surface of wall or roof (m2)	100
heat flow qw (see table)	1,6

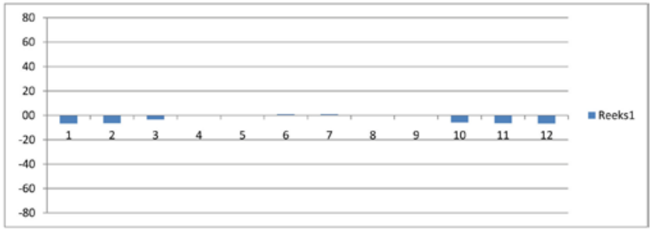
ϕ External heat loads (W)			
ZTA, glass	0,15	U,win (W/m2K)	1
sun blinds factor; z	0,8	U,wall (W/m2K)	0,2
q,conv max.	350	U,floor (W/m2K)	0,2
sun intensity; fd	0,5	U,roof (W/m2K)	0,2

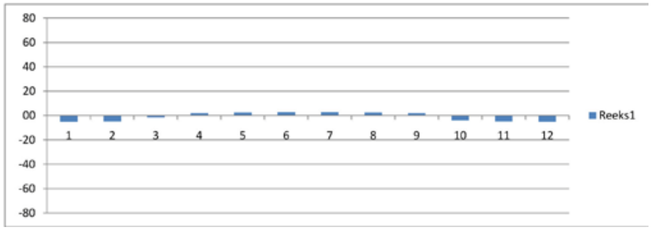
ϕ inf,vent = qair * ρ * c * Δti,o	
qair = 0,2-0,3*(volume/3600 (m3/	0,015
ρ	1,2
c	1000

			INPUT							OUTPUT (per50m2)	550M2	
TIME	ϕ Int.	X ratio +	ϕ sun,gl X qconv	ϕ tr+ven X Δt			Δt	ϕ sun,cl				
JANUARI										W	kW	W / m2
2	450	0	0	0	28	-20	38	-9	152	-750	-8,3	-15
4	450	0	0	0	28	-20	38	-9	152	-750	-8,3	-15
6	450	0,5	0	0	28	-19	38	-9	152	-497	-5,5	-9,94
8	450	1	0	260	28	-18	38	-9	152	-244	-2,7	-4,88
10	450	1	0	350	28	-16,5	38	-9	152	-202	-2,2	-4,04
12	450	1	0	245	28	-14,8	38	-9	152	-154,4	-1,7	-3,088
14	450	1	0	175	28	-14,8	38	-9	152	-154,4	-1,7	-3,088
16	450	1	0	125	28	-16,5	38	-9	152	-202	-2,2	-4,04
18	450	1	0	50	28	-18	38	-9	152	-244	-2,7	-4,88
20	450	0	0	0	28	-19	38	-9	152	-722	-7,9	-14,44
22	450	0	0	0	28	-20	38	-9	152	-750	-8,3	-15
24	450	0	0	0	28	-20	38	-9	152	-750	-8,3	-15
APRIL / OCTOBER												
2	450	0	0	0	28	-15	38	-9	152	-610	-6,7	-12,2
4	450	0	0	0	28	-14	38	-9	152	-582	-6,4	-11,64
6	450	0,5	0	0	28	-12	38	-9	152	-301	-3,3	-6,02
8	450	1	0	260	28	-10	38	-9	152	-20	-0,2	-0,4
10	450	1	0	350	28	-8	38	-9	152	36	0,4	0,72
12	450	1	0	245	28	-6,5	38	-9	152	78	0,9	1,56
14	450	1	0	175	28	-6,5	38	-9	152	78	0,9	1,56
16	450	1	0	125	28	-8	38	-9	152	36	0,4	0,72
18	450	1	0	50	28	-10	38	-9	152	-20	-0,2	-0,4
20	450	0	0	0	28	-12	38	-9	152	-526	-5,8	-10,52
22	450	0	0	0	28	-14	38	-9	152	-582	-6,4	-11,64
24	450	0	0	0	28	-15	38	-9	152	-610	-6,7	-12,2
JULY												
2	450	0	0	0	28	-10	38	-9	152	-470	-5,2	-9,4
4	450	0	0	0	28	-9	38	-9	152	-442	-4,9	-8,84
6	450	0,5	0	0	28	-6	38	-9	152	-133	-1,5	-2,66
8	450	1	0	260	28	-3	38	-9	152	176	1,9	3,52
10	450	1	0	350	28	-1	38	-9	152	232	2,6	4,64
12	450	1	0	245	28	0	38	-9	152	260	2,9	5,2
14	450	1	0	175	28	0	38	-9	152	260	2,9	5,2
16	450	1	0	125	28	-1	38	-9	152	232	2,6	4,64
18	450	1	0	50	28	-3	38	-9	152	176	1,9	3,52
20	450	0	0	0	28	-6	38	-9	152	-358	-3,9	-7,16
22	450	0	0	0	28	-9	38	-9	152	-442	-4,9	-8,84
24	450	0	0	0	28	-10	38	-9	152	-470	-5,2	-9,4

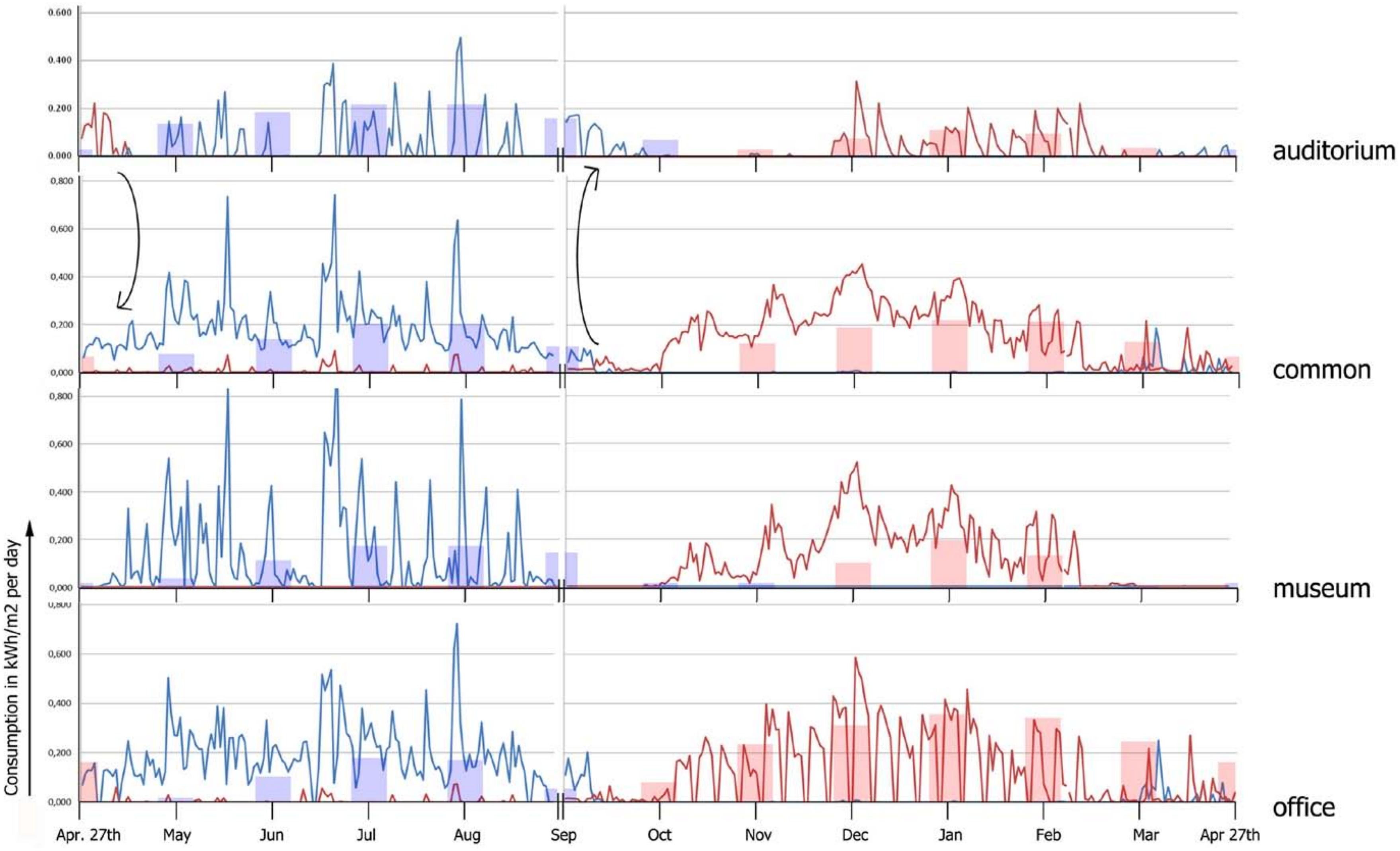
REQUIRED POWER PER DAY W/m2



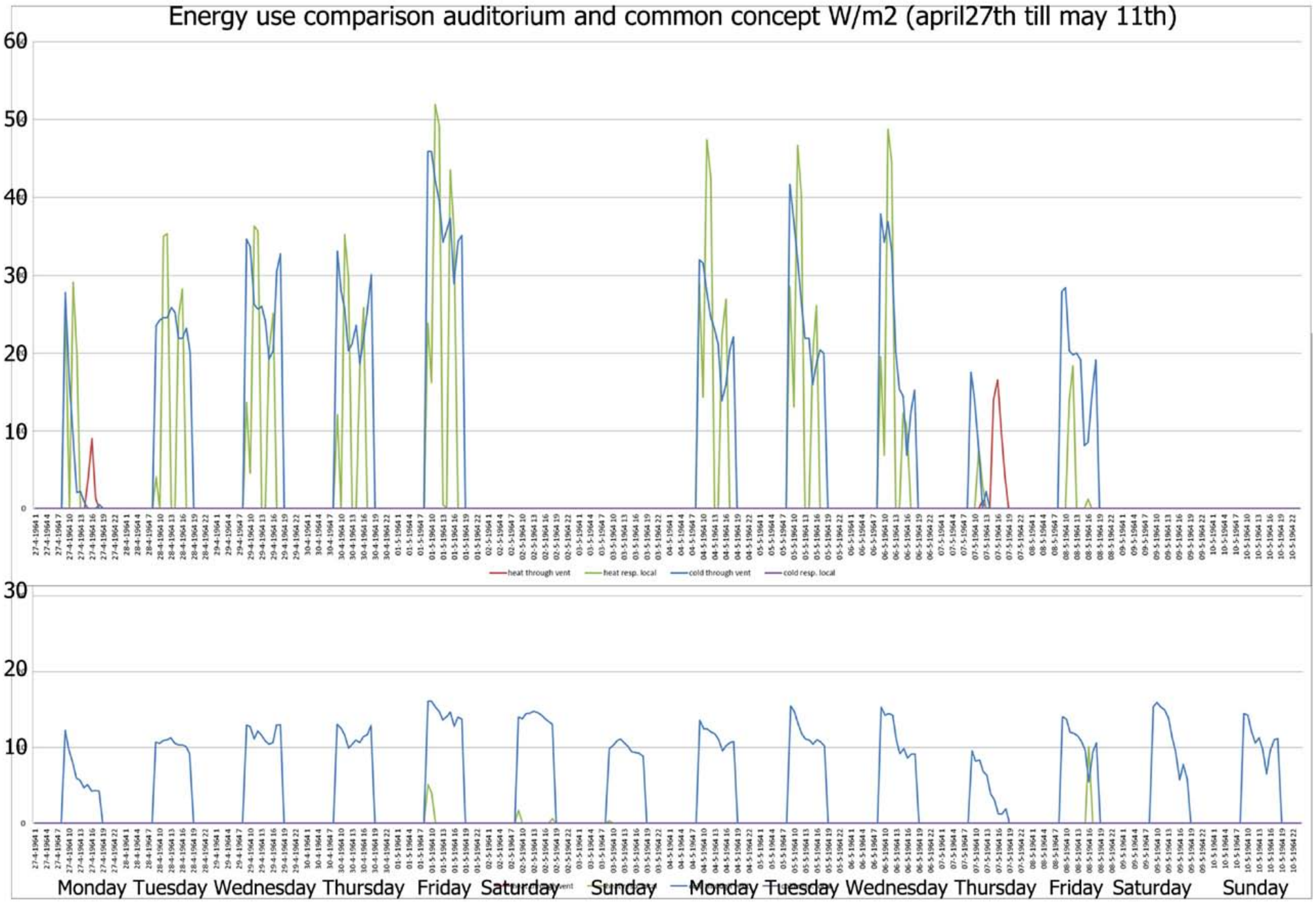




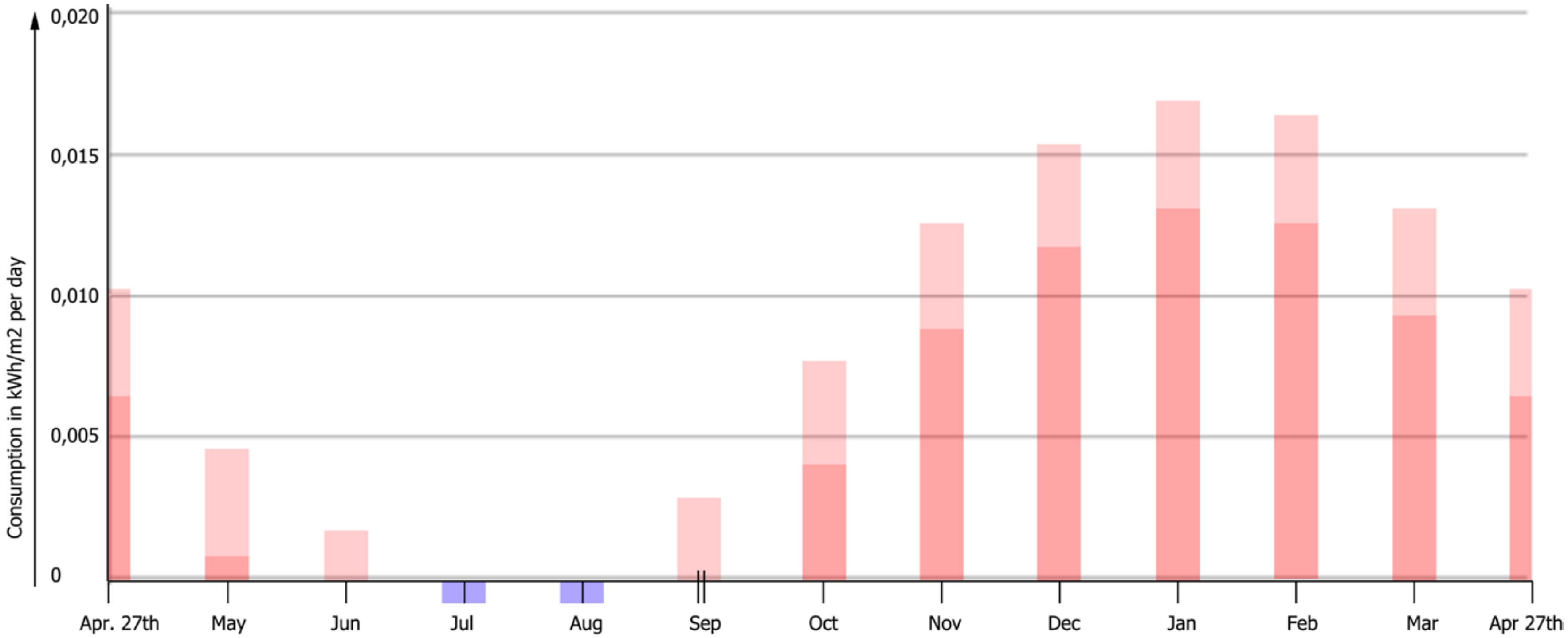
Annex 13: Comparison energy consumption of four concepts



Annex 14: Two week analysis "Auditorium concept" and "Common concept"



Annex 15: Energy consumption reduction for heating of “Archive concept” kWh/m2/day



Total kWh/m2/year	Summer	Winter	Total
Heat	--	--	3,04
Cold	--	--	0

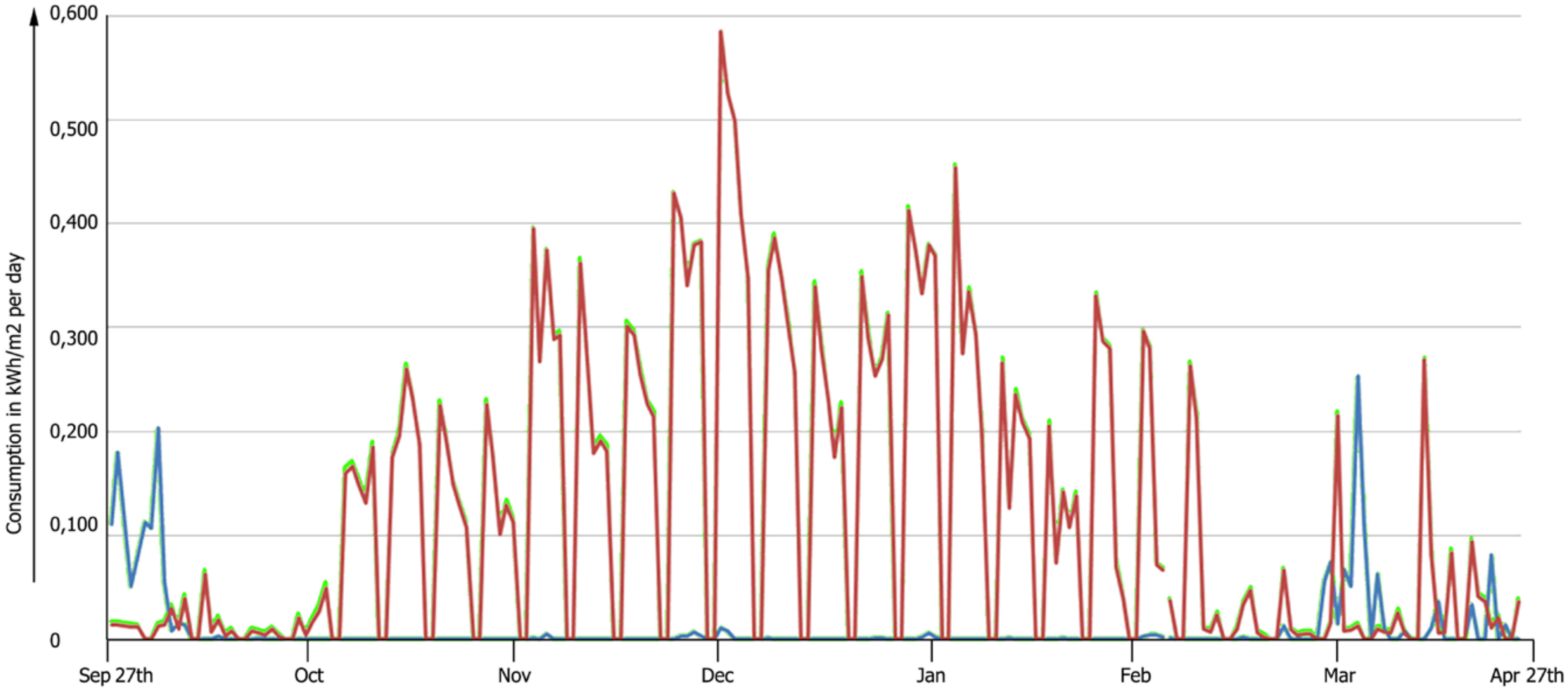
Total kWh/m2/year	with exchange total
Heat	1,99
Cold	0

Manual calculation

- total cold demand (kWh/m2 per day
- total heat demand (kWh/m2 per day

Total reduction for heating and cooling of the “archive concept” 3,04 to 2,99 = 34,5 %

Annex 16: Energy consumption reduction for heating of “Office concept” kWh/m2/day



Total kWh/m2/year	Summer	Winter	Total
Heat	0,12	24,62	24,74
Cold	10,06	1,49	11,55

same with exchange total

Heat	0,12	24,19	24,31
Cold	10,06	1,49	11,55

Dynamic calculation

- total heat demand (kWh/m2 per day
- deducted heat (kWh/m2 per day
- total cold demand (kWh/m2 per day

Reduction on total consumption for heating	1,8 %
Reduction on total consumption for heating and cooling	1,2 %

Total reduction for heating 1,8 % for total floor area of 1000m² office space

Annex 17: Energy consumption table

				Aquifer Blanace		Heating		Cooling	Ventila.	Air treat	Energy concsumption by users				Int. Input
						WP Input	Pump In	Pump In							
components	m2	demand cold kWh/m2	demand heat kWh/m2	total demand cold kWh 100%	total demand heat kWh 7/8 (COP7)	total electric demand kWh 1/8 (COP7)			ventilation 4,2 kWh/m2	de-humidifying kWh	appliences	tot. Appliences kWh	lighting	tot. Lighting kWh	Tot. Int. Load kWh
office	1000	11	25	11000	21875	3125	5	5	4200		18*9*5*48	38,9	6*9*5*48	12,9	51.800
common	6100	11	31	67100	165462,5	23637,5	31	31	25620		5*12*351	21	6*12*351	25,2	281.820
museum	1850	4	29	7400	46943,75	6706,25	9	9	7770		5*10*351	17,5	10*10*351	35,1	97.310
auditorium	1400	25	18	35000	22050	3150	7	7	5880		2*6*5*48	2,8	10*6*5*52	15,6	25.760
archive	1000	0	3	0	2400	600	5	5	2100	1100	2*8*5*48	3,8	2*8*5*48	3,8	7.600
	11350														

					heat uti. 50-100%	
kitchen cold storage (COP4)	24			11440	-14305	2865
kitchen freezer (COP2)	16			12050	-18000	6026
server space	24			28080	-18965	9850

TOTAL concsumption for climate	55960	57	57	45570	1100	102744	kWh
TOTAL concsumption users						464290	kWh

			heat shortage
Aquifer balance	172070	207461,3	35391 kWh

Compensation energy roof

Solar panel	1850 x	120 kWh		222.000 kWh
Heat gains Climate ROOF	1850 x	21,1 kWh	39035 kWh	
Surplus			3644 kWh access heat	119.256 kWh

Heat shortage aquifer compensated by energy roof

All climate installations can be powered by energy generated on site

Energy surplus 120.000 kWh