



Building design integrated energy simulation tools: Háskolatorg as case study

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Abstract

Today's architects design highly glazed buildings with aesthetics, space transparency and daylight accessibility in mind. Glazing components however are crucial to the design and performance of a building but their energy efficiency has become more and more questioned, as there is risk of a high cooling and heating demand, during summer and winter respectively. They affect building's indoor comfort and energy budget in many ways.

Energy use and environmental degradation have been linked because of the heavy reliance on mechanical aspects of building design to solve climate related heating, cooling and lighting problems induced by an inadequate building design approach.

In the context of building design, local climate is one of the important criteria to be considered. The local natural environment should act as a building tool to enhance comfortable indoor climate. Thus, well-designed architecture is a climate responsive architecture that takes advantage of free energy in the form of heat and light of natural environment, so that buildings are conducive to the occupant's requirements of comfort using surrounding climatic conditions; in relation to ambient air temperature and humidity, wind speed and solar radiation.

Significant energy consumption, however, can be reduced in building operation during the earlier phases of architectural design. Design improvement done with the aid of decision support simulation software is available to help architects predict the energy demand associated with different design option. It has been suggested that it could reduce energy use by 75% in new buildings.

Since there is need to understand energy building usage performance in cold climates, hence, for this study, the Háskolatorg building, at the University of Iceland in Reykjavík was chosen as case study. DesignBuilder© energy simulation tools have been used to assess its energy balance, as a prelude to improving decision making related to building envelope design. This process is driven by the commitment to studying the building's

potential low energy usage goal, while identifying potential improvement in the building design.

Therefore, in this thesis a methodology is introduced for determining that appropriate thermal insulation, glazing type and shading elements can reduce the heat conducted through the building envelope has been introduced. Both cooling and heating strategy were studied since they are crucial and influence Háskolatorg building energy balance and building energy usage. Further, it is projected that when architects begin to work with integrating environmental climate, building energy, and comfort related factors in the design process, the balancing of these demands can be expected to result in new, broader paradigms for low-energy architecture.

*I dedicate this work to my dear wife Steinunn Laufdal and my children;
Thelma Tara and Aron Andri.*

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Abbreviations

CAD	Computer Aided Design
CEN	European Committee for Standardization
CoP	Coefficient of Performance
DB	DesignBuilder simulation Tools
DHW	Domestic Hot Water
DOE	Department of Energy of the United States
EC	European Community
EPBD	Energy Performance of Building Directive
EPW	EnergyPlus Weather files
HT	Háskolatorg
HVAC	Heating, Refrigerating and Air-Conditioning
IBD	Integrated Building Design
IEA	International Energy Agency
IEQ	Indoor Environment Quality
IWEC	International Weather for Energy Calculation
POE	Post occupancy evaluation
Q₁,...,Q₁₈	survey question number one(Q ₁) to question number eighteen(Q ₁₈).
QP	QuestionPro web based survey
WBDG	Whole Building Design Guide

Operationalisation of terms

Computer and equipment heat gains:	Heat gain due to computer and other IT-related equipment.
Cooling setback setpoint temp.:	the low level of cooling required for some buildings during unoccupied periods to reduce start-up cooling the next morning.
Cooling Setpoint temperatures:	Defines the ideal temperature in the space when cooling system is to be started.
External infiltration:	Heat loss through air infiltration (non intentional air entry through cracks in building fabric).
External ventilation:	Heat loss due to entry of outside air through the air distribution system.
gbXML:	Green Building XML schema, referred to as "gbXML", was developed to facilitate the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models.
General lighting:	Heat gain due to general lighting
Glazing:	The total heat loss from the zone through the exterior glazing.
Heating set point temperature:	Defines the ideal temperature in the space when heating is required.
Heating setback setpoint temp.:	Some buildings require a low level of heating during unoccupied periods to avoid condensation/frost damage, or to prevent the building becoming too cold and to reduce peak heating at start-up. Mainly used at night times and week-ends
Latent Load:	Cooling required to remove unwanted moisture to an air-conditioned space.
Miscellaneous:	Heat gain due to miscellaneous equipment.
Occupancy:	Sensible gain due to occupants

Primary energy:	the energy embodied in natural resources prior to undergoing any human-made conversions or transformations
Roofs thermal load:	Sum of heat loss from the zone through the roofs.
Solar gains:	Solar radiation passing through exterior windows
Total cooling:	the rate at which total energy (sensible + latent) is removed from the inside air and return air in order to bring the air to specific temperature and humidity ratio.
Walls thermal load:	Sum of heat loss through the exterior walls
Zone heating:	Energy supplied into the zone to maintain internal heating temperature setpoint temperature.
Zone sensible cooling:	the sensible cooling effect on the zone of any air introduced into the zone. HVAC cooling contribution to the zone heat balance

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1 Introduction

Buildings have a substantial share of the energy consumption all over the world (Al-Hamoud, 2000). Over 80% of energy used, takes place during the operation phase of a building, when energy is used for heating and cooling, ventilating, lighting, appliances and other applications. It is believed that only 10 to 20% of the energy consumed is attributed for material extraction, manufacturing, transportation, construction, maintenance, renovation and demolition (UNEP-SBCI, 2009).

Energy use and environmental degradation have been linked because of the heavily reliance on the mechanical aspects of building design to solve climate related heating, cooling and lighting problems induced by an inadequate building design approach (The Energy Research Group, School of Architecture, University College of Dublin, 1993). Poor design of buildings and systems not only wastes resources and energy and cause adverse impacts to the environment, but also creates an uncomfortable and unhealthy indoor environment (Zhai, 2006). Efforts toward designing and operating energy efficient building have been enhanced, by shifting resource allocation such as reducing the space air-conditioning load through the design and use of climate responsive technology and materials in buildings (Al-Hamoud, 2000), both meet the occupants needs for thermal and visual comfort and require less energy to run, subsequently the impact on the environment reduced (Roulet, 2006).

Potential energy savings could be realized (Shameri, Alghoul, Sopian, Zain, & Elayeb, 2011) through basic decisions concerning site, building orientation, its basic form, the arrangement of spaces, the construction and quality of the environment. These decisions can be made in architectural response which is in harmony with its environment (Silvia & Almeida, 2011). An attempt should be made to take advantage of the natural phenomena surrounding the building, instead of fighting the influence of nature with expensive and often environmentally-destructive heating, cooling, and lighting equipment and the energy they consumes.

Significant energy consumption can be reduced in building operation during the earlier phases of architectural design (Shameri, Alghoul, Sopian, Zain, & Elayeb, 2011), through design improvement, conducted with the aid of decision support simulation software. It has been suggested that such software could reduce energy use by 75% in new buildings (Goldstein, Tessier, & Khan, 2010).

An early stage climate sensitive design is considered as a strategy to mitigate this trend of negative impact regarding building energy usage. Simultaneously, energy reduction strategies for building operation must be addressed by architects, integrating design with energy performance analysis tools (Klein, et al., 2012). It consists of recognizing the potential of the building envelope to control the heat and light entering the building and also organizing the natural energy flows brought by the sun, wind and temperature differences that can provide heating for winter, cooling in summer and lighting all year around (The Energy Research Group, School of Architecture, University College of Dublin, 1993).

1.1 Research problem

Today's architects design highly glazed buildings with aesthetic, space transparency and daylight accessibility in mind. However, glazing components are crucial to the design and performance of a building but their energy efficiency has become more and more questioned, as there is risk of a high cooling and heating demand, during summer and winter respectively. They affect a building's indoor comfort and energy budget in many ways (Kuhn, Herkel, Frontini, Strachan, & Kokogiannakis, 2011).

In addition, it is unusual for architects to conduct predictive energy simulations during the "brainstorming" phase of a project, thus building designs hailed as being "green" or "low-energy" are, in the vast majority of cases, never subjected to a rigorous analysis until they are already built or in the process of construction (Lehar & Glicksman, 2003).

Because the energy efficiency of a building depends highly on the façade construction, it is generally acknowledged that highly glazed buildings require very careful study during design stage (Poirazis, Blomsterberg, & Wall, 2008).

At present, numbers of reliable and well known energy simulation models exist for the energy assessment of buildings (Kim & Degelman, 1998). Energy simulation not only

allows the analysis of building energy performance but as also promises to reduce the future impact of buildings on the environment by helping architects predict the energy demand associated with different design options (Goldstein, Tessier, & Khan, 2010). Each new tool presents its inherent complexities, making them both inaccessible and a deterrent on the motivation of building designers, architects and engineers to use it in the early design stages (Urban & Glicksman, 2007). Many practicing architects consider therefore, the use of such simulation as a wearisome task that calls for the support of building energy specialists during the design process. Thus, these simulation tools have been regarded as design analysis tool for energy specialists, not a design synthesis tool for architect (Kim & Degelman, 1998). Consequently, opportunities for energy reduction in building designs are often missed (Urban & Glicksman, 2007).

Building is manmade infrastructure existing in conditions determined by climate, location environment and its tenant's requirement. Climate together with location of the infrastructure and end-users needs presents limitation and conditions on the building, its construction materials, architectural style, and energy conditioning. The building site environment however can benefit indoor climate, when it is taken into account and planned for likewise. The role of the environment and especially the impact of solar radiation should be assessed carefully during the conceptual study of the energy balance of a building (Chwieduk, 2008).

Poirazis and colleagues pointed out the lack of knowledge, regarding to the overall performance of highly glazed buildings in Nordic condition (Poirazis, Blomsterberg, & Wall, 2008). In order to gain knowledge on the possibilities and limitations for glazed buildings in Iceland, this project was initiated, and the highly glazed university building Háskolatorg was chosen as a case study.

1.2 Study aims

The aim of this study is to assess the energy balance of Háskolatorg through the use of energy simulation tools, as a prelude to improving decision making related to design building envelope. This process is driven by commitment to study of the potential building low energy usage goal, while identifying potential improvements in building design.

1.3 Justification of study

Building is an infrastructure existing in condition determined by climate, location environment and its tenant's requirement. The building site environment however can benefit its indoor climate, when it is taken into account and planned for at the conceptual stage (Chwieduk, 2008). Building simulation tools have been regarded as design analysis tools for energy and design synthesis for architects, they support decision making in order to improve building quality and further harmonize the building with its environmental site. This study is therefore justifiable in optimizing architecture design in the Reykjavik climate, through the support of DesignBuilder (DB) (DesignBuilder, 2005) simulation tool.

1.4 Research questions

The answer to the following questions makes up the backbone of the present research.

1. What are Háskolatorg building energy balance and the significant design parameters that influence its energy usage?
2. What strategies may result in the potential reduction of Háskolatorg's energy usage?
3. Is DesignBuilder simulation an architects friendly tools and instrumental in improving decision making for building design?
4. How can energy simulation tool such as DesignBuilder be used efficiently during design process?
5. How satisfied are the occupants of Háskolatorg with the indoor environment qualities of the building?

1.5 Thesis structure

This study has six main chapters. The first chapter provided an introduction, and presented the research problems, study aims, study justification and research questions.

The background of this thesis and its theoretical framework is presented in chapter two. This emphasizes the theories of the building envelope and the process of its interaction with the surrounding environment. Basic understanding of the natural processes of energy flow and their interactions with building elements and building orientation in perspective is described. Architecture integrated energy simulation tools and potential Architecture

climate responsive climate design were expounded. Furthermore, the importance of daylighting in building design is explained.

The third chapter describes the methodology and data collections used in this study. The methodology enumerates how the energy simulation tools and calculation were conducted. It contains of the input data constructions, openings, activity, and HVAC description, along with to the DesignBuilder (DesignBuilder, 2005) simulation tools core concept and workflow explanations. In addition, it explains how the survey was carried out and implemented.

The fourth chapter presents the results from the simulations and the survey. All year, all summer and all winter followed by weekly summer and winter simulations results are described. Furthermore daylighting simulation and survey outcomes are illustrated.

The fifth chapter presents the analysis and discussions of the results and the findings of the research and potential limitations are presented.

The sixth chapter presents the final conclusion and followed up by recommendation for further studies.

2 Background

It has been realised that current methods in modern architecture are not sustainable over the long term (McDonough & Braungart, 2003). Typical approaches are intended at using energy and materials more efficiently. By clearly understanding natural processes and their interactions with human needs in perspective, architects can design and create buildings that are pleasant, functional productive and regenerative; thus more harmonious and responsive to its environment (John, Croome, & Jeronimidis, 2005).

2.1 Climate responsive building

Buildings provide vital shelter against the outdoor climate. Furthermore, they create an artificial indoor climate based on given micro-climate of the surroundings (see Figure 1). Architectural components forming the thermal envelope; such as walls, roofs, windows, and floors; separate the microclimate and indoor climate and thus significantly affect indoor climate. Buildings are measured as “climate modifiers” that could take advantage of local weather to enhance their architectural integrity and environmental quality (Nasrollahi, 2009).

Therefore, determining thermal energy balance and indoor comfort conditions are important for the architecture of building. Knowledge of solar radiation availability and its transmission through the building envelope to the interior helps architects to design climate responsive, thus energy efficient buildings (Chwieduk, 2008).

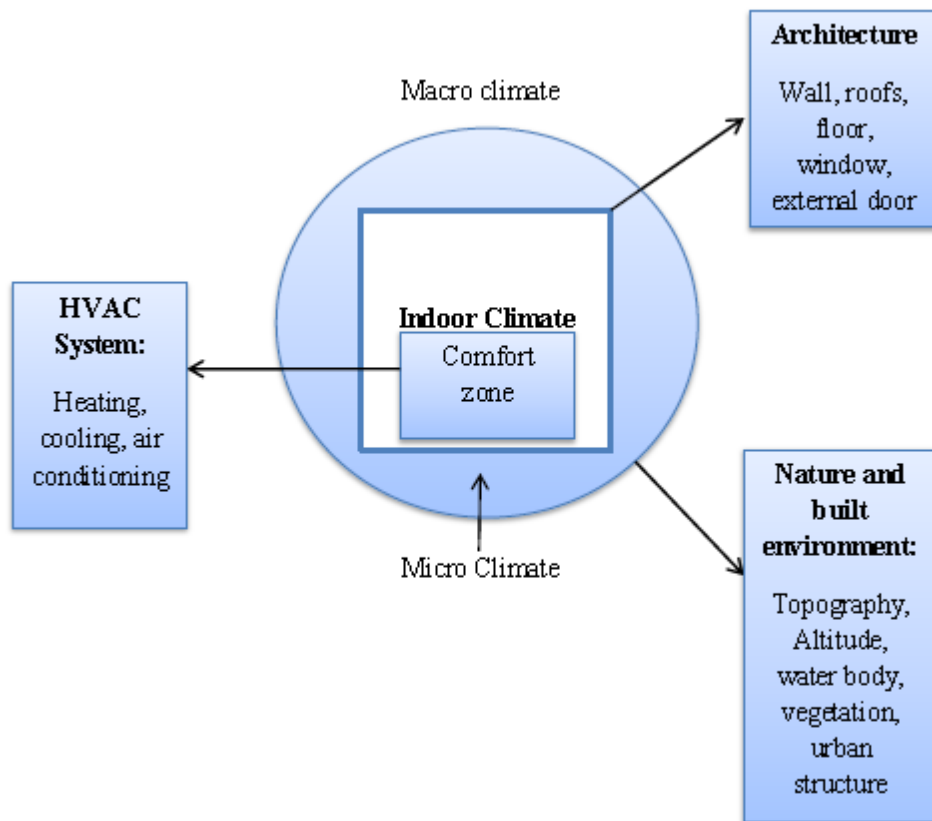


Figure 1: Relationship between climate and architecture (Nasrollahi, 2009)

2.1.1 Materials

This chapter contains basic descriptions of materials that could be found in any textbook on thermodynamics or building envelopes. Parts of the following descriptions are from McMullan (1998) book's on environmental science in building.

Heat energy tends to transfer from high temperature to low temperature regions. If several bodies at different temperatures are close together, then heat will exchange between them until they are at the same temperature. The equalising temperature occurs the same manner as heat transfer takes place in a building. It occurs by three basics forms of transfer:

- Conduction
- Convection
- Radiation

Conduction is the transfer of heat energy through a material without the molecules of the material altering their basic positions. Conduction can happen in solids, liquids, and gases although the speed will vary. At the place where the material will be heated the molecules gain energy and this energy is transferred to neighbouring molecules which then become hotter. The transfer is always from the warmer region (faster vibration) to the cooler region (slow in vibration). Different materials conduct heat at different rates (Moore, 1993).

Poor conductors are called insulators and include most liquids and gases. Porous materials are also poor conductors of heat, tend to be good isolators and are of particular interest in regulating heat conduction through the fabric of a building.

Convection is the transfer of heat energy through a material by the bodily movement of particles. Convection can occur in fluids and gases but never in solids. It is commonly known that air is a poor conductor of heat yet it is possible to heat all the air in room from a single panel; through the process of convection. When air is heated and expands. The expanded air is less dense causing it to rise, displaced by the cooler air surrounding it. The new air is then heated and the process repeats itself, giving rise to convection current. The natural convection that occurs in building causes warm air to flow from the lower to the upper stories.

A body emits or absorbs energy at a rate that depends on the nature and temperature of its surface. Good absorbers are good emitters; poor absorbers are bad emitters. Surface which appear dark absorb light and heat better, and rough surfaces absorb and emit more heat than polished surfaces.

Radiation is the transfer of heat by electromagnetic waves. When molecules on a substance vibrate, they give off radiant energy in the form of electromagnetic radiation. Energy is transferred from a warm substance to a cooler substance. These waves travel until they strike a surface and are absorbed. The molecules at the receiving surface absorb some of the radiant energy and convert it to heat energy (Moore, 1993).

2.1.2 Buildings

Buildings or shelter in general are the main instrument for satisfying human comfort requirements. It modifies the natural environment to approach best possible condition of liveability. It should filter, absorb or repel environment elements according to human's

comfort requirements. Preferably, the satisfaction of all physiological needs would constitute the standard or criterion of an environmentally balanced shelter (Olgyay, 1992).

Climate responsible buildings are fundamentally more responsive to their climate and location. In other words, these buildings take advantage of their local climate environmental conditions to regulate the internal environment matching thermal conditions. This reduces the need for the active use of HVAC systems, therefore reducing energy requirement. The main aim of climate responsible design is to offer comfortable living conditions with minimal and meaningful input of artificial energy (Gut & Ackerknecht, 1993).

Olgyay (1992) emphasised that approaches in contemporary architecture toward achieving man's physiological well-being and aesthetic should be justified by treating local climate as primary influencing factor of architecture expression.

Climate has imperative effects on the energy performance of a building, in both winter and summer, and on the durability of the building fabric. Although the overall features of the local climate are beyond human control, the design of a building can have a significant influence on the climatic behaviour of the building.

2.1.3 Floor plan design: Room location and arrangement

Different spaces in the building have different requirement conditions throughout the day. They also receive varying amount of energy from their surrounding environment, especially from the sun, and lose varying amount of energy according to their location. Therefore designing a building's floor plan, its allocation of spaces, and arrangement of rooms affect its energy consumption. It is therefore crucial that room location and orientation must match the desired conditions for each space. The heat gains and losses of each room must be compatible with its intended required indoor condition. Accordingly, important space (of activity, for instance) must be located and oriented toward environment advantage (Nasrollahi, 2009).

Because the position and movement of the sun and interior heat transfer is predictable, it is possible to design building that maximises the benefit of the sun's movement (Moore, 1993).

2.1.4 Building shape

Building forms and shapes should conform to favourable or adverse impacts of the thermal environment. Therefore, certain shapes are preferable to others in a given surrounding (Olgyay, 1992). Building shape and construction greatly influence how much of the climate and internal loads are actually translated into heating and cooling requirement (Nasrollahi, 2009). With respect to the total heat loss of the whole building, building form and the overall heat transfer coefficient (U-value) determines heat loss through the building envelope. The thermal performance of the building envelope surrounding a building is influenced also by the building forms (Oral & Yilmaz, 2003).

2.1.5 Compactness and Elongation

The heat transfer between the building and the environment depends significantly on the exposed surfaces. The ratio between the surface and volume of a building is an important factor of heat transfer because a compact building gains less heat during the daytime and loses less heat at night (Gut & Ackerknecht, 1993). Therefore, loss of heat through the building envelope can be reduced by creating a compact building form. The smaller the area of outside wall per heated volume, the less energy is required to operate the building (Goulding, Lewis, & Steemers, *Energy Conscious Design: A prime for Architects*, 1992).

2.1.6 Orientation

The most important design parameters affecting indoor thermal comfort and energy conservation in building scale is orientation (Oral & Yilmaz, 2003). The orientation of a building is the indicator of the amount of heat gained from solar radiation through building envelope. For that reason, the intensity of solar radiation affecting surfaces facing in different directions will be different. Hence, the amount of heat gained from solar radiation in building volume is a function of the building envelope's orientation (Erdim & Manioglu, 2011).

Orientation strongly relates a building to the natural environment, such as the sun, wind, weather patterns, topography, landscape, and views (Olgyay, 1992). Decisions made in site planning and building orientation will have impacts on the energy performance of the building over its entire life cycle.

2.1.7 Building envelope

Building envelope is what separates the indoor and outdoor environments of a building. It is a key factor that determines the quality of the indoor conditions regardless of transient outdoor conditions (Sadineni, Madala, & Boehm, 2011)

The building envelope has a crucial function of preventing the direct effects of climatic variables such as external air temperature, humidity, wind, solar radiation, rain, snow, and others. Generally the envelope is composed of two type of material, opaque and transparent, although translucent materials are sometimes included. Its measurable effect depends on its thickness and its thermophysical properties. Both transparent and non-transparent parts of a building thermal envelope can lose heat, by transmission through thermal conduction (Nasrollahi, 2009).

The thermal envelope of building can also lose thermal energy through infiltration and radiation. Increasing the thermal resistance of the building elements, such as walls, roofs, and floors, can reduce their conduction heat loss. And this can be achieved by thermal insulation for non-transparent elements. Transparent elements can also gain heat from direct and diffuse solar radiation, especially when its characteristic is carefully chosen, such as multi-layer glazing with low conductivity gas (Nasrollahi, 2009).

2.1.8 Thermal insulation

In order to maintain a constant temperature within a building it is necessary to restrict the rate at which heat energy is traded with its surroundings. Maintaining heat inside a building for as long as possible conserves energy consumption and consequently the building running cost. Thermal insulation is the main factor in reducing the loss of heat from buildings (McMullan, 1998). Because warmth is a valuable commodity and it will seek every possible means of escape through walls, roofs, windows and floors, heat transfer from building components can be mitigated by choice of insulating materials.

For opaque solid building elements, conduction is the main heat transfer process. In order to reduce the magnitude of heat flow in a resistive manner, thermal insulation provides restriction to heat flow (Smith, 2005). Since conduction is the main mode of heat transfer and air provides good resistance to heat flow, many insulation products are based on materials that have numerous layers of pocket of air trapped within them. Such material

tends to be low density; for instance porous materials with a large proportion of void filled with air, or those made with low conductivity elements (Straube, 2006).). Some insulation includes cellulose, rock wool, fibreglass, polystyrene, urethane foam. As they have much higher thermal resistance than conventional building materials, the resistance of opaque(dense) wall increases dramatically as insulation is added to the wall (Nasrollahi, 2009).

Most materials with high strength have relatively high density, such as concrete, wood, plastic, and most building material strength drops alongside decreases in their density. Therefore, the need of low density or high porosity insulating materials reduces most of its structural capacity. As a result, low density insulation layers such as glass fibre batt, and foamed plastics are used to control heat flow, while high density, high strength, high conductivity materials such as steel studs and concrete are used to support structural loads (Straube, 2006).

2.1.9 Windows

Energy transfer through a window

Windows are crucial elements in the energy balance of a building. Currently, they have become a major and critical aspect of the building envelope. The role of windows in building's energy balance increases with their size due to their relatively quick response to fluctuation in outdoor environmental conditions, such as ambient temperature and solar radiation. Thus windows are one of the most important factors from an architectural perspective both in relation to aesthetics in building design and also for architectural energy efficiency (Sadineni, Madala, & Boehm, 2011).

A window is responsible for direct solar gains. Solar radiation is transmitted through the window and enters the interior of the building directly. The window's orientation, inclination angle, size and construction, as well as optical properties of the glazing, determine the rate of solar radiation entering a building. Solar radiation that passes through the window is absorbed and accumulated in the building construction elements: walls, floors, furniture etc. The solar energy entering the building could be reduced by applying overhang, wing walls, and other architectural devices that shade the window in a planned way (Chwieduk, 2008).

Windows are therefore a crucial element in both heat loss and heat gain. Because of its lower resistance and higher thermal conductivity, more heat flows through glazing than through insulated skin, per unit of area (Arasteh, Selkowitz, Apte, & LaFrance, 2006). Thus, windows lose more heat than the opaque elements of the thermal envelope (Goulding & Lewis, 1997).

To reduce the heat loss of windows through conduction, the thermal resistance of their glass and frame must be increased. This, as well as the reduction of heat loss through the glass, is achieved through insulated or multi-layer glazing (double, triple or quadruple) and the use of gas in the void between the glass layers.

In winter, thermal energy can radiate through windows from the warm internal environment to the cold external environment. Therefore the windows must be controlled with regard to radiative heat loss. The use of low emissivity (or low-E) coatings glazing, reduces winter heat loss, via transmission, through transparent parts of the thermal envelope. Low-emissivity or low-E coatings dramatically reduce radiative heat transfer through double-glazed windows, thus lowering a window's U-value (increasing R-value). Furthermore, some low-E coatings similarly reduce overall solar heat gains by reflecting solar infrared radiation, a remarkable benefits in cooling dominated climate (Arasteh, Selkowitz, Apte, & LaFrance, 2006).

Coating the interior face of a glass surface with a thin layer of metal or metallic oxide reflects a significant amount of radiant heat, reducing the heat loss through radiation. To reduce that heat loss, especially via thermal radiation, movable insulation systems can also be used for glazing surfaces. This insulation, in the form of movable panels, curtains, and shutters, covers the windows during winter nights (Nasrollahi, 2009).

Heat flow in building can be dramatically affected by solar gain through windows which are exposed to either direct or reflected sunlight. Therefore, the building energy flow must account for the solar gain through windows. This heat can determine the performance of a modern building with relatively high window coverage (Straube, 2006).

Window benefits and disadvantages

Windows have many benefits; nevertheless they are the main weak thermal link when incorrectly designed. Discomfort arises in summer, both from the rise of air temperature

due to heat gains and due to the rise in radiant temperature from the glass surface itself. Radiant effects are further increased if the occupant experiences direct sunlight. In winter, cold window surfaces cool the adjacent internal air; this will also be accompanied by cool radiant temperatures and may lead to discomfort (Smith, 2005).

Windows can admit solar heat when it is needed to offset heating energy needs, and reject solar gain to reduce cooling loads. They can significantly mitigate a building's peak electricity demand and offset much of building's lighting needs during daylight hours. To realize these benefits windows must have better fixed properties, such as a lower U-value, and should also incorporate dynamic capability that allow trade-offs between winter and summer conditions, glare and view, daylight and solar gains (Arasteh, Selkowitz, Apte, & LaFrance, 2006).

2.1.10 Walls

Building envelope determines the energy exchange between outdoor environment and indoor space and hence governs the overall energy performance of the building (Sozer, 2010).

The over-all function of external walls is both to moderate solar radiation, temperature extremes, moisture, dust and wind and also to provide a barrier or filter for noise, fire, particulate matter; while contributing to the form and aesthetic of a building. Thus the first step in exterior wall design is to determine the outdoor environment and establishment of the desired indoors environments (John, Croome, & Jeronimidis, 2005).

The thermal resistance, or R-value of the wall is important as it affects the building energy consumption heavily, especially in high rises and large buildings, where the ratio between wall and total envelope area is high (Sadineni, Madala, & Boehm, 2011).

Because walls separate the indoor and outdoor environments, they tend to lose and gain heat and accordingly affect the indoor environment. Wall orientation also affects the levels of heat loss and gains. The interior surfaces temperature of walls affects the radiant temperature which in turn significantly affects indoor thermal comfort. Hence, in order to prevent excessive heat transfer by conduction between indoor and outdoor, insulating the walls is of great importance (Nasrollahi, 2009).

2.1.11 Roofs

Roofs are an important part of building envelopes which are highly susceptible to solar radiation and other environment changes, hence influencing the indoor comfort conditions for the occupants. Roofs are the part of the building that receives most of the solar radiation and its shading is difficult. They are moreover accounts of heat gain and loss, especially in buildings with large roof areas (Sadineni, Madala, & Boehm, 2011); as a result, roofs should be planned and constructed with special care.

The thermal performance depends to a great extent on the shape of the roof and the construction of its skin, whereas the carrying structure has little influence. The shape of the roof should be in accordance with precipitation, solar impact and utilisation pattern (pitched, flat, vaulted, etc.) (Gut & Ackerknecht, 1993). The roof type which is component of the building form has an important impact on annual energy consumption (Erdim & Manioglu, 2011).

2.1.12 Colours of Walls and Roofs

Building external envelope colours determine the impact of solar radiation on the building and its absorption. In effect a fraction amount of the solar energy striking the building is actually absorbed by the building envelope, influencing its heat gains and indoor temperature. The fraction amount of solar energy is reflected away, without having any effect on the building's thermal conditions (Nasrollahi, 2009). The amount of solar energy absorbed by the walls or roofs depends not only on the amount of incident radiation, the angle at which it strikes the wall and the absorbing capacity of the material, but also the condition of the wall surface; dark, unpolished surfaces absorb more energy than light coloured polished surfaces (Goulding, Lewis, & Steemers, 1992)

2.2 Heat transfer

2.2.1 Heat loss

There are a number of factors that affect the rate at which heat is lost from buildings. These factors are:

- Insulation of the building
- Area of the external shell
- Temperature difference

- Air change rate
- Exposure to climate
- Efficiency of services
- Use of building

As the insulation of the external of the fabric of the building increases, the heat loss from the building decreases. The greater the area of external surfaces (which is the exposed perimeter area) the greater is the rate of the heat loss from building. Furthermore, the large difference between the outside and inside temperature the building increases the rate of heat lost by conduction and ventilation. This loss therefore affects the inside air design temperature.

Air flow in a building occurs through windows, doors, gaps in construction and ventilators. Ventilation may be controlled or it may be accidental infiltration. Warm air leaving the building carries heat and is replaced by colder air. The wind that blows on the building may also affect the air change rate. Thus, when air blows across a wall or roof surface, the rate of heat transfer through that component increases.

Occupation will also influence the energy a building consumes. The number of hours per day and days per year that a building is used has great effect on energy consumption. Buildings are often unoccupied during the night and, needs to be pre-heated before occupancy (McMullan, 1998).

2.2.2 Fabric heat transfer calculation

The transmission of heat through the materials of walls, roofs, and floors is the main cause of fabric heat loss from a building. Assuming the steady state conditions, the heat loss for each element from building could be calculated by the following formula:

$$P_i = UA \Delta T \quad (2)$$

Where

P_i :	rate of fabric heat loss Heat energy lost/time (W)
U :	U-value of the element considered (W/m ² K)
A :	area of that element (m ²)

$\Delta T =$ difference between the temperatures assumed for the indoor and outside environment (K)

2.2.3 Ventilation loss

The loss warm air and its replacement by the colder air causes ventilation heat loss from a building. The rate of such heat loss is calculated by the following formula:

$$P_v = c_v NV\Delta T / 3600 \quad (3)$$

Where

P_v :	rate of ventilation heat loss (W)
c_v :	volumetric specific heat capacity of air (J/m^3K)
=	specific heat capacity (J/kgK) X density (Kg/m^3)
N:	air infiltration rate for the room (the number of complete air change per hour)
V:	volume of the room (m^3)
ΔT :	difference between the indoor and outside air temperatures (K)

2.2.4 Heat gains

The casual heat gains in a building are determine by these factors:

- Radiation from the sun and sky
- Casual heat gains from occupants and equipment in the building.

The following factors determine the heat gained in building by radiation from the sun:

- Geographical latitude of the site, which determines the height of sun in the sky.
- The orientation of the building on the site, such as whether a room is facing north or south.
- The season of the year which also affects the height of the sun in the sky
- The local cloud conditions, which can block solar radiation
- Location, time of the day, orientation of surface and inclination
- The angle between the building surfaces and the sun, because maximum gain occurs when surfaces are at right angles to the rays from the sun
- The nature of the glass window, whether it absorbs or reflects any radiation
- The nature of the roofs and walls, because heavyweight materials behave differently to lightweight materials.

The heat from the sun falling on a surface varies throughout days and the year.

Various activities and equipments in building cause casual heat gains. The major sources of such heat are as follows:

- Heat from occupants (people)
- Heat from lighting
- Heat from cooking and water heating
- Heat from machinery, refrigerators, electrical appliance

Table 1: example of heat emissions from casual sources (McMullan, 1998)

Type of source	Typical heat emission
Adult person (for 20°C surroundings)	
Seated at rest	90W
Walking slowly	110W
Medium work	140W
Heavy work	190W
Lighting	
Fluorescent system giving 400 lux	20W/m ²
equipment	
Desktop computer	150W
Computer printer	100W
Photocopier	800W

During winter, casual heat gains may form a higher proportion of the total heat.

2.2.5 Heat balance

Human thermal comfort requires that, building indoor temperature is kept constant at a specified level. Likewise, the storage of goods requires constant temperatures. To maintain constant temperature, generally buildings require heating and cooling, and both of these processes involve consumption of energy.

2.2.6 Calculation of energy

Heat is defined as a form of energy. Power is defined as the rate (divided by time) at which energy is used. The true heat or energy use can be determined when the period of time considered is decided. Therefore the quantity of energy used over a given period depends upon both power (rate of energy use) and upon the time involved (McMullan, 1998).

The general formula is expressed this way:

Energy=Power X Time or

$$E=Pt \quad (4)$$

2.2.7 Energy balance

After determining heat loss and heat gains, it is conceivable to calculate the extra energy needed to balance the losses and gains to give a constant temperature. The heat balance is described by the general expression:

Fabric heat loss + Ventilation heat loss = Solar heat gains + Casual heat gains + Energy for Heating or Cooling

The state of building's energy requirements at any given time depends on the current state of the heat losses and gains. However, these factors can vary but it is useful to consider the total effect over a standard heating season (McMullan, 1998).

2.3 Daylighting

2.3.1 Daylighting and architecture design

Daylighting strategy and architectural design are inseparable. Daylight not only replaces artificial lighting, reducing lighting energy use, but also influences both heating and cooling loads.

Architects have used daylight to extend wide spaces and create, openings large enough to distribute daylighting to building interiors. Although, artificial light sources and glazed façade has opened designer answers to the constraints of daylighting (International Energy Agency (IEA), 2000), but the presence of natural light can bring occupants a sense of well being, awareness to the wider environment and offering alternative long distance view

which is relaxing to the eye after a close work. Thus natural light can have a beneficial effect on human health (International Energy Agency (IEA), 2000), comfort, and productive work environments for occupants (Wymelenberg & Meek, 2011).

The increased use of daylight in buildings also holds great potential to produce energy savings and diminish the need for mechanical devices to cool rooms overheated by low efficiency electric lighting appliances (Goulding & Lewis, 1997). Furthermore, as a key piece of the visual experience, daylight can serve as a dramatic design element and create a striking new generation of spaces. For these reasons most design teams are interested in including daylight in their projects. However, it is still an exception that daylight is designed to provide the main source of illumination; and rarely are architects equipped with the skills necessary to deliver comfortable and productive daylit spaces that have the potential to integrate with electric lighting systems to effectively save energy. Therefore, the prospective benefits of daylighting designs are often unrealized (Wymelenberg & Meek, 2011). Consequently, many buildings designed with extensive glazing for the purpose of providing daylight and views were operating with blinds permanently. Presents conditions, without realizing the qualitative or energy benefits of daylight and views to the exterior (Meek & Breshears, 2010).

Energy savings have proven to be the most difficult daylighting benefit to realize because daylighting implicates multiple design disciplines, such as that the daylighting provides visual comfort and pleasure to its occupants. The electric lighting design supports using daylight as the primary ambient light source and adequate daylight to be harvested (Wymelenberg & Meek, 2011).

2.3.2 Daylight availability

Daylight strategies depend on the availability of natural light which is determined by the latitude of the building site and the conditions immediately surrounding the building, such as the presence of obstruction, local site and prevalent climate. Daylight availability not only depends on the latitude but also on building orientation; each orientation will require a particular design emphasis. Hence the daylight design solution and understanding the operating condition of the building's facade requires studying both the climate and availability of daylight at the construction site (International Energy Agency (IEA), 2000)

2.4 Cooling strategy

The use of operable shading devices impacts building loads significantly. The need exists for analyzing of window shading devices in the design of energy efficient buildings through energy simulation tools (Lomanowski & Wright, 2009).

2.4.1 Solar control and shading devices

Current architectural trends, exhibit highly glazed facades therefore the management of solar gains is a central consideration in energy efficient building design. Solar gains through windows represent the most variable and largest gain in a building (Lomanowski & Wright, 2009).

To prevent overheating through solar gains in cooling periods and to decrease the cooling energy consumption of buildings, the glazing surfaces of buildings must be protected from unwanted solar gains in summer. This is achieved by blocking the sun's rays with shading devices before they reach the building (Stack, Goulding, & Lewis, 2000).

To achieve a comfortable internal temperature, a number of measures such as solar control, external gains, internal gains, ventilation, and natural cooling should be taken into account (Goulding, Lewis, & Steemers, 1992). However, building cooling loads could significantly increase if southern orientation of building with large window areas and without appropriate solar control strategies may result in overheating during summer. Therefore, the building's exterior glazing, must have proper shading devices and must be correctly selected and designed (Lomanowski & Wright, 2009)

2.4.2 Shading devices

Shading devices are both architectural and non-architectural elements which, with the use of seasonal difference of solar angles, provide shade on the glazing surface in warm periods while permitting the sunrays to enter the building in cold periods. Sun angles; particularly solar altitude angle; vary depending on the time of year. When necessary, this can be used to shade windows. Shading devices may be external, internal or mid-pane, fixed, movable or retractable, permanent or seasonal, horizontal or vertical, manual or automated.

Shading systems, which are shaped according to the changing seasonal sun path, can effectively control the sun's direct radiation. If designed correctly, they can also partially block diffuse and reflected radiation during the summer but not winter (Olgyay, 1992).

Shading devices not only have a shading function, but can also serve as daylighting or insulating devices.

2.4.3 Typology of shading devices

Designing a shading strategy through the selection of different type of shading devices should be determined by building's location, orientation, type and use, sky conditions, such as direct, diffuse and reflected solar radiation components and other light sources.

Horizontal shading devices, such as overhangs and horizontal louvers are preferable for blocking high angle sunlight. They are therefore more efficient for south-facing facades in the northern hemisphere and north-facing facades in the southern hemisphere. However, vertical louvers are more suitable for east and west-facing windows (Stack, Goulding, & Lewis, 2000) because vertical shading devices such as fins can block low angle sunlight shining on the east and west facades thus making them not suitable.

2.4.4 External and Internal Shading Devices

Exterior devices are the most effective in reducing heat gains because they intercept and dissipate most of the heat in solar radiation before it reaches the building surfaces. They have two general forms: fixed and movable. Fixed external shading refers to horizontal overhangs, vertical fins, and trees. Movable external shades are suitable for Northern European climate but need to be robust (Stack, Goulding, & Lewis, 2000).

Internal shading devices are movable or retractable elements that are used on the inner face of a window within an occupied space. They are typically in the form of roller or venetian blinds, curtains and draperies. Internal shading devices do not obstruct direct sunlight until it has passed through the glazing. The solar radiation is thus absorbed by the shading devices, converted into heat, and released into the room. Consequently, they have limited thermal efficiency.

For internal shading devices color, material, and degree of translucency have a significant influence on efficiency. Light colored and reflective devices reflect some solar radiation back outside, while rough and dark colors absorb it (Stack, Goulding, & Lewis, 2000).

2.4.5 Overhang

When correctly designed and applied to a south-facing facade, the horizontal overhang; such as indicated on Figure 2; can provide complete shading during midsummer and permit solar penetration in winter. The overhang length is determined by the width of the

aperture and the latitude. The depth is determined by latitude, window height, and the vertical distance between the window and the Overhang (Stack, Goulding, & Lewis, 2000).

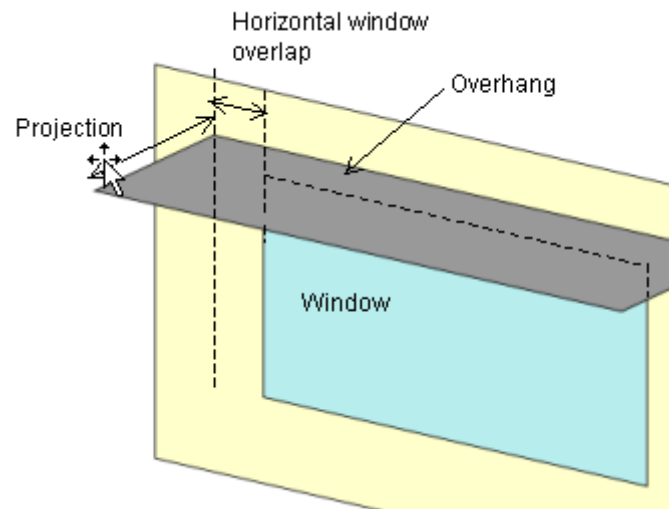


Figure 2: Overhand perspective, source: DesignBuilder(2005)

2.4.6 Louvers

External Louvers (Figure 3) are increasingly used to provide solar protection for glazed surfaces on building. Louvers are adjustable exterior shading devices which consist of a series of horizontal or vertical parallel slats. These slats are adjustable to moderate sunlight entering the room.

They are capable of controlling direct sunrays with different altitude angles, reflected and diffuse radiation, and also vision, while permitting ventilation. They can be controlled from inside or outside. Adjustable louvers are of two kinds: horizontal and vertical. Horizontal louvers are suitable for south facing windows because they can better prevent high summer sun and permit low winter sun to enter the room (Oliveira & Marrero, 2006). However, in east and west facing windows, horizontal louvers cannot provide effective protection from the low-angled sunlight of morning and afternoon, whereas vertical louvers can. They are proven to be able to decrease by 85% to solar heat gains (Olgyay, 1992).

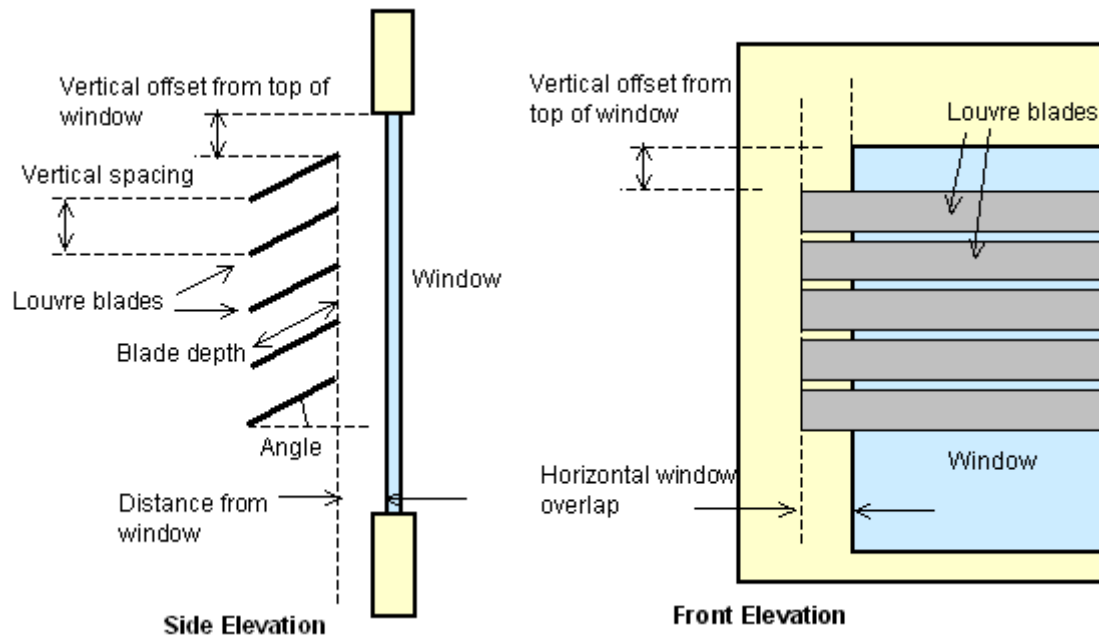


Figure 3: Louvre side and front elevation. source: DesignBuilder(2005)

2.4.7 Roller Blind

A rolled blind is a kind of movable shading device with a series of small slats that are lowered along a track when shading is needed. The lower the shade is pulled, the further closed the slats become; when fully extended the blind allows no light to enter. There are two kinds of roller blinds: exterior and interior. Exterior roller blinds can be highly effective in reducing solar gains but will eliminate views and impede ventilation (Olgyay, 1992); therefore they can reduce solar heat gain through windows between 61% and 19%. Although internal roller blinds are not efficient, they can serve a heat insulation function through convection and radiation in winter.

2.5 Integrated building design

2.5.1 Energy simulation tool for energy analysis

Energy performance simulation programs are powerful tools to study and analyze energy performance and thermal comfort during a building's life-cycle. Energy simulation tools predict the energy performance of a given building and thermal comfort for its occupants. In general, they support the understanding of how a given building operates according to certain criteria and enable comparisons of different design alternatives.

As illustrated in Figure 4, the input mainly consists of the building geometry, internal loads, HVAC systems and components, weather data, operating strategies and schedules,

and simulation specific parameters. A major benefit of energy simulation in design today is the ability to compare architectural design alternatives (Maile, Fischer, & Vladimir, 2007). The integration of a design knowledge-base in energy simulation tools is therefore required to support quality decision making (Attia, Beltran, Herde, & Hensen, 2009).

Architects are looking for tools that can support sustainability design decisions and make detailed comparisons between different building design and equipment measures (Augenbroe, 2002).

Architects in their work, are more comfortable with a tool that provides graphical representation of simulation input and output. They would prefer to build their simulation in a 3D environment, to be able to create comparative reports for multiple alternatives, and to assure quality control for the simulation input parameters (Attia, Beltran, Herde, & Hensen, 2009).

2.5.2 Architecture and integrated building design

Research by BRE (Building Research Establishment) and others reported that about 50% of building failure originates from design, an integrated approach to building design, is required to improve building quality (Hong, Zhang, & Jiang, 1996).

The Integrated Design Process (IDP) is center around the capacity to integrated knowledge from engineers and architecture in order to answer complicate problems connected the environmental design of buildings (Aschehoug & Andresen, 2011). This method was proven to enhance creativity and indentify new opportunities and make innovative solutions in a new building design (Sadineni, Madala, & Boehm, 2011).

Thus building energy modeling can be useful as a support tool used in early stages of the design to get the idea of what approaches and design schemes are the most promising for given projects.

To sum up, architects and designers, both have the available computer simulation tools, as tools for predicting energy use and indoor climate but also serves as evaluation and design support tools to achieve the targeted building quality. (Attia, Beltran, Herde, & Hensen, 2009).

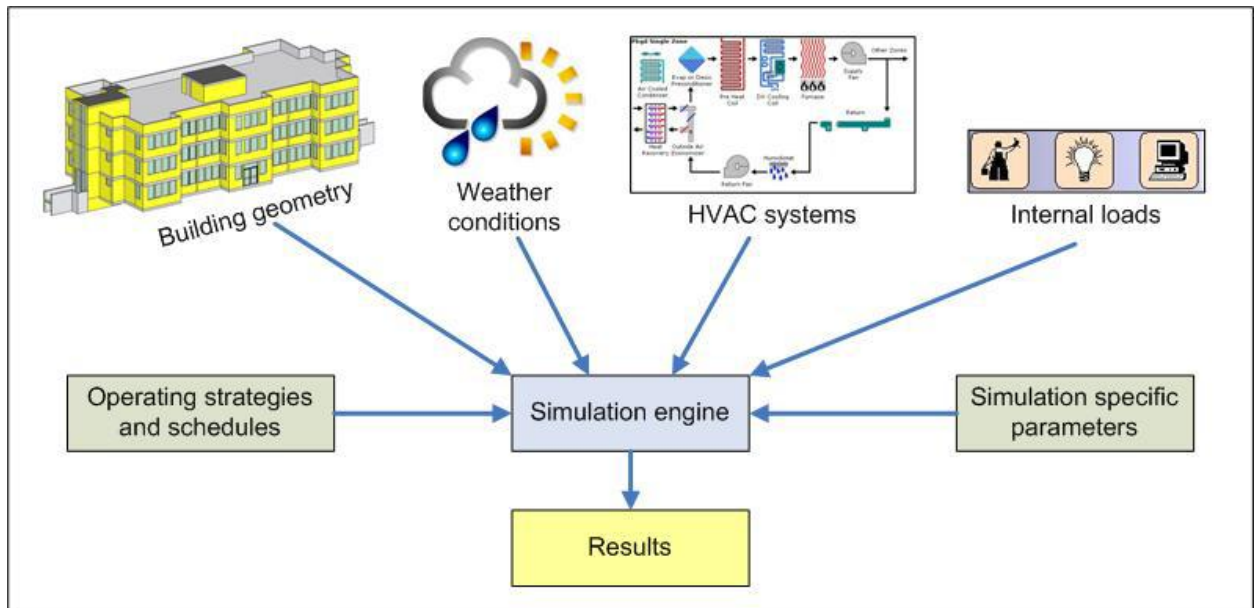


Figure 4: General data flow of simulation engines (Maile, Fischer, & Vladimir, 2007)

2.5.3 Architectural integrated design process

Successful design requires integrating many types of information into a combined whole. The core of integrated design process is the search for synergies or harmony between attributes such as climate, design, and system to condition Indoor Environment Quality (IEQ). IDP is a collaborative approach that draws upon the needs, expertise, and insights of a multidisciplinary team throughout a project, as is illustrated in figure 4. This will produce a combined performance that exceeds the sum of their individual performances (WBDG, 2010).

The integrated design process is characterized by the consideration of climate as resources rather than a burden, occupancy schedules as flexible rather than fixed. Thermal and visual comfort standards are related to people, not spaces difference between task and ambient requirement. Furthermore, building and site design as opportunities to reduce or eliminate HVAC system loads (Energy Studies in buildings Laboratory, 2006). IBD's "whole-building" approach is to assure that the design process is interdependent, rather than as separate components. This viewpoint helps to make certain that systems work harmoniously rather than against one another (Andresen, Kleiven, Knudstrup, & Heiselberg, 2011) as shown in figure 5.

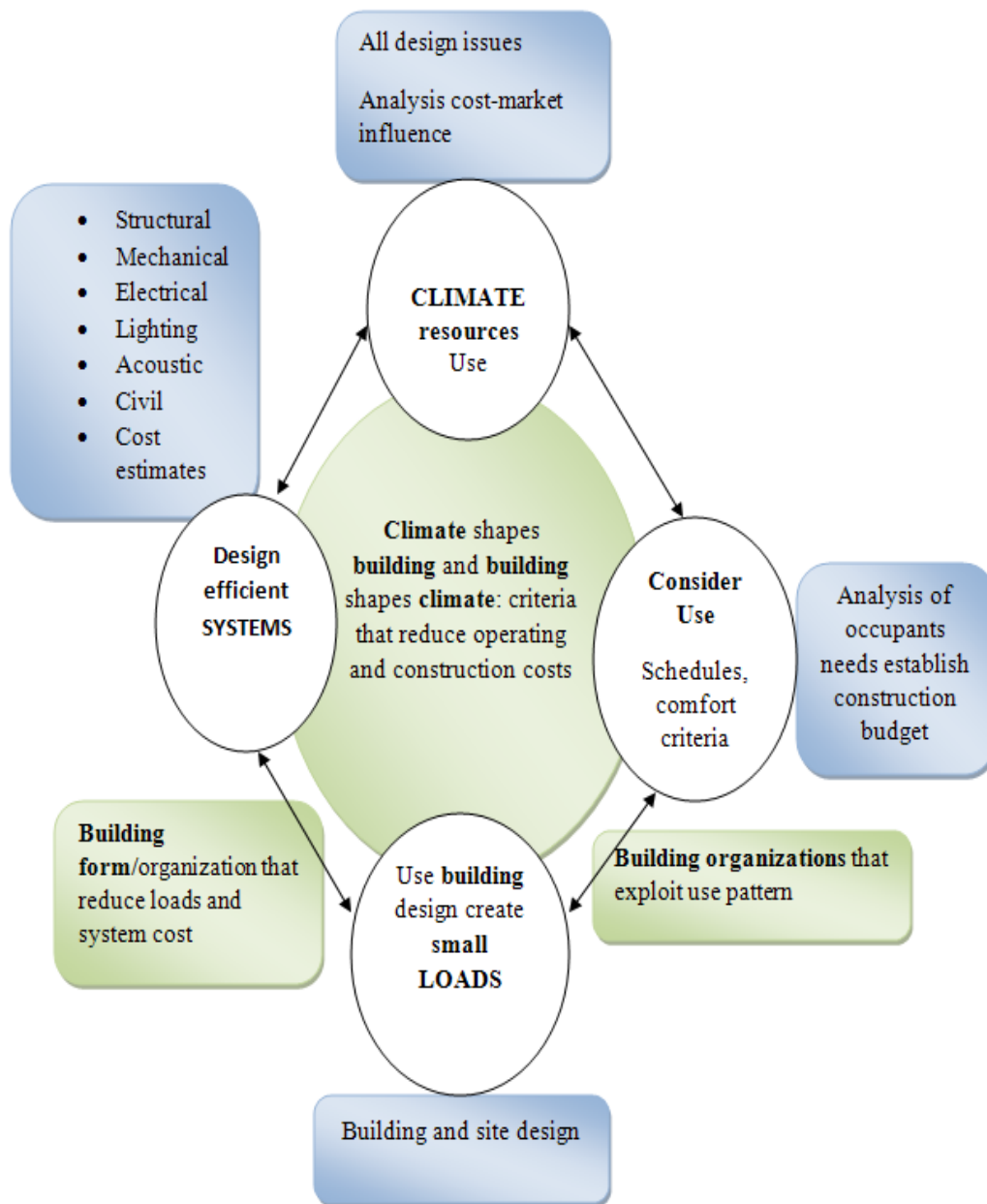


Figure 5: Close loop building integrated design process (Energy Studies in buildings Laboratory, 2006)

2.6 Rules and regulations

Given the long lifespan of most buildings, the energy efficiency of new buildings will influence its energy consumption for many years. Energy efficiency requirements in building codes or energy standards for new buildings are therefore among the most

important single measures for buildings' energy efficiency. Construction of buildings offers convincing opportunities for energy efficiency, as decisions made during a building's design phase entail smaller costs with greater potential energy savings relative to later intervention. Therefore, building codes requirement in regard to energy efficiency is to ensure that concern is taken for energy efficiency at the design phase and can help to realize the large potentials for energy efficiency in new buildings. Energy efficiency requirements for new buildings are set in different ways. Based on national or local traditions they can either be integrated in the general building codes or standards for new buildings, or they can be set as separate standards for energy efficiency (Laustsen, 2008).

Though most energy efficiency requirements in building codes followed local, state or national tradition, the past decade has shown a trend in supranational collaboration to develop international energy efficiency requirements or standards. An example of the European Energy Performance in Buildings Directive (EPBD) effective in January 2006, that required European Union member states to set up requirements for energy efficiency in new buildings

To supplement the EPBD, the European Union aims to establish a model building code for energy efficiency for the European region (2006 EU Action Plan for End-use Efficiency) and to develop CEN standards for energy performance calculation and provide guidance to ensure that energy management becomes integrated into organizational business structure.

2.6.1 Iceland

The main piece of legislation in Iceland that addresses energy efficiency in buildings is Act n°160/2010 on construction chapter I, contains its objectives, which include the promotion for good energy efficiency in operation of buildings.

Regarding Energy Performance of Building Directive (EPBD 2002/91/EC) implies that the Nordic countries should have implemented energy labelling systems; Iceland has decided not to implement an energy labelling system due to its favourable energy supply (Andresen, Thomsen, & Wahlstrom, 2010).

2.6.2 Nordic countries

In Norway, the building labelling system was introduced in July 1st 2010. Denmark implemented an energy labelling system for all buildings already in 1997.

The Nordic countries requirements set for energy efficiency are believed to be among the stricter in Europe. All the Nordic countries have implemented the EPBD, except Iceland (Andresen, Thomsen, & Wahlstrom, 2010).

Table 2: Definitions for total or primary energy demand including weighting factors

Denmark

The total primary energy demand of the building for supplied energy for heating, ventilation, cooling, domestic hot water and, where appropriate, lighting. Where A is the heated floor area in m². Weighting factor for heat in the primary energy calculation is 1.0 and for electricity 2.5

Dwellings	$(70+2200/A)$ kWh/m ² per annum
Other buildings	$(95+2200/A)$ kWh/m ² per annum

Finland

No requirement in BC2010, primary energy in BC2012. (contains requirement on specific technical performance(U-values and air tightness))

Iceland

No requirements on specific technical performance, only U-value and air tightness

Norway

Total energy demand: separate requirements for 13 different building categories, calculated with Oslo climate and standardised used. As general rule 40% of heat demand has to be supplied by other sources than grid electricity or fossil fuels, but exceptions are possible

One family house	125kWh/m^2 per annum+ $1600/\text{m}^2$ heated floor area
Apartment building	120 kWh/m^2 per annum

Sweden

Delivered energy excluding household appliances (kWh/m² per annum). Solar thermal or photovoltaic systems placed on the building site are not included in the energy performance requirements

	Southern Sweden:	Central Sweden	Northern Sweden:
Dwellings	110	130	150
Premises	100	120	140
All building heated with electricity	55	75	95

Energy terms explanation

- Primary energy is the energy embodied or contain in natural resources prior to undergoing any human-made conversions or transformations.
- Delivered energy is energy content as it is received by the consumer

2.6.3 European Union

European parliament approved an amendment 2002 Energy performance of the Energy Performance of Building Directive (EPBD 2002/91/EC) published in June 2010. The Directive requires member States to take the necessary measure to ensure that minimum energy performance requirements for buildings are set (Andresen, Thomsen, & Wahlstrom, , 2010). The directive proposes that all new buildings built after 31 December 2018 will have to produce as much energy as they consume on site (Ferrante & Cascella, 2011), and by 31 December 2020, all new buildings will have nearly zero energy requirements (Andresen, Thomsen, & Wahlstrom, 2010).

3 Methodology

DesignBuilder (DB) energy analysis program was used to model Háskolatorg building, located in Reykjavik, Iceland. This building will be called “reference building” or “Háskolatorg building” throughout this study. DB Computer simulations can provide convenient and quick prediction of the reference building energy assessment and potential (Wang, Gwilliam, & Jones, 2009).

In this study, DB simulation was used to predict or calculate weekly, all summer, all winter and annum energy consumption. In order to run the program, virtual 3D model of the reference building has been drawn and thermal zones were described within the virtual building, based on the information about the size, shape and function, of the reference building. Simplification of the original plan of the reference building however was adopted to facilitate the analysis, since it is considered as early design method. The annual, peak hourly heating and cooling loads for each zone has been calculated. These calculations were made based on details design of the reference building and the Reykjavík Weather file that was inserted in DB simulation tool.

Furthermore, a survey web based software QuestionPro (QP) was conducted to assess the building performance relating to Occupant/tenant’s behaviour, since they are rich sources of information about the indoor environmental quality of the building and its effect on productivity and comfort.

3.1 Data collection

DB input construction, opening, and glazing data was collected from the Architectural drawing provided by the building authority in Reykjavik (Hornsteinn and Ingimundur Sveinsson, 2006). Complementary data, such as lighting and office equipment heat loads needed for the simulation were supplied by Almenna verkfræðistofan (Almenna verkfræðistofan, 2005). As for the Reykjavík weather file needed for the DB simulation software were available by the website of United States Department of Energy (U.S. Department of Energy, 2012).

The university of Iceland facilities management provided information on the current number of students registered in the spring of 2011, as well as usage and costs for hot and cold water and electricity over one year period from 01 September 2010 until 31 August 2011. The schedule of office hours and class timetable in the reference building was provided by the same management at the University (Rekstrarstjóri fasteigna, 2011).

Reykjavík weather data was collected from the Icelandic meteorology office (Icelandic Met Office, e.d.).

3.2 Research area: Reykjavik

The present research was focused on the City of Reykjavík, which is located in south-western of Iceland, on the southern shore of Faxaflói bay, with a population of around 120.000. It is the heart of Iceland's economic and government activity. Its geographic coordinates are latitude 64.14° north, longitude 21.9° west, and has an average altitude of 37 m above current sea level. The climate of the city is considered sub polar oceanic due to Iceland's geographic situation near the border between warm and cold ocean currents. Iceland enjoys long periods of sunshine almost 24 hours, during the first half of summer, which extends from late May until early September. The winter season, however is characterized by long night (Einarsson, 1984).

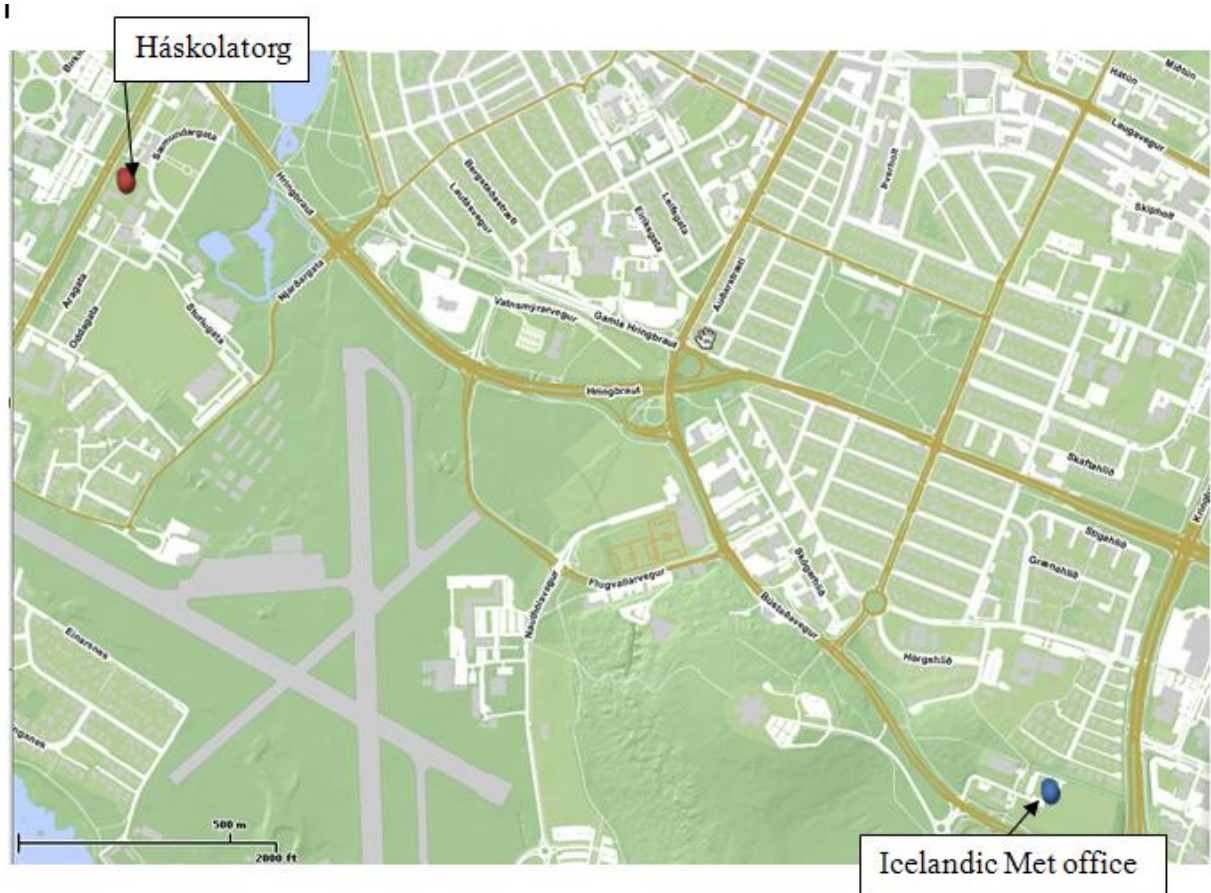


Figure 6: Reykjavík Map. source: (Reykjavíkborg, 2012)

The city's coastal location does make it prone to wind and gales are common in winter. Temperatures very rarely drop below -15°C in the winter, and summer temperatures are rather cool with fluctuations between 10 to 15°C , with some exceptions of over 20°C . Spring tend to be sunniest season; May in particular. Annual sunshine hours in Reykjavík can exceed around 1300 (Icelandic Met Office, e.d.).

It is noteworthy that the Háskolatorg building is situated around 1 km from the Icelandic Meteorology Office; such as shown on Figure 6; where the Reykjavik weather data originally were collected.



Figure 7: Average monthly sun hours in Reykjavik, Iceland. (World Weather and climate Information, 2011)

3.2.1 Iceland and geothermal space heating

In a cold country like Iceland, home heating needs are grater than in most countries. Geothermal resources have been developing slowly but yet, currently contribute about 90% of household space heating nationwide. Today, space heating is the largest component in the direct use of geothermal energy in Iceland. 47% of geothermal energy of 16,468 GWh is believed to be the used in space heating in 2008, as illustrated in figure 8 (Björnsson, Guðmundsdottir, & Ketilsson, 2010). the average space heating energy usage per building is about 179 kWh/m² per year (City of Reykjavik, 2011).

The. use of geothermal energy for space heating and electricity generation has also benefited the environment. The benefit lies mainly in lesser CO₂ emissions compared to fossil fuel power plants. It was calculated that Iceland has avoided emissions of about 4,9 Mt of CO₂, from using geothermal energy for space heating and power generation or nearly 170% of total country emissions in 2008 (Björnsson, Guðmundsdottir, & Ketilsson, 2010).

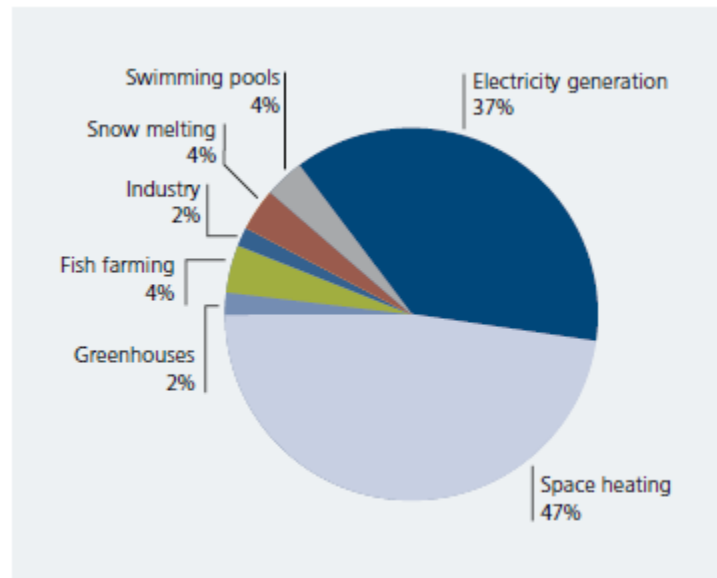


Figure 8: Sectorial share of geothermal energy in Iceland in 2008. source: (Björnsson et al., 2010)

3.3 Simulation tools

3.3.1 DesignBuilder core concepts

DesignBuilder© (DB) simulation was used because of its combines rapid building modelling and relative ease of use. DB is a software tool for creating and assessing building design and can be used effectively at any stage of the design process. It is a user-friendly modelling environment with virtual building model, from the concept stages where just a few parameters are needed to capture the building design to much more detailed building models for established designs.

Data templates were facilitated by loading common building constructions, activities, HVAC & lighting systems into the design by selecting from drop-down lists. These templates were edited to resemble the reference building information data. This, combined with data inheritance, allows global changes to be made at building, block or zone level. Default data was inherited from the level above, so blocks inherited their data from the building level; zones inherit their data from blocks, surfaces from zones and opening from surfaces, as shown in Figure 9 (DesignBuilder, 2005). This arrangement has permitted to make settings at building level which could be active throughout the whole building.

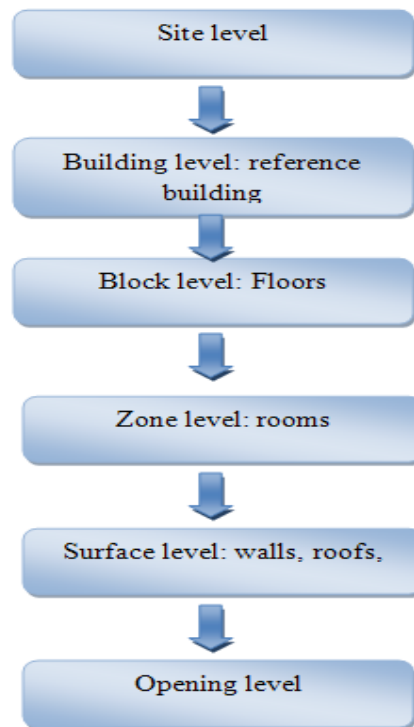


Figure 9: Model data hierarchy and data inheritance. source: (DesignBuilder, 2005)

The DB simulation assessed different capabilities such as:

- building energy balance and performance,
- Detailed analysis of commonly used heating and cooling system.
- Daylighting models to calculate savings in electric lighting.

A comprehensive range of simulation were shown in annual, monthly, daily or hourly, sub-hourly intervals for energy consumption, heating and cooling loads, and heat transmission through the building fabric including walls, roofs, glazing, infiltration, ventilation. These simulations were screened to investigate the effect of variations in design parameters on a range of performance criteria (DesignBuilder, 2005).

Building energy simulation has analyzed the reaction of the building 'skin and geometry in response to the internal loads taken account of solar heat gain, heat gain from occupants, electricity lights and equipment, and heat gained or lost through infiltration or by conduction through the walls, roof, and glazing (Sozer, 2010).

3.3.2 DesignBuilder simulation tool workflow

The workflow of DB was started by selecting of Reykjavík as the location and uploading the corresponding weather through file in EPW format, followed by the creation of specific of thermal building model geometry with the integrated computer Aided Design (CAD) interface. In this study, the reference emulation building was the 3D geometry represented needed for the energy simulation tools. A DXF files has been imported from AutoCAD to DB programme, used as footprint. Specific templates represent country and selection of parameters, such as material and constructions, provided by DB have been edited to imitate the reference building. A List of other definable parameters, included internal loads such as occupancy patterns and activities, construction type, openings which describe windows and doors, lighting and HVAC systems was added (DesignBuilder, 2005 and Maile, Fischer, & Bazjanac, 2007).

Once the definition of all these input parameters was completed, DB was launched to perform summer week, winter week, all winter, all summer and annual simulations.

3.3.3 Weather data file for DB simulations

In order to make hourly energy simulations, hourly weather data is required. DB uses a weather file known by the name EnergyPlus Weather (EPW). This file represents the average of 30 years of Reykjavik weather data. It is an International Weather for Energy Calculation (IWEC) file, provided by the U.S. Department of Energy website. IWEC was a product of the research by the American Society of Refrigerating and Air-Conditioning Engineers (ASHRAE). The Department of Energy (DOE) has licensed the IWEC data from ASHRAE. These data contain mainly the following: hourly data outside dry bulb temperature, outside dew point temperature, wind speed, wind direction, solar altitude, solar azimuth, atmospheric pressure, direct normal solar and diffuse horizontal solar (DesignBuilder, 2005).

3.4 Building characteristics

3.4.1 Reference building

For this study, a simplified model was drawn using DesignBuilder CAD interface. The model was three storeys high, and used the existing Háskolatorg building at the University of Iceland (Hornsteinn and Ingimundur Sveinsson , 2006), Reykjavik as a reference

building, as shown in figure 10. This building exhibits a number of features that makes it an interesting modelling object. Not only was Háskólatorg expected to serve academic functions involving primarily office administration and large lecture halls but also a bookshop, cafe and restaurant which has often been used for lunch and studying. The first floor consists of lecture halls, storage, toilet and an open reading hall, as shown in figure 12. The second floor contains a computer room, reading room, offices, kitchen, bookstore storage, waste storage and an open restaurant, exhibited on Figure. 13. The third floor as shown on Figure. 14 have both offices and meeting rooms.

The building was made with large number of zones but reduced compared to the existing number of rooms, in order to simplify and avoid excessive simulation time. The height of the building is 11,8 m with a net floor area of 8139,2 m². Heights between floors are 4,050 m, 3,726 m, and 4,024 m respectively for first floor, second floor and the third floor to the roof structure. The interaction of glass and exposed concrete are the predominant material of the building. The south and east facades of the building are characterized by large areas of glazing which open from the 2nd to the 3rd floors in addition to a skylight, situated on the south side of the roof.

Háskólatorg is situated at the centre of the University of Iceland. The building is situated at the west of Lögberg or the building of law department; it is at the north side of the building of the sports centre, north west of the building of Gimli, and at the south side of the main building of the University of Iceland, as exhibited in figure below



Map of the University of Iceland. Source: (University of Iceland, 2011)



Figure 10: Háskolatorg building perspective © Christopher Lund

As shown in Figure 11, Háskolatorg was set as the building level for DB simulation tool set up. First, second and third floors were set as block levels and the different rooms in every floor were designated as zones. All the zones are set to standard type which explains the way they are occupied during certain times during week days.

Building information sizes

Háskolatorg building area(m ²)	8139
Building height (m)	11,8
Háskolatorg building volume(m ³)	96.040
University Square zone area (m ²)	1.096
Building wall surface area (m ²)	1965
Building window surface area (m2)	525
University Square glazing facade area(m ²)	321
Háskolatorg building roof area (m ²)	1909

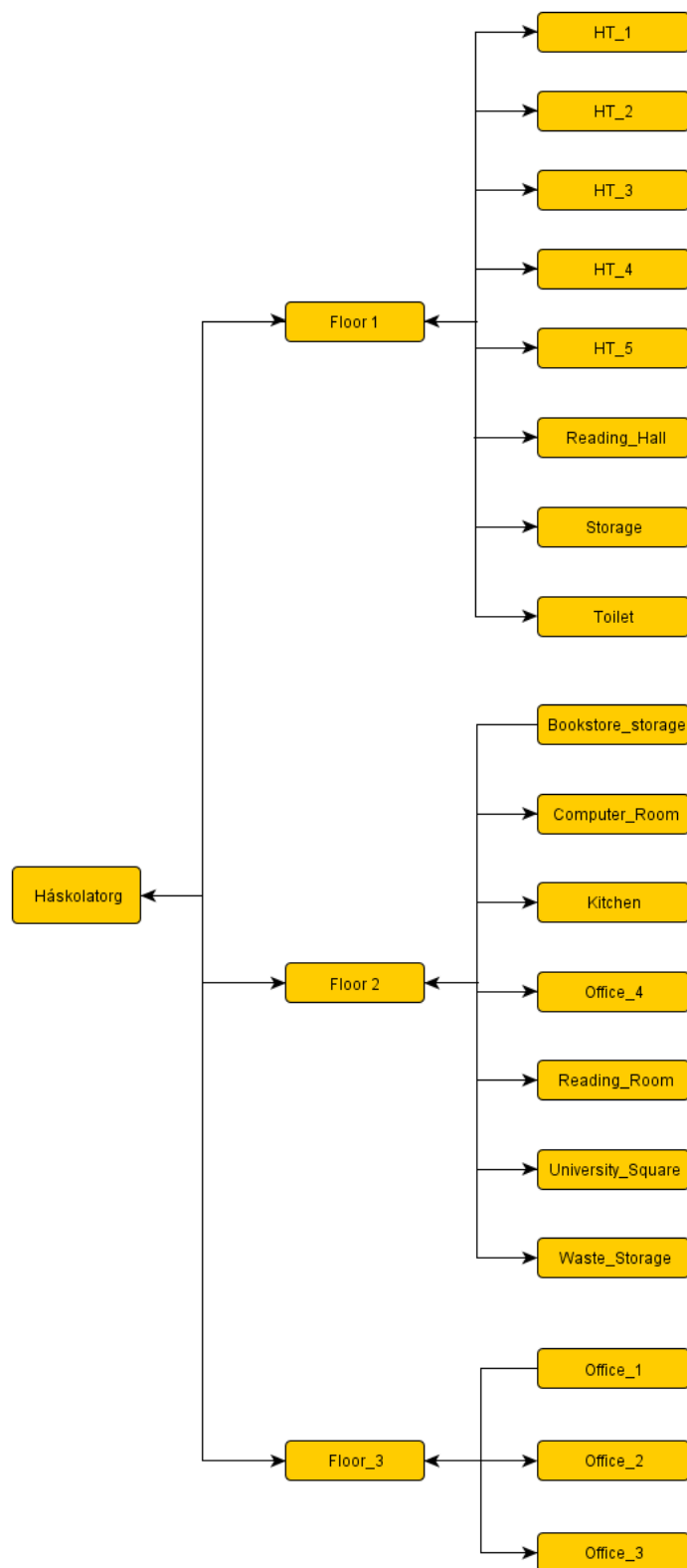


Figure 11: Chart of the building, block and zone levels

3.4.2 First floor zone description

The first floor of Háskolatorg is made of 8 zones, consisted of 3 larges lecture halls, 2 medium lecture rooms, toilet, a storage room and a reading Hall. It is emphasised that the opening between 1st floor and 2nd floor; such as it is on the reference building; has been omitted for the energy model.

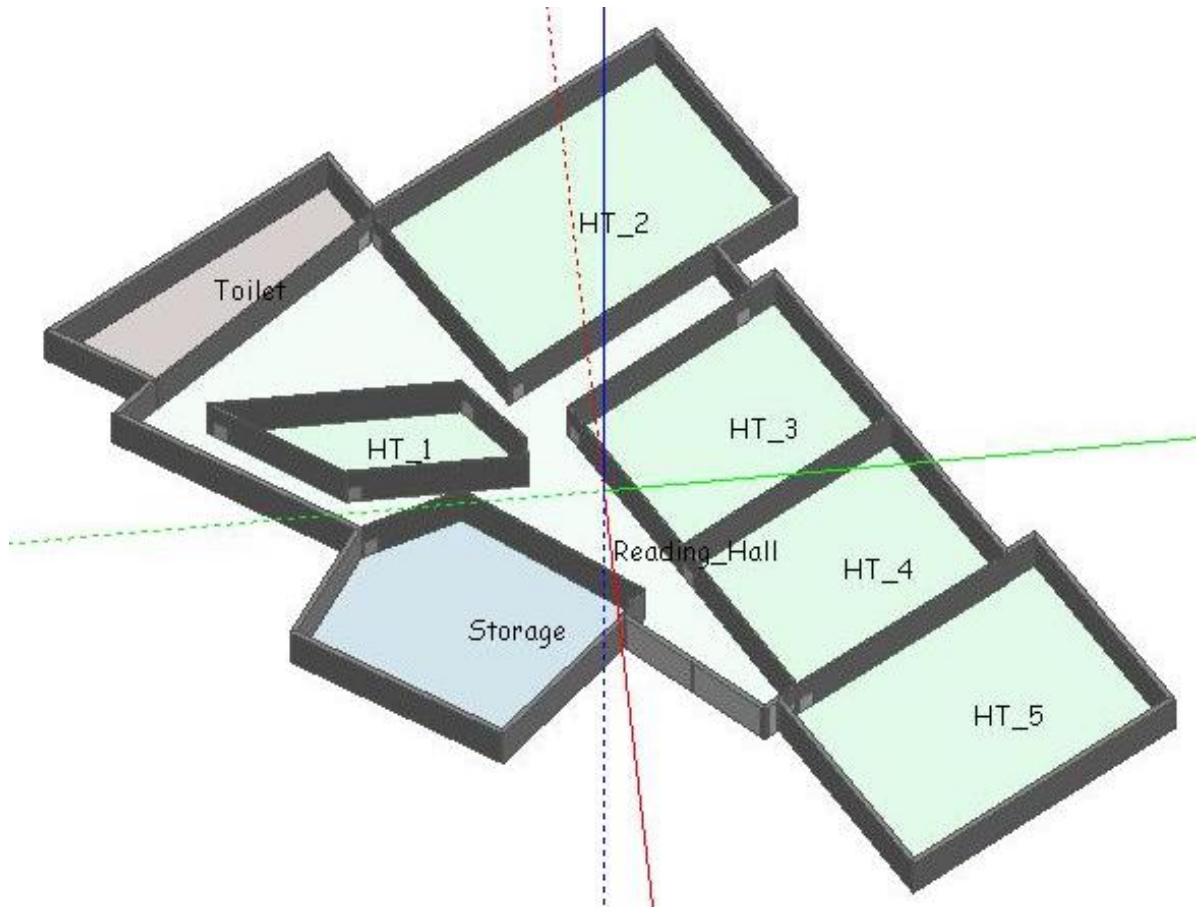


Figure 12: Háskolatorg first floor

Table 3 : First floor zones description

Zone	Zone type	Zone floor area(m ²)
HT_1	Lecture room	96,7
HT_2	Lecture room	378,9
HT_3	Lecture room	237,1
HT_4	Lecture room	238,1

HT_5	Lecture room	338,1
Reading Hall	Reading/seating /eating	515,05
Storage	Storage space	251,3
Toilet	restroom	134,7

3.4.3 2nd floor zone description

The second floor of Háskolatorg was made of 7 zones. They are the University Square which is the main focus of this study, a medium reading room, a computer room, offices, kitchen, waste storage and bookstore storage. The University Square is mainly used by student for reading, eating, and meeting.

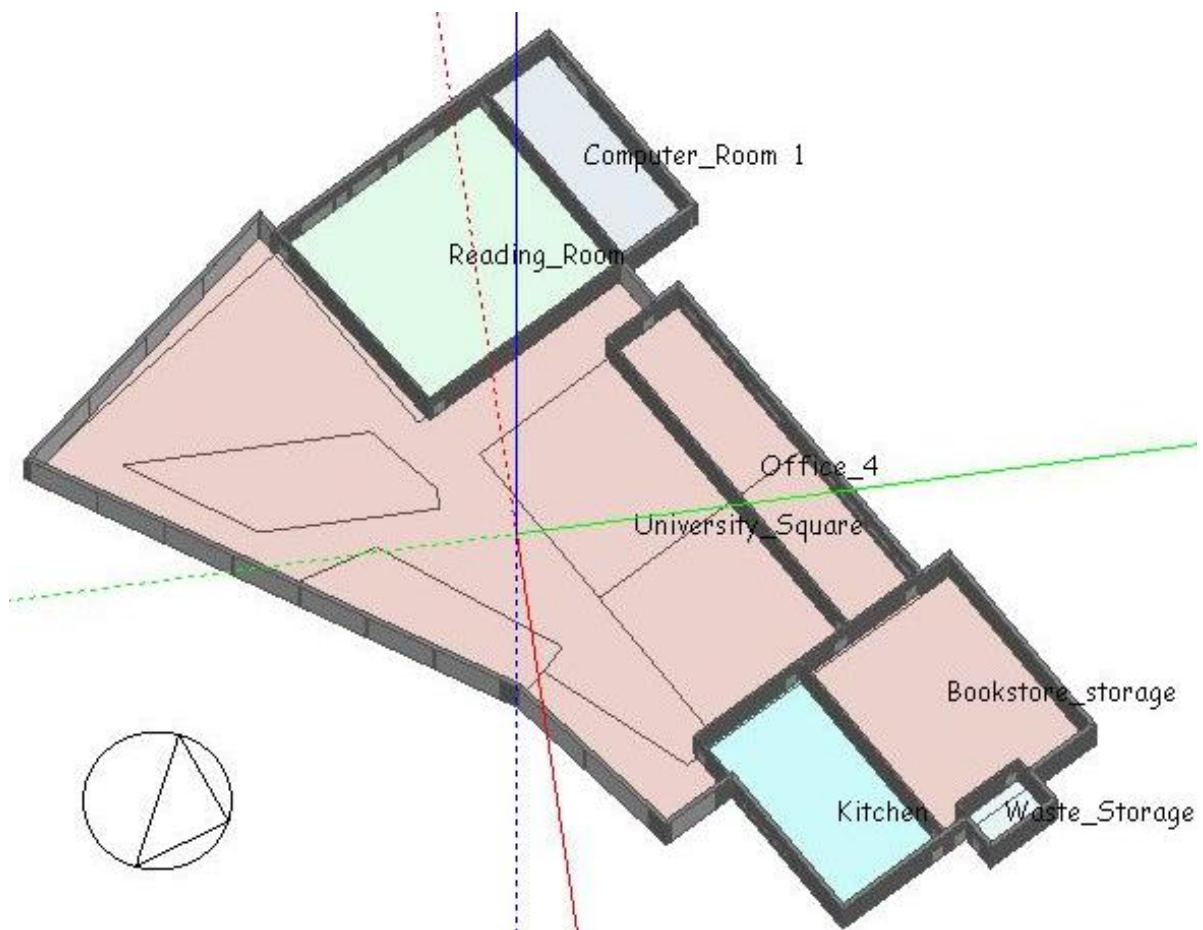


Figure 13: Háskolatorg 2nd floor

Table 4: Second floor zones description

Zone	Zone type	Zone floor area(m ²)
Computer_Room_1	Computer lab	95,4

Reading_Room	Reading space	280,7
Offices_4	Office and consultation	164,3
Book_storage	storage	199,8
University Square	Reading/restaurant	1096,95
Waste storage	storage	19,4
Kitchen	Food preparation	142,0

3.4.4 3rd floor zone description

The 3rd floor of Háskolatorg building is mainly 3 zones of office activity. The opening_to_Square zone was merged with the University Square zone

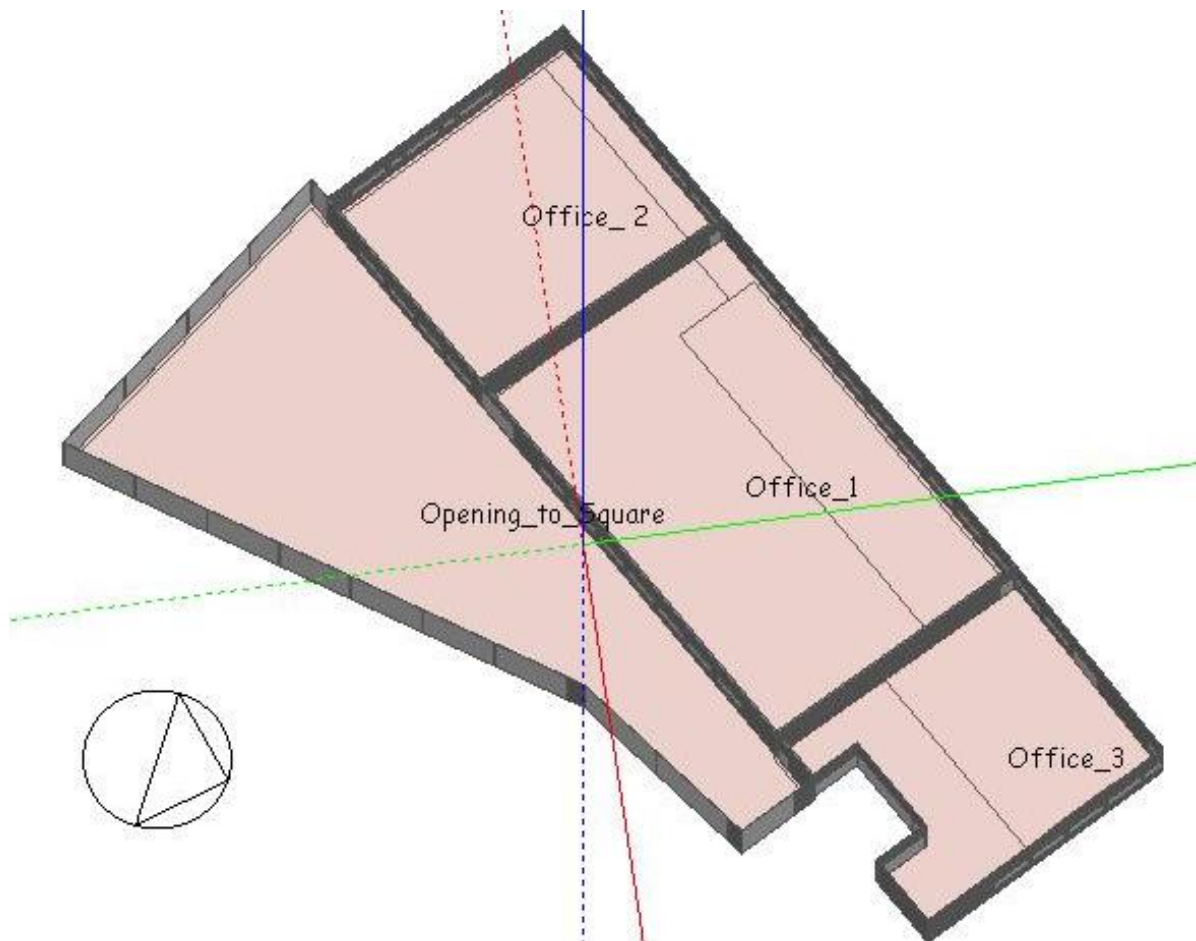


Figure 14: Háskolatorg 3rd floor

Table 5: third floor zones description

Zone	Zone type	Zone floor area
Office_1	Office	604,8
Office_2	Office	321,1
Office_3	Office	287,3
Opening_to_Square	Connect to Univesty_Square	697,5

3.5 Construction characteristics input

Construction data was defined on the building level to allow the block and zone levels to inherit the data from the building level. All construction data was provided by the drawings of the architects (Hornsteinn and Ingimundur Sveinsson , 2006)

3.5.1 Exterior wall

The structural exterior wall has an outermost layer of 220 mm of dense concrete, faced from the inside with 75 mm of Rockwool and a layer of polyethylene as vapour barrier, in addition to 2 layers of 13 mm of gypsum board, giving the structure a U-value of 0,364 W/m²-K, exhibited in table 6

Table 6: External wall layer description (innermost to outermost layer)

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Gypsum	0,013	0,250	1000	900
Gypsum	0,013	0,250	1000	900
Polyethylene	0,002	0,500	1800	980
Rock wool	0,075	0,033	710	100
Concrete	0,220	1,130	1000	2000

3.5.2 Internal partition

Internal partitions were based on the internal partition of the reference building and consisted of 75 mm rock wool, sandwiched between 2 layers of 13 mm gypsum, giving it a U-Value of 0,287 W/m²-K as shown on table 7

Table 7: Internal partition layer description

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Gypsum	0,013	0,250	1000	900
Rock wool	0,075	0,033	710	100
Gypsum	0,013	0,250	1000	900

3.5.3 Roof

The roof structure was based from the detail drawing of the reference building. It consisted of 13 mm of gypsum board as the innermost layer, with 3 layers of rock wool insulation, 75 mm, 250 mm, and 75mm in thickness followed by 15 mm of plywood and a layer of roofing felt membrane, overlaid by 100 mm of deep gravel. The roof structure U-Value was 0,079 W/m²-K, as exhibited in table 8

Table 8: Roof structure partition layer description (innermost to outermost layer)

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Gypsum	0,013	0,250	1000	900
Rock wool	0,075	0,033	710	100
Rock wool	0,250	0,033	710	100
Rock wool	0,075	0,033	710	100
Plywood	0,015	0,150	2500	560
Roofing Felt	0,002	0,190	837	960
Gravel	0,100	0,360	840	1840

3.5.4 Ground Floor

The ground floor structure was based on the reference building, constituting of a 120 mm cast concrete innermost layer, and a polyethylene layer as a thermal barrier, followed by a 100 mm polystyrene isolation. Considering the soil layer, giving the U-Value to 0,28 W/m²-K as shown on table 9. A soil layer however, is not required for the European code energy calculation.

Table 9: Ground floor structural layer description (innermost to outermost layer)

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Concrete	0,120	1,130	1000	2000
Polyethylene	0,002	0,500	1800	980
Polystyrene	0,100	0,035	1400	25
Soil(earth)	0,500	1,280	880	1460

3.5.5 External Floor

It was the structure external floor but yet roof of some spaces of the 1st floor of the building, such as the toilet and the storage room. The structure data was recorded based upon the drawing of the reference building. From the outermost layer, this structure was made up of a soil layer of 300 mm; roofing felt membrane and 210 mm of concrete. Under the concrete slab, rock wool served as insulation and was closed by gypsum board finish. The U-Value of the external floor was 0,146 W/m²-K as listed in Table 10.

Table 10: External floor structural layer description (innermost to outermost layer)

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Gypsum	0,013	0,250	1000	900
Rock wool	0,200	0,033	710	100
Concrete	0,210	1,130	1000	2000
Roofing felt	0,002	0,190	840	960
Soil(earth)	0,300	1,280	880	1460

3.5.6 Internal floor

This structure was recorded using the structural data above; the building reference. This structure was mainly the floor structure between storeys. It was designed with a 200 mm thick cast concrete, overlaid with 80 mm of cement mortar. The layer description was exhibited in Table 9 and the U-value of the internal floor was 1,764 W/m²-K

Table 11: Internal floor structural layer description

Layer	Thickness d (m)	Conductivity λ (W/m-K)	Specific Heat C (J/kg-K)	Density ρ (kg/m ³)
Cement	0,080	0,720	840	1860
Concrete	0,210	1,130	1000	2000

3.5.7 Glazing and Skylight

Window data was simplified, and similar as to the information described from the reference building which, was a 6 mm double clear glazed low-E coatings panes, clear glass and 13 mm air filled cavity, achieving a U-value of 1,9 W/m²-K.

The skylight was made of 8 mm double glazed panes, clear glass, and an argon gas filled 12 mm cavity yielding a U-value of 2,499 W/m²-K.

3.6 Activity data input

The data covers occupancy, equipment usage suitable design internal temperatures, illuminance levels and ventilation rate per person have been loaded.

3.6.1 Building level

At the building level an edited generic template was downloaded, covers metabolic rate of 0,90 value, representing the average of men metabolic rate at 1 and women at 0,85. Clothing level of occupants for summer was designed at a value of 1clo, and in winter at 1,5 clo.

In order to calculate annual simulations, the Icelandic holiday schedule was listed and loaded at building level, as shown in table 12.

Table 12: Iceland Holidays schedule

Name	Start date	Number of days
New year	January 01 st	1
Maundy Thursday	April 05 th	1
Long Friday	April 06 th	1
Easter	April 08 th	1
2 nd Easter	April 09 th	1
1 st day of Summer	April 19 th	1
International worker's day	May 01 st	1
Ascension	May 17 th	1
2 nd Pentecost	May 28 th	1
Shopkeeper holiday	August 06 th	1
Christmas	December 25 th	1
2 nd day of Christmas	December 26 th	1

3.6.2 All zones environmental controls

All zones indoor environmental control: to define the setting of the heating of the thermostat in the zones space when heating were required, correspond with temperature control calculation option as air temperature, the heating setpoint temperature was set at 20°C. The reference building proposed required low level of heating during unoccupied periods to avoid condensation/frost damage or to prevent the building becoming too cold and to reduce peak heating requirements at start up, the heating setback setpoint Temperature was set at 12°C.

The ideal temperature, such as the setting of the cooling thermostat, in zones spaces when cooling is required corresponding with temperature control option as air temperature, the Cooling Setpoint Temperature was set at 26°C. As for the building requirement of low level of cooling during unoccupied periods to prevent the building becoming too hot and to reduce the start up cooling load the next morning, the Cooling Setback Setpoint Temperature was set at 32°C.

3.6.3 First floor zones

Lecture Halls HT_1, HT_2, HT_3, HT_4, HT_5

In the 1st floor of the building: HT_1, HT_2, HT_3, HT_4, HT_5 zones have been set with a common edited activity generic template HT-classroom, it is because these zones are sharing the same function as lecture rooms. Domestic Hot Water (DHW) was set at the value of 0,15 l/m²-day.

The occupation schedules were the result of an average of 5 weeks of compound time schedules provided by the University administration.

Minimum fresh air requirement are designated by Icelandic building regulation regarding lecture rooms and were set at 11,2 l/s,m² (Mannvirkjastofnun, 2012) .The desired lighting level at the sensor or the lighting level produced at that sensor position at night if the overhead electric lighting were operating at full input power, was set at 300 lux, as typical value for lecture room (McMullan, 1998), however some zone lighting level data have been calibrated. The computer gain in every Lecture room was manually calculated according to the volume of occupancy and schedule provided by the University (Rekstrarstjóri fasteigna, 2011). As for environment control; heating setpoint temperature was set at 20°C, heating set back at 12°C. The cooling setpoint temperatures was set at 26°C and cooling setback temperature was set at 32°C in all zones on the first floor.

Table 13: First floor lecture rooms average daily hour occupancy

Lecture room	Average daily hour occupancy
HT_1	6
HT_2	5,17
HT_3	6,9
HT_4	5,35
HT_5	5,4

Zone HT_1 Activity

Table 14: Zone HT_1 Activity tabulationActivity templete

Area (m2)	Occupancy (people/m2)	Schedules	Days
96,7	0,15	8 am-2 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	300	11,2

Equipments

Computer
gains(W/m²)
6

Zone HT_2 Activity**Table 15: Zone HT_2 Activity tabulation**Occupancy

Area (m ²)	Occupancy (people/m2)	Schedules	Days
378	0,15	8 am-1 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	200	11,2

Equipments

Computer

gains(W/m²)
6

Zone HT_3 Activity

Table 16: Zone HT_3 Activity tabulation

Occupancy

Area (m ²)	Occupancy (people/m2)	Schedules	Days
237	0,01	8 am-3 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(1/s-m2)
26	26	200	11,2

Equipments

Computer
gains(W/m²)
6

Zone HT_4 Activity

Table 17: Zone HT_4 Activity tabulation

Area (m ²)	Occupancy (people/m2)	Schedules	Days
238	0,01	8 am-5 pm	5

Environmental Control

Heating setpoint temperature(°C)	Heating setback(°C)	Cooling setpoint temperatures(°C)	Cooling setback(°C)
20	12	26	32

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(1/s-m2)
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26	26	200	11,2
<u>Equipments</u>			
Computer gains(W/m ²)			
6			

Zone HT_5 Activity

Table 18: Zone HT_5 Activity tabulation

Occupancy

Area (m ²)	Occupancy (people/m2)	Schedules	Days
338	0,15	8 am-2:20pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	200	11,2

Equipments
Computers gains(W/m²)
6

Zone Reading_Hall Activity

Table 19: Zone Reading_Hall activity tabulation

Areas(m ²)	Occupancy (people/m ²)	Schedules	Days
516	0,08	8 am-5 pm	7

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	300	11,7

Equipments

Computer gains(W/m ²)	Miscellaneous gain (W/m ²)
1	15

The Reading_Hall zone on the first floor was set with an edited generic template activity HT_Hall/lecture theatre/assembly area, because this zone was able to accommodate around 87 seated people. This zone is used mainly for reading, assignment and eating during lunch time. The DHW was set at of 0,15l/m²-day.

The occupation schedules were results of numerous of seat sighting counts of the number of occupants in the Reading_Hall zone. Because of its 24/7 hour occupancy nature, this zone has hypothetical set an average of 9 hours time of occupancy which elapsed from 8 am until 8 pm. the density of occupancy was hypothetically set at an average of 0,05 people/m².

.The minimum fresh air was set at 11,7 l/s-person in accordance with the Icelandic building regulation. The desired lighting level was set at 300 lux, as typical value for a lecture room. Computer heating gain was set at 1 W/m². Miscellaneous gain were set at 15 W/m² because of the automatic vendor machines present in this zone

Zone Storage Activity

Table 20: Zone Storage activity tabulation

Activity templete

Areas (m ²)	Occupancy (people/m ²)	Schedules	Days
251	0,01	8 am-4 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling(°)	Mech. Ventilation (°)	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m ²)
26	26	50	11,7

The storage zone on the first floor, was set with generic activity template 24x7 Warehouse storage, it is because this zone's purpose was year round storage for the University. The occupancy schedule however was set at 8 am until 4 pm, or normal office typical hour. The occupancy density was set at 0,01; the minimum level possible as this area was occupied only during the moving in and out of furniture or utilities. It is used as storage for chairs, billboard, and other equipment. The DHW was set at the value of 0,0011/m²-day.

The minimum fresh air was set at 11,2 l/s-person in accordance with the Icelandic building regulation. The desired lighting level was set at 50 lux.

Zone Toilet Activity

The toilet zone was assigned the generic activity template HT_Toilet.. The occupancy schedule was set from 8 am until 8 pm, like the Reading_Hall zone and occupancy density set at 0,05. The DHW was set at the default value of 0,11/m²-day.

The toilet minimum fresh air was set at 15 l/s-m² in accordance with the Icelandic building regulation. The target illuminance level was set at 200 lux, as is typical value for a restroom.

Table 21: Zone toilet activity tabulation

Areas (m ²)	Occupancy (people/m ²)	Schedules	Days
134	0,05	8 am-8 pm	7

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m ²)
26	26	200	15

3.6.4 Second floor zones

The second floor there contains 7 zones described as book storage, computer room, kitchen, office, reading room, University Square, and waste storage. The environment control heating setpoint temperature was set at 20°C, heating set back temperature at

12°C. The cooling setpoint temperature was set at 26°C and cooling setback temperature was set at 32°C in all zones on the second floor of Háskolatorg.

Bookstore storage

Generic activity template 24x7 Warehouse storage was used for the bookstore storage zone. The occupancy schedule was set from 12 am until 4 pm, such as a typical office workday. Occupancy density was set at 0,01 for 5 days a week. The DHW was set at the default value of 0,02 l/m²-day. The minimum fresh air was set at 0,2 l/s-m² according to the Icelandic building regulation. The target illuminance level was set at 200 lux.

Table 22: Zone Bookstore_storage activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m ²)	Schedules	Days
199	0,01	12 am- 4 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m ²)
26	26	200	0,2

Equipments

Office equipement
gains(W/m²)
1,77

Zone Computer_Room Activity

Generic activity template HT_Computer lab was created for the Computer room zone. The occupancy schedule was set from 12 am until 16 pm. Occupancy density was set at 0,01 people/m² for 7 days a week and the DHW was set at of 0,01 l/m²-day.

The minimum fresh air was set at 11,2 l/s-m² in accordance with the Icelandic building regulation. The target illuminance level was set at 200 lux.

Table 23: Zone computer room activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m ²)	Schedules	Days
199	0,1	8 am-10 pm	5
<u>Ventilation setpoint Temperatures</u>			
Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m ²)
26	26	200	11,2
<u>Equipments</u>			
Computer gains(W/m ²)			
20			

Zone Kitchen Activity

Generic activity template HT_Food preparation was set for the kitchen zone. The occupancy schedule was set from 9 am until 18 pm. Occupancy density was set at 0,05 people/m² for 6 days a week.. the DHW was set at the default value of 0,33/m²-day. The minimum fresh air was set at 5,6 l/s-m² in accordance with the Icelandic building regulation. The target illuminance level was set at 500 lux. Catering, process and miscellaneous heat loads were both set at 15W/m².

Table 24: Zone kitchen activity tabulation

<u>Activity templete</u>			
Area (m ²)	Occupancy (people/m ²)	Schedules	Days
142	0,05	9 am-6 pm	6
<u>Ventilation setpoint Temperatures</u>			
Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m ²)
26	26	500	5,6
<u>Equipments</u>			
Miscellaneous Gains(W/m ²)	Catering gains(W/m ²)	Process gains (W/m ²)	
15	15	15	

Offices_4

Generic activity template HT_office and consulting areas was set for the Office_4 zone. The occupancy schedule was set from 8 am until 4 pm, like typical office hour. Occupancy density was set at 0,1 people/m² for 5 days a week. The DHW was set at the default value of 0,01/m²-day. The minimum fresh air was set at 1,7 l/s-m² in accordance with the Icelandic building regulation. The target illuminance level was set at 400 lux. Computers heat gains were set at 5W/m².

Table 25: Zone Office_4 activity tabulation

Area (m ²)	Occupancy (people/m ²)	Schedules	Days
164	0,05	8 am-4 pm	5
<u>Ventilation setpoint Temperature</u>			
Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air Mech. Vent(l/s-m ²)
26	26	400	1,7
<u>Equipments</u>			
Computers gains(W/m ²)			
5	0	0	0

Zone Reading room Activity

For the Reading_room zone, the occupancy schedule was set from 8 am until 8 pm, Occupancy density was set at 0,05 people/m² for 5 days a week. The DHW was set at 0,15/m²-day. The minimum level of fresh air was set at 5 l/s-m² in accordance with the Icelandic building regulation. The target illuminance level was set at 200 lux. Computer heat loads were set at 6 W/m².

Table 26: Zone Reading_Room activity tabulation

Activity template

Area (m ²)	Occupancy (people/m ²)	schedules	days
280	0,05	8 am-20 pm	7

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent (l/s-m ²)
26	26	200	5

Equipments

Computer
gains(W/m²)
6

Zone University Square Activity

University Square is mainly a place where students and staff eat lunch. It is also a place for studying and meeting friends. The University Square almost open 24/7, but for this study the schedule was set from 8 am until 7 pm. Occupancy density was set at 0,01 person/m² a daily average. The DHW consumption rate was at 0,01 l/m. Average daily computer usage gains were set at 1 W/m², as is described in Table 25

Table 27: Zone University_Square activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m ²)	Schedules	Days
1096	0,02	8 am-7 pm	7

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation)	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s- person)
26	26	300	11,2

Equipments

Computer
gains(W/m²)
1

Zone Waste storage Activity

Mainly, this zone is used for storing waste from the kitchen and bookstore. The activity schedule was set from 12 am until 2 pm, the occupancy density was minimised at 0,01 person/m² and the DHW consumption rate was set 0,001. The minimum level of fresh air was set at 15 l/s-m², in accordance to the Icelandic building regulation. The target illuminance was set at 300lux, such as shown in Table 26

Table 28: Zone Waste_Storage activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m2)	Schedules	Days
19	0,01	12 am-14 pm	6

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	200	15

3.6.5 Third floor zones

The third floor included 3 standard office type zones. They were scheduled to 8 hours office work day activity; from 8 am to 4 pm. Their DHW was set at 0,01/m²-day. The minimum level of fresh air was set at 1,7l/s-m² in accordance with the Icelandic building regulation. The environment control; heating setpoint temperature was set at 20°C, heating set back at 12°C. As for the cooling setpoint temperatures was set at 26°C and cooling setback temperature was set at 32°C in all zones in the second floor of Háskolatorg building. The environment control; heating setpoint temperature was set at 20°C, heating set back at 12°C. The cooling setpoint temperatures was set at 26°C and cooling setback temperature was set at 32°C in all zones in the second floor of Háskolatorg building.

Zone Office 1 Activity

Table 29: Zone Office_1 activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m2)	Schedules	Days
604	0,02	8 am-4 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	300	2

Equipments

Computer gains(W/m ²)	Office Equipement gains(W/m ²)
1	1

Zone Office 2 Activity

Table 30: Zone Office_2 activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m2)	Schedules	Days
321	0,02	8 am-4 pm	5

Ventilation setpoint Temperatures

Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air mech. vent(l/s-m2)
26	26	300	1,7

Equipments

Computer gains(W/m ²)	Office Equipement gains(W/m ²)
1	5

Zone Office 3 Activity

Table 31: Zone Office 3 activity tabulation

Activity templete

Area (m ²)	Occupancy (people/m ²)	Schedules	Days
287	0,06	8 am-4 pm	5
<u>Ventilation setpoint Temperatures</u>			
Nat. ventilation cooling	Mech. ventilation	Lighting target illuminance(lux)	Minimum fresh air Mech. Vent(l/s-m ²)
26	26	400	2
<u>Equipments</u>			
Computer gains(W/m ²)	Office Equipement gains(W/m ²)		
1	1		

3.7 Lighting

The lighting tab was set at the building level and was therefore inherited by all blocks and zones. A generic lighting template was chosen as “best practice”, which was 3,30W/m²-100lux. This lighting has a surface mount luminaire type and a radiant fraction of 72%.

3.8 Heating, ventilation and air conditioning (HVAC)

In model options data tab, HVAC has been simply defined, meaning that the heating and cooling system is modelled using basic algorithms. HVAC system sizing was not part of the study; therefore input for the calculation going was allocated as shown in table 30

Table 32: HVAC parameters tabulation

Mechanical ventilation

Outside air definition method: Minimum fresh air(sum per person + per area)		
operation	Seasonal control	Days
8 am-22 pm	All year	7

Heating

Heating system (CoP): 1		
Operation	Seasonal control	Days

6 am-18 pm	All year	7	
<u>Cooling</u>			
Cooling system (CoP): 1,67			
Operation	Seasonal control	Days	
6 am-18 pm	Summer only	7	
<u>Domestic Hot Water(DHW)</u>			
Operation	Water delivery temperature(°C)	Mains supply temperature(°C)	
8 am-18 pm	65	40	
<u>Natural ventilation</u>			
Outside air definition method: by zone			
Operation	Outside air(ac/h)	Seasonal control	Days
7 am- 22pm	0,5	Summer only	7

3.9 Simulation calculations

3.9.1 Cooling loads calculation

A cooling load calculation is carried out to determine the cooling load required to meet the hottest summer design weather setting based upon the weather file for Reykjavík (see subchapter 3.3.3). Calculation of cooling load to system calculation transition is not always clear. The first step is for the software to analyze the instantaneous solar gain of the space, based on weather and building information. Next this gain is converted to the cooling load for which the system is sized (Waddell, Kaserekar, Arup, & Ten, 2010).

For this study, the cooling system controls internal air temperatures to meet the setpoint temperature specified on the activity tab at 26°C for all zones. The selection of start and end days for the simulation period could be done randomly for the summer period through the weather file, or designated as a typical period as determined by the programme as shown in table 31.

Table 33: Cooling design simulation typical period

Simulation	Typical period
Summer design week	27 th July-2 nd August
Summer typical week	10 th August-16 th August
All Summer	1 st April-30 th September

3.9.2 Heating load calculation

Heating load calculation are carried out to determine the size of heating load required to meet the coldest winter design weather conditions likely to be encountered in Reykjavik. DesignBuilder carries out the calculations using the EnergyPlus dynamic thermal simulation engine.

This study simulation calculated heating load required to maintain the temperature set point in each zone at 20°C and displays the total heat loss broken down by:

- Glazing
- Walls
- Partitions
- Solid floors
- Roofs
- External infiltration
- Internal natural ventilation such as heat lost to spaces through windows, vents, door, and holes.

The total heat loss in each zone was multiplied by a safety factor to give a recommended heating design capacity which is not discussed in this study.

The start and end days of the simulation period could be chosen randomly during the winter period defined by the weather file, or could be selected as typical period determined by the programme as is shown in table 32.

Table 34: Heating design simulation typical period

Simulation	Typical period
------------	----------------

Winter design week	20 th January- 26 th January
Winter typical week	13 th January-19 th January
All winter	1 st October- 31 st march

3.10 Survey

3.10.1 Implementation

In addition, a web based software QuestionPro (QP) survey was conducted to assess the building performance as relate to Occupant/tenant's behaviour, since they are rich sources of information about the indoor environmental quality of the building and its effect on productivity and comfort.

This survey was distributed via email and Facebook. QP Software was automatically collected and recorded the responses (QuestionPro, 2012). Survey participation was voluntary and anonymous and respondents could opt at any time. The survey was conducted from February 28th, 2012 until March 18th, 2012. During this timeframe, 352 viewed the survey, 338 started; only 264 respondents completed the survey. The completion rate was 78,11%. The average time spent completing the survey was 4 minutes.

The survey included a short introduction informing building occupants of the aims of the survey and the importance of their perception regarding the performance of the building. The core questions of the survey used to assess the occupant's satisfaction were in the following Indoor Environmental Quality(IEQ) areas: the background of the occupants, thermal comfort, indoor air quality, lighting and energy performance perception.

Upon starting the survey, participants click through a series of question on their occupation, gender, time spent in Háskolatorg, indoor temperature followed by an evaluation of their satisfaction with different aspects of their occupancy environment. Satisfaction is rated on a scales ranging from "very satisfied" to "very dissatisfied" with neutral midpoint. Respondents who indicated dissatisfaction were the lower 2 points on the scale. The respondents who indicated satisfaction were the upper 2 points. Open ended question were also designed in some topics.

Tailoring the survey in this fashion enabled diagnostic information to be gathered on the building's potential letdowns.

3.10.2 Reporting results

Data was reported using an automated web-based tool. A real-time summary could be access at anytime (QuestionPro, 2012). Cross tabulation analysis was undertaken to better understand the possible inter-relation between survey parameter. The survey results are in Chapter 4.

3.11 Háskolatorg heating and electricity metered data collection

Daily metered data was collected in the technical room of Háskolatorg building, from the 20th of March until the 26th of March, every day at 1 pm. Information on daily electricity energy consumption and hot water level used for the heating for the building was gathered from the electricity energy and hot water, flow meter as shown in the figure 15. List of daily consumption of electricity and hot water and calculations is included in Annex B.

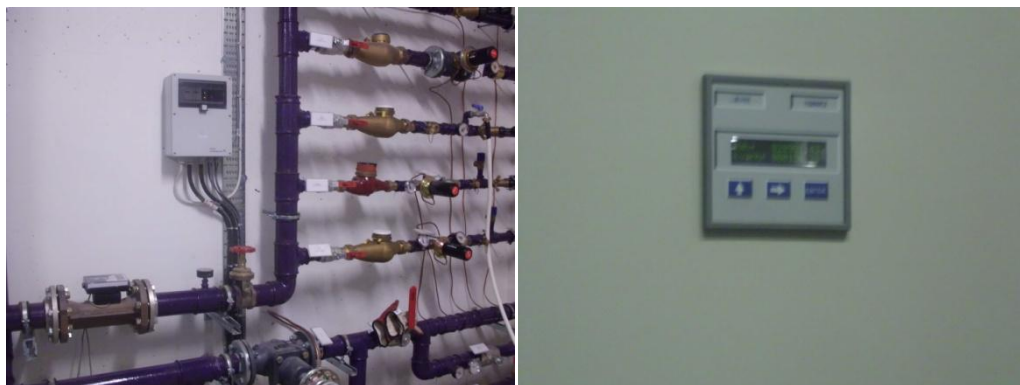


Figure 15 Háskolatorg building Electricity energy meter and hot water flow meter

4 Results

All weather graphs were generated through DesignBuilder simulation based on the Reykjavik weather file described in sub chapter 3.3.3. As for the results on internal gains, fabric and ventilation loss were generated by the DesignBuilder simulation tool described in chapter 3.9 on simulation calculations. Furthermore, a comparative summary of the simulation results for Háskolatorg building and the University Square zone was written..

4.1 All year simulation results

All year simulation occurs from the 1st of January until the 31st of December, with the 12 holidays listed in table 12 holidays days described on Table 12 have taken into consideration in this simulation. This chapter is arranged as follow:

It starts with the illustration of the Reykjavik weather environment based on weather data input (see subchapter 3.3.3) followed by both Háskolatorg building and University Square zone internal gains, fabric and ventilation loss throughout all year. In addition, Háskolatorg system loads were added, as was a brief summary comparing the internal gains, fabric and ventilation loss between Háskolatorg building and the University Square zone.

4.1.1 All year Reykjavík temperatures and Háskolatorg indoor temperatures, wind speed and direction and solar radiations

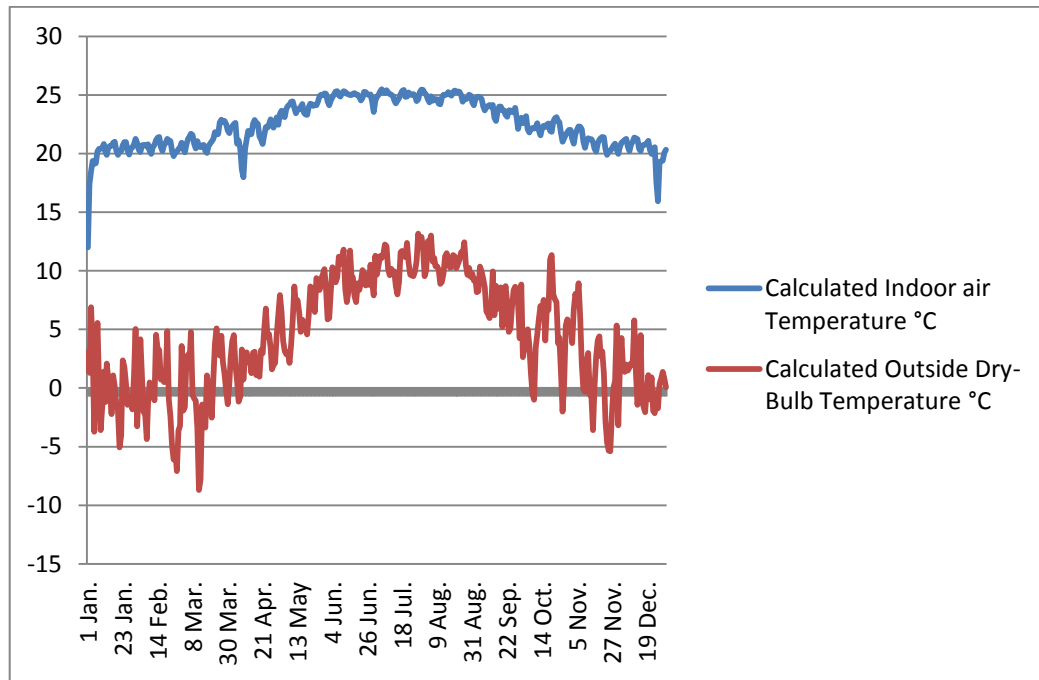


Figure 16: Reykjavík all year outside dry-bulb temperature and Háskolatorg calculated indoor air temperature

The simulation has shown in Figure 16 that Háskolatorg Indoor air temperature was maintained between 20°C to 25°C. The minimum indoor temperature occurred on the 1st of January at 12°C and the maximum occurred on the 5th of July at 25,48°C. As for the Outside dry-bulb temperature, the minimum temperature has occurred of -8,7°C occurred on March 12th and the maximum temperature was recorded from Reykjavík weather file on the July 28th at 13,15°C.

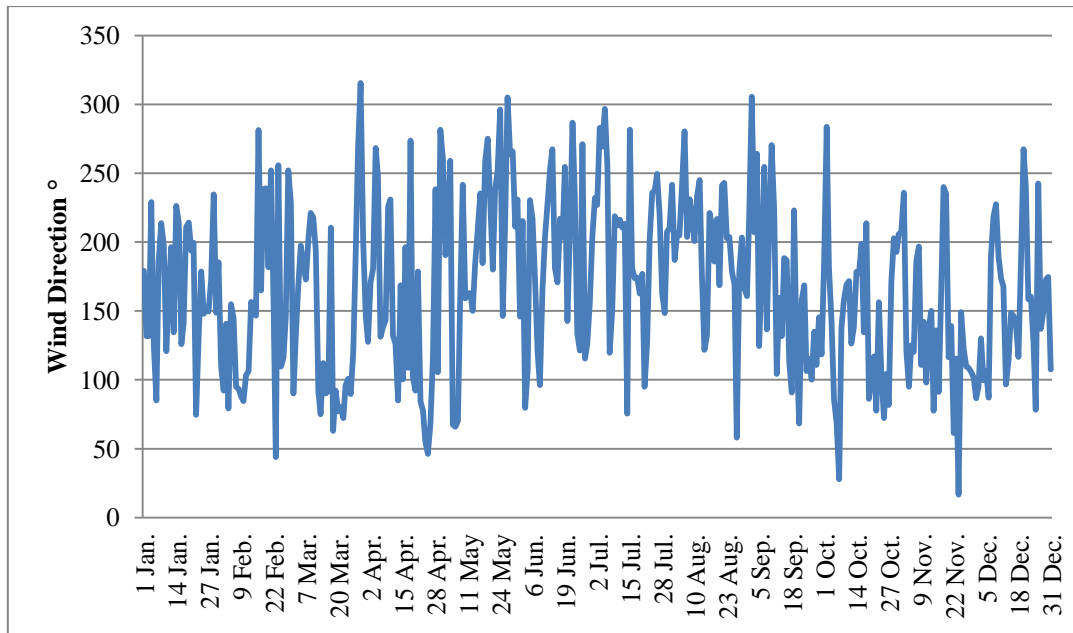


Figure 17: Reykjavík all year wind direction

As shown in figure 17 has, Reykjavik wind direction is prevalent from south East mainly during winter and common wind direction from south West occurs during summer.

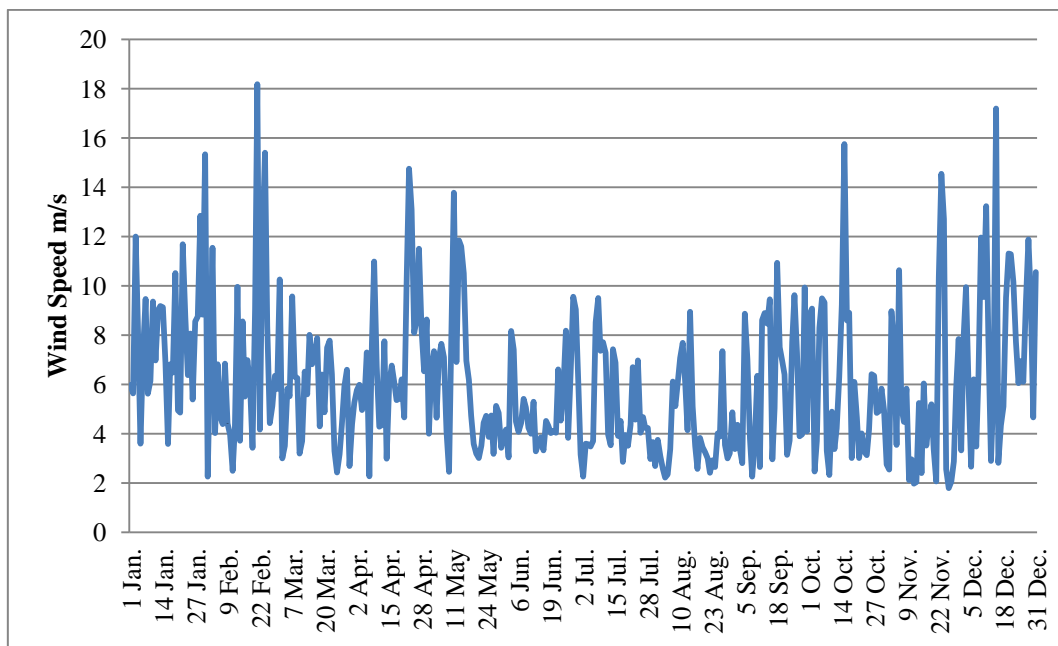


Figure 18: Reykjavík all year wind speed

According to the simulation results for wind speed shown in figure 18, Reykjavík all year wind speed average was registered at 6 m/s. The maximum wind speed was registered on

February the 21st at 18,17 m/s , the minimum wind speed in Reykjavík was recorded on the 26th of November at 1,78 m/s.

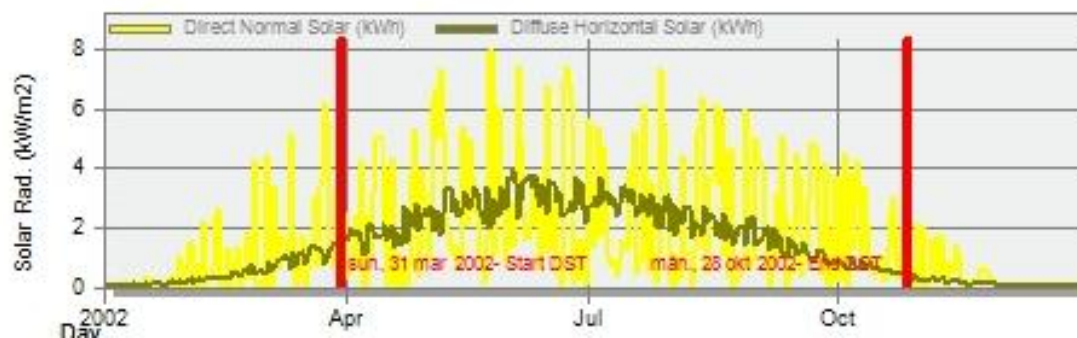


Figure 19: Reykjavík all year direct normal and diffuse horizontal solar radiation

Throughout all year, the weather file input showed 63 days of no direct normal solar radiation in Reykjavík where the maximum input was at 7,95 kWh/m² on the 26th, of May. Maximum input diffuse radiation in Reykjavík took place on the 3rd of June at 3,9 kWh/m² and the minimum on December 22nd at 0,016 kWh/m².

4.1.2 All year Háskolatorg building internal gains

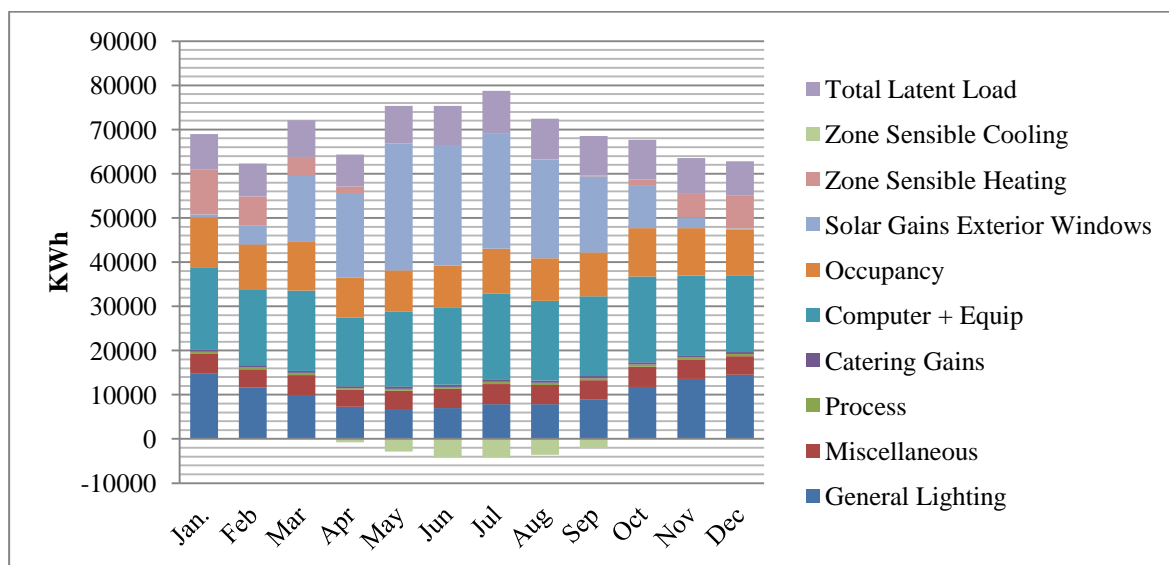


Figure 20: Háskolatorg building all year internal gains

Table 35: Háskolatorg building all year total internal gains

components	Gen. lighting	Miscellaneous	Process	Catering	Comp. & equip.
kWh	77.751	33.471	5792	5792	39.994

components	occupancy	Solar gains	Zone sensible heating	Zone sensible cooling	Total latent load
kWh	57.135	172882	74.551	-6.465	40.103

As shown in table 33 and figure 20, all year solar gains were the most significant gain of the building all year internal gains components, followed by general lighting.

4.1.3 All year Háskolatorg building fabric and ventilation loss

Table 36: Háskolatorg building all year fabric and ventilation loss

Components	Glazing	Walls	Ground floors	Roofs	External infiltration	External vent
kWh	-192.794	-76.338	-51.050	-25.392	-47.020	-45.031

As shown on table 34 and figure 21, all year Háskolatorg building glazing exhibited the most energy loss, for 192.794 kWh, followed by the building walls energy loss component, which was, 76.338 kWh, for all year.

The most glazing loss occurred during the month of March at 19.016 kWh and the minimum of 12.659 kWh occurred in August. On the other hand, maximum loss for the walls of 7.237 kWh occurred in January; while the minimum loss has been recorded on July at 5582 kWh.

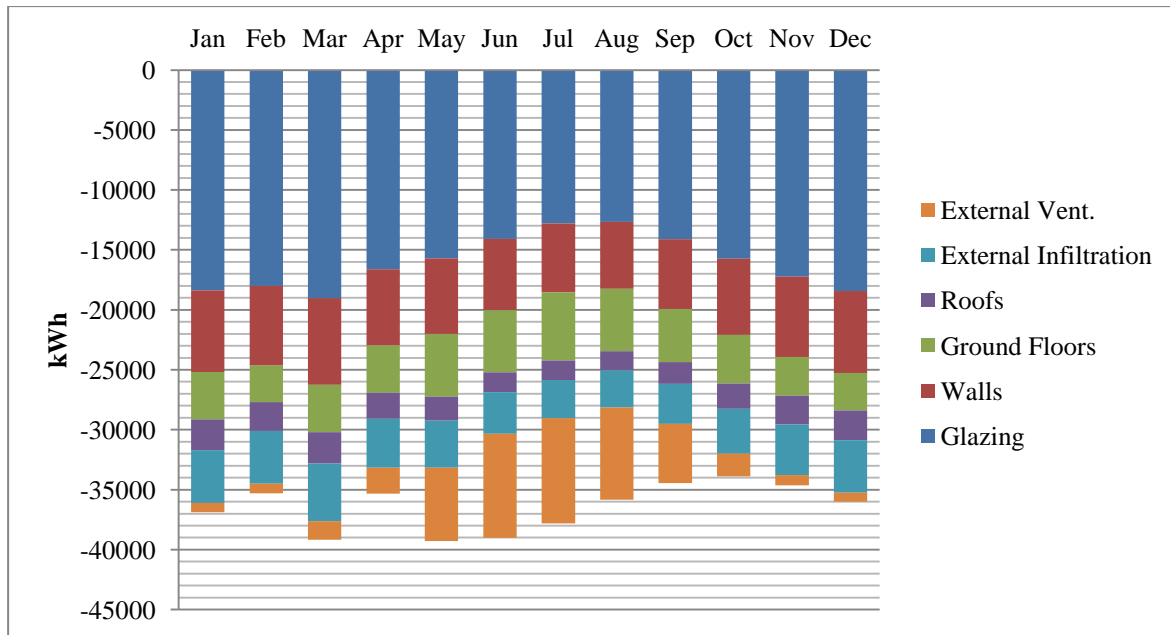


Figure 21: Háskolatorg building all year fabric and ventilation loss

4.1.4 All year Háskolatorg building system loads

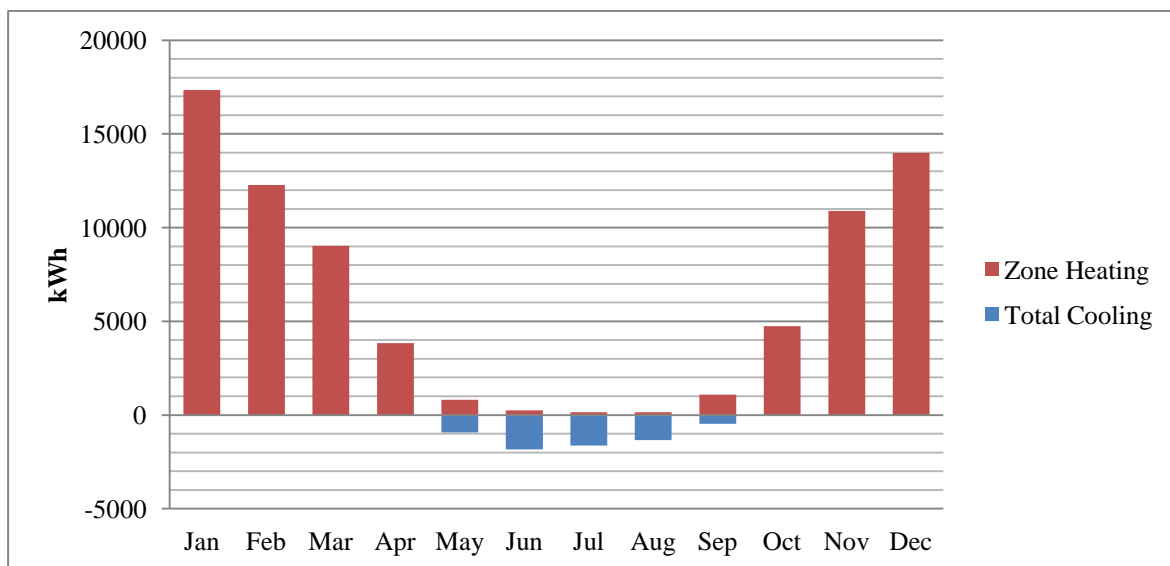


Figure 22: Háskolatorg building all year system loads

As it indicated in figure 22; throughout the year the Háskolatorg building has 2 system loads components: zone heating and total cooling. Zone heating was operating mainly from October until April, with very little zone heating from May until the end of September. The All year amount of zone heating was recorded at 74.551 kWh, with the maximum load registered on January at 17.344 kWh and the minimum occurring on July at 146 kWh.

Total cooling was operating from the month of April until the month of September; with total all year amount of 6.235 kWh. The maximum amount of total cooling system loads occurred on June at 1.838 kWh and the minimum of 25 kWh occurred in April.

4.1.5 All year University Square zone internal gains

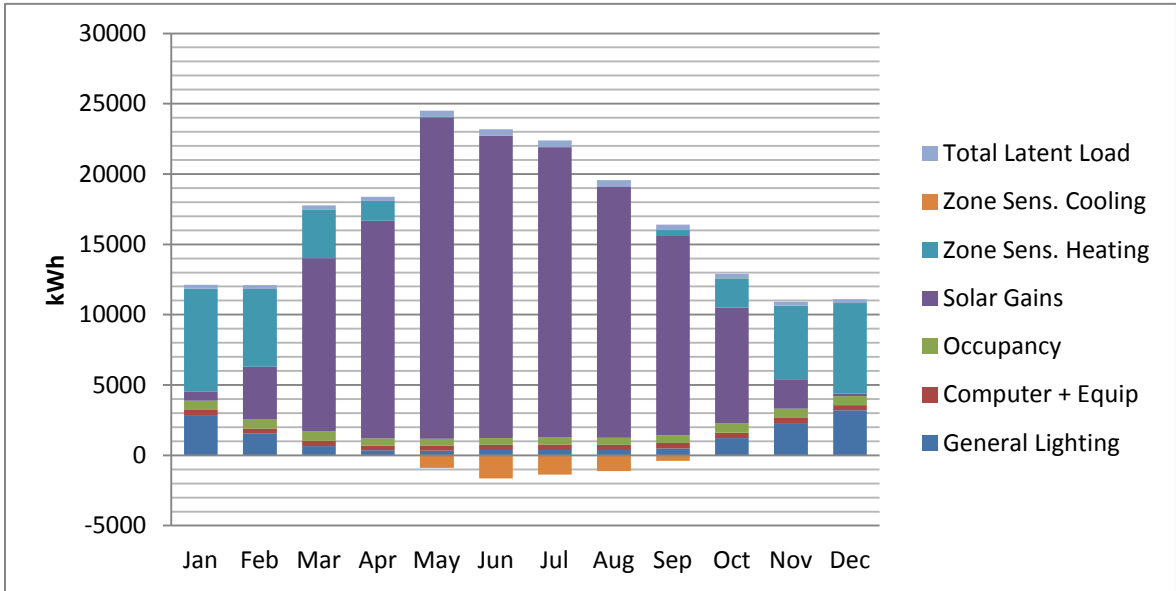


Figure 23: University Square zone all year internal gains

Throughout the year, the University Square zone experienced significant internal solar gains at the total amount of 139.798 kWh, with maximum gains of 22.846 kWh occurring in May and minimum amount of 197 kWh taking place in December.

4.1.6 All year University Square zone fabrics and ventilation energy loss

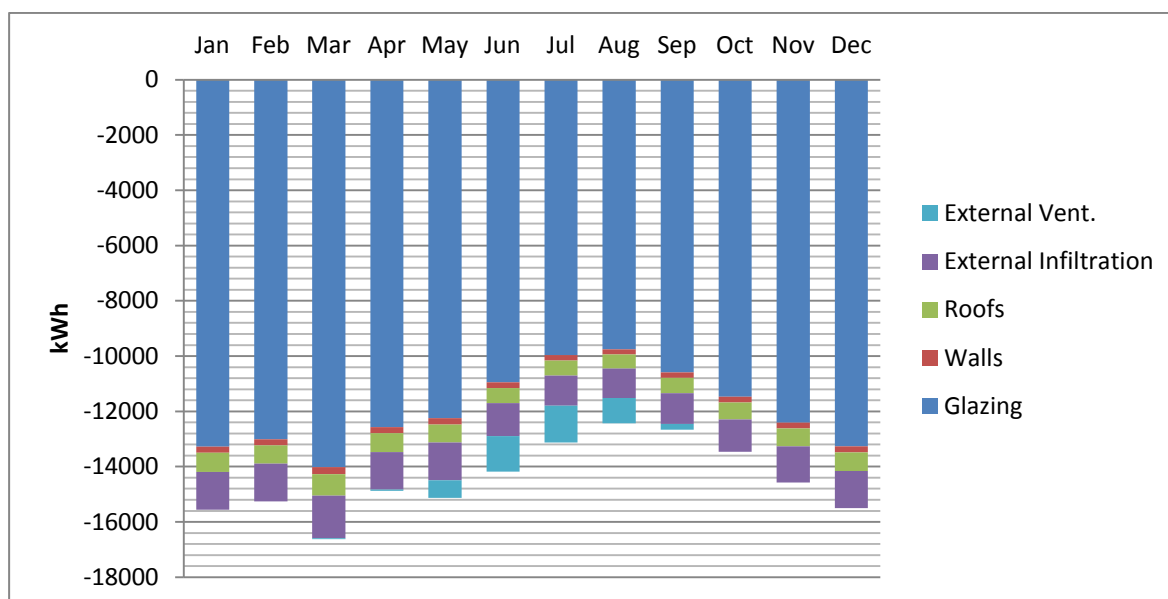


Figure 24: University Square all year fabric and ventilation energy loss

The University Square zone fabric glazing has registered a significant energy loss throughout the year. The total amount of the loss was 143.515 kWh, with the maximum glazing energy loss 14.019 kWh occurring on March and the minimum energy loss of 9.750 kWh. Occurring in August

4.1.7 Summary

A comparison of all year internal gains of Háskolatorg building and the University Square zone is illustrated in the table 35. Internal gains components such as General lighting, computer and equipment, occupancy, solar gains, zone sensible cooling, heating and total latent loads were listed. all year fabric and ventilation energy loss is shown in the same table. Components such as glazing, roofs, walls, and external infiltration and ventilation were considered.

Table 37: All year Háskolatorg building and University Square zone comparison internal gains, fabric and ventilation energy loss

Components	<u>Internal gains</u>	
	Building(kWh)	University Square zone(kWh)
General lighting	77.751,3	14.110

Computers and equi.	33.471	4.428
Occupancy	57.135	6.933
Solar gains	172.882	139.798
Zone sensible cooling	-6.465	-5.470
Zone sensible heating	74.551	31.847
Total latent loads	40.103	4.228
Σ Total	455.953	195.874

Fabric and ventilation loss

Glazing	-192.794	-143.515
Walls	-76.338	-2.771
Roofs	-25.392	-7.561
External infiltration	-47.020	-15.282
External vent	-45.031	-4.452
Σ Total	-386.577	-173.374

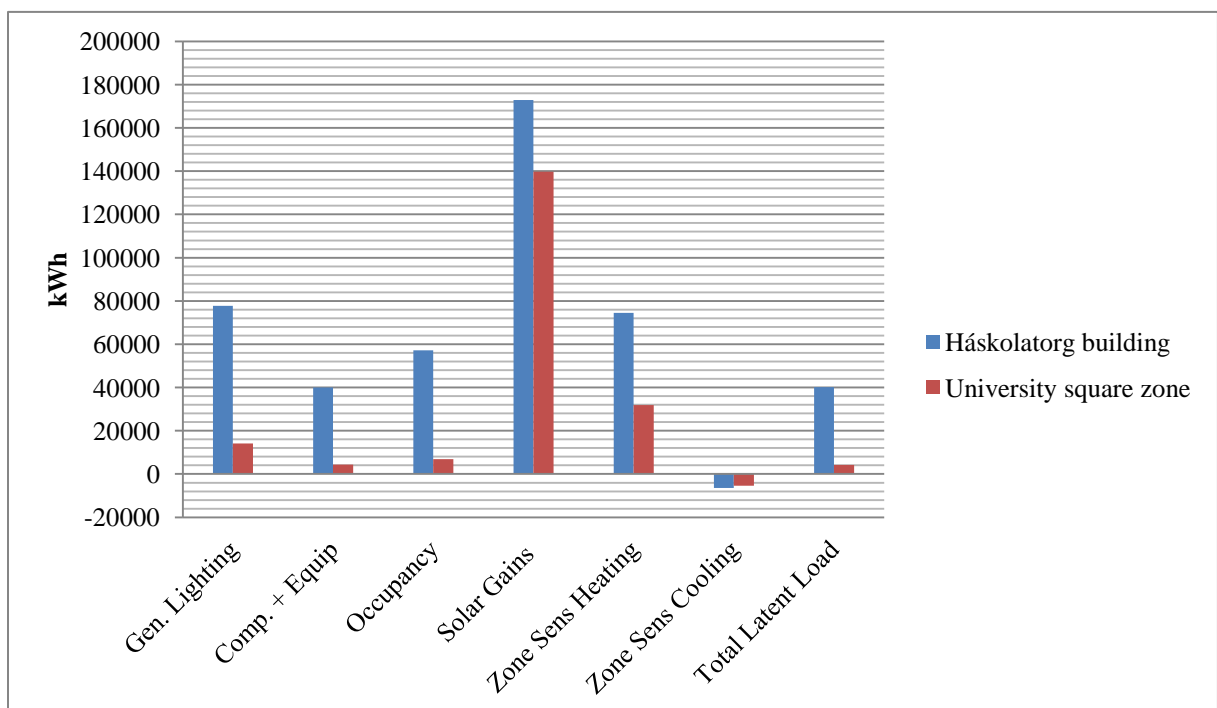


Figure 25: all year Háskolatorg building and University Square zone internal gains comparison

On table 35, solar gains were the most significant internal gains in Háskolatorg building, with a total amount of 172.882 kWh. All year solar internal gains of the University Square zone represented 80% of Háskolatorg building gains.

The second most significant all year gains in Háskolatorg building were due to general lighting, with a total amount of 77.751 kWh. All year solar gains of the University Square zone represented 18% of the total gains in Háskolatorg building.

All year zone sensible heating gains were the third most significant gains in Háskolatorg building, at 74.551 kWh. University Square zone occupancy gains represented 42% of total occupancy gains of Háskolatorg building.

The fourth most significant gains in Háskolatorg building were from occupancy, measured at 57.135 kWh. University Square zone lighting gains were 12% of the total general lighting energy gains in Háskolatorg building.

Total latent load represented the next most significant internal gains in Háskolatorg building, at 40.103 kWh. The total latent load for the University Square zone was only 10% of the total gains in Háskolatorg building.

39.994 kWh of all year total gains in Háskolatorg building were due to computer and equipment. The University Square zone all year zone sensible gains were 11% of the total gains in Háskolatorg.

The least all year total significant Háskolatorg building internal gains were zone sensible cooling, of 6.465 kWh. University Square zone all year sensible cooling gains represented 84% of the total gains of Háskolatorg building.

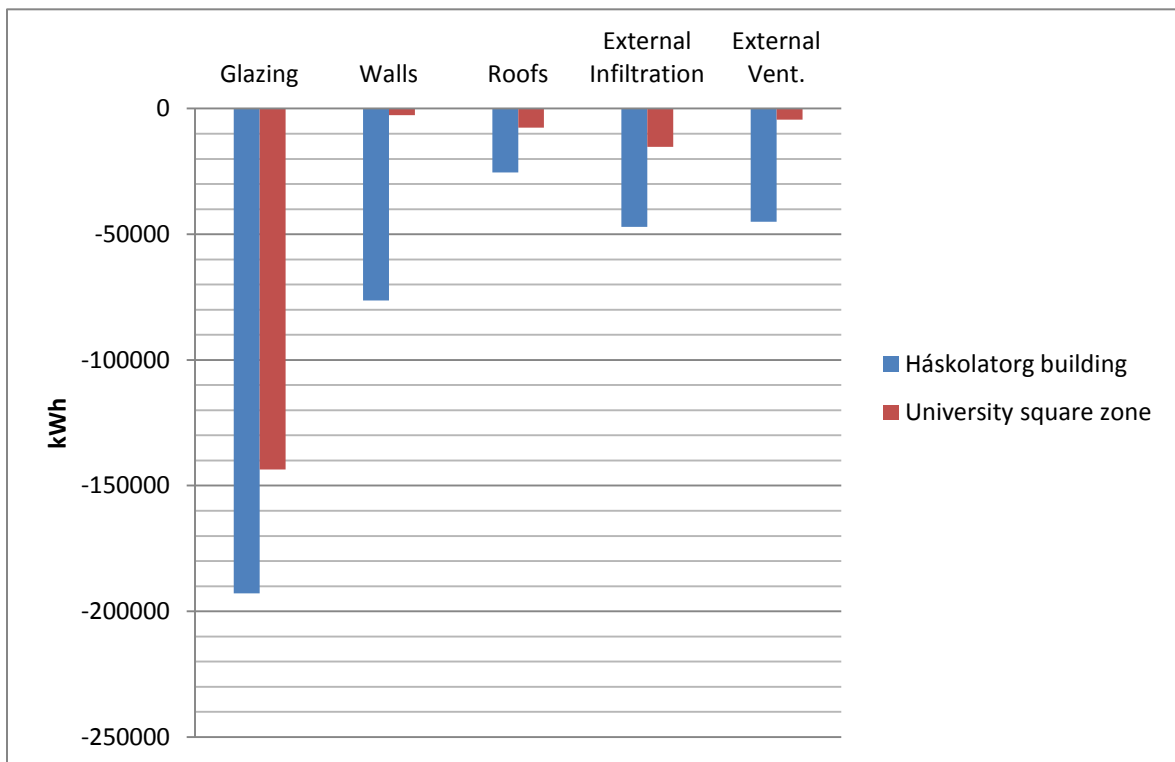


Figure 26: All year Háskolatorg building and University Square zone fabric and ventilation loss comparison

The most significant all year loss of Háskolatorg building was from glazing, with a total amount of 192.794 kWh. The University Square zone all year exterior ventilation loss was 74% of the total annual loss in Háskolatorg building

The second most significant all year loss for Háskolatorg building was from wall fabric, with a total annual amount of 76.338 kWh. the University Square zone all year energy loss from glazing represented only 3% of the total annual loss in Háskolatorg building

The next most significant all year loss for Háskolatorg building was from external infiltration, with a total annual amount of 47.020 kWh. University Square zone all year energy loss from external infiltration represented 32% of the total annual loss in Háskolatorg building.

The fourth most significant all year loss in Háskolatorg building was due to external ventilation, with a total of 45.031 kWh. The University Square zone all year energy loss from external ventilation represented 9% of the total annual loss in Háskolatorg building.

The least significant all year loss for Háskolatorg building was due to roofs, with a total of 25.392 kWh. The University Square zone all year energy loss from roofs represented 29% of the total annual loss from roofs in Háskolatorg building, as shown in Figure 26.

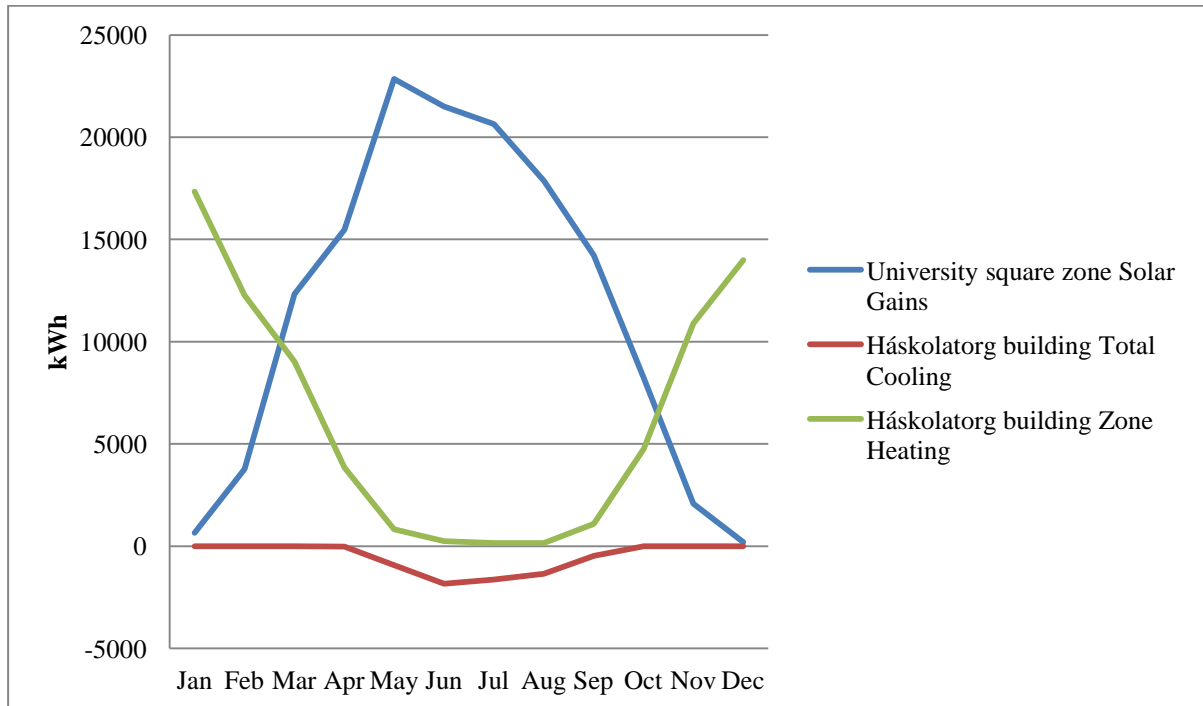


Figure 27: All year Háskolatorg building system loads and University Square zone solar gains comparison

As shown in Figure 27, all year Háskolatorg building system loads and University Square zone solar gains were compared. In January, Háskolatorg buildings has the highest load of zone heating, which decreased progressively as the season moved towards summer and reached the minimum in August. From August until December, the zone heating increased progressively, as winter neared. The University Square zone solar gains occurred the other way around with its minimum in January and December, in the middle of the winter, and reached its maximum in May. It is clear that as the solar gains in University Square zone h increased, the Háskolatorg building system loads decreased, and when the system load zone heating was at its maximum output, University Square zone solar gains were at its minimum.

System loads of total cooling only occurred during some part of summer when solar heating was at its maximum.

4.2 All winter simulation results

All winter simulation took place from the 1st of October until the 31st of March. All results are based on the input data, inserted into and generated by DesignBuilder. This chapter is structured as follow:

The results start with the illustration of the Reykjavik weather environment followed by both Háskolatorg building and University Square zone internal gains, fabric and ventilation energy loss throughout the winter. In addition, Háskolatorg system loads were included as was a brief summary comparing internal gains, fabric and ventilation loss between Háskolatorg building and University Square zone.

4.2.1 All winter Reykjavik temperature and Háskolatorg indoor temperature, wind speed and direction and solar radiation

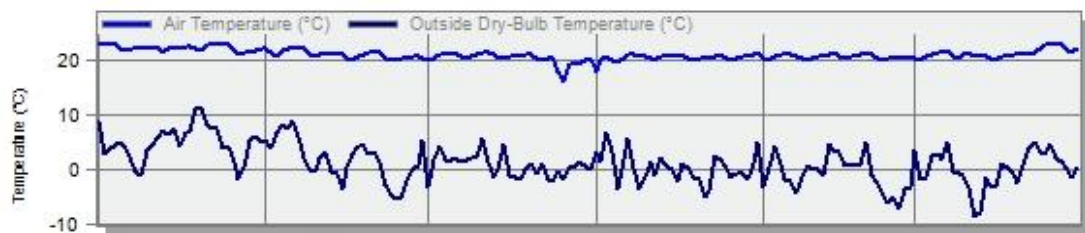


Figure 28: All winter daily air temperature

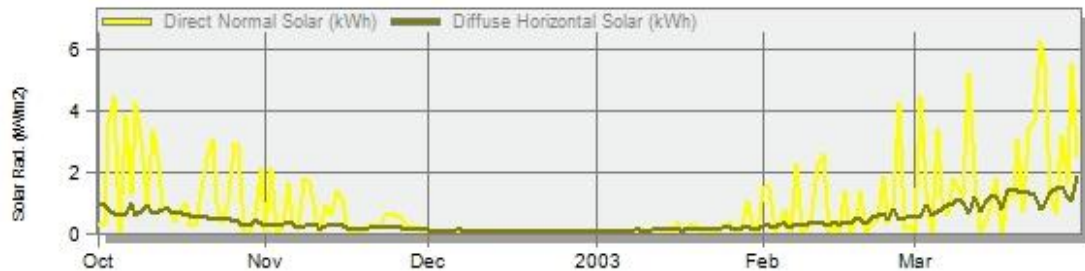


Figure 29: All winter daily solar radiation

The All winter minimum outside dry bulb temperature occurred in March at $-8,7^{\circ}\text{C}$, while the maximum temperature occurred in both October and November at $11,35^{\circ}\text{C}$. The average temperature in October was $4,8^{\circ}\text{C}$, $3,4^{\circ}\text{C}$ in November, $0,6^{\circ}\text{C}$ in December and from January until March the average outside dry bulb temperature was zero, as shown on figure 28.

The indoor temperature was maintained at an average of 20°C throughout the winter. All winter direct normal solar radiation maximum occurred in march at 6,2 Wh/m². The direct normal solar average of every winter month is shown in table 36:

Table 38: All winter direct normal solar radiation average monthly

Wh/m ²	October	November	December	January	February	March
Average	1,59	0,53	0,27	0,11	0,8	1,48

All winter diffuse solar radiation maximum occurred in March at 1,8 Wh/m², the minimum, or no radiation occurred in November, December, and January. The monthly average for direct normal solar radiation in winter are shown on table 37:

Table 39: All winter diffuse solar radiation average monthly

Wh/m ²	October	November	December	January	February	March
Average	0,59	0,18	0,11	0	0,3	0,7

4.2.2 All winter Háskolatorg building internal gains

Throughout the winter period Háskolatorg building had the most significant gain in zone sensible heating at 66.592 kWh, with a maximum gain recorded on January at the amount of 14.580 kWh, while the minimum zone sensible heating was recorded on October at the amount of 4.828 kWh, as shown in Figure 30. The overall total of Háskolatorg building internal gains recorded at 241.398 kWh.

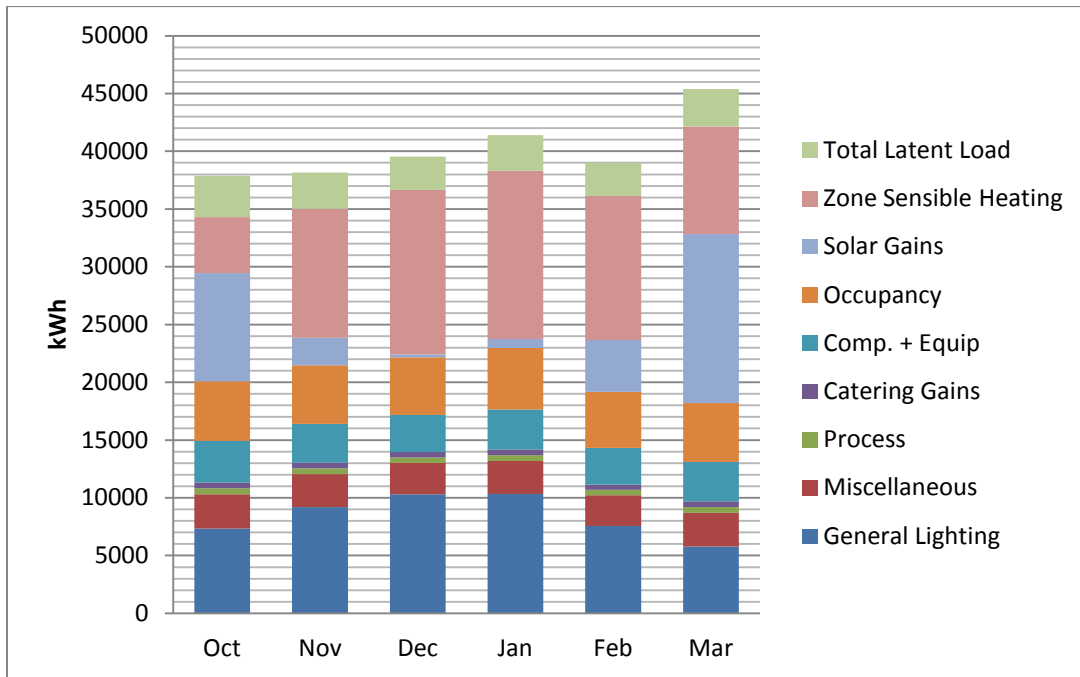


Figure 30: All winter Háskolatorg building internal gains

4.2.3 All winter Háskolatorg building fabric and ventilation loss

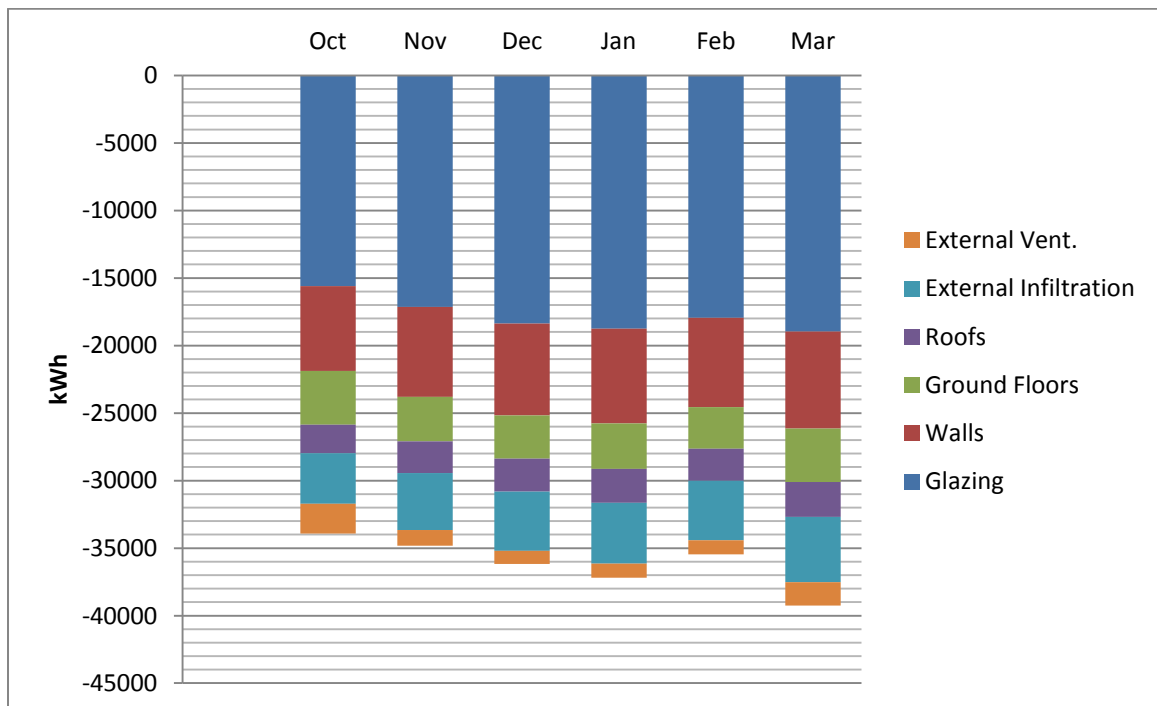


Figure 31: All winter Háskolatorg building fabric and ventilation loss

The most significant all winter energy loss for Háskolatorg building most significant was from glazing, or 106.787 kWh. The maximum loss was measured in March at 18.962 kWh, while the minimum loss occurred in October at 15.500 kWh, as exhibited in figure 31.

4.2.4 All winter Háskolatorg building system loads

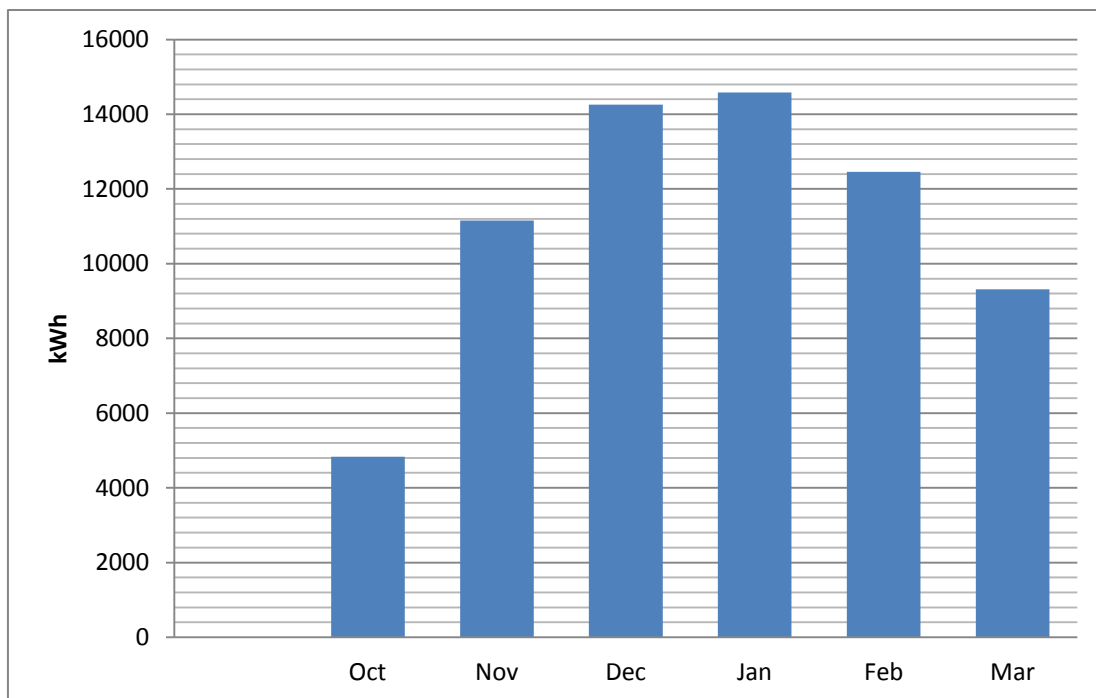


Figure 32: All winter Háskolatorg building monthly system loads

All winter building system loads consisted only of zone heating. In December and January, the system loads have reached 14.253 kWh and 14.580 kWh respectively. October presented the lowest Háskolatorg building system load zone heating at 4828 kWh, as shown in figure 32.

4.2.5 All winter University Square internal gains

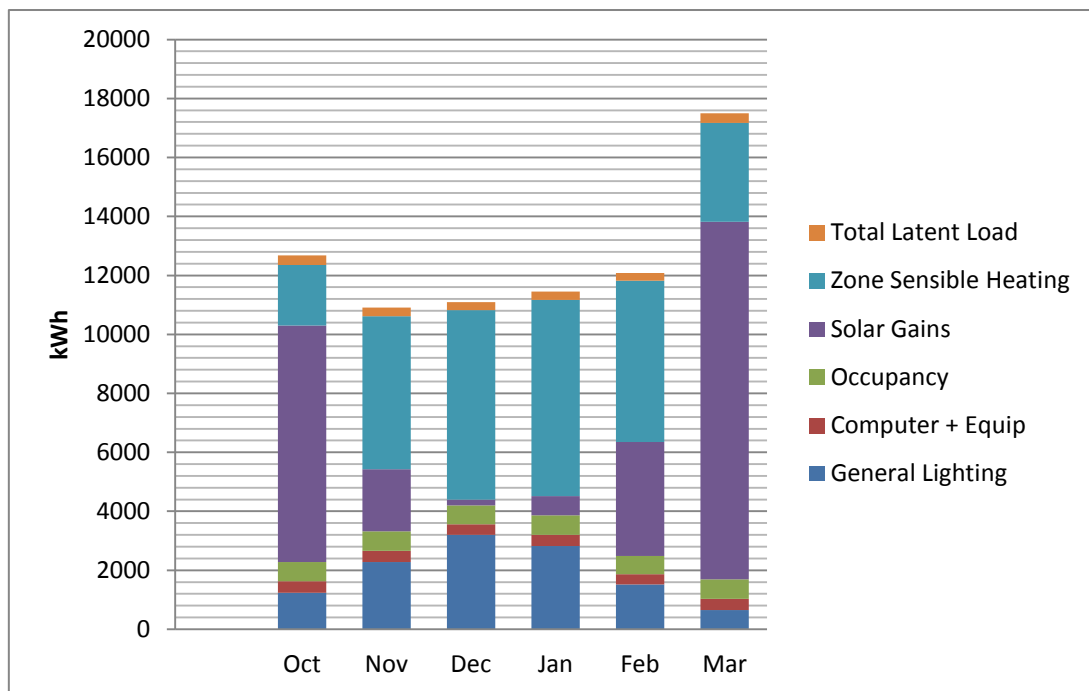


Figure 33: All winter University Square zone monthly internal gains

All winter period zone sensible heating represented most University Square internal gains. The maximum internal gains were measured in January at 6.644 kWh. The minimum gains zone sensible heating took place in October at 2049 kWh. The total amount of zone sensible heating in University Square during the winter was at 29.148 kWh.

All winter period solar gains represented the second significant internal gains in University Square zone. March showed the maximum solar gains in the University Square zone, at 12.122 kWh. The minimum solar gains were measured in December at 191 kWh. The total amount of solar gains in University Square during all winter has been at 26.960,8 kWh.

The general lighting is the third most significant source of internal gains for the University Square zone. The maximum acquisition was in December at 3.199 kWh. The minimum gains happened in March, at around 648 kWh. The total general lighting gains were 11.708 kWh all winter.

Occupancy gain is the fourth most significant source of internal gains for the University Square zone. Maximum gains were measured in January at 662 kWh, while the minimum

was measured in February at 617 kWh. The total occupancy gains were at 3.895 kWh all winter.

As for the total amount of computer and equipment gains and total latent load, those levels were measured at 2239 kWh and 1747 kWh respectively, as shown in Figure 33.

4.2.6 All winter University Square fabric and ventilation loss

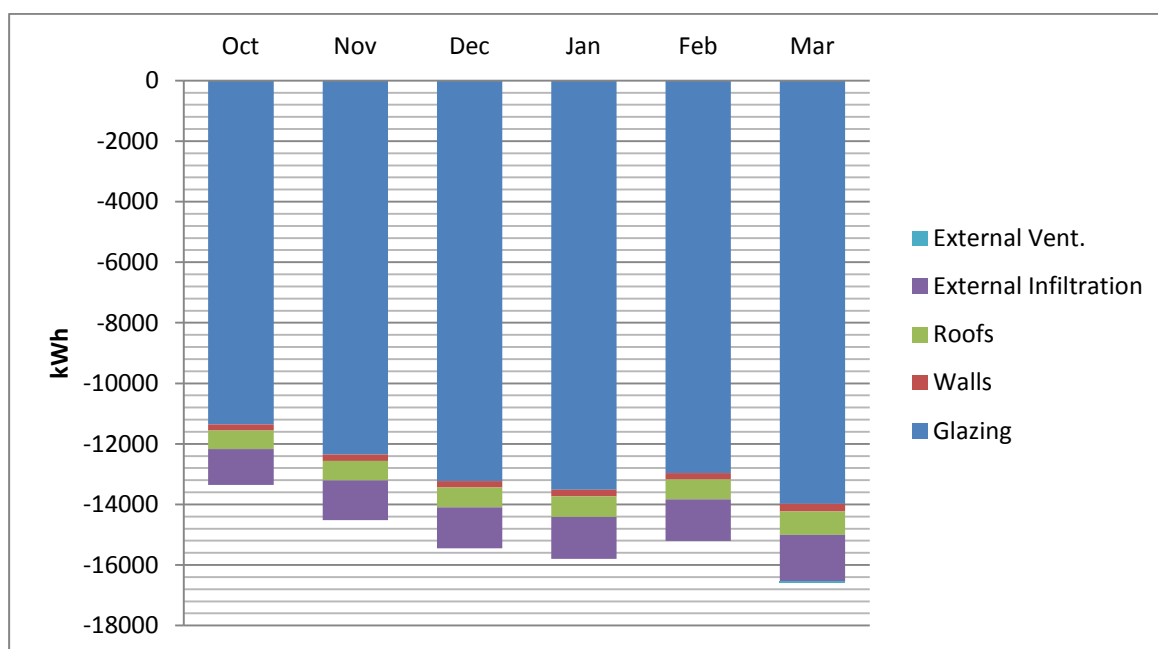


Figure 34 All winter University Square monthly fabric and ventilation energy loss

All winter glazing fabric at University Square zone has lost a staggering total energy of 90.920 kWh throughout the winter season. The maximum occurred the month of March at 16.599 kWh. The minimum was measured in October at 13.351 kWh, as shown in figure 34.

4.2.7 Summary

Table 40: Háskolatorg building internal gains, fabric and ventilation loss all winter summary

components	<u>Building Internal gains</u>					
	October	November	December	January	February	March
General lighting	7350	9198	10309	10329	7567	5775
Computers and equi.	3599	3372	3234	3461	3183	3423

Occupancy	5153	5063	4973	5332	4858	5088
Solar gains	9367	2391,2	242	777	4484	14638
Zone sensible heating	4828	11155	14253	14580	12457	9316
Total latent loads	3589	3143	2888	3075	2878	3243
Σ Total	33.889	34.325	35.901	37.557	35.430	41.486
<u>Fabric and ventilation loss</u>						
Glazing	-15600	-17151	-18370	-18363	-17938	-18962
Walls	-6289	-6642	-6808	-6996	-6623	-7188
Roofs	-2120	-2355	-2439	-2512	-2360	-2597
External infiltration	-3737	-4220	-4379	-4283	-4415	-4821
External vent	-2208	-1163	-979	-1055	-1035	-1735
Σ Total	-33.917	-34.830	-36.175	-37.194	-35.458	-39.252

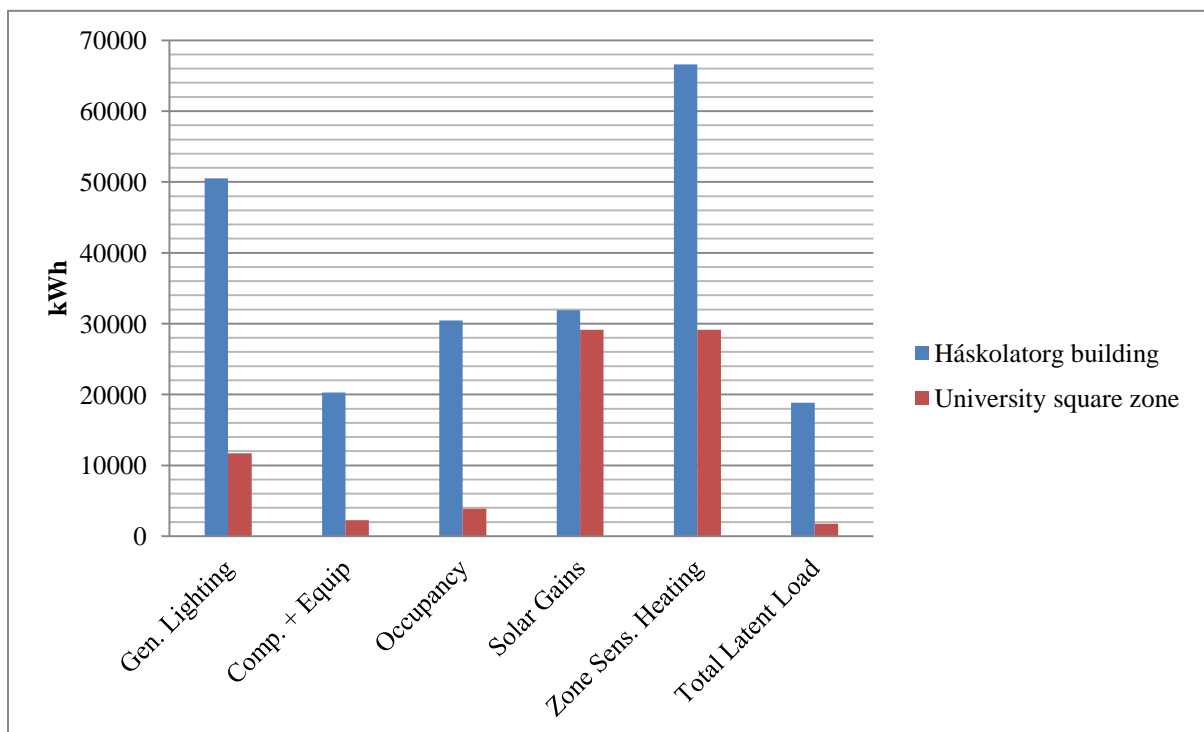


Figure 35: All winter Háskolatorg building and University Square zone internal gains comparison

Throughout winter period; from October 1st until March 31st; Háskolatorg building had overall internal gains of 241.398 kWh, including general lighting, computers and equipment, occupancy, solar gains, zone sensible heating , total latent loads, process, catering and miscellaneous. In the same period the University Square zone had overall internal gains of 75.700 kWh. Thus, 31% of the overall internal gains of Háskolatorg building originated from the University Square zone internal gains.

Table 41: University Square zone internal gains, fabric and ventilation loss summary

<u>University Square Internal gains</u>						
Month	October	November	December	January	February	March
General lighting	1235	2283	3199	2824	1516	648
Computers and equip.	387	375	362	375	350	387
Occupancy	659	661	640	662	617	654
Solar gains	8023	2102,7	191,4	658,1	3862,1	12122,9
Zone sensible heating	2049	5197	6425	6644	6459	3362
Total latent loads	317	284	274	283	264	323
<u>Fabric and ventilation loss</u>						
Glazing	-11.360	-12.354	-13.230	-13.515	-12.962	-13.980
Walls	-197	-206	-212	-219	-213	-249
Roofs	-610	-647	-658	-680	-651	-772
External infiltration	-1183	-1306	-1350	-1385	-1375	-1550
External vent	-29	0	0	0	0	-183

As shown in Figure 35, all winter zone sensible heating gains were the most significant components of internal gains in the building. Overall gains by Háskolatorg building, reached a total of 66.592 kWh. Simultaneously, University Square zone was accountable for 43% of the total all winter Háskolatorg building zone sensible heating.

The second most significant all winter overall internal gains originated from general lighting. Háskolatorg building gained 50.531 kWh, while at the same time, the University Square zone was responsible for 23% of the building general lighting gains during the winter.

The third most significant internal gains were solar gains. Háskolatorg building accumulated all winter solar gains of 31.902 kWh. University Square contributed 91% of the Háskolatorg building total solar gains.

All winter occupancy gains for Háskolatorg building were 30.470 kWh, while the University Square zone accumulated 3.895 kWh. Consequently, all winter University Square zone occupancy gains represented 12% of the Háskolatorg building gains.

The fifth most significant all winter Háskolatorg building internal gains were computer and equipment gains, at 20.274 kWh. University Square zone contributed 2.239 kWh of the amount, or 11% of the building total computer and equipment gains.

The least significant all winter gains were due to the total latent loads; Háskolatorg building accumulated 18.818 kWh from this source, whereas 1.747 kWh were from the University Square. This indicated that all winter University Square zone total latent load was only 9% of the Háskolatorg building total latent loads.

Table 42: All winter Háskolatorg building system loads summary

<u>Háskolatorg building system loads</u>						
Month	October	November	December	January	February	March
Zone heating	4.828	11.155	14.253	14.580	12.457	9.316

During winter months, zone heating was the only Háskolatorg building system load, with the total amount of throughout all winter was at 66.592 kWh, as shown on table 40.

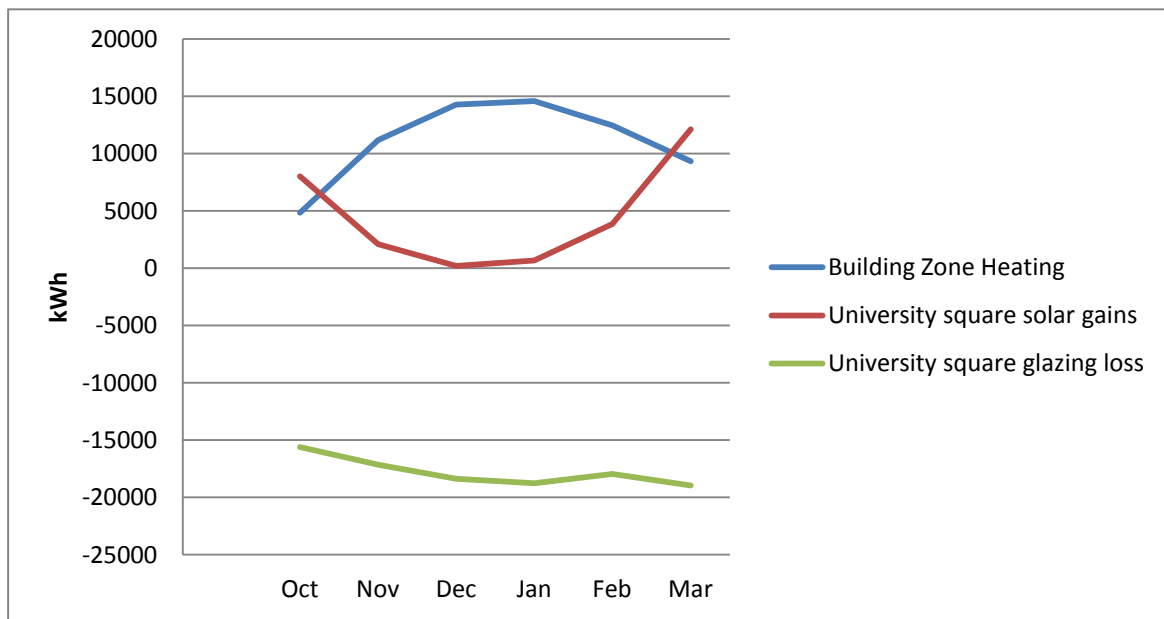


Figure 36: All winter Háskolatorg building system loads heating, University Square zone solar gains and glazing loss comparison

As shown in Figure 36, the Háskolatorg building system load of zone heating was influenced by the amount of solar gains through the expansive glazing of the University Square; as solar gain decreased, the building system loads increased their input, as expected. When the solar gains in the University Square zone increased, the building system loads decreased as a result. The glazing heat loss in University Square zone has no apparent significant effect on the fluctuation of solar gain and building system load.

As shown in Figure 37, all winter Háskolatorg building overall total fabric and ventilation loss was 386.577 kWh, while the University Square zone lost 173.374 kWh. That means that the loss from the University Square zone represented 44% of the Háskolatorg building loss over the winter period.

Glazing is the main source loss was measured in Háskolatorg building, at 192.794 kWh, while at the same time University Square zone lost 143.515 kWh of heat through glazing. The University Square zone contributed 74% of the loss of the whole building through its large exterior glazing throughout the winter period.

The second most significant all winter heat loss was through the walls of Háskolatorg building at 76.338 kWh, while University Square zone lost 2.562 kWh; which represented 3% of the overall Háskolatorg building loss through walls all winter.

The third most significant all winter heat loss from Háskolatorg building was through exterior infiltration at 47.020 kWh, at the same time as the University Square zone lost 15.282 kWh. The all winter amount of University Square zone heat loss through exterior infiltration represented 32% of the overall Háskolatorg building exterior infiltration throughout the winter.

The fourth most significant source of loss for Háskolatorg building was through the exterior ventilation at 45.031 kWh while the University Square zone has had only 4.452 kWh of loss throughout the winter. The amount of the University Square exterior ventilation loss was just 9% of the Háskolatorg building total loss throughout the winter.

The least significant all winter heat loss from Háskolatorg Building occurred through the roofs, or 25.392 kWh. The University Square zone lost 7.561 kWh, representing 29% of the total loss through roof fabric of the Háskolatorg building throughout the winter, as shown in Figure 37.

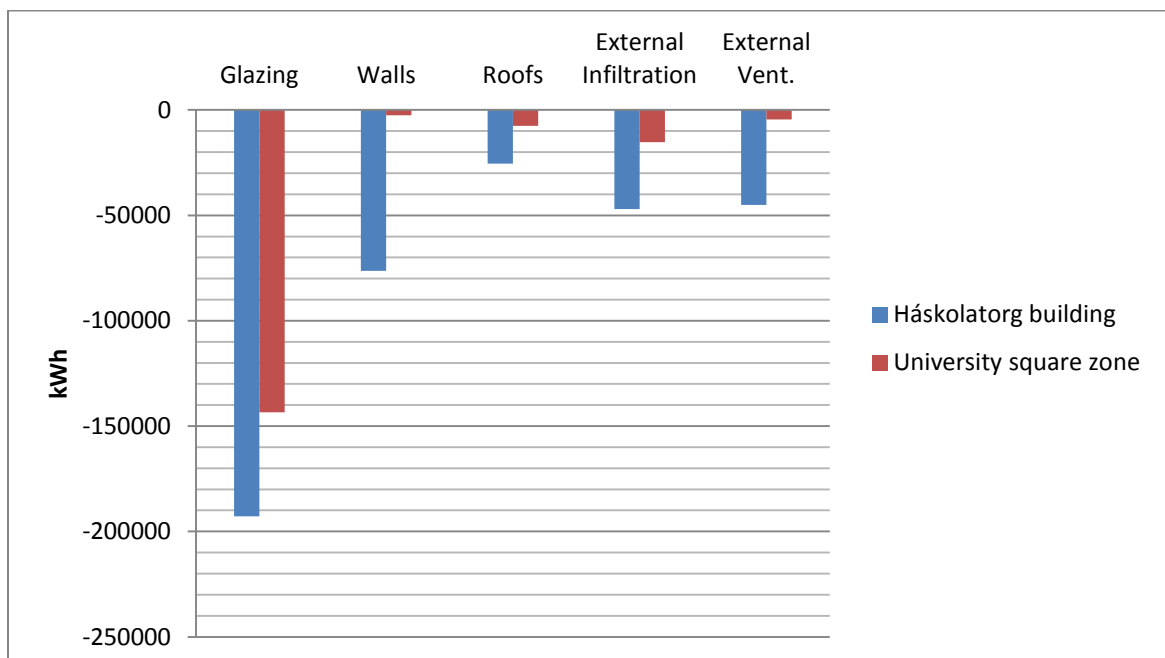


Figure 37: All winter Háskolatorg building and University Square zone fabric and ventilation

4.3 All summer simulation results

4.3.1 Reykjavík All summer air temperature and sun radiation

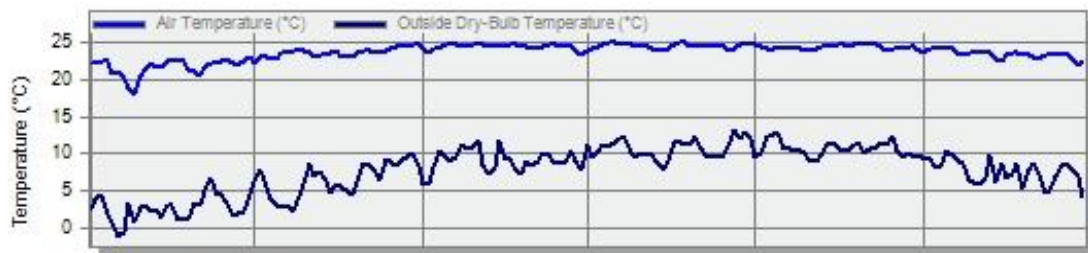


Figure 38: All summer daily air temperature

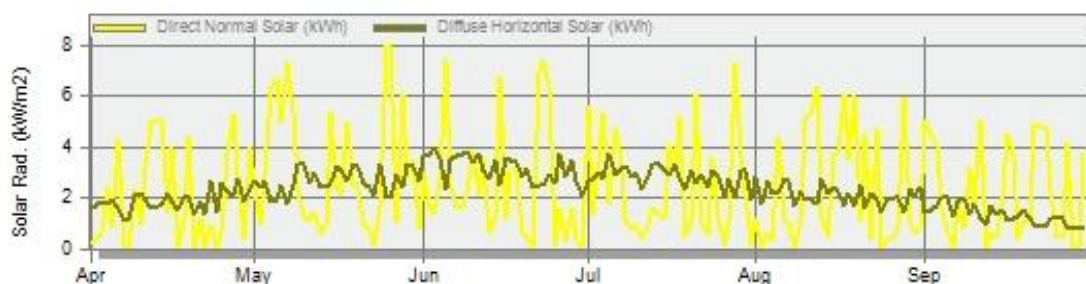


Figure 39: all summer daily Solar eadiation

The all summer minimum outside dry bulb temperature occurred in both April and May at $-1,1^{\circ}\text{C}$. The maximum temperature occurred in July at $13,15^{\circ}\text{C}$. The average temperature in April was $2,5^{\circ}\text{C}$, $4,5^{\circ}\text{C}$ in May, $9,09^{\circ}\text{C}$ in June, $10,7^{\circ}\text{C}$ in July, $10,6^{\circ}\text{C}$ in August and $10,6^{\circ}\text{C}$ in September, as is shown on figure 39. As for the indoor air temperature throughout the summer has was around 24°C .

Both the all summer direct normal solar radiation maximum and minimum occurred in April at $5,28 \text{ Wh/m}^2$ and $2,01 \text{ Wh/m}^2$ respectively. The direct normal solar radiation average of every month is as shown in Table 41:

Table 43: All summer direct normal solar radiation average monthly

Wh/m^2	April	May	June	July	August	September
Average	2,01	3,1	2,4	2,4	2,3	2,5

All summer diffuse solar radiation maximum occurred in June at 3,1 Wh/m², and the minimum has happened in September at 1,3 Wh/m². The diffuse solar radiation of all summer for monthly average were as shown in table 42.

Table 44: All summer diffuse solar radiation monthly average

Wh/m ²	April	May	June	July	August	September
Average	2,01	2,6	3,1	2,9	2,1	1,3

4.3.2 All summer Háskolatorg building internal gains

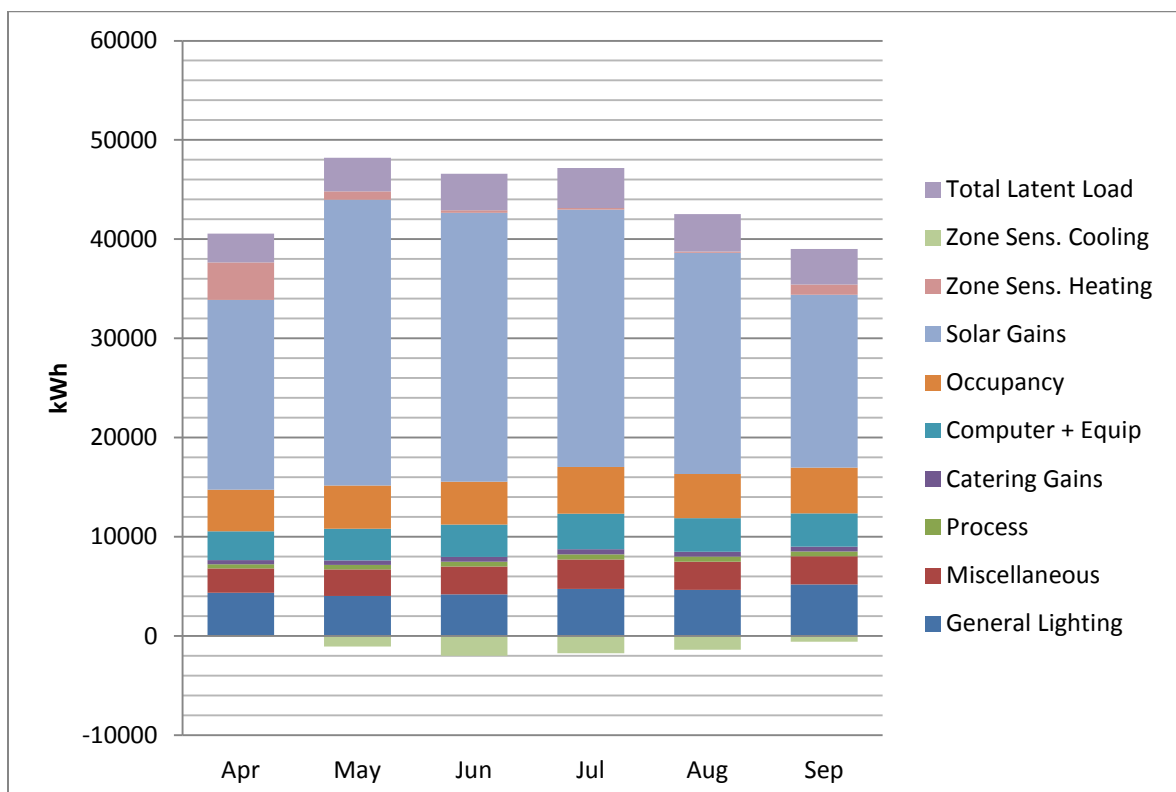


Figure 40: All summer Háskolatorg building internal gains

As shown in figure 40, all summer Háskolatorg building, the most significant internal gains were solar gains of 140.728 kWh. The minimum all summer solar gain was measured in September at 17.425 kWh, while the maximum gain occurred in May at 28.828 kWh.

4.3.3 All summer Háskolatorg building fabric and ventilation loss

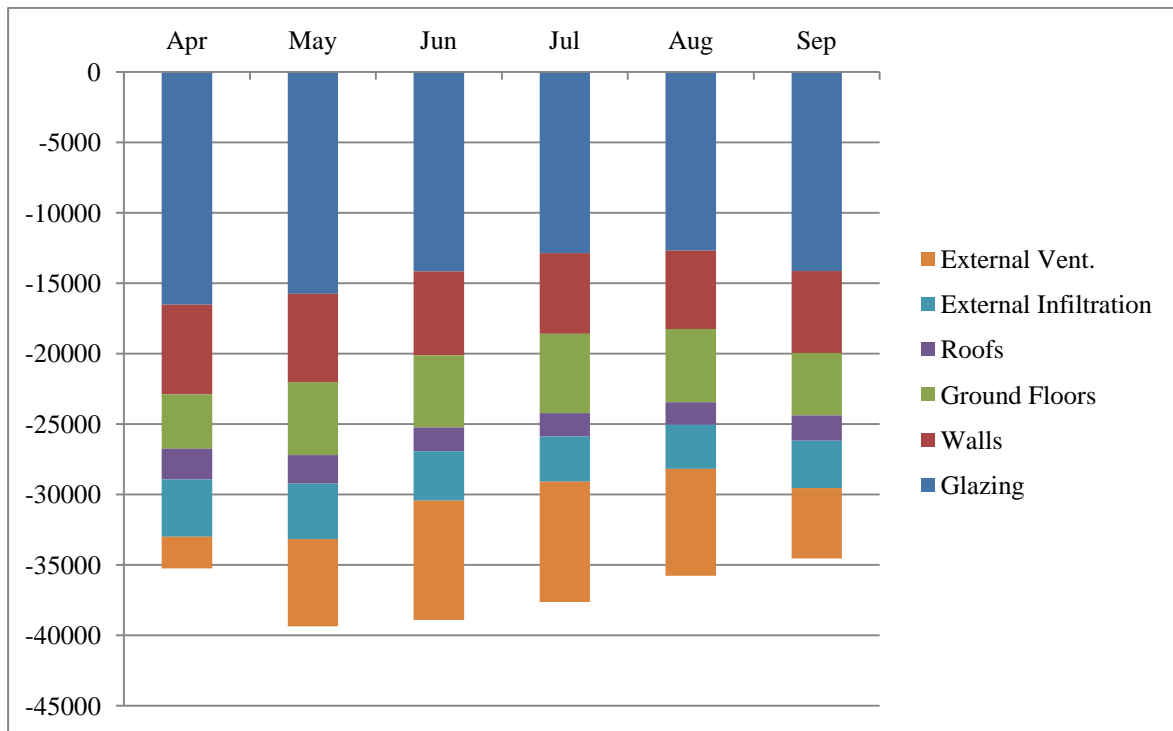


Figure 41: All summer Háskolatorg building fabric and ventilation loss

Throughout the summer, the most significant loss from the Háskolatorg building was from glazing, at 86.178 kWh. The maximum loss was calculated in April at 16.541 kWh, while the minimum loss of Háskolatorg building from glazing throughout summer was at 12.690 kWh and occurred in August.

4.3.4 All summer building system loads

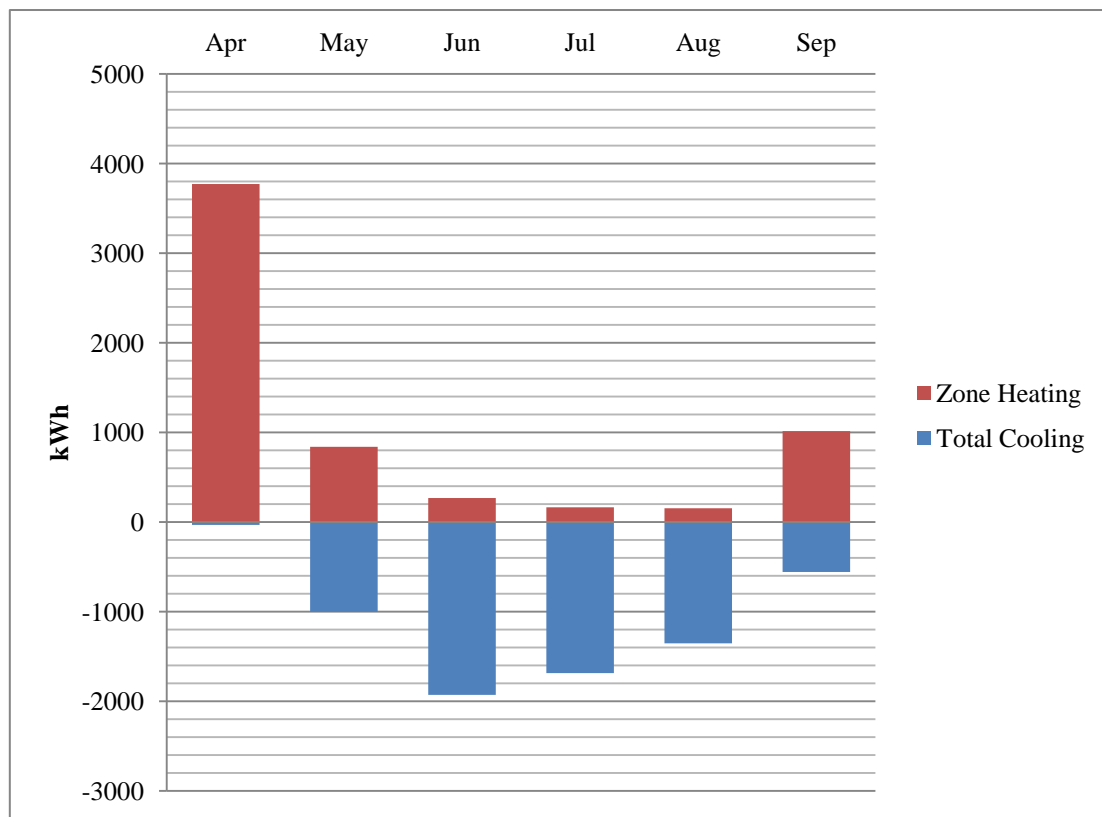


Figure 42: All summer Haskolatorg building system loads

All summer building system loads consisted of zone heating and total cooling. Throughout the summer the total amount of zone heating was 6199 kWh and the total amount of total cooling was 6573 kWh.

The all summer maximum zones heating load was 3.769 kWh, and was measured in April. The minimum load was 152 kWh occurring in both July and August. Simultaneously, the maximum total cooling has happened in June at 1.931 kWh and the minimum cooling load, all summer was in April at 34 kWh.

4.3.5 All summer University Square internal gains

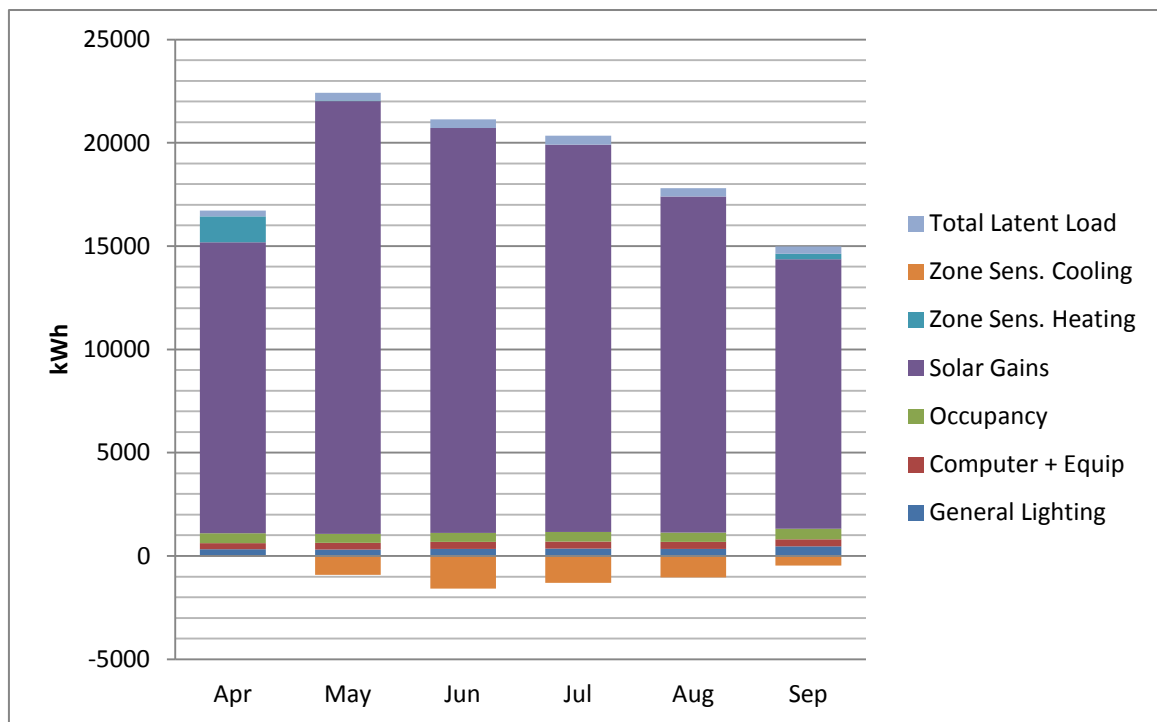


Figure 43: All summer University Square zone internal gains

As shown in figure 43, all summer period, calculation the month of May has shown the maximum solar gains in the University Square zone, at 20.953 kWh. The minimum solar gains of 13.053 kWh were in September.

The University Square zone second most significant internal gains were from zone sensible cooling. Zone sensible cooling total cooling were 5.332 kWh throughout the summer months. The maximum cooling loads occurred in June at 1.578 kWh. The minimum gains on zone sensible cooling took place in April at 35 kWh.

Occupancy, total latent, general lighting, computer and equipment were contributing to the University Square zone internal gains..

4.3.6 All summer University Square fabric and ventilation loss

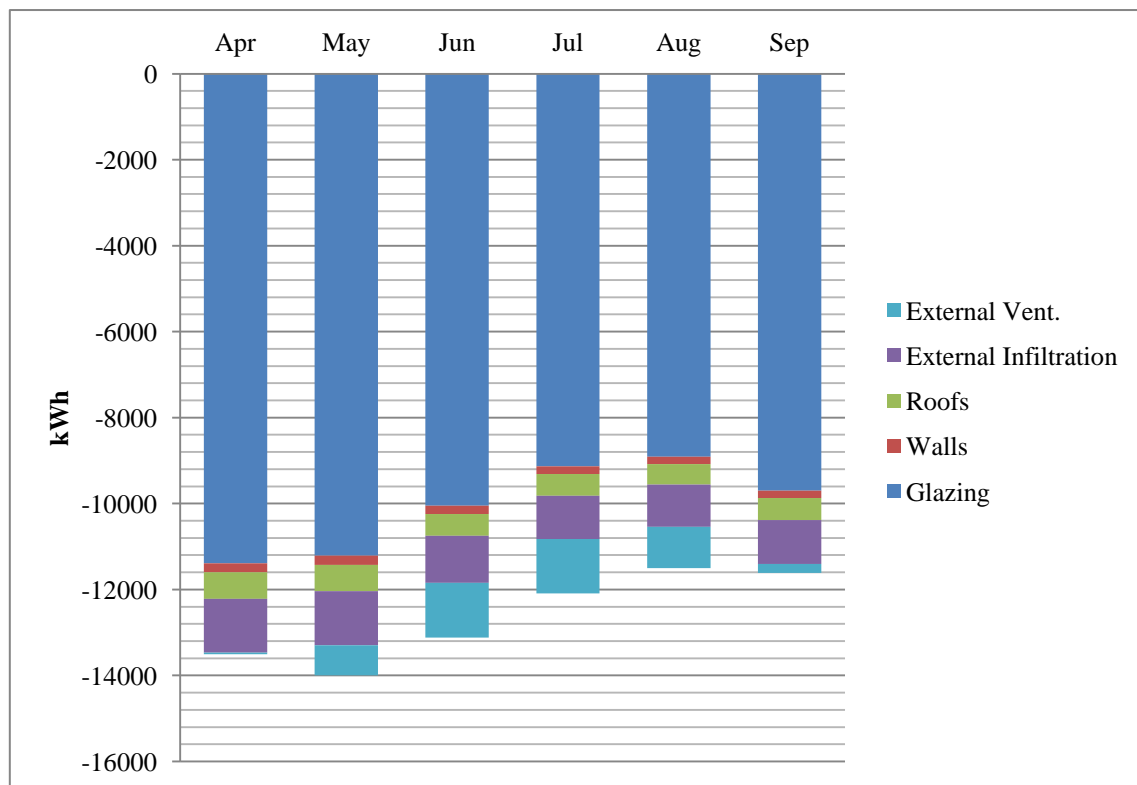


Figure 44: All summer University Square fabric and ventilation loss

All summer glazing fabric in University Square zone lost a total of 60.391 kWh. The maximum loss of 11.387 kWh occurred in April, while the minimum loss of 8.913 kWh occurred in August as shown in figure 44.

4.3.7 Summary

Table 45: Háskolatorg building internal gains, fabric and ventilation loss summer summary

components	<u>Building Internal gains</u>					
	April	May	June	July	August	September
General lighting	4350	4038	4182	4742	4654	5201
Computers and equi.	2905	3183	3284	3599	3372	3372
Occupancy	4182	4363	4323	4703	4456	4617
Solar gains	19156	28828,7	27100,2	25931,6	22286,4	17425,5
Zone sensible	-39	-1071	-2022	-1733	-1388	-578

cooling						
Zone sensible heating	1356	105,4	28,1	17,1	16,8	130,9
Total latent loads	7255,7	8395,9	9023,9	9740,7	9195,4	8912,4
Σ Total	40504	47125	44577	45435	41125	38413
<u>Fabric and ventilation loss</u>						
Glazing	-16541	-15760	-14177	-12870	-12690	-14138
Walls	-6345	-6259	-5939	-5733	-5571	-5820
Roofs	-2165	-2012	-1680	-1658	-1600	-1795
External infiltration	-4084	-3936	-3392	-3193	-3128	-3358
External vent	-2232	-6190	-8496	-8560	-7589	-4994
Σ Total	-35248	-39358	-38924	-37648	-35771	-34544

In table 43 the total internal gains; including miscellaneous, process and catering gains were included in the calculation.

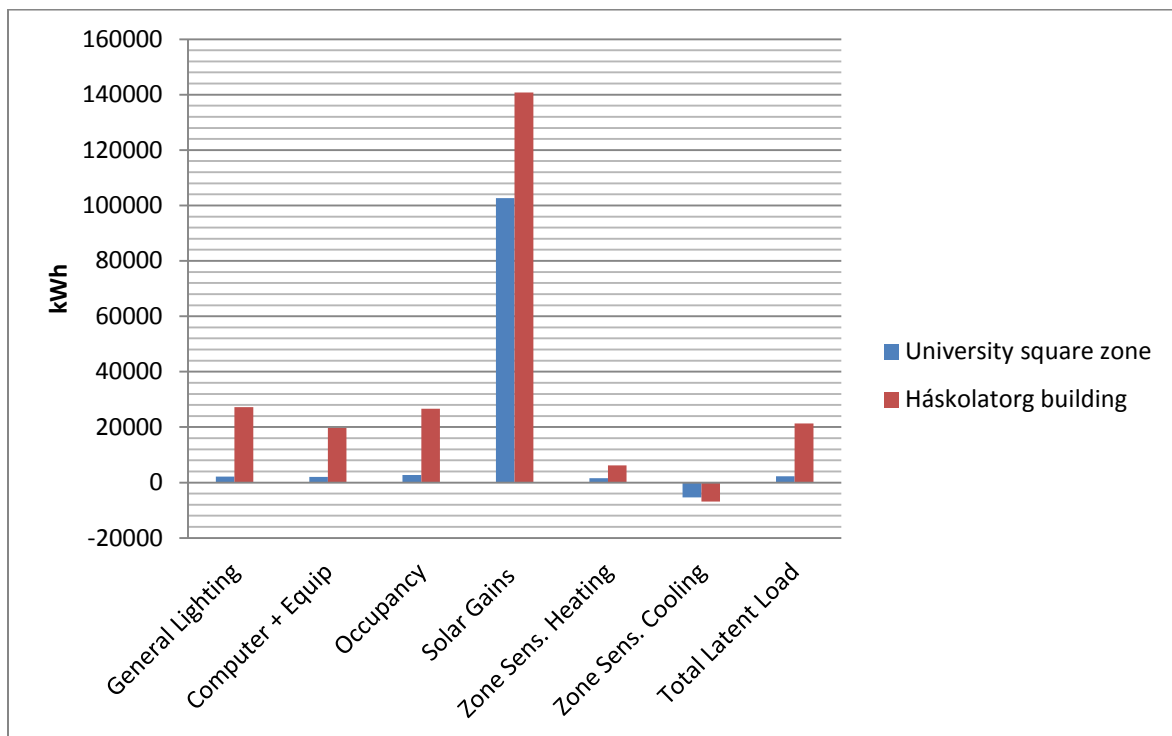


Figure 45: All summer Háskolatorg building and University Square zone internal gains comparison

Throughout the summer period from April 1st until September 31st, Háskolatorg building had overall internal gains of 257.181 kWh, including miscellaneous, catering and process gains. During the same period the University Square zone had registered internal gains of 108.076 kWh. Therefore, 42% of the overall internal gains of Háskolatorg building originated from the University Square zone internal gains.

Table 46: University Square zone internal gains, fabric and ventilation loss

Month	<u>University Square Internal gains</u>					
	April	May	June	July	August	September
General lighting	320	316	338	349	340	464
Computers and equi.	296	319	342	353	342	342
Occupancy	477	430	439	452	452	506

Solar gains	14090	20953	19588	18755	16264	13053
Zone sensible cooling	-35	-908	-1578	-1308	-1040	-461
Zone sensible heating	1260	32	0	0	0	255
Total latent loads	269	374	422	437	409	355
Σ Total	16679	21517	19553	19041	16768	14516
<u>Fabric and ventilation loss</u>						
Glazing	-11387	-11214	-10047	-9131	-8913	-9697
Walls	-209	-216	-193	-182	-171	-175
Roofs	-618	-607	-507	-503	-477	-509
External infiltration	-1249	-1257	-1094	-1004	-976	-1024
External vent	-43	-702	-1275	-1266	-964	-208
Σ Total	-13508	-13999	-13118	-12087	-11503	-11616

As shown in tables 43 and 44, all summer solar gains were very significant among internal gains components. The overall gains of the Háskolatorg building were 140.728 kWh. Simultaneously, the University Square zone had overall solar gains of 102.705 kWh. Subsequently, the all summer solar gains for the University Square zone were staggering a 72% of Háskolatorg building gains.

The second most significant all summer gains were from general lighting; Háskolatorg building has accumulated at 27.168 kWh, whereas the University Square zone was calculated at 2.130 kWh. This means that the all summer University Square general lighting gains represented only 7% of the Háskolatorg building general lighting gains.

All summer occupancy gains for Háskolatorg building were 26.646 kWh, while University Square zone has accumulated 2.759 kWh from the same source. The all summer University Square zone occupancy gains were therefore 10% of the Háskolatorg building gains.

The fourth most significant components were the total latent load. Háskolatorg building all summer total latent loads was 21.302 kWh, of which the University Square zone gained 2.269 kWh. Thus, all summer University Square zone total latent load was 10% of the Háskolatorg building overall total latent load.

All summer, the fifth most significant total internal gains originated from computers and equipment. Háskolatorg building gained 19.719 kWh, while during the same period; the University Square zone accumulated 1.995 kWh, suggested that the University Square zone gain contributed 10% of overall gains of the Háskolatorg building from computers and equipments throughout the summer.

All summer the sixth most significant internal gains were the zones sensible cooling. Háskolatorg building accumulated 6.834 kWh of all summer zone sensible cooling gains, while the University Square zone accumulated zone sensible cooling of 5.332 kWh. As a result, all summer University Square a zone solar gain contributed 78% of the overall zone sensible cooling of Háskolatorg building.

All summer the least significant internal gains in Háskolatorg building were due to the zone sensible heating. Háskolatorg building zone sensible heating load was 6.199 kWh, while the University Square zone gained 1.548 kWh. As a result, the University Square zone represented 24% of Háskolatorg building's all summer zone sensible heating gains.

Table 47: All summer Háskolatorg building system loads summary

<u>Háskolatorg building system loads</u>						
Month	April	May	June	July	August	September
Total cooling	-34	-1004	-1931	-1686	-1356	-559
Zone heating	3769	835	266	160	152	1014

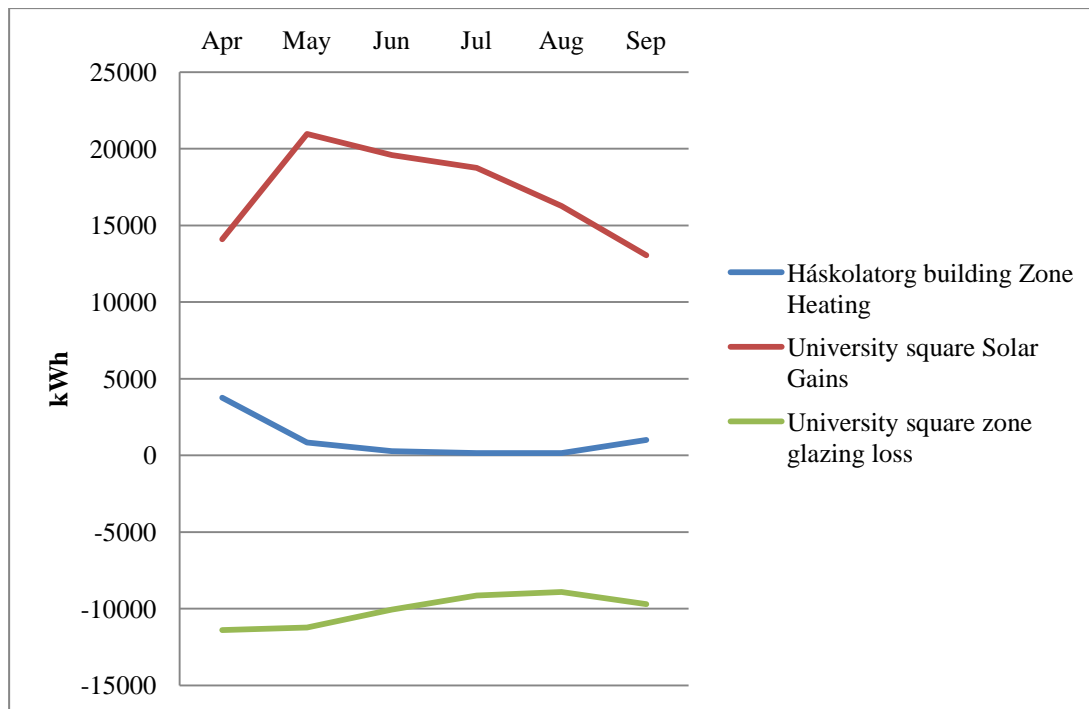


Figure 46: All summer Háskolatorg building system loads total cooling; university Square zone solar gains and glazing loss comparison

As shown in figure 46, the maximum solar gains of the University Square zone occurred on May, while Háskolatorg heating system loads decreased by 22% from its April amount, which was 3769 kWh. Simultaneously, total cooling increased 28 times from its April value. It is conclusive that when University Square zone solar gain increased, building heating loads were decreasing and cooling increasing to maintain the set point temperature indoor. Conversely, when the University Square zone solar gains decreased, Háskolatorg building heating system loads gradually increased and the cooling loads decreased. For instance in September, Háskolatorg building total cooling decreased by 55% compared to the maximum amount of cooling in May. the University Square zone solar gains decreased to 62% of the amount of solar gains in May. Building heating system loads also decreased to 82% of its amount of May levels, but increased by factor of 6 compared to August system heating loads.

This analysis has unveiled that the University Square zone solar gains through glazing greatly influenced the building system loads set to maintain the setpoint temperature during summer period.

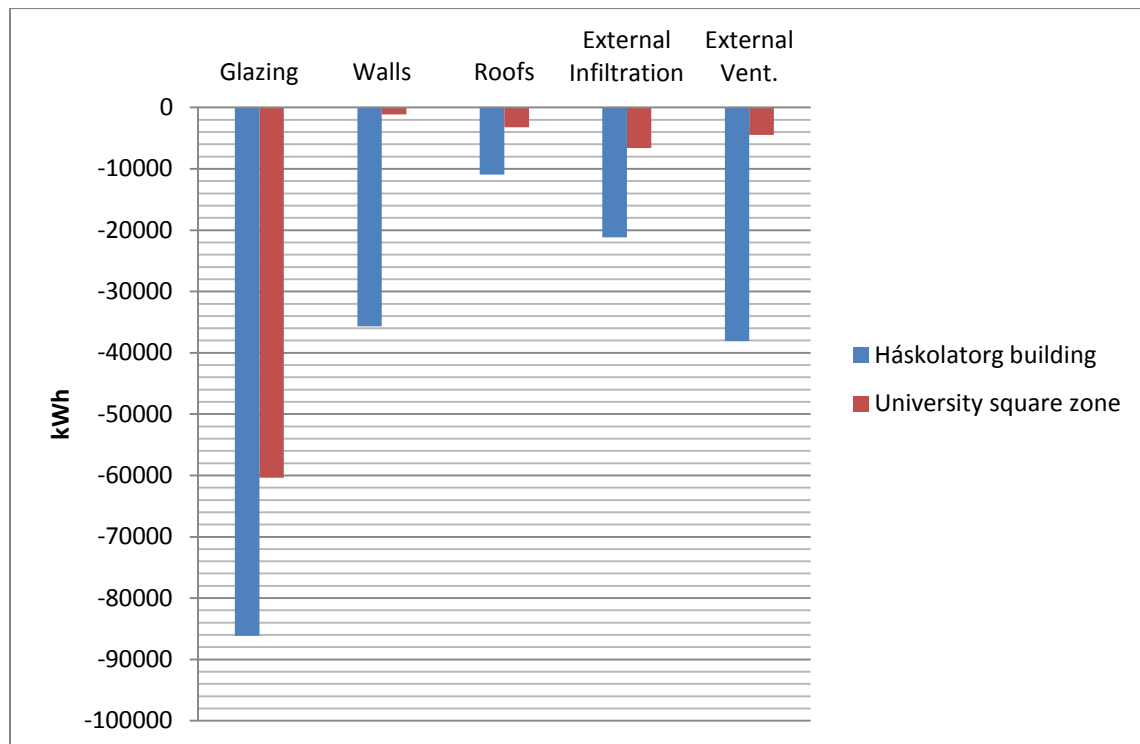


Figure 47: All summer Háskolatorg building and University Square zone fabric and ventilation loss

All summer Háskolatorg building fabric and ventilation total loss was 221.496 kWh, while University Square zone loss was 75.833 kWh. Hence, all summer University Square zone loss through fabric and ventilation was 34% of the Háskolatorg building, as shown in figure 47.

All summer Háskolatorg building's most significant loss was from glazing or 86.178 kWh, while University Square zone lost 60.391 kWh. The all summer loss of the University Square zone through glazing contributed 70% of Háskolatorg building loss.

All summer Háskolatorg building's second most significant source of loss was exterior ventilation, or 38.063 kWh, while the University Square zone lost 4.461 kWh. The University Square zone contributed 11% Háskolatorg building's all summer exterior ventilation loss.

All summer Háskolatorg building's third most significant loss was through walls or 35.670 kWh, whereas the University Square zone lost 1.148 kWh. the University Square zone has enhanced the all summer loss through walls by only 3% of Háskolatorg building loss.

All summer the fourth most significant loss for Háskolatorg building was through exterior infiltration, or 21.193 kWh, while the University Square zone lost 6.606 kWh. The University Square zone contributed 31% of Háskolatorg building loss to the all summer loss through exterior infiltration.

All summer the least significant loss was through roofs, or 10.912 kWh, while the University Square zone lost 3.224 kWh. the University Square zone supplemented the all summer loss through roofs by 29% of Háskolatorg building loss.

It is worth noting that the ground floor energy loss from the building throughout summer was at the amount of 29.478 kWh, and there was no contribution of the University Square zone since it is located on the second floor.

4.4 Winter week results

In this simulation the winter week was scheduled from Sunday January 20th until Saturday January the 26th. This chapter starts with the an illustration of the Reykjavik weather environment base upon weather file input data (see subchapter 3.3.3) and is followed by both Háskolatorg building and the University Square zone internal gains during and fabric and ventilation loss during the winter week. In addition Háskolatorg system loads were reviewed and a brief summary comparing internal gains, fabric and ventilation loss between Háskolatorg building and University Square zone was included..

4.4.1 Háskolatorg Winter week temperature, wind speed, solar radiation

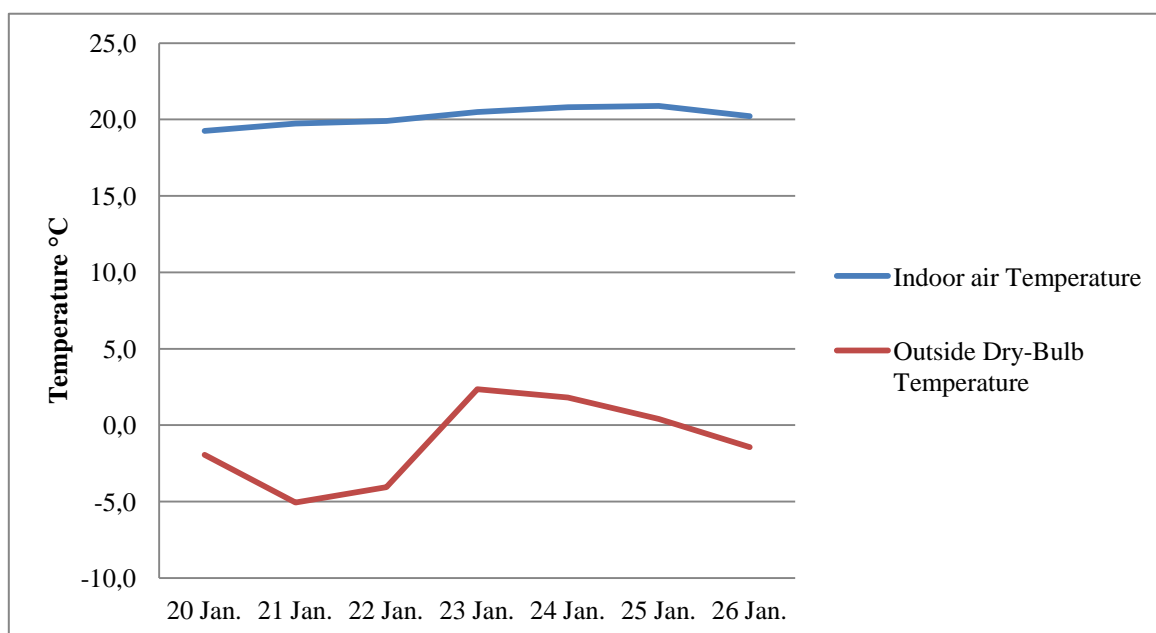


Figure 48: Winter week Reykjavík and Háskolatorg indoor air temperatures

Table 48: Winter week Reykjavík outside Dry-bulb temperature

Day of the week	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Date	20 th	21 st	22 nd	23 rd	24 th	25 th	26 th
Outside Dry-bulb Temperature (°C)	-1,9	-5,1	-4,1	2,4	1,8	0,4	-1,4

During the scheduled winter week the minimum indoor air temperature was 19,24°C on Sunday, January 20th , while the minimum outside dry-bulb temperature of -5°C occurred on Monday, January 21st. During the same week the maximum indoor air temperature of 20,89°C measured on Friday the 25th of January, whereas the maximum outside dry-bulb temperature was at 2,35°C on the 23rd of January. The average indoor air temperature was 20,18°C and the average outside dry-bulb was -1,13°C, as shown in figure 48.

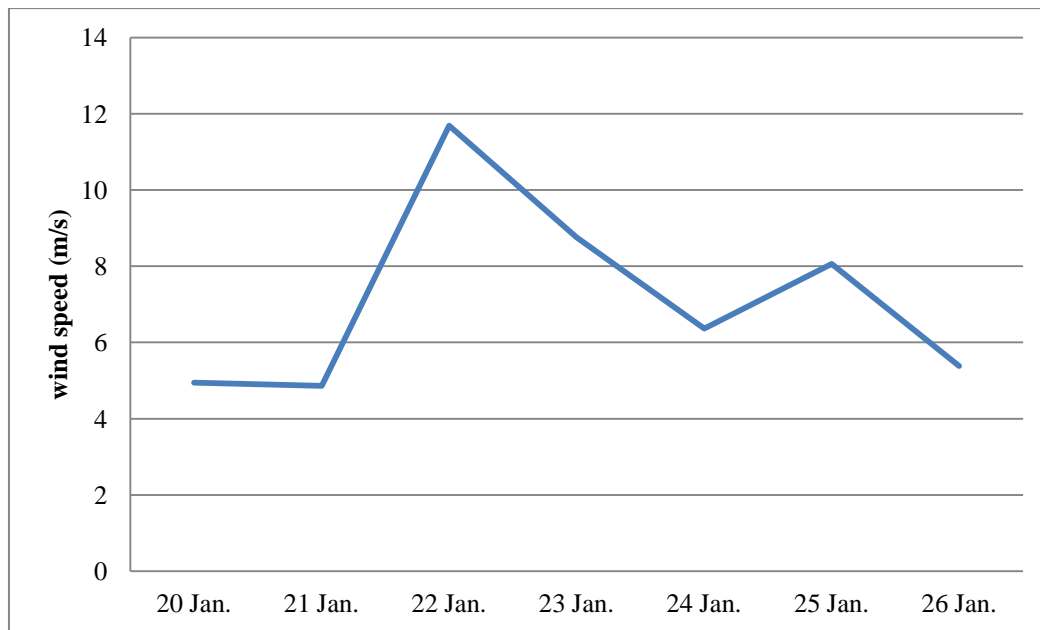


Figure 49: Winter week Reykjavík wind speed

A Prevalent south-east wind was registered in Reykjavík during the winter week, with an average wind speed of 7,15 m/s. Optimum wind speed was registered on Tuesday, the 22nd of January at the speed of 11,68 m/s, and the minimum speed was recorded on January the 21st at the speed of 4,85 m/s as shown in Figure 49.

The maximum normal solar radiation in Reykjavík was measured on Saturday the 26th of January at 0,39 Wh/m², while the minimum normal solar radiation was on Tuesday the 22nd until Wednesday the 23rd of January at null radiation.

Additionally, Reykjavík maximum diffuse horizontal solar radiation was reported on Saturday the 26th of January at 0,18 Wh/m². The minimum diffuse horizontal solar radiation was confirmed on Wednesday the 23rd of January at 0,07 Wh/m², as shown in figure 50.

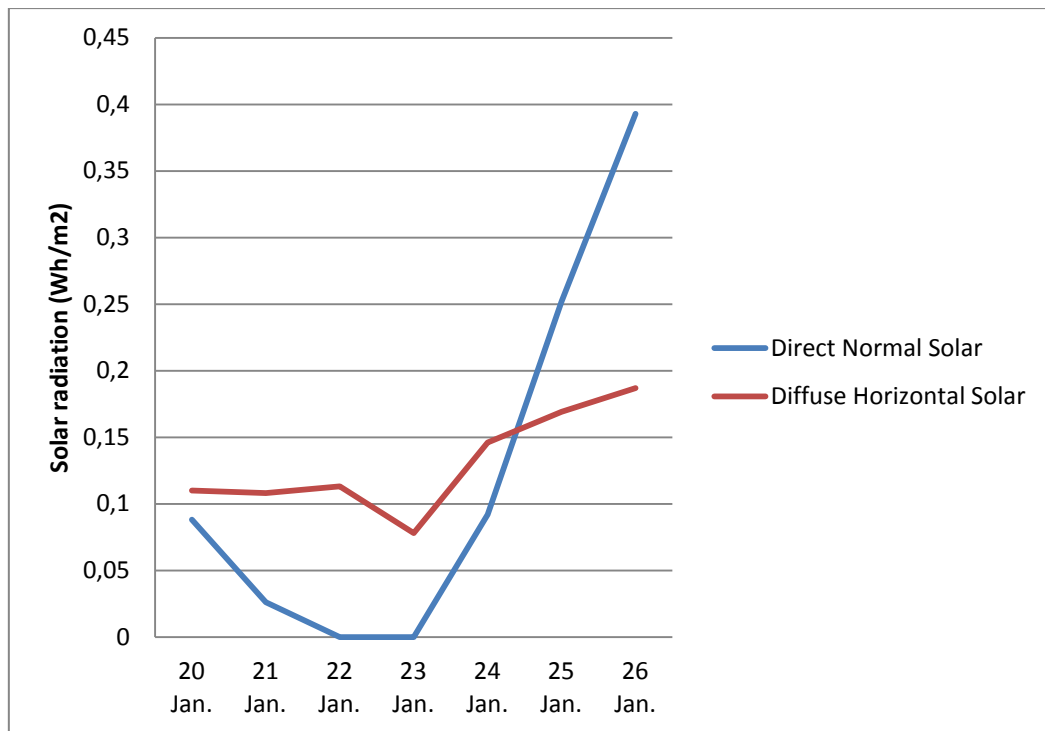


Figure 50: Reykjavík winter week solar radiation

4.4.2 Winter week Háskolatorg building internal gains

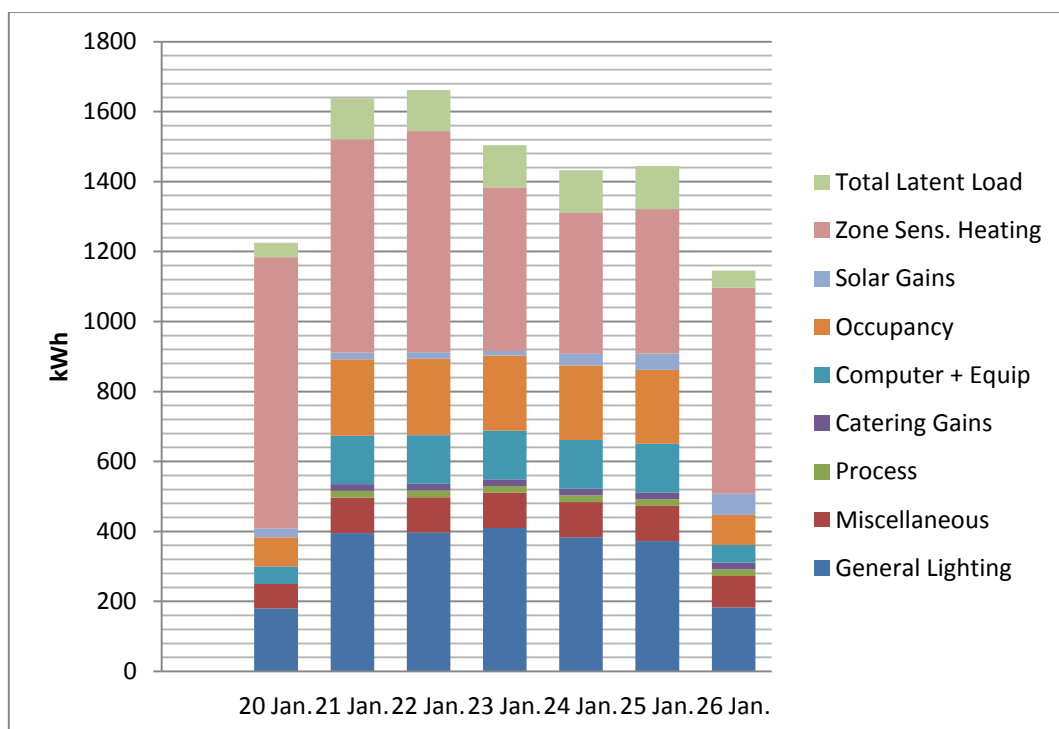


Figure 51: Winter week Háskolatorg building internal gains

Throughout the winter week that started on Sunday 20th of January, zone sensible heating gains were the most significant gain in Háskolatorg building at the total amount of 3.888

kWh. Zone sensible heating gains on Sunday the 20th were the maximum gain at 774 kWh, while the minimum gain was calculated on Friday the 25th of January at 412 kWh.

General lighting was the second significant gain in Háskolatorg building, was calculated at 2.321 kWh, the maximum general lighting gain was registered on Wednesday 23rd of January at 409 kWh, the minimum energy gains was marked on Sunday 20th January at 179 kWh.

The third significant internal gains in Háskolatorg building was occupants at the total amount of 1.244 kWh. The maximum amount has happened on Monday the 21st and Tuesday the 22nd of January at 218 kWh, while the minimum amount was recorded on Sunday the 20th of January at 82 kWh.

The fourth significant internal gains in Háskolatorg building during winter week were computer and equipment gain. The maximum and constant gain was calculated from Monday 21st of January until the Friday the 25th of January. The minimum amount gain in computer and equipment was marked on the 2 weekend days.

The fifth significant internal gains in Háskolatorg building was total latent load at the total amount of 690 kWh. The maximum amount has occurred on Friday the 25th of January at 123 kWh, as the minimum amount was manifested on Sunday the 20th of January at 41 kWh.

The sixth significant internal gains in Háskolatorg building was Miscellaneous gain at the total amount of 663 kWh. The maximum amount has happen from Monday the 21st of January at 100 kWh until the Friday the 25th, while the minimum amount was calculated on Sunday the 20th of January at 69 kWh.

Solar gains were expected to be low during winter. It was only the seventh internal gains in Háskolatorg building with a total amount of 217 kWh during winter week. The maximum gain was calculated on Saturday the 26th of January at 60 kWh, while the minimum gain was on Wednesday the 23rd of January at 12 kWh.

The process and Catering gains were the least significant of internal gains in Háskolatorg building. Both have confirmed the same total amount of 115 kWh during the winter week. Process and Catering gains were both in constant amount of 19 kWh from Monday the 21st

of January until Saturday the 26th of January. Only Sunday the 20th that process and catering gains were null.

4.4.3 Winter week Háskolatorg building fabric and ventilation

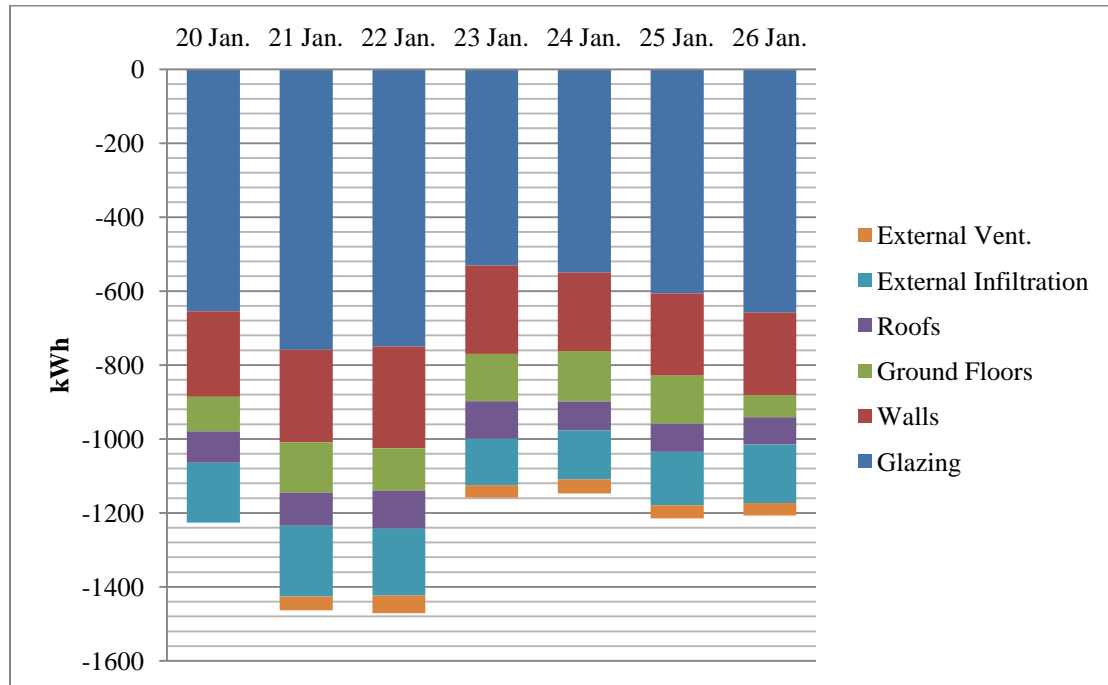


Figure 52: Winter week Háskolatorg building fabric and ventilation loss

During the winter week, that has started the Sunday 20th of January until the Saturday 26th, Háskolatorg building has registered fabric and ventilation loss overall amount of 8888 kWh, as shown in figure 52.

The most significant loss was from the Glazing of the amount of 4.509 kWh, with a maximum amount of 758 kWh that has occurred on Monday the 21st of January, while the minimum has happen on Wednesday the 23rd at 531 kWh.

The second significant Háskolatorg building loss was from the walls fabric. Minimum loss was of the amount of 211 kWh and has occurred on Thursday 24th July, while the maximum loss was on Tuesday 22nd of January at 275 kWh. The total energy loss through walls fabric during the winter week mentioned above was recorded at 1.653 kWh.

Building external infiltration energy minimum loss was of the amount of 125 kWh on Wednesday 23rd January, the maximum loss was occurred on Monday 21st of January at

191 kWh. The total loss due to external infiltration during the summer week was recorded at 1094 kWh.

The fourth significant loss from Háskolatorg building was from the ground floors. Minimum loss was of the amount of 58 kWh and occurred on Saturday 26th January, as the maximum loss was on Monday the 21th of January at 137 kWh. The total energy loss through the ground floor throughout the summer week was recorded at 797 kWh

The fifth significant loss in Háskolatorg Building was the external vent. The maximum loss was on Thursday 24th of January at 38 kWh. The total loss due to external vent during the summer week was recorded at the amount 226 kWh.

The least significant Háskolatorg building during the winter week was from the roofs. The roofs fabric energy maximum loss was of the amount of 103 kWh on Tuesday 22nd January, while the minimum loss was on Saturday the 26th of January at 74 kWh. The total energy loss through roofs fabric during the winter week was calculated at 605 kWh.

4.4.4 Háskolatorg building winter week system loads

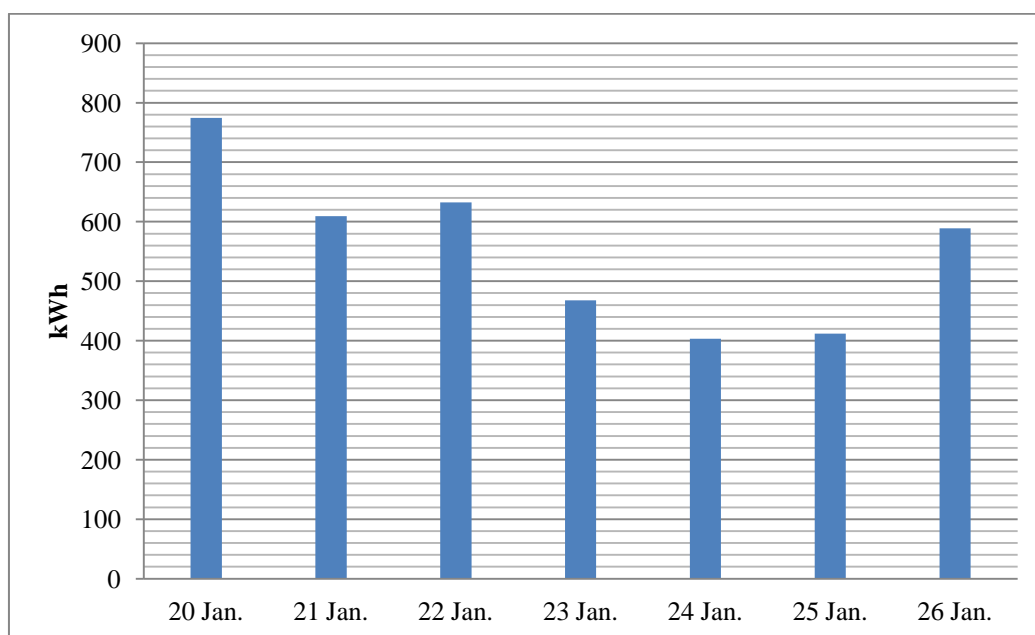


Figure 53: Háskolatorg building winter week system loads: zone heating

From the January 21st until the January 26th, Háskolatorg building system loads reached the amount of 3888 kWh, with maximum at 740 kWh, and occurred on Sunday 20th of January, while the minimum load was on Thursday the 24th of January at 403 kWh.

4.4.5 Winter week University Square zone internal gains

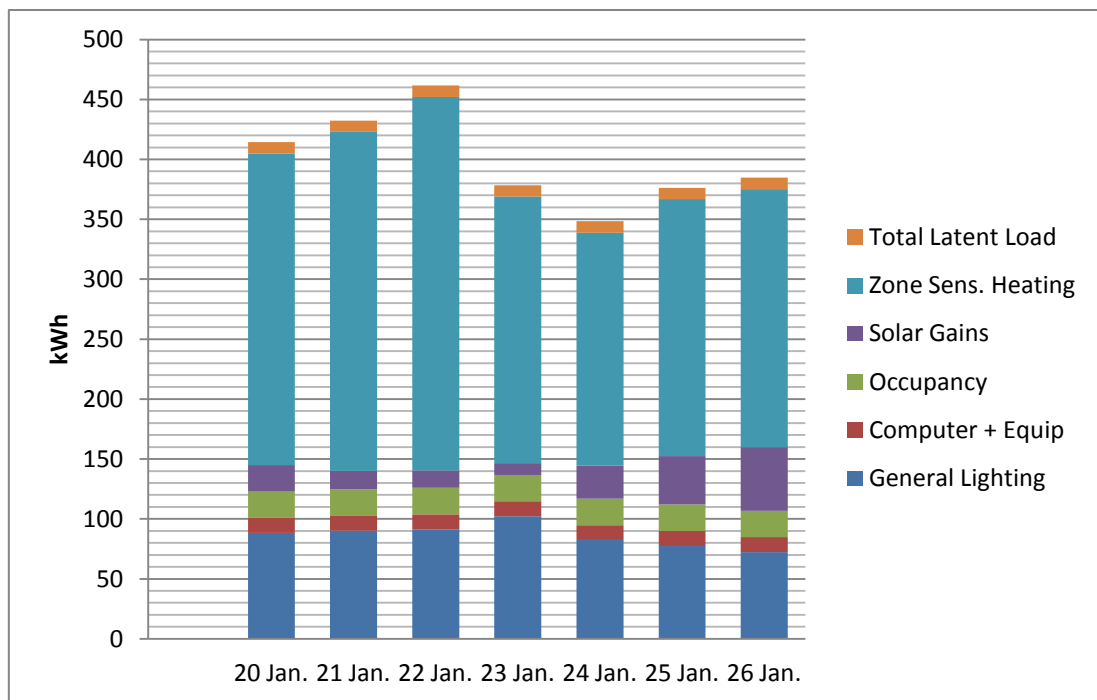


Figure 54: Winter week University Square internal gains

During the winter week, that has started the Sunday 20th of January until the Saturday 26th, University Square zone has accumulated internal gains overall amount of 2.796 kWh, as shown in figure 54.

The most significant University Square zone internal gains was the zone sensible heating. Maximum amount was calculated at 311 kWh on Tuesday 22nd of January; the minimum amount heating was considered on Thursday 24th of January at 194 kWh. The zone total sensible heating during the winter week was 1701 kWh.

The second University Square zone significant internal gains were general lighting. On Saturday 26th of January, general lighting gain has exhibited minimum amount at 72 kWh, while the Wednesday 23rd of January, the general lighting was the maximum gains registered at 102 kWh. The total general lighting during the winter week was at 603 kWh.

University Square zone solar gains through external windows during the summer week optimum amount was record on Saturday 26th of January at 52 kWh, while the minimum gains was calculated on Wednesday 23rd of January at 9,7 kWh. The University Square zone total solar gains were recorded at 182 kWh.

For the University Square occupancy gains was at constant amount throughout the winter week at 22 kWh. The total occupancy gain for University Square during the summer week was noted at 154 kWh.

The computer gain at University Square zone has remained constant all winter week at 12 kWh. The total gains during that time was 87 kWh..

The least significant University Square zone was the total latent loads. Throughout the week the total latent load was constant at 9,4 kWh each day. The total latent during winter week was calculated and at 66 kWh, as shown in figure 54.

4.4.6 Winter week University Square zone fabric and ventilation

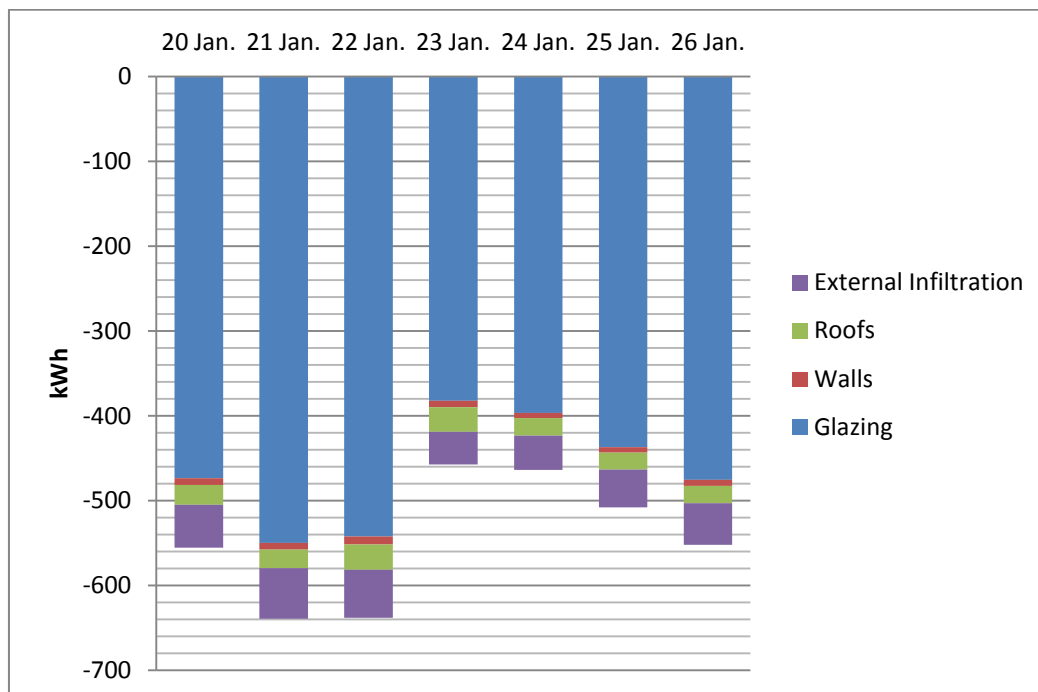


Figure 55: Winter week University Square zone fabric and ventilation loss

During the winter week starting on Sunday the 20th of January the University Square zone overall energy loss was 3815 kWh. The maximum loss of 639 kWh occurred on 21st of January, while the minimum loss of 457 kWh happen on the 23rd.

The most significant loss in the University Square zone was from glazing fabric. The minimum glazing loss was 382 kWh on Wednesday 23th of January; the maximum loss was on Monday 21st at 549 kWh. The total loss during the winter week was recorded at 3257 kWh.

The second most significant loss from the University Square zone was from external infiltration. The University Square zone external minimum loss from external infiltration energy was 38 kWh on Wednesday, the 23rd of January, the maximum loss on Monday the 21st of January at 59 kWh. The total loss during the winter week was recorded at 339 kWh.

During the winter week the maximum energy loss through roof fabric was 29 kWh on Tuesday the 22nd of January, the minimum loss of 19 kWh was on Friday the 25th of January. The total roofs energy loss during the winter week was recorded at 164 kWh.

The least significant loss from the University Square zone was from the wall fabric. University Square wall fabric energy minimum loss was 6 kWh on Thursday 24th January; the maximum loss was 9 kWh on Tuesday the 22nd of January. The total energy loss during the winter week was recorded at 53 kWh, as shown in figure 55.

4.4.7 Summary

Table 49: Comparison summary between Háskolatorg building and University Square zone

components	<u>Internal gains</u>	
	Háskolatorg building(kWh)	University Square zone(kWh)
General lighting	2321	603
Computers and equi.	795	87
Occupancy	1244	154
Solar gains	217	182
Zone sensible heating	3888	1701
Total latent loads	690	66
Σ Total	9157	2796
	<u>Fabric and ventilation loss</u>	
	Háskolatorg building(kWh)	University Square zone(kWh)
Glazing	-4509	-3257
Walls	-1653	-53
Roofs	-605	-164
External infiltration	-1094	-339

External vent	-226	0
Σ Total	-8090	-3815

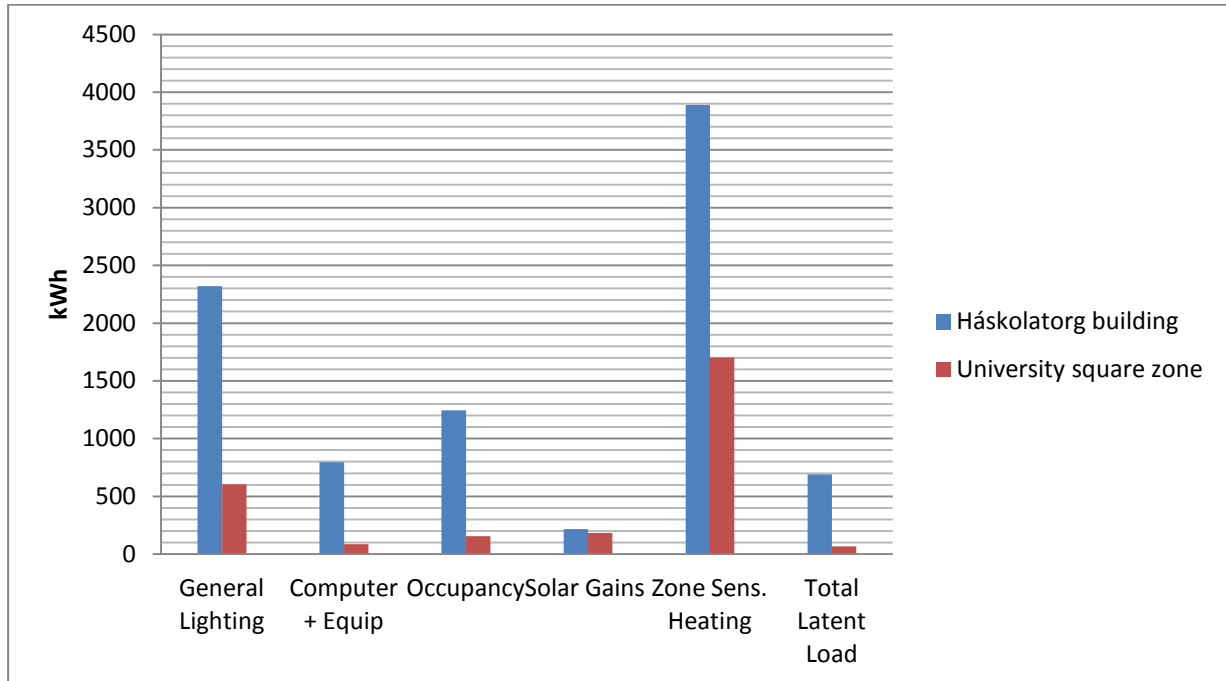


Figure 56: Winter week Háskolatorg building and University Square zone internal gains comparison

The most significant component during the winter week period was the zone sensible heating. Winter week zone sensible heating was calculated at 3888 kWh for Háskolatorg building, while the University Square zone has gained 1701 kWh. Hence, winter week University Square zone sensible heating was 43% of the Háskolatorg building overall zone sensible heating gain.

The second most significant overall winter week internal gains originated from general lighting. Háskolatorg building gained 2.321 kWh, while during the same period, the University Square zone contributed 603 kWh. That indicates that the University Square zone gains were 26% of overall gains of the Háskolatorg building.

Winter week occupancy gains for Háskolatorg building were 1.244 kWh, with the University Square zone contributing 154 kWh. Therefore, winter week University Square zone occupancy gains represented 12% of the Háskolatorg building gains.

Winter week computer and equipments gains were fourth significant among the components of internal gains in the Háskolatorg building. Háskolatorg building total gains, has reached the amount of 795 kWh. At the same time, University Square zone has registered overall computer and equipments gains at the amount of 87 kWh. Thus winter week University Square zone computer and equipments gains were just 11% of Háskolatorg building gains.

The fifth significant winter week gains have been the total latent loads; Háskolatorg building has accumulated at the amount of 690 kWh, whereas the University Square has contributed the amount of 66 kWh. This has conveyed that the winter week University Square zone total latent load was only 9% of the Háskolatorg building total latent loads.

The least significant internal gains were the solar gains. Háskolatorg building has accumulated during winter week solar gains at the amount of 217 kWh, while the University Square has contributed solar gain at the amount of 182 kWh. That would be translated that all winter University Square zone solar gains has been 83% of the overall solar gain of Háskolatorg building, such as shown on Figure 56.

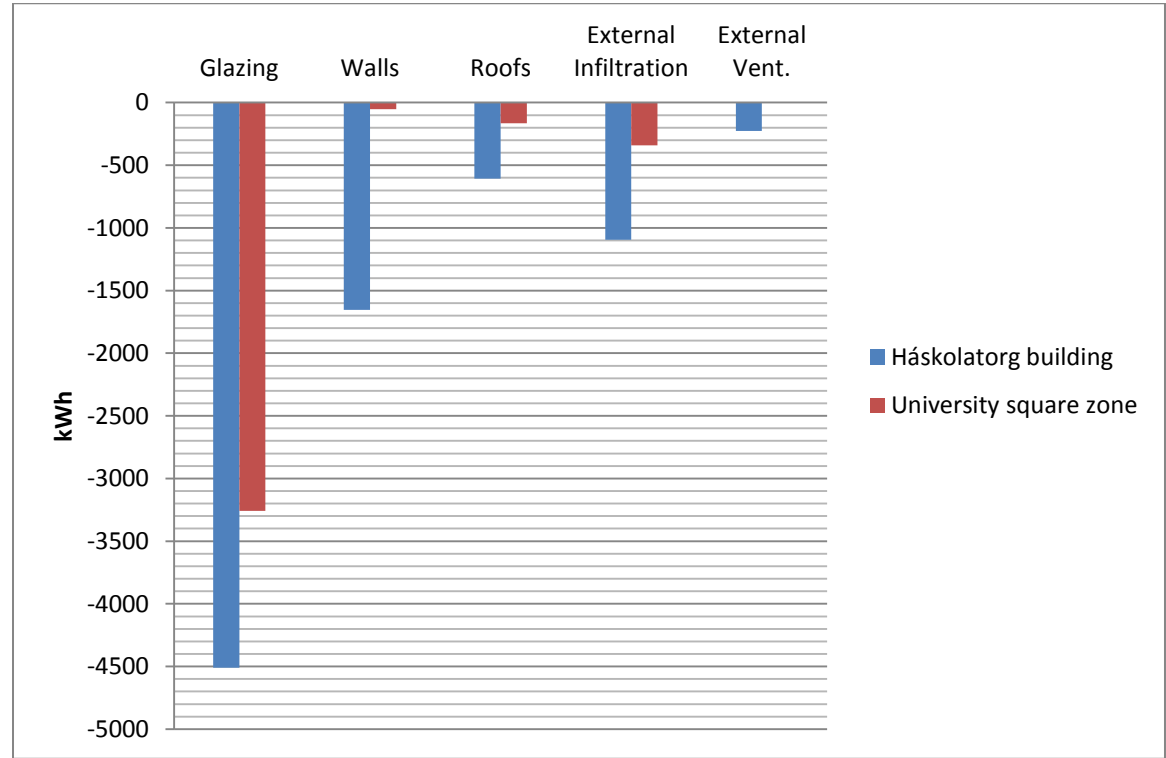


Figure 57: Winter week Háskolatorg building and University Square zone fabric and ventilation loss

As shown in figure 57, throughout winter week from Saturday 20th of January until Friday 26th of January; Háskolatorg building overall fabric and ventilation loss was 8.090 kWh, while the University Square zone lost 3.815 kWh. That means that the loss of the University Square zone was 47% of the Háskolatorg building loss over the winter week period.

Glazing is main source of loss that was calculated for Háskolatorg building, with losses of 4.509 kWh, while at the same time the University Square building lost 3257 kWh of heat through glazing. The University Square zone contributed 72% of the loss of the whole building through its large exterior glazing throughout the winter week period.

The second most significant winter week heat loss from Háskolatorg building was through the walls at 1.653 kWh, whereas the University Square zone lost 53 kWh; representing 3% of the overall Háskolatorg building loss through walls throughout winter week.

The third most significant winter week heat loss from Háskolatorg building was through exterior infiltration at 1.094 kWh, while the University Square zone lost 339 kWh. The winter week University Square zone heat loss through exterior infiltration was 31% of the overall Háskolatorg building exterior infiltration throughout the winter week.

The fourth most significant winter week heat loss from Háskolatorg Building was from the roofs at 605 kWh, while the University Square zone lost 164 kWh. The University zone loss was 27% of the total heat loss through roofs of the Háskolatorg building throughout the winter week.

The least significant loss of Háskolatorg building was loss through exterior ventilation at 226 kWh while the University Square zone had no loss or gain, throughout the winter week.

4.5 Summer week simulation results

The summer week in this simulation was from Saturday, July the 27th until the Friday, August the 2nd. This chapter starts with the illustration of the Reykjavik weather environment, based on the weather input data file (see subchapter 3.3.3) followed by both Háskolatorg building and University Square zone internal gains and fabric and ventilation loss during the summer week. In addition Háskolatorg system loads is reviewed and a brief

summary comparing internal gains, fabric and ventilation loss between Háskolatorg building and University Square zone is included.

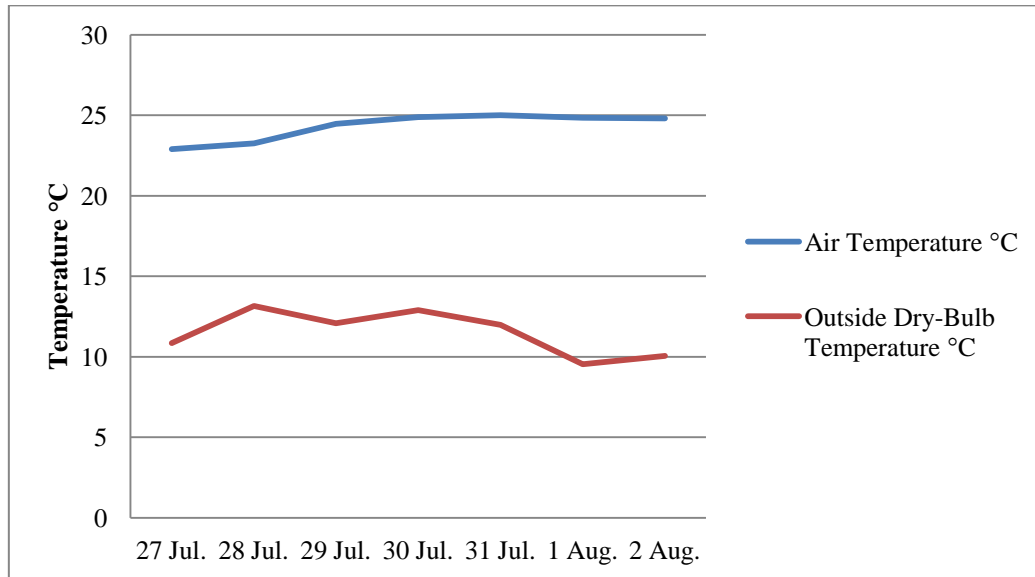


Figure 58: Summer week Háskolatorg site temperature DesignBuilder generated

During the summer week, the minimum indoor air temperature of 22,89°C was recorded on 27th of July. The minimum outside dry-bulb temperature of 9,53°C occurred on the 1st of August. During the same week, the maximum indoor air temperature of 24,99°C was recorded on the 31st of July, the maximum outside dry-bulb temperature was confirmed at 13,15°C on the Sunday 28th of July. The average indoor temperature was 24,30°C and the outside dry-bulb was 11,50°C, as shown in figure 58.

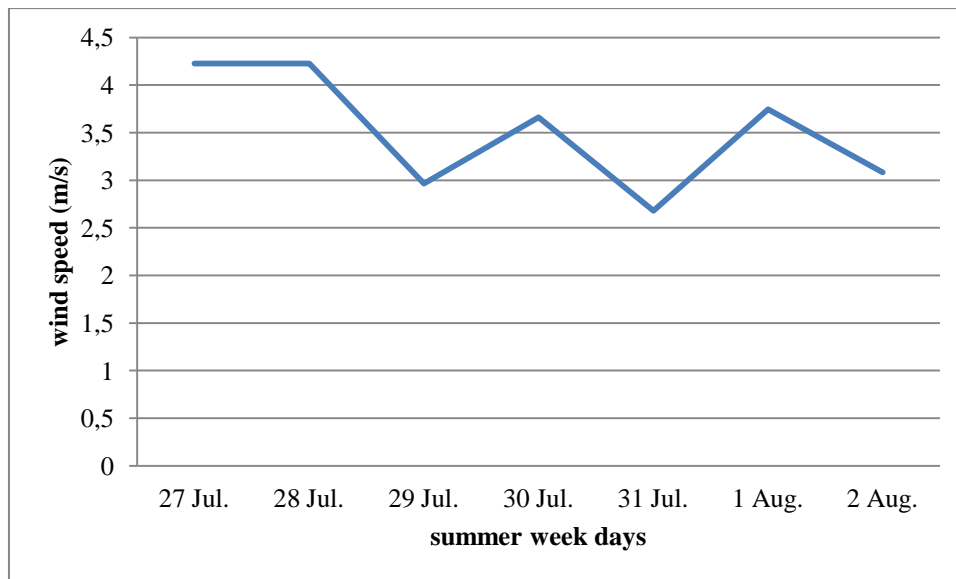


Figure 59: Summer week Reykjavík wind speed

A prevalent south east wind was recorded in Reykjavík during the summer week; with average wind speeds of 3,4 m/s, optimum wind speed from Saturday 27th until Sunday ,the 28th of July and a minimum wind speed of 2,67 m/s, as was recorded on Tuesday July 31st.

The maximum normal solar radiation was reported in Reykjavík on Sunday the 28th of July at 7,8 Wh/m². The minimum normal solar radiation was confirmed on Friday the 2nd of August at 0,003 Wh/m².

Additionally, the maximum diffuse horizontal solar radiation in Reykjavík was reported on Monday the 29th of July at 3,06 Wh/m², while the minimum diffuse solar radiation was confirmed on the Friday the 2nd of August at 1,76 Wh/m², as shown in Figure 60.

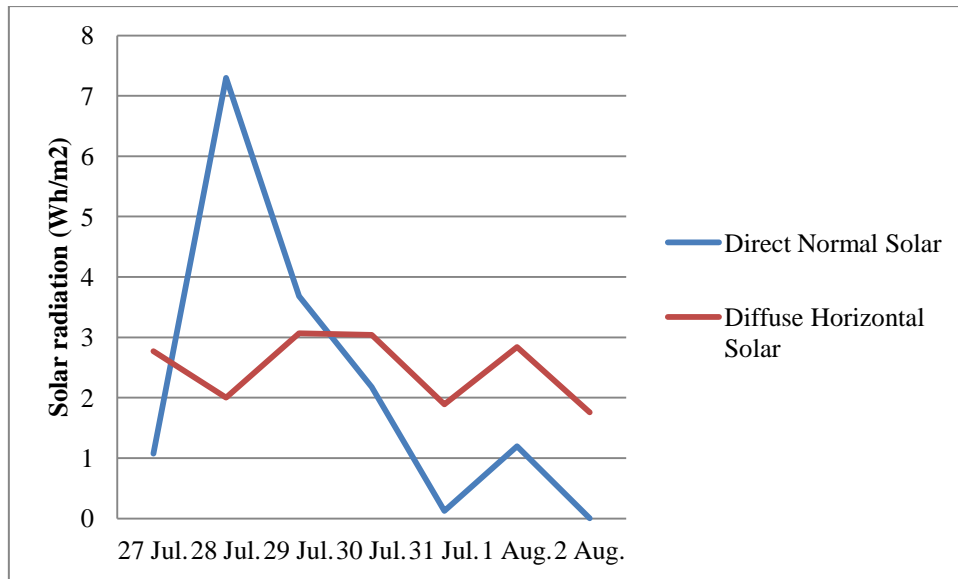


Figure 60: Reykjavík summer week solar radiation

4.5.1 Summer week Háskolatorg building internal gains

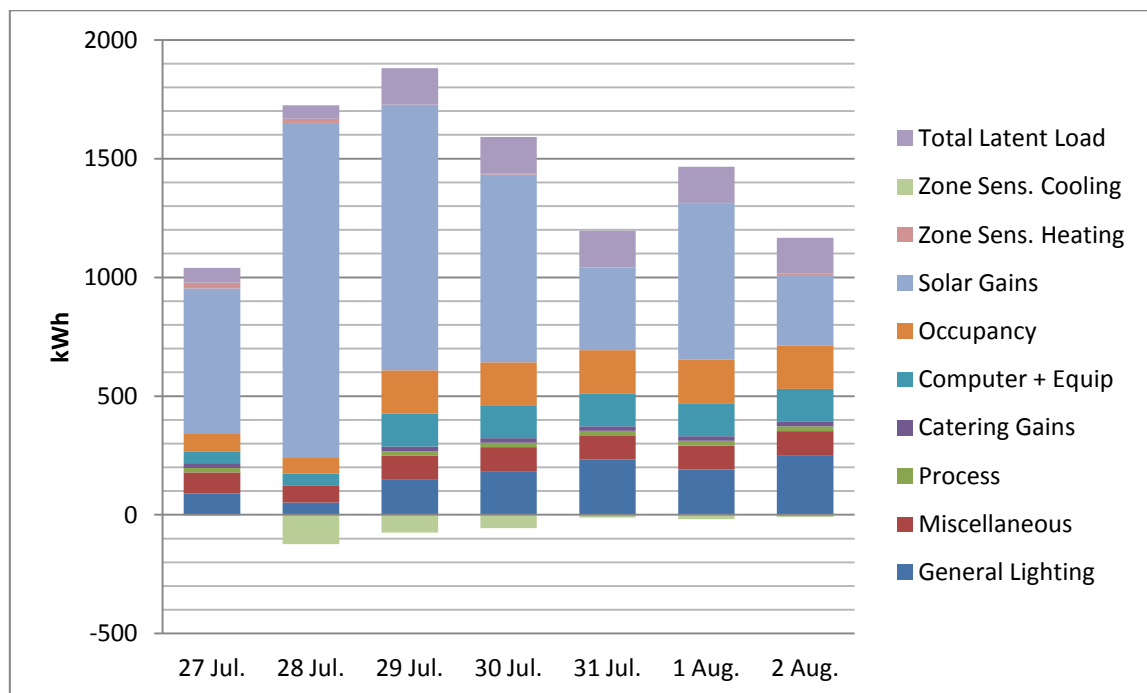


Figure 61: Summer week Háskolatorg building internal gains

Throughout summer week, Háskolatorg accumulated total internal gains of 9.766 kWh. The minimum amount of internal gains was measured on Saturday the 27th of July at 1.035 kWh and the maximum occurred on the 29th of July at 1.804 as is shown in Figure 61.

Throughout the summer week, Háskolatorg building's most significant gain was solar gains. Total solar gains through exterior windows for the summer week were 5224 kWh in total. The maximum gains were reported on 28th of July at 1410 kWh. The minimum gains were listed at 292 kWh on the 2nd of August.

The second most significant internal gains in Háskolatorg building were from general lighting. During the summer week, Háskolatorg building had total internal casual gain from general lighting of 1.151 kWh, the maximum energy gains were recorded on Friday the 2nd of August at 252 kWh, the minimum consumption was calculated on Sunday the 28th July, at 90 kWh.

The third significant internal gains in Háskolatorg building was from occupancy. The internal gains from occupancy during summer week were listed as 1050 kWh in total. The maximum energy gain occurred on Friday the 2nd of August, at 183 kWh. The minimum occupancy gain was listed on Sunday the 28th of July at 66 kWh, as shown in figure 61.

The fourth most significant internal gains in Háskolatorg building was due to total latent loads. During the summer week, the total latent loads were calculated at 844 kWh. The maximum total latent loads were registered at 155 kWh on Tuesday the 30 July, while the minimum total latent loads were reported at 57 kWh on the Sunday 28th July.

The fifth significant internal gains in Háskolatorg building was the computer and office equipment. Computer and office equipment were gaining energy of the total amount of 795 kWh for the summer week. During the 5 working weekdays, computer and equipment gains was constant at 138 kWh, as for the minimum was registered during both Saturday the 27th and Sunday the 28th of July at 50 kWh.

Total miscellaneous gains; due to the presence of automatic snack and beverage machines in the building; during the summer week was around 663 kWh, with constant energy gain was registered from Monday 29th of July until 2nd of August. The maximum consumption was about 100 kWh. The minimum energy gain was 69, and was registered on Sunday 28th of July.

The seventh significant internal gains in Háskolatorg building was zone sensible cooling. During the summer week simulation, the total amount of the zone sensible cooling was

listed at 296 kWh. The optimum amount was reported on Sunday the 28th of July at 122 kWh, the minimum was recorded on Saturday the 27th of July at 3 kWh

Both process and catering total energy gains during the summer week was at 115,09 kWh. Process and catering energy gains was constant in all working days of the week expect the Sunday the 28th of August gains were null, while the other days were at 19 kWh.

The least significant internal gains in Háskolatorg building was zone sensible heating. During the summer, the amount of the zone sensible heating total loads for Háskolatorg building was listed at 63 kWh. The maximum zone sensible heating amount was recorded on 27th of July at 23 kWh, the minimum zone heating amount was reported on 31st of July at 1,5 kWh.

4.5.2 Summer week Háskolatorg building fabric and ventilation

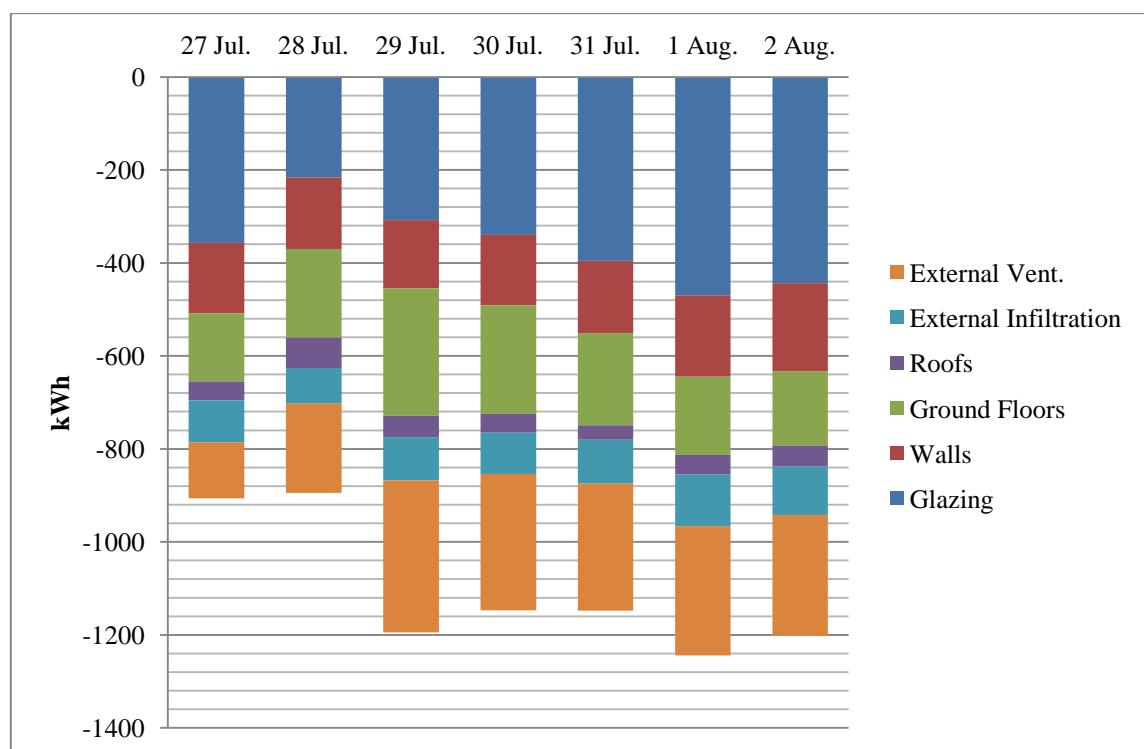


Figure 62: Háskolatorg building summer week fabric and ventilation loss

During the summer week, the total amount of fabric and ventilation loss was 7.736 kWh. The minimum fabric and ventilation loss of 894 kWh occurred on 28th of July, while the maximum loss happened on the 1st of August at 1.244 kWh, as shown in figure 62.

The most significant energy loss of Háskolatorg building was from the building glazing fabric. The minimum loss was 216 kWh on Sunday, the 28th July, the maximum loss was on Thursday 1st of August at 469 kWh. The total loss through glazing during the summer week was 2.530 kWh.

The second most significant energy loss in Háskolatorg Building was from external ventilation. The minimum loss from external ventilation was 120 kWh on Saturday, 27th July. The maximum loss was on Monday, 29th of July at 326 kWh. The total loss due to external ventilation during the summer week was noted at 1.744 kWh.

The third most significant energy loss from Háskolatorg building was from the ground floors. The minimum loss of 146 kWh occurred on Saturday, the 27th July. The maximum loss was on Monday, the 29th of August at 273 kWh. The total energy loss during the summer week was recorded at 1.369 kWh.

The fourth most significant energy loss from Háskolatorg building was through the walls. The minimum loss of 168 kWh through walls fabric occurred on Tuesday, the 30th of July. The maximum loss was on 2nd of August, at 1.202 kWh. The total energy loss through walls during the summer week was recorded at 1.122 kWh.

The fifth most significant energy loss from Háskolatorg building was through internal infiltration. The minimum loss through external infiltration was 76 kWh on Sunday 28th July. The maximum loss was on Thursday, the 1st of August at 111 kWh. The total loss due to external infiltration during the summer week was recorded at 657 kWh.

The least significant energy loss from Háskolatorg building was through the roof. During the summer week, the maximum energy loss through roof fabric was 65 kWh, on Sunday the 28th of July. The minimum loss was on Wednesday, the 31st of July, at 30 kWh. The total energy loss through roof fabric during the summer week was recorded at 311 kWh.

4.5.3 Summer week Háskolatorg building system loads

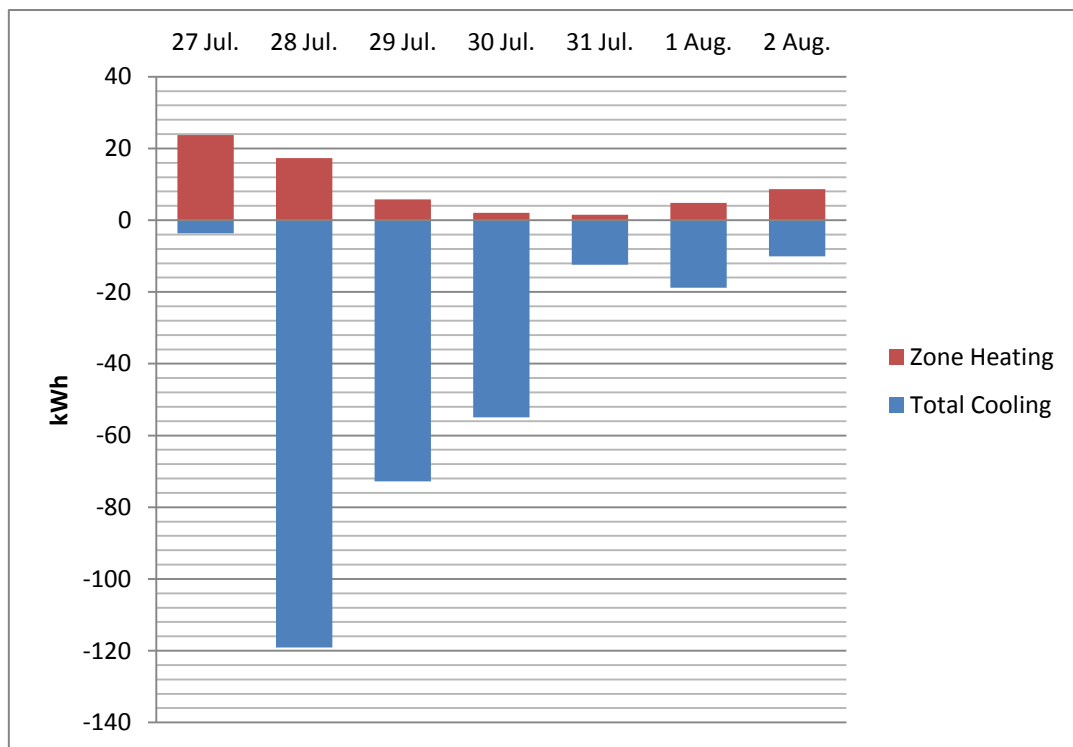


Figure 63: Summer week Háskolatorg building system loads

Throughout the summer week, building system total loads were at 355 kWh. The minimum energy load occurred on Saturday, the 2nd of August at 18 kWh, while the maximum amount happened on Sunday, the 28th of July at 136 kWh, as exhibited in table 63.

The building system loads during the summer week consisted of both total cooling and zone heating.

The total amount of total cooling was 291 kWh, with the maximum load on Sunday, 28th of July at 119 kWh. The minimum occurred on Saturday, the 27th of July at 3 kWh.

The total amount of zone heating was 63 kWh, with the maximum load of 23 kWh on Saturday, the 27th of July. The minimum occurred on Wednesday, the 31st of July at 1,5 kWh.

4.5.4 Summer week University Square zone internal gains

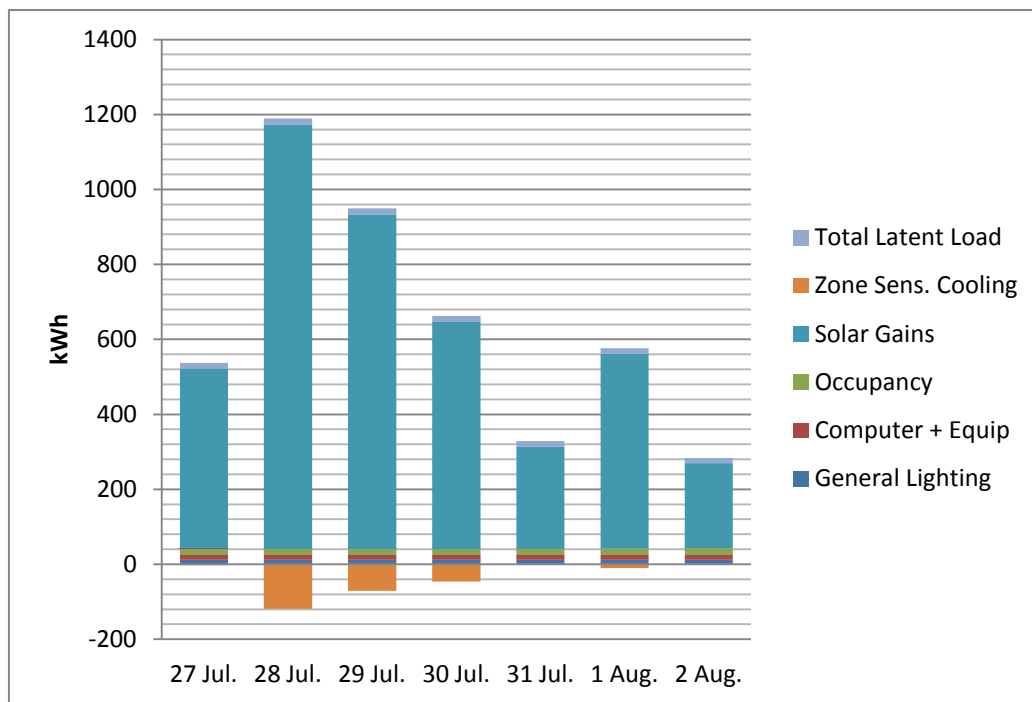


Figure 64: Summer week University Square internal gains

Figure 64 shows the internal casual gains of the University Square zone during the summer week from Saturday, the 27th of July until Friday the 2nd of August. The total internal gains for the University Square zone during that period were 4.276 kWh. The maximum gains occurred on Sunday, the 28th of July at 1070 kWh, while the minimum gains were recorded on the 2nd of August at 283 kWh.

The most significant internal gains in the University Square zone during the summer week were solar gains. The optimum amount was recorded on Sunday the 28th of July at 1132 kWh, while the minimum gains were recorded on Friday, the 2nd of August, at 227 kWh. The University Square zone was 4131 kWh.

The next most significant internal gains in University Square zone were from zone sensible cooling. The optimum cooling was listed on the 28th of July at 118 kWh. The total zone sensible cooling during the summer week was 249 kWh.

The third most significant internal gains in University Square zone was from occupancy. Occupancy gains on Monday the 29th of July were the minimum of 15 kWh, while the maximum gains were recorded on Friday 2nd of August at 18 kWh. The total occupancy gains for University Square during the summer week were noted at 115 kWh.

Total latent loads maximum amount was calculated at 16 kWh on Monday, the 29th of July. The minimum was measured at 13 kWh on Friday, August 2nd. The sum of total latent loads during the summer week was 105 kWh.

The fifth most significant internal gains in the University Square zone were the computer and equipment gains. Computer and equipment remained constant all week at 12 kWh. The total gains during the summer week were 87 kWh.

The least significant internal gains in the University Square were from general lighting. General lighting gains were constant from Saturday, the 27th of July until Friday, the 2nd of August at 86 kWh. The total artificial lighting during the summer week was at 86 kWh.

4.5.5 Summer week University Square zone fabric and ventilation loss

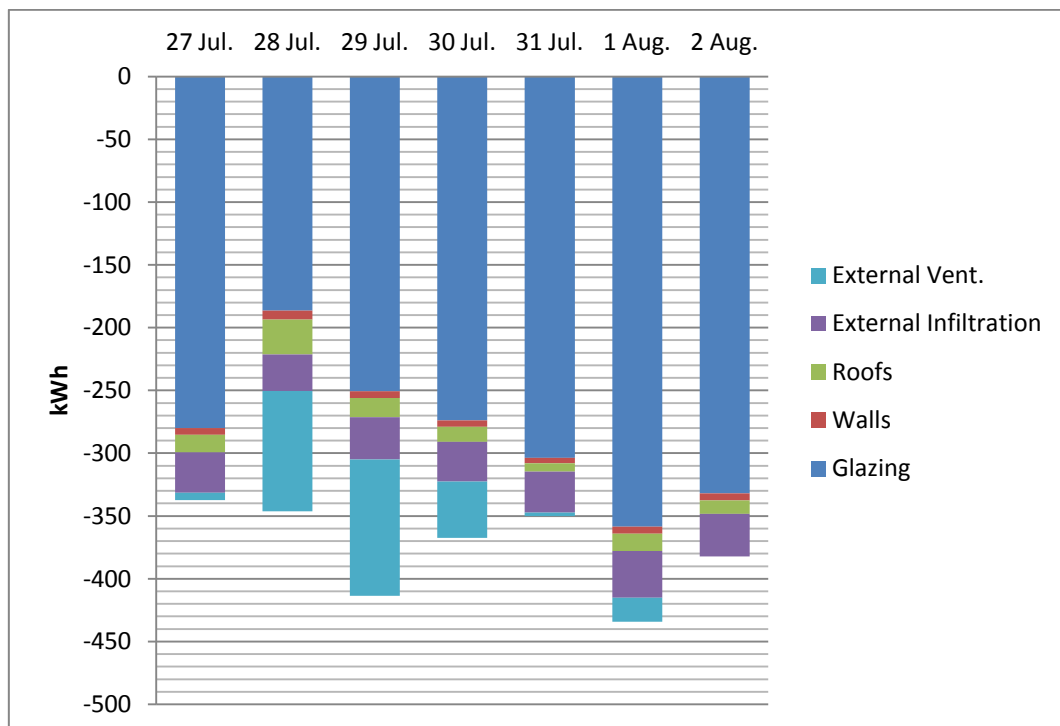


Figure 65: Summer week University Square zone fabric and ventilation loss

During the summer week from Saturday, the 27th of July until the 2nd of August, University Square zone fabric and ventilation lost 2.631 kWh of energy as shown in figure 65.

The most significant loss of University Square zone during the summer week was from the glazing fabric. The minimum loss was 186 kWh on Sunday, the 28th of July, while the

maximum loss was on Thursday, the 1st of August at 358 kWh. The total loss through glazing fabric during the summer week was recorded at 1.984 kWh.

The second most significant loss in University Square zone was from external ventilation. The minimum energy loss was on Friday, the 2nd of August. The maximum loss was on Monday, the 29th of July at 108 kWh. The total due to external ventilation loss during the summer week was recorded at 277 kWh as shown in figure 65.

The next most significant loss from University Square zone was external infiltration. Energy minimum loss was of the amount of 29 kWh on Sunday, the 28th July, the maximum loss was on Thursday, the 1st of August, at 37 kWh. The total loss, due to external infiltration during the summer week days was calculated at 230 kWh.

The fourth most significant loss in the University Square zone was from the roof fabric. During the summer week, the roof fabric maximum energy loss was 27 kWh on Sunday, the 28th of July, while the minimum loss was on Wednesday, the 31th of July at 6,5 kWh. The total energy loss through roof fabric during the summer week was recorded at 100 kWh

The least significant loss in University Square zone was from the wall fabric. The minimum energy loss was 4,5 kWh on Wednesday, the 31st of July, while the maximum loss was on Sunday, the 28th of July at 6,9 kWh. The total energy loss through walls during the summer week was recorded at 38 kWh.

4.5.6 Summary

Table 50: Comparison summary between Háskolatorg building and University Square zone

components	<u>Internal gains</u>	
	Building(kWh)	University Square zone(kWh)
General lighting	1151	86
Computers and equi.	795	87
Occupancy	1050	115
Solar gains	5224	4131

Zone sensible cooling	-296	-249
Total latent loads	884	105
Σ Total	9766	4276

Fabric and ventilation loss

Glazing	-2530	-1984
Walls	-1122	-38
Roofs	-311	-100
External infiltration	-104	-230
External vent	-1744	-277
Σ Total	7736	-2631

9766 kWh, result of the Háskolatorg building internal gains were taking account of the internal gains from miscellaneous, process, catering. In addition the building fabric and ventilation loss 7736 kWh was accounted for the ground floor loss as well.

As shown in Figure 66, summer week solar gains were very significant among the components of internal gains in the building. Overall gains by Háskolatorg building were 5.224 kWh. Simultaneously, the University Square zone had overall solar gains of 4.131 kWh. This suggested that summer week University Square zone solar gains were a staggering 79% of Háskolatorg building gains.

The second most significant summer week gains were the general lighting gains. Háskolatorg building accumulated 1.879 kWh in lighting gains, whereas the University Square registered 127 kWh. Therefore, the summer week University Square general lighting gains were only 6% of the Háskolatorg building general lighting gains.

Summer week occupancy gains for Háskolatorg building were 1050 kWh, while University Square zone accumulated 115 kWh. Therefore, University Square zone summer week occupancy gains were 10% of the Háskolatorg building gains.

During the summer week period, the fourth most significant component was the total latent load. The Háskolatorg building total latent load was 884 kWh, while University Square zone gained 213 kWh. Thus, all summer University Square zone total latent load was 9% of the Háskolatorg building overall total latent load during the summer week period.

The fifth most significant summer week overall internal gains originated from computers and equipment. Háskolatorg building gained 795 kWh, while during the same period; University Square zone accumulated 105 kWh. Thus University square zone gains were 11% of overall gains of the Háskolatorg building from computers and equipment throughout summer week.

Summer week sixth significant internal gains were the zones sensible cooling. Háskolatorg building has accumulated all summer zone sensible cooling gains at 296 kWh, while the University Square zone has accumulated zone sensible cooling at 246 kWh. As a result, summer Week University Square zone solar gains was 84% of the overall zone sensible cooling of Háskolatorg building.

Summer week the least significant summer week internal gains of Háskolatorg building were from the zone sensible heating. The Háskolatorg building zone sensible heating load was 37 kWh, while University Square zone gained nothing.

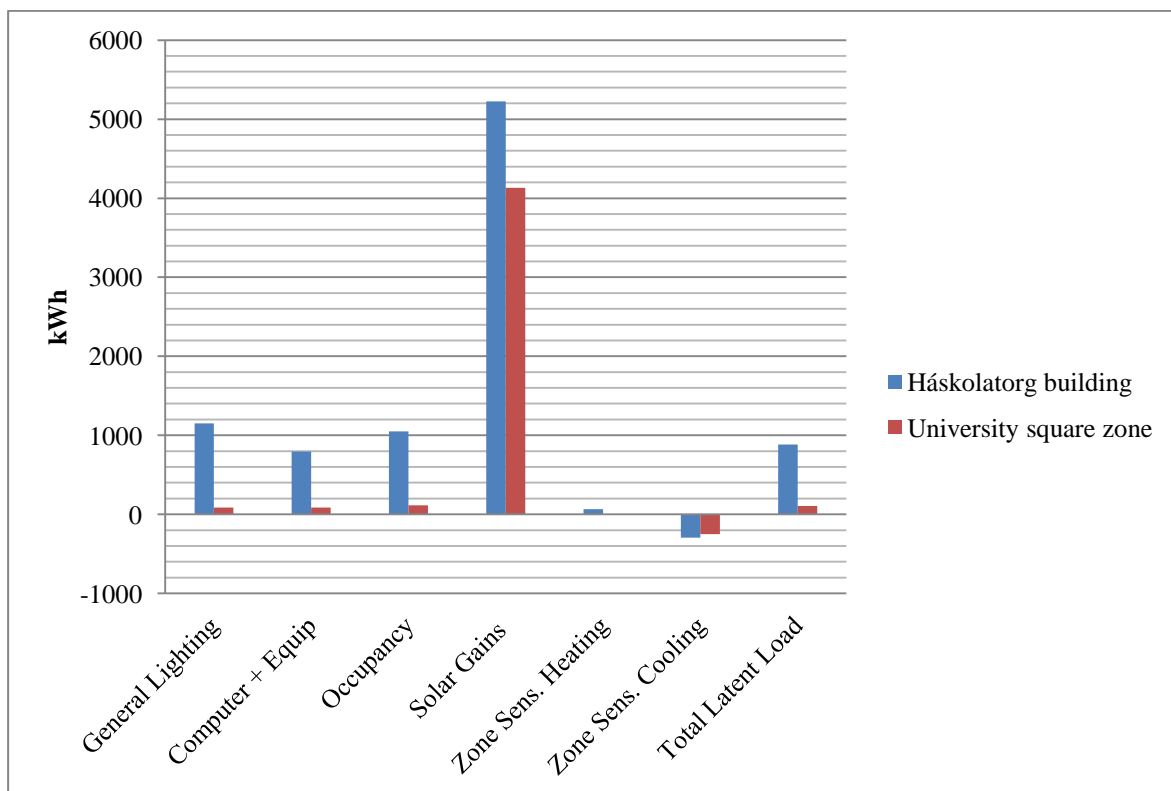


Figure 66: Summer week Háskolatorg building and University Square zone internal gains comparison

During the summer week Háskolatorg building fabric and ventilation overall loss was 7.736 kWh, while the University Square zone loss was 2631 kWh. Hence, University Square zone summer week loss through fabric and ventilation was 34% of the loss of Háskolatorg building, as shown in Figure 67.

The summer week's most significant loss was from glazing, or at 2.530 kWh, while University Square zone lost 1.984 kWh. University Square zone supplemented the summer week loss through glazing by 78% of Háskolatorg building loss.

The summer week's second most significant loss was from exterior ventilation at 1.744 kWh, while University Square zone lost 277 kWh. University Square zone contributed to the summer week loss through exterior ventilation by only 15% of Háskolatorg building loss.

The summer week's third most significant loss was through the walls at 1.122 kWh, while University Square zone lost 38 kWh. University Square zone contributed the summer week loss through walls by only 3% of Háskolatorg building energy loss.

The summer week's fourth most significant loss was through exterior infiltration at 657 kWh, while University Square zone lost 230 kWh. University Square zone contributed the summer week loss through exterior infiltration by 34% of Háskolatorg building loss.

The summer week's least significant loss was through roofs at 311 kWh, while the University Square zone lost 109 kWh. University Square zone contributed the summer week loss through roofs by 32% of Háskolatorg building loss.

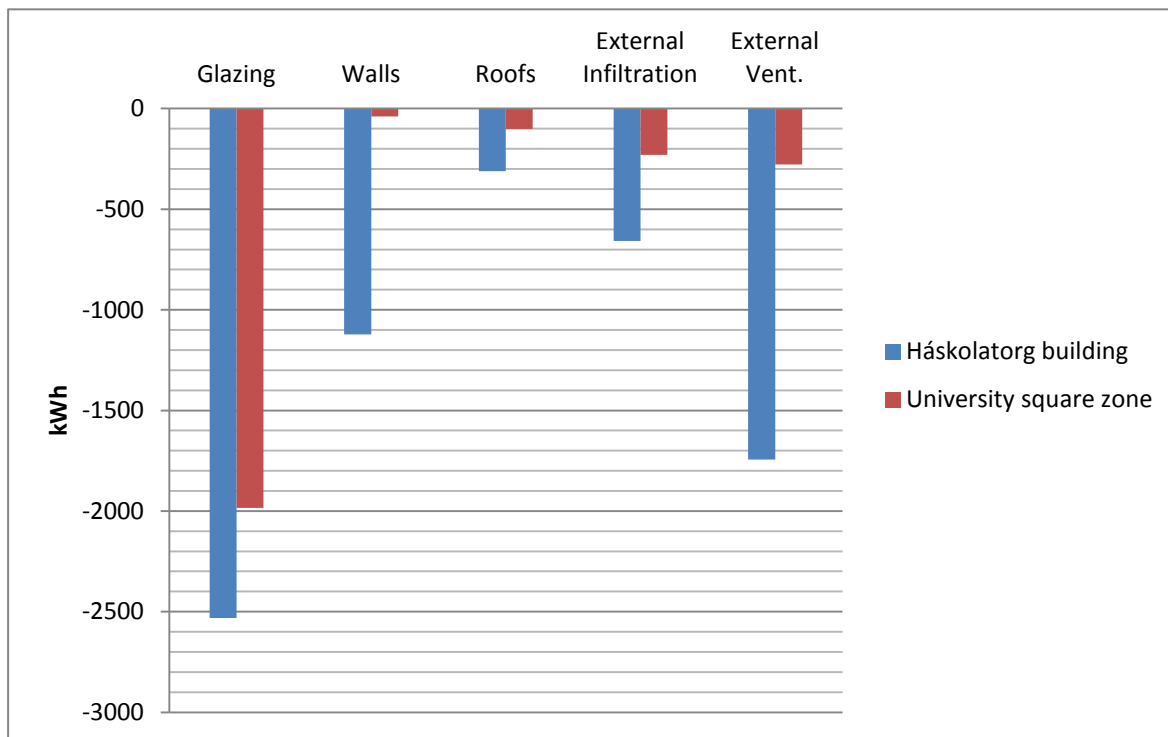


Figure 67: Summer week Háskolatorg building and University Square zone fabric and ventilation comparison

Table 51: Winter and Summer week of University Square zone internal gains comparison

kWh	General lighting	Comp. & equip.	Occupancy	Solar gains	Zone sensible cooling	Zone sensible heating	Total latent load
Winter week	603	87	154	182	0	1701	66
Summer week	86	87	115	4131	-249	0	105

The internal gains of University Square zone during the winter and summer weeks as shown in table 49 were compared as follows:

In solar gains, summer week solar gains were 22 times more than solar gains during winter week. In general lighting, winter week internal gain was over 6 times than summer week internal gain. In computers and equipment internal gains, they were even. In occupancy, winter week gains were around 50% more than the occupancy gains during the summer week.

Further, zone sensible cooling was only operated during the summer week, while zone sensible heating were only sources of gain during winter week.

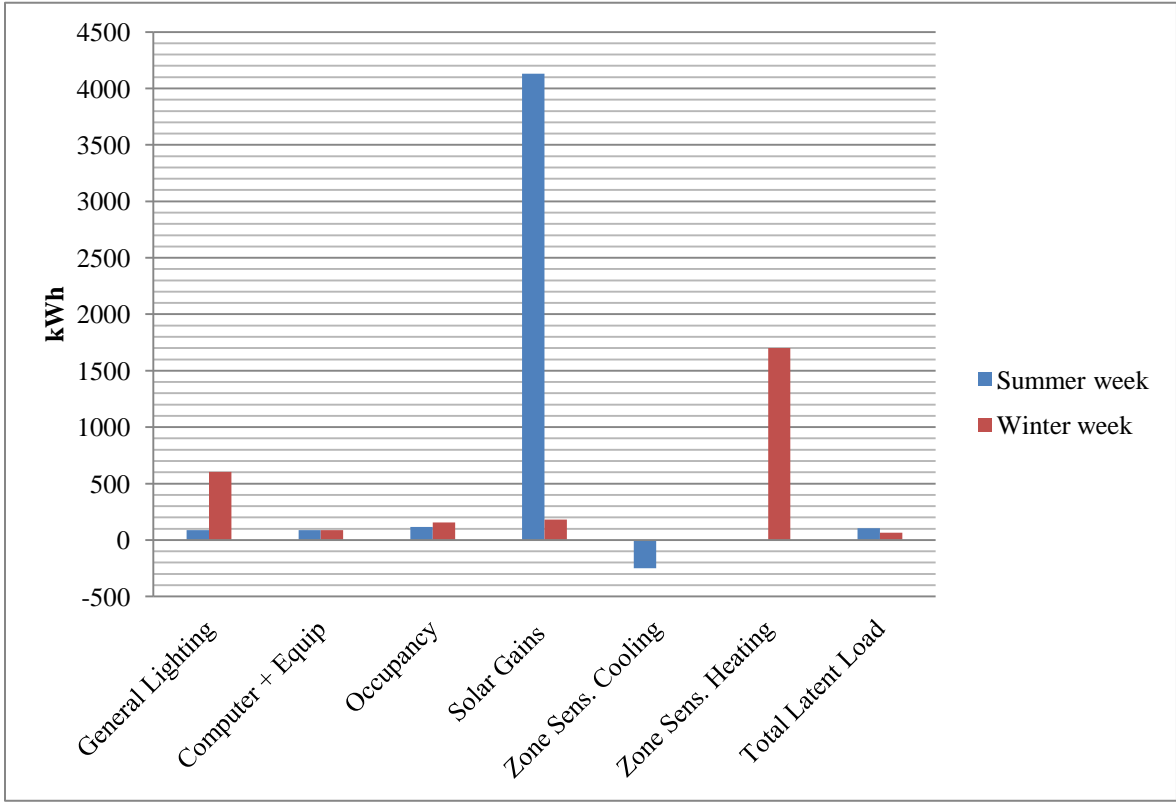


Figure 68: Winter and Summer week of University Square zone internal gains comparison

Fabric and ventilation loss of University Square zone during the winter and summer weeks, as shown in table 50 were compared as follows:

During the summer week, the >University Square zone lost 60% of the energy lost from glazing during the winter week. Summer week external infiltration loss was 68% of the loss during the winter week. During summer week University Square roofs fabric lost 60% of the winter week loss. As for the energy loss through walls, summer week loss was 72% of the loss during the winter week. Further, external ventilation loss occurred only during summer week.

Table 52: Winter and Summer of University Square zone fabric and ventilation comparison

kWh	Glazing	Walls	Roofs	External infiltration	External ventilation

Winter week	-3257	-53	-164	-339	0
Summer week	-1984	-38	-100	-230	-277

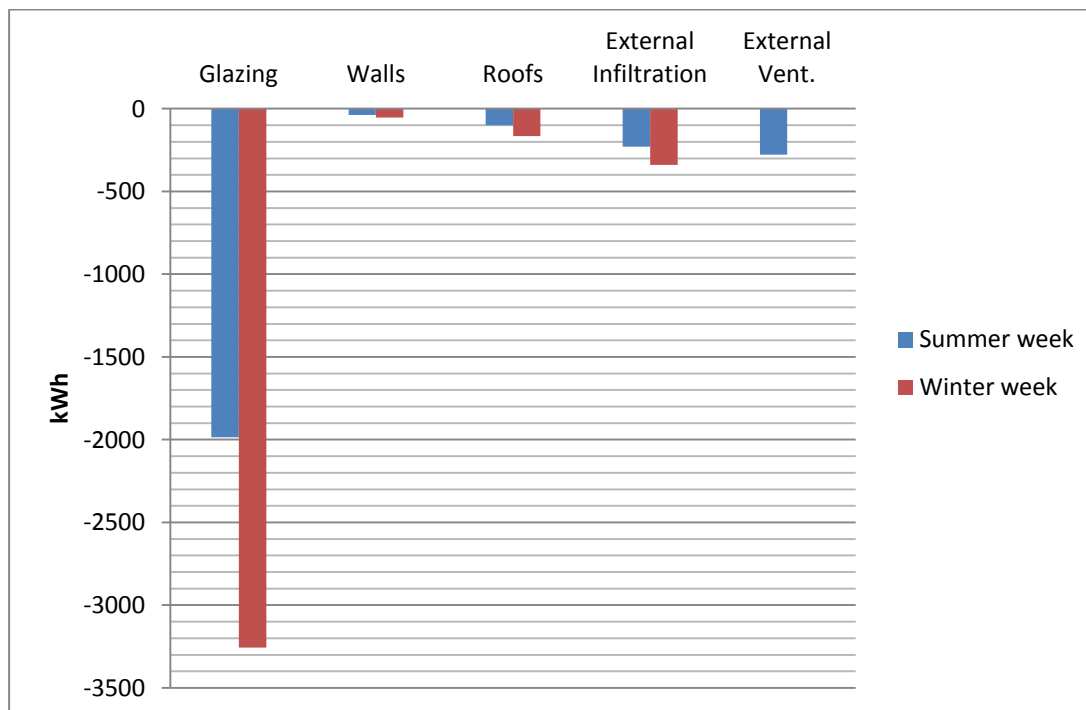


Figure 69: Winter and Summer week University Square fabric and ventilation loss comparison

Figure 70: Winter and Summer week of University Square fabric and ventilation loss comparison

As for the winter and summer comparison of Háskolatorg building system loads, summer loads were 9% of the total winter system loads, as shown in table 51. Summer week loads consisted of total cooling and zone heating loads, while the winter week loads were exclusively zone heating loads.

Table 53: Winter and Summer week of Háskolatorg building system loads

kWh	Total Cooling	Zone heating
Winter week	0	3888
Summer week	291	63

4.6 Heating strategy

During the winter period, it is crucial to retain heat in the building as long as possible. In order to reduce heat loss during cold weather, indoor window shade such as curtain can work as insulation to slow the heat loss. In this simulation; a scenario of indoor curtain with low reflectance and low transmittance, was installed, and scheduled from midnight until 7 am in the morning in the University Square zone glazing at Háskolatorg. Figure 70 shows the comparison between the exterior glazing of Háskolatorg building with curtains down for 6 hours during the night and the building without a scheduled curtain closure.

Further, Háskolatorg building system loads were compared with and without scheduled night curtain down, as is shown on table 52. These simulations were scheduled from October 1st until March 31st or all winter time period.

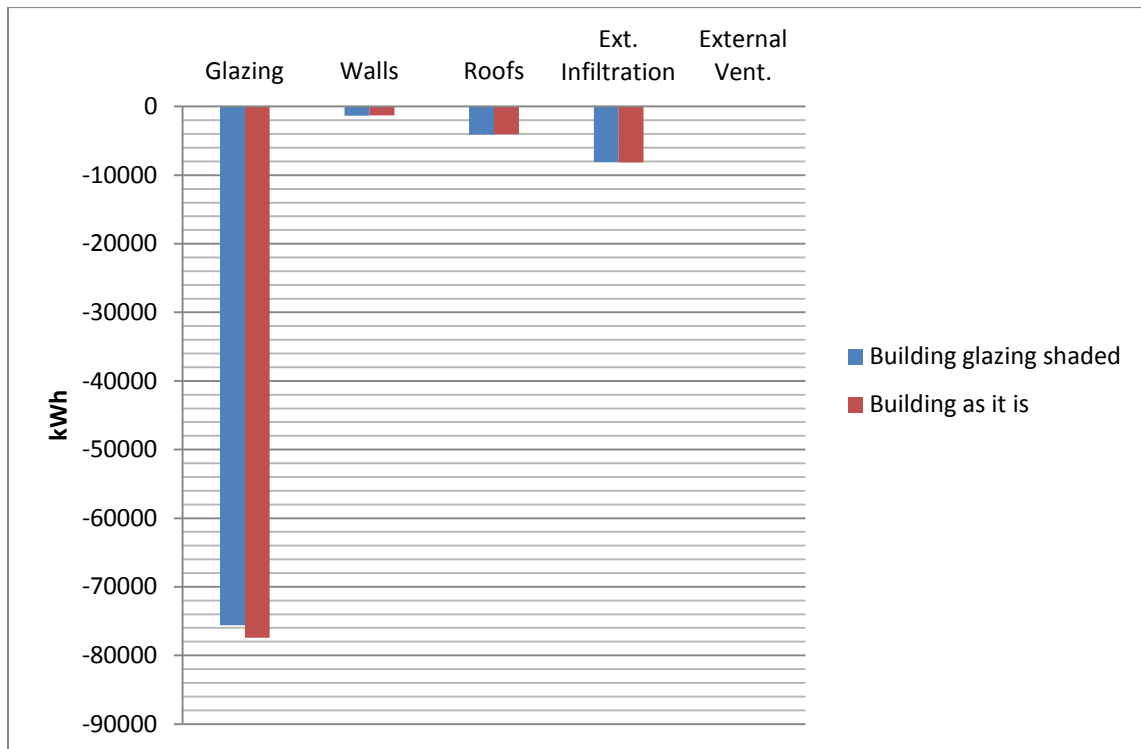


Figure 71; University Square zone fabric and ventilation loss comparison

Table 54: University Square zone fabric and ventilation loss comparison

	Glazing	Walls	Roofs	External infiltration	External ventilation
Uni. Square zone as it is	-77.403	-1.298	-4.020	-8.151	-45

Uni. Square zone with shaded window	-75.588	-1.313	-4.076	-8.111	-47
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Table 55: Háskolatorg building system loads and Heating strategies

System loads	Zone heating (kWh)
Háskolatorg building(Uni. Square zone as it is)	66.592
Háskolatorg building(Uni. Square zone & window shade)	63.982

In Figure 70, comparing the University Square zone in winter with and without window shade, fabric and ventilation loss indicated that University Square zone window shaded glazing energy loss was only 97% of University Square zone with windows no shades.

The University Square zone with window shaded energy loss from walls was slightly higher than energy loss from walls in University Square zone with window without shade.

In roof fabric, energy loss from the University Square zone with shaded window was also moderately high compared to the zone without shaded window.

External ventilation in the University Square zone with shaded window was a loss compare to the zone without shaded window.

External infiltration in the University Square zone with shaded window was bit higher than compared energy loss compare to the zone without the shaded window.

Table 53, shows that using a shaded window midnight until 7 am in University Square external glazing saved Háskolatorg building energy system loads only 4% of energy loaded when University Square zone did not have scheduled window shading.

4.7 Cooling strategy

During the summer, unwanted solar gains through glazing can be excessive Because a cooling strategy is a process that is inextricably linked with architectural design of buildings and their environment, it is crucial, before taking measures to dissipate unwanted

heat, and to know how the build up of the excessive heat can be prevented or limited in the first place (Goulding, Lewis, & Steemers, 1992).

In this subchapter, different shading devices were individually simulated for the reference building in order to analyze its efficiency in sun shading compared to Háskolatorg building such as it was designed. These sets of simulations were conducted during all summer period, from 1st of April until the 30th of September. These simulations include fixed shading devices: 0,5 m and 1 m louver on the exterior glazing of Háskolatorg building such as explained in subchapter 2.4.6 and 1,5 m extension of overhang shading device, as described in subchapter 2.4.5. Adjustable shading such as window blinds (see subchapter 2.4.7) was also considered as a fourth device to compare to the current building design. Results of Háskolatorg building system loads individual simulation sets are shown in figure 71.

4.7.1 All summer shading devices analysis

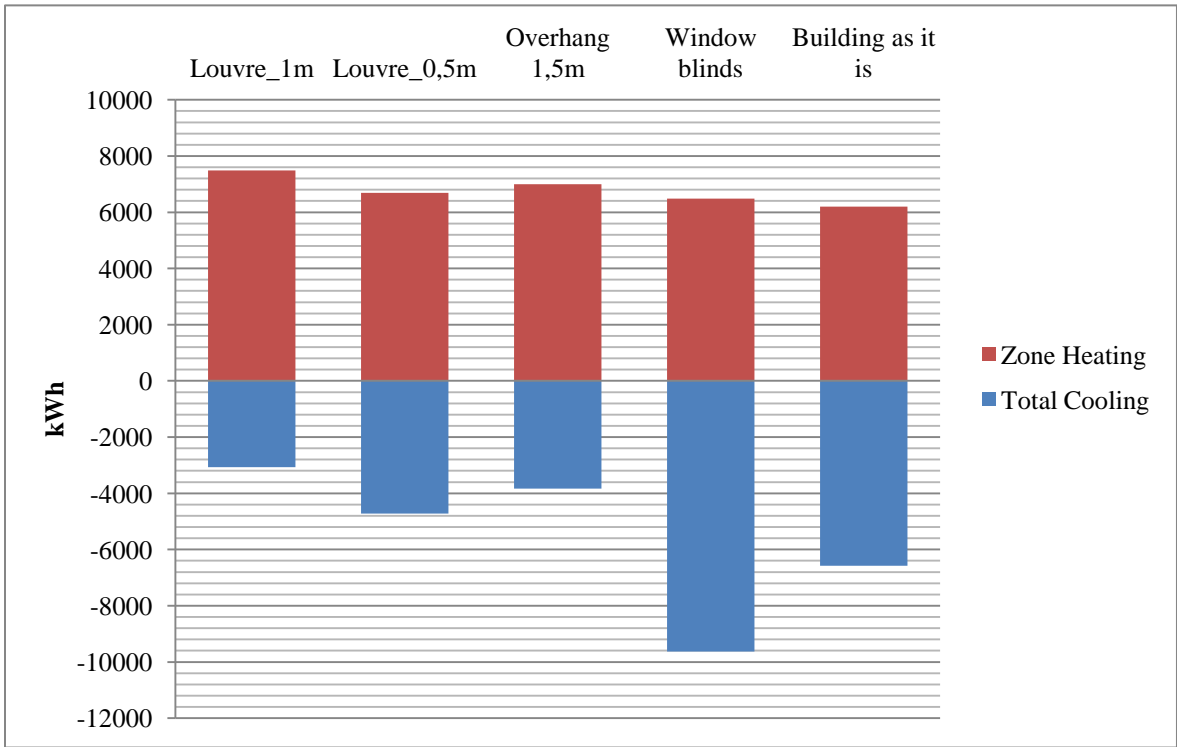


Figure 72: All summer Háskolatorg building system loads and shading devices comparison

Table 56: All summer Háskolatorg system loads shading devices comparison tabulation

Shading devices	Total Cooling (kWh)	Zone Heating(kWh)

Louvre 1 m	-3066	7485
Louvre 0,5m	-4721	6686
Window blids	-9634	6489
Overhang 1,5m	-3835	6995
Building as it is	-6573	6199

Comparing the installation a 1 m louver to the current building design shows that after the installation of a louver, total cooling was 46% of the total cooling of Háskolatorg building as it is. The zone heating with the louver, however was 18% higher than Háskolatorg building as it is. In conclusion, installing 1 m of louver on the exterior glazing of University Square zone could save about 18% energy loaded by the system of Háskolatorg current design during the all summer period.

Comparing the installation of 0,5 m louver to the current building design shows that after installation of louver, total cooling was 76% of the total cooling of Háskolatorg building as it is. The zone heating with the louver, however was 8% higher than Háskolatorg building as it is. It has turned out that, installing 0,5 m of louver on the exterior glazing of University Square zone could save about 11% energy loaded by the current design system of Háskolatorg during all summer period.

Installing an overhang of 1,5 m, has shown that Háskolatorg building system loads total cooling were 58% of the current design. Zone heating with the overhang was 12% higher than the current building design. Subsequently, installing a fixed 1,5 m overhang device on the exterior glazing of Háskolatorg has saved the building system loads by 16% to the current Háskolatorg design during all summer period.

Furthermore, using indoor adjustable devices such as window blinds, building system loads in total cooling were 32% higher than the total cooling of the current design. The zone heating with the window blinds were also higher by 5% of the zone heating of the current design. To conclude, installing window blinds from 11 am until 16 were proven to not save energy for Háskolatorg building. Calculation results has shown that the building system loads increased by 21%. Thus, not only do window blinds not prevent the sun's heat from entering the glazing, they also do not increase energy efficiency and they further hinder occupant's views.

4.8 Reykjavik radiation calculation

In order to facilitate architects designing buildings in an energy efficient way, knowledge of solar radiation availability and its transmission through a building envelope; such as glazing; to the interior is crucial. It could be vital for the reduction of energy consumption in modern buildings to utilise its outdoor environment and surroundings free energy; such as sun radiation; as much as possible (Chwieduk, 2008).

Based on Marteinson's (2002) calculation of Reykjavik solar gains through a window with 2 clear panes, average cloudiness; no shadowing reflection from ground 0%. These data are based upon Reykjavik daily radiation calculated on the 15th of every month. Results are exhibited as follows:

Table 57: Reykjavik solar radiation through window with 2 clear panes, average cloudiness, no shadowing/shielding reflection from ground 0%

Wh/m ²	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Horizontal	51	308	1086	2246	3513	3469	3618	2962	1432	515	104	18
Vertical wall	24	135	356	689	1121	1347	1278	861	480	203	47	8
East Wall	34	223	783	1394	2009	1882	2002	1760	951	368	70	9
South Wall	166	647	1650	1866	2122	1748	1933	2134	1610	932	321	39

Measurement for the skylight and the glazing of the University Square zone were provided by the energy model of DesignBuilder. In this calculation, University Square zone glazing was considered at the true north, east, and south, while the skylight was considered on horizontal plan.

Table 58: University Square zone glazing measurement generated by DesignBuilder

Window position	Window area(m ²)
Skylight(Horizontal)	17
North	31
East	401
South	186

Results of the calculation of energy solar gains through the glazing of University Square zone have shown that the total amount of solar gains through the east side glazing were the most significant at 4.605 kWh. The next most significant were the energy through the south side glazing at 2.866 kWh. The third most significant was through the skylight at 328 kWh. The least most significant was through the north side glazing.

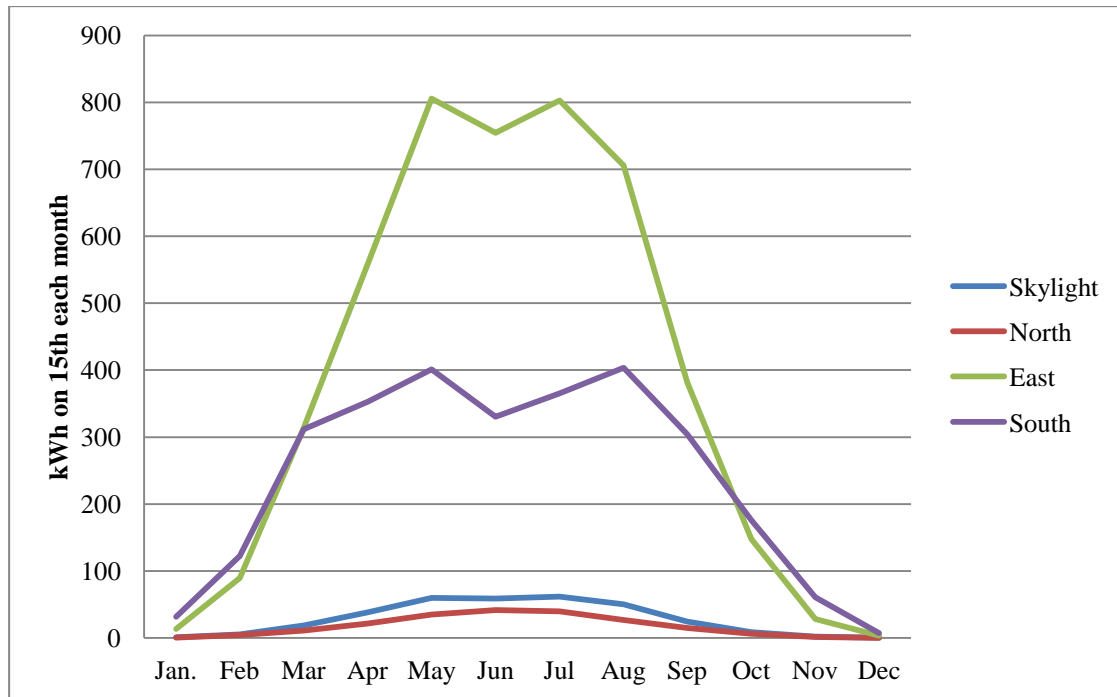


Figure 73: University Square zone radiation through windows(calculated on every 15th of the month)

University Square zone solar gain, results of Háskolatorg simulation on the 15th of each month and calculated energy gains through 2 clear panes glazing of University Square under average cloudiness were compared on figure 73.

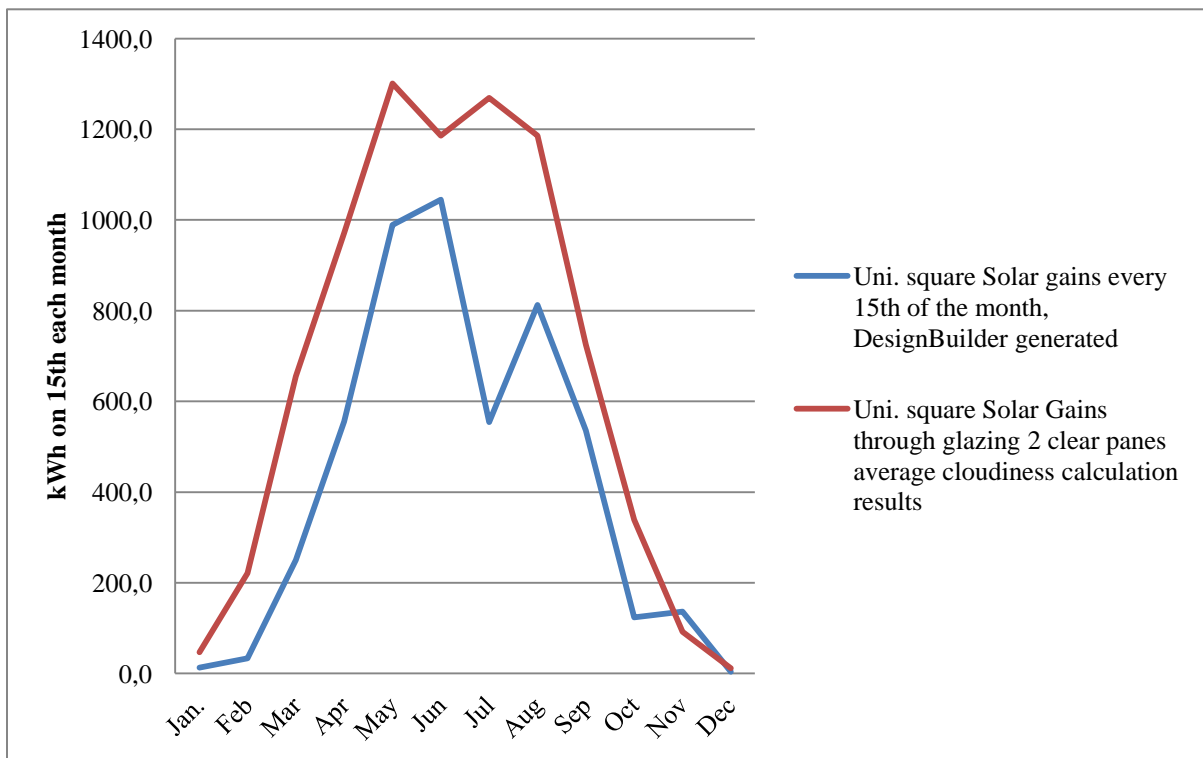


Figure 74: University Square solar gains simulation results and calculated average cloudiness solar radiation on the 15th each month

Table 59: University Square solar gains every 15th of the month DesignBuilder generated and University Square solar gains through glazing, 2 clear panes average cloudiness calculation results

Month	Uni. Square solar gains every 15 th of the month DesignBuilder generated (kWh)	Uni. Square Solar gains through glazing 2 clear panes average cloudiness calculation results (kWh)
January	12	46
February	33	221
March	249	655
April	555	971
May	989	1301
June	1044	1185
July	554	1269
August	812	1186

September	535	724
October	123	338
November	136	91
December	3,4	11

The total amount of the calculated solar gains through 2 clear panes glazing, under average cloudiness condition was at 8003 kWh and the total amount of DesignBuilder generated every 15th of the month was at 5052 kWh. Thus University Square zone solar gains were 63% of the average cloudiness solar gains, no shadowing and shielding reflection. However, the university Square solar gains DesignBuilder software generated on the 15th of the month were calculated under the condition of the neighboring building shadowing and shielding as shown in figure 75.

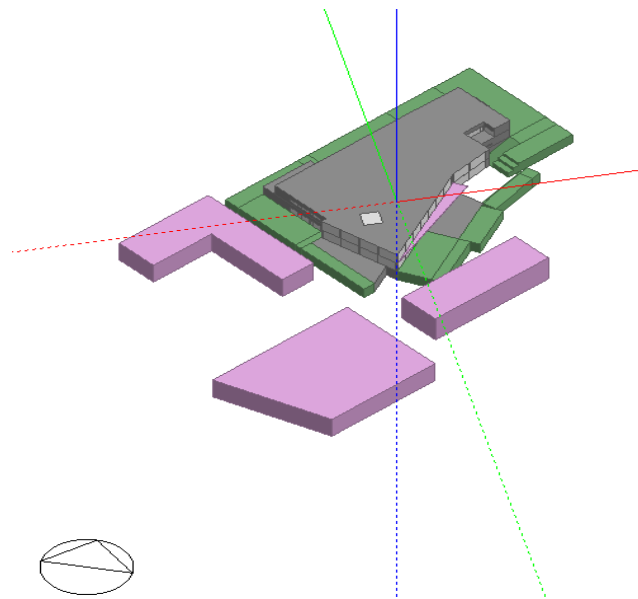


Figure 75: Háskolatorg building and neighbouring buildings 3D model DesignBuilder generated

This results indicated that DesignBuilder monthly University solar gains results were an average of 60% of the calculated University Square solar gains through glazing 2 clear panes under average cloudiness condition on the 15th of each month calculation results.

In addition, the results of calculated solar gains on every sides of glazing of University Square could be used for solar load management when architects decide both indoor space arrangement and function and as well the glazing and wall ratio to achieve the building design intended, thus building with low energy use and more harmony with its outdoor environment.

4.9 Háskolatorg Week Metered data calculation and DesignBuilder simulation results comparison

As described on subchapter 3.11, daily metered data were collected and calculated (see Annex B) was compared to DesignBuilder simulation energy prediction results. The collection of the metered data and the simulation were scheduled from March the 20th until March the 26th. The results are illustrated as follows:

kWh	March 20 th	March 21 th	March 22 nd	March 23 rd	March 24 th	March 25 th	March 26 th
Metered data calculation results	3508	2914	3345	2219	2809	1674	2483
DesignBuilder simulation results	50	44	30	27	34	22	9

Comparing the results of metered data energy demand and DesignBuilder, It is clear that the simulation results are far lower. DesignBuilder simulation results were about 10% of the metered data calculation results.

Given the significant influence of weather conditions on building, especially a highly glazed such as Háskolatorg, it is important to use a reliable climate data. Downloading Reykjavík climate data from DOE website seems attractive but the risk of some significant discrepancy is higher and could very well impact the building energy simulation prediction

results. It is important that the climate file is representative of Háskolatorg building site. Therefore, it is suspected that this could be the explanation of such large error margin

In addition, the assumption of occupancy was likely underestimated and also suspected the explanation of the DesignBuilder lower energy prediction. After the submission of this thesis, further analysis will be undertaken.

4.10 Survey results

4.10.1 Indoor Environment Quality (IEQ) factors

Thermal comfort

Question 6(Q6): How satisfied are you with the temperature in Háskolatorg during winter time?

280 responded to Q6 and 18,21% of them claimed to be very satisfied with the thermal comfort in Háskolatorg, 29,64% expressed that they are somehow satisfied of the indoor thermal comfort, 30,71% voiced their neutrality, 12,86% and 4,64% stated respectively that they were somehow dissatisfied and very dissatisfied, furthermore 3,93% chosen other reasons as shown in figure 76.

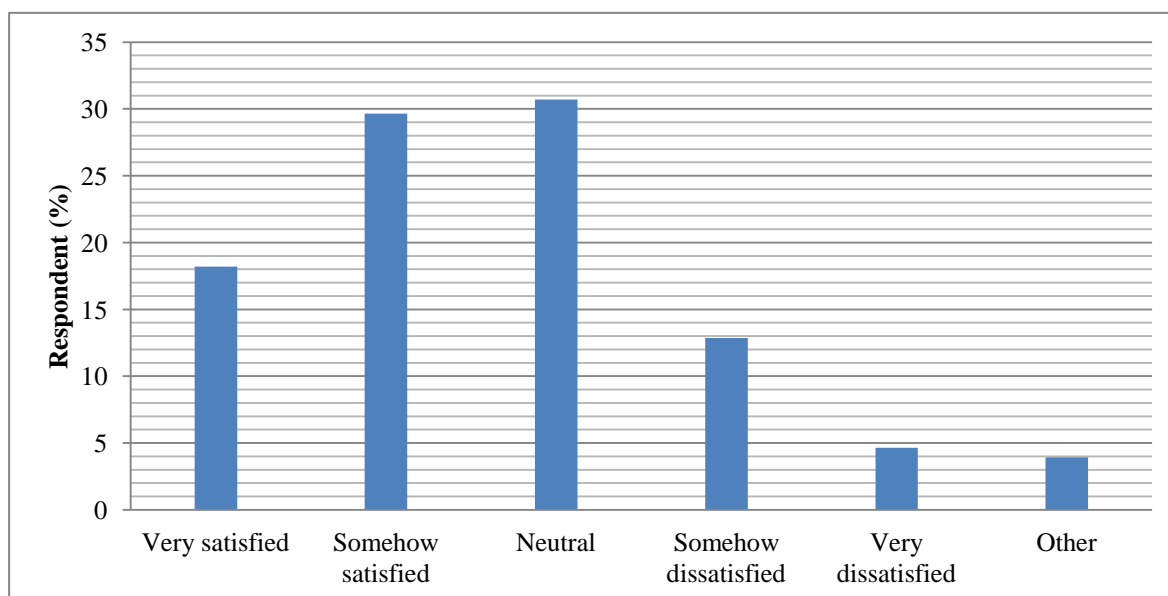


Figure 76: Respondents thermal comfort satisfaction (N=280)

Indoor air quality

Question 12(Q12): How satisfied are you with the air quality in Háskolatorg?

For Q12, among 267 respondents, 32,58% claimed to be very satisfied with the indoor air quality in Háskolatorg, 43,82% expressed to be somehow satisfied, 20,60% voiced their neutrality, only 1,87% and 1,12% stated they or very dissatisfied respectively as shown on figure 77.

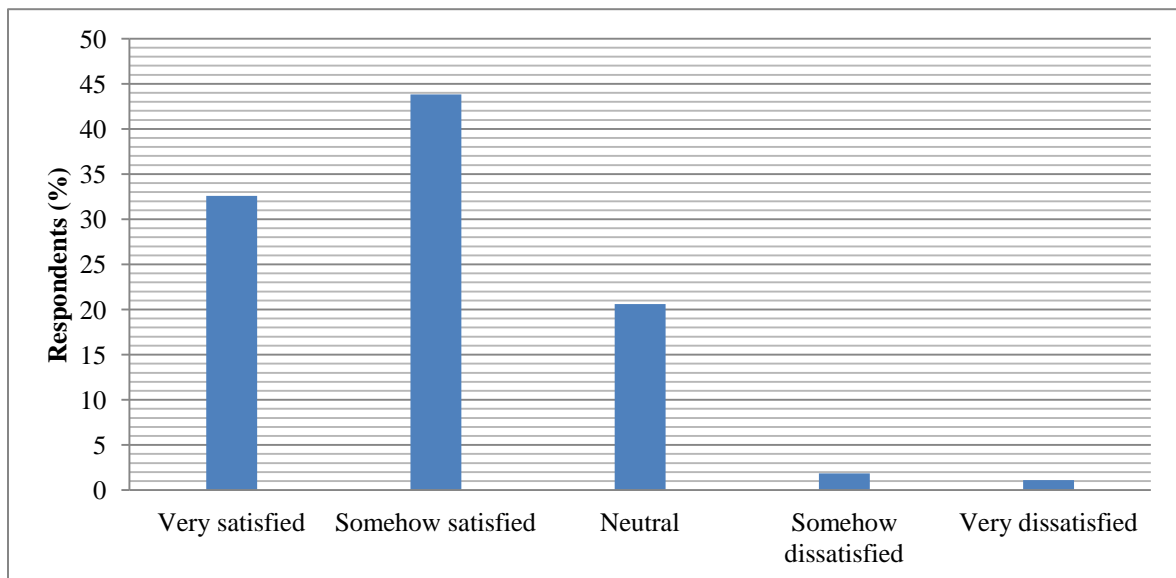


Figure 77: Respondents indoor air quality satisfaction (N=267)

Visual comfort

Question 14(Q14): How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?

For Q14, among the 259 respondents, 23,55% responded very satisfied to the visual comfort in Háskolatorg, 34,79% claimed to be somehow satisfied, 27,80% voiced their neutrality, 11,97% and 1,93% have stated that they were somehow dissatisfied and very dissatisfied such is exhibited in figure 78.

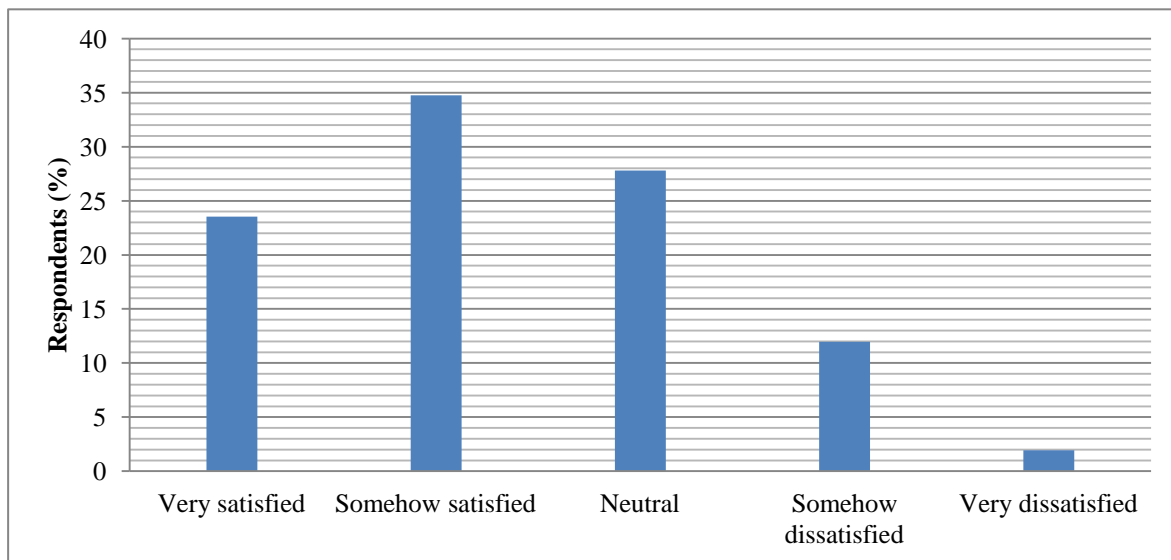


Figure 78: Respondents visual comfort satisfaction (N=259)

Building Energy efficiency

Question 16(Q16): Considering energy use, how efficient is this building performance in your opinion?

For Q16, among 252 respondents, 0,79% claimed that the building energy efficiency were outstanding, 9,52% said that the energy performance was excellent, 20,56% claimed its performance to be good, 18, 65% stated its performance was average , 4,76% claimed that the energy performance of the building is poor and 35,71% expressed that they were not informed, as shown in figure 79 .

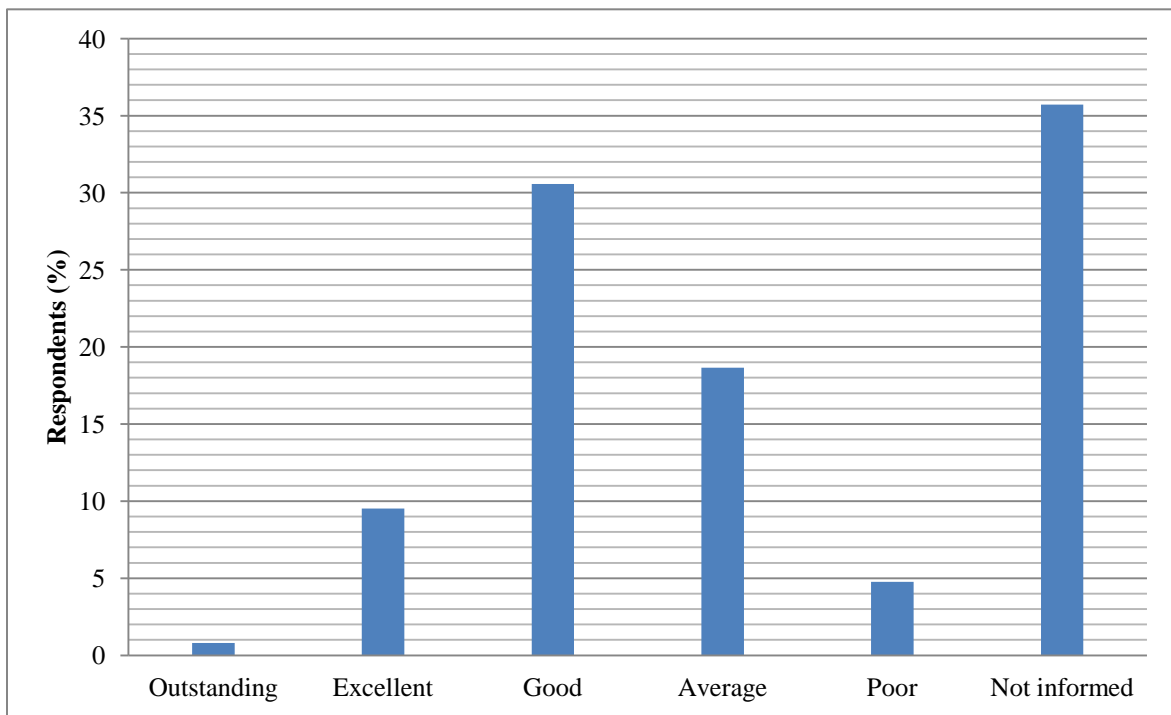


Figure 79: Háskolatorg building energy use performance respondents perception (N=252)

Building overall satisfaction

Question 18(Q18): How satisfied are you with the building overall?

For Q18, among the 250 respondents that completed the survey, only 24% claimed to be very satisfied and 45% somehow satisfied with the overall performance of the building. About 69% could be categorized as satisfied when those that were very satisfied and somehow satisfied respondents results are summed up, as shown in figure 80.

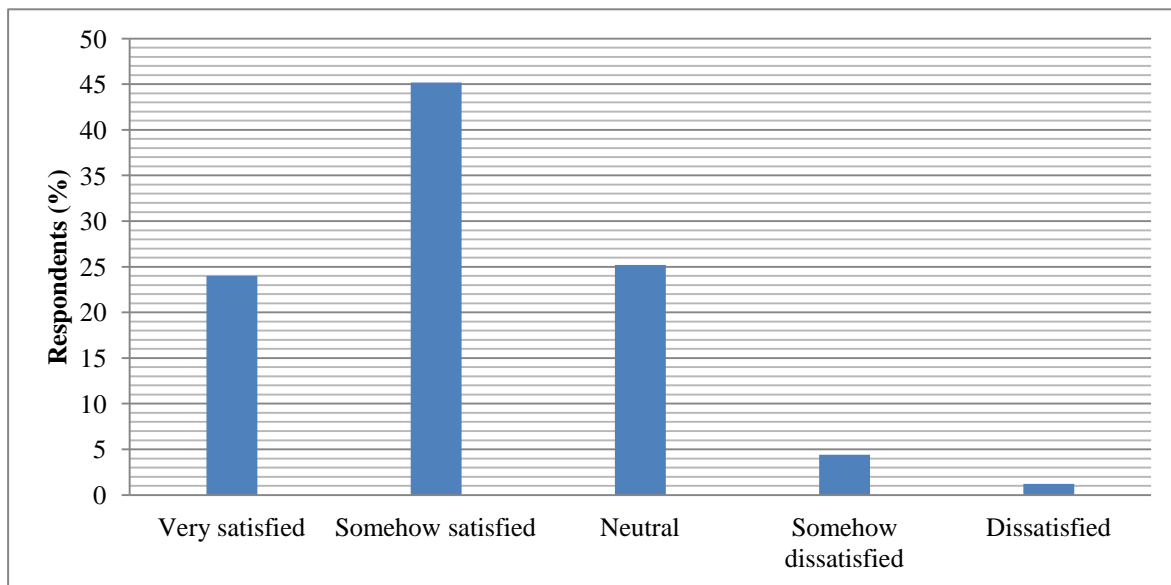


Figure 80: Háskolatorg building overall satisfaction (N=250)

3 bins for categories of respondents were created in order to further analyse the feedback from occupants:

The first bin included the respondents that were overall very satisfied and somehow satisfied and were grouped in the satisfied bin. They represent 69% of the respondents to Q18 or 173

The second bin included who reported being neutral to the overall building satisfaction, and was considered as the neutral bin. They represent 25% of the respondents of Q18 or 63

The third and last bin included was the respondents that stated they were somehow or very dissatisfied and grouped as the dissatisfied bin respondents. They represent 5% of the respondents to Q18 or 14.

Survey questions to be looked at for the next analyses

Question 2(Q2): what is your gender?

Question 3(Q3): In typical week, how long time do you spend in Háskolatorg?

Question 4(Q5): if you spend time seating in Háskolatorg, do you use your laptop?

Question 9(Q9): If you have to choose a seat within half meter, how far do you want to sit from the exterior glazing wall? _____m(meter)

Question 15(Q15): Overall, does the lighting quality enhance or interfere in your comfort quality?

Question 16(Q16): considering energy use, how efficient is this building performing in your opinion?

4.10.2 Respondents overall building satisfied bin

Of Q2, 100 respondents, 78 % were female and 22% were male. In Q3 asked about the time they spend in Háskolatorg every week. Of 178 respondents 21% of them spent at least 10 minutes. Respondents who reported spending 11 to 30 minutes were 28%, 49% declared they spend more than 30 minutes in Háskolatorg. In Q5 59 % of respondents acknowledged that they use laptop while in Háskolatorg, and 41% do not. In Q9, 45% respondents among 172 confirmed that they would choose to seat close to the exterior glazing if they had the opportunity to choose their seat in Háskolatorg. 55% stated that they would not choose a seat close to the exterior glazing. Q15, asked if the lighting interfere or enhance their comfort quality. 15% of the 169 respondents reported that the lighting enhanced their comfort quality. 28% expressed that their comfort is somewhat enhanced by the lighting. 48% declared neutral and 7% and 2% reported that lighting were somewhat interfered with their comfort quality.

Q16, asked about their views on the building performance and energy efficiency. Only 1% of respondent claimed that the building was outstanding in energy efficiency, 13% declared that it was excellent, 38% reported that the building was good in its energy performance, 14% reported it as average, while a further 3% and 31% stated that the building has poor performance or that they were not informed on the energy usage of the building of Háskolatorg respectively.

4.10.3 Respondents overall building neutral bin

Among the 63 respondents to Q2, 82,5 % were female and 17,5% male. Q3 asked about the time they spend in Háskolatorg every week, of the 63 respondents 38% mentioned that they spent at least 10 minutes. Respondents reported spend 11 to 30 minutes were 29%, 39% declared that they spent more than 30 minutes in Háskolatorg. In Q5, 54 % of

respondents reported that they used a laptop while in Háskolatorg, 45% reported not using laptop. In Q9, 39% respondents of 63 confirmed that they would choose to seat close to the exterior glazing if they had the opportunity to choose their seat in Háskolatorg. 60% of them stated they would not choose to seat close to the exterior glazing. Q15, asked if the lighting interferes with or enhances their comfort quality. 8% of the 62 respondents reported that the lighting enhances their comfort quality. 14% expressed that their comfort quality is somewhat enhanced by the lighting. 56% declared it neutral and 17% and 3% reported that the lighting was somewhat interfering or interfering with their comfort quality.

Q16, asked their about their view on the building's energy efficiency performance, only 1% of respondent claimed that the building was outstanding in energy efficiency, 13% declared that it was excellent, 14% claimed that it was good, 38% stated it was average, and a further 3% and 31% reported that the building has poor performance or they were not informed about the energy usage of the building of Háskolatorg respectively.

4.10.4 Respondents overall building dissatisfaction

Of the 14 respondents to Q2, 57 % were female, 43% male. Q3 asked about the time they spend in Háskolatorg every week, of the 14 respondents 21% mentioned that they spend at least 10 minutes. Respondents who reported spending 11 to 30 minutes were 14%, 50% declared that they spend more than 30 minutes in Háskolatorg. For Q5, 43 % of respondents reported using a laptop while in Háskolatorg, 57% reported not using laptop. In Q9, 23% respondents of the 13 peoples stated that they would choose to seat close to the exterior glazing if they had the opportunity to choose their seat in Háskolatorg. 70% of them stated that they would not choose to seat close to the exterior glazing. Q15, asked if the lighting interferes with or enhances their comfort quality. 7% of the 14 respondents reported that the lighting enhanced their comfort quality. None expressed that it is somewhat enhanced by the lighting. 50% declared it neutral, 21% of respondents reported that the lighting was somewhat interfering and another 21% declared that the lighting interfered to their comfort quality.

Q16, asked about their views on the building's energy efficiency. None of 14 respondents claimed that the building was outstanding in energy efficiency, no one reported it was excellent, 21% called it both it good and average, while a further 28% each reported that the building has poor performance and they were not informed about the energy usage of the building of Háskolatorg, respectively.

5 Analysis and discussions

5.1 Simulation

This study assessed the effect of the building envelope on energy internal gains, fabric and ventilation loss and building total system loads. The results show evidence that, a fully glazed zone such as University Square zone greatly influences the flow of heat energy in the overall building energy balance and its system loads designed to maintain the desired setpoint temperature and thermal comfort. In other words, understanding the trade of heat between the outdoor environment and the building indoor spaces; and through careful design of the components of glazing facade both the thermal comfort quality and energy conservation can be achieved.

But because drawing building requires harmonising several environment factors to be separately satisfied and to balance to one another. Háskolatorg building has a large glazing facade that provides better daylighting but also causes greater heat loss in winter and larger heat gains in summer. Thus, an early stage study involving the building and its surrounding environment is needed and energy simulation tools such as DesignBuilder can be instrumental enhancing architects' ability to design buildings that meet seasonally varying energy needs. As a result, Architects and designers can create a more balanced building that is more energy efficient.

5.1.1 Occupancy

Háskolatorg building yearly occupancy simulation results show that occupancy gains were 11% of total Háskolatorg building energy gains, as is on table 35. Since occupants have the ability to manipulate heating (14%), cooling (1%), computer and equipment load (7%) and lighting (15%) control, the use of a detailed occupant model can have a significant effect on energy demand predictions, as well as maximum and minimum indoor temperatures. This has demonstrated the importance of modelling occupancy at a higher level of details than is generally done in energy simulation practices.

Even though occupancy data input simulation was simplified for the Háskolatorg simulation, it is however recognized that occupant behaviour is widely regarded as one of

the most significant sources of uncertainty in the prediction of building energy use. This is because, occupants perform many difficult to predict and complex actions every day.

Further, it is confirmed that Háskolatorg building energy performance is both significantly affected by design and operating issues, which occupancy mainly accounts for

5.1.2 Building envelope

Walls

Walls are a predominant fraction of a building envelope and are expected to provide thermal comfort within a building. In Háskolatorg building, walls represent about 59 % of the external structure shell of the building, characterised by the thermal transmittance U-value at $0,364 \text{ W/m}^2\text{-K}$. Throughout the year walls are exposed to the ailment of the outdoor environment.

Even though, the walls surface area exposed to the outdoor environment is considerable, all year walls loss represented 17% of the yearly total energy loss from Háskolatorg building, as is shown on table 35.

During the all summer period Háskolatorg building lost around 47% of the total annual walls loss from the building, while the building lost about 52% during the all winter period.

Looking to the summer (Figure 65) and winter week (Figure 55) simulation results have indicated that during summer, walls in Háskolatorg building were losing 72% of the energy loss from walls in winter. Thus the difference of energy loss between the two periods is 28%.

Loss from walls element is influenced by both the size of the external structure shell exposed, which represents 59% of the Háskolatorg building total external shell and its walls thermal transmittance coefficient U-value. Further, the larger temperature difference between the indoors and outside during winter than summer time confirms the large heat loss rate during winter than summer.

Glazing

The Háskolatorg building glazing component is characterised by both loss and gain of energy all year. Glazing accounts for 44% of the annual overall fabric and ventilation loss from Háskolatorg building (Table 35). During all summer time, Háskolatorg building glazing fabric lost around 38% of the total building energy loss, while all winter the building lost about 49%. But when comparing winter and summer glazing loss, results show that all summer glazing loss was 80% of all winter loss.

Further, winter week simulation results show that Háskolatorg building summer week glazing energy loss was 57% of the winter week loss.

This demonstrates that winter loss is greater than summer loss because, first of all glazing surface area exposed perimeter is around 41% of the building external shell. The greater the area of external exposed surface the greater is the rate of heat loss. This also explains that 74% (Figure 26) of annual energy loss of Háskolatorg building was from the University Square zone, as more than 60% of its perimeter area is glazing.

Looking at walls and glazing yearly loss, confirms that walls loss was merely 17% of annual total loss for the building, while glazing loss represents a massive 44% of the total annual energy loss of Háskolatorg building. This reveals that the smaller the thermal transmittance U-value, the smaller the heat loss, and conversely as the thermal transmittance increases the greater the heat loss from a building. In Háskolatorg building, the wall input U-value was $0,364 \text{ W/m}^2\text{-K}$, while the exterior glazing was $1,9 \text{ W/m}^2\text{-K}$.

This indicates that a large glazing facade such as that of the University Square zone requires a lot of heating and cooling just to maintain comfort. When the space is exposed to the sun, it requires cooling, while those in the shade need heat.

Figure 73 shows that if the glazing is orientated as true north, south, east and Horizontal, University Square building could benefit by 40% of the current amount of solar gains under average cloudiness sky, with no shadowing and shielding. The orientation; and sky condition by which the glazing is under condition; and size of the glazing is therefore crucial determinant of the rate of heat gains in a highly glazed zone such as University Square.

The Reykjavík climate should be looked at because a large difference between the temperature inside and outside the building increases the rate of heat lost by conduction and ventilation. During summer the temperature difference between indoors and outdoors is comparatively small compare to during the winter; thus the rate of heat loss from the building is grater during winter.

It is evident that daylight can offset the need for electric lighting and provide a psychologically healthy connection to the outdoors, but question remains if such 69% of glazing to wall ratio in Háskolatorg building is needed for that. It is because numerous studies have indicated that a window to wall ratio over 60% would not reap daylight benefits, and in most case 40 % is optimum (White, Dec, Troy, & Thornton, 2008).

Often glazing is a typical design problem, because it requires architects to balance the desire of thermal comfort, energy efficiency, and light quality with the equally important desire for view, daylight, and connectivity to the outdoor environment.

Many designers have shown that beautiful and high performance buildings can result from a proper balance. All too often, however, it appears architects choose all glass curtain walls because they make it easy to create a sleek, smooth and lustrous facade impression, while leaving the complicated details to others; such as mechanical engineers and manufacturers; to deal with.

Roofs

Roofs are a critical part of the building envelope that is highly susceptible to solar radiation and other environmental changes, in this manner influencing the indoor comfort conditions for the occupants. Roofs account for a potentially large amount of heat gain and loss, especially in buildings with large roof areas such Háskolatorg building. The result from DesignBuilder model has provided the main roof area of Háskolatorg building at 1909 m². The roof of Háskolatorg building accounted for 5% of yearly total loss of Háskolatorg building, as is indicated in table 35.

The roofs have its exterior structural shell 100 % exposed and it is a large area as it was defined above. But because of its large, almost horizontal surface and its total exposure, comparatively to the walls heat loss, roofs have a low heat loss rate and smaller thermal conductivity at 0,079 W/m²-K.

The potential solar energy gains through roofs were not included in the DesignBuilder simulation; however the existence of a skylight on the University Square zone roof contributes to the rate of heat loss accounted for by the building's roof.

5.1.3 Shading devices

To reduce Háskolatorg building system cooling loads in summer, the glazing of the University Square zone must be protected from solar radiation with shading devices. Shading devices not only provide environmental comfort for human occupancy but also reduce the total cooling energy consumption by building during summer or cooling periods. The simulation results; as shown on figure 71 and table 54 revealed a clear difference between shading device alternatives in terms of how they reduces cooling energy consumption.

Integrating different design constraints, such as building regulation, standard and architectural approaches, and designers should be able to choose shading devices carefully, that are thermally efficient and help to reduce cooling loads without altering architectural aesthetic.

The scheduled night shade simulation for 6 hours in Háskolatorg building, simulation shows that night hours of window shading could reduce the all winter heating energy system loads by almost 4% of the current calculated loads. The heating load maybe trivial but it confirms that DesignBuilder simulation tools could be crucial to be integrated to early design building potential assessment and decision making to achieve quality and an energy efficient building.

5.1.4 Energy simulation for architects

The experience of using building energy simulation yielded reasonable satisfaction with the simulation results. But as a novice energy modeller and non-engineer user, it has been expected that with some degree of fine-tuning of the settings and data inputs, the simulation results could be aligned with the metered data. It is however still not meet the expectations of architects accustomed to using sophisticated Computer aided design (CAD) and 3D modelling tools. Compare to other software for architects, DesignBuilder's ability to select and organised model object seems limited. Further the system of templates and attributes inheritance gives the impression of both inflexibility and un-adaptability.

Architects also have to learn as well to better their model, because approaching the geometries, schedules, and construction types with minute level of details are much more appropriate for architectural modelling than a building simulation.

However, as integrated design is adopted by designers, the energy simulation tool can play a key role in achieving a successful balanced building, harmonized to its environment. DesignBuilder could still facilitate to undertake task such as manipulation of façade details to determine their relationships with heating and cooling loads of buildings. These tasks consist of robust analysis of the building, of each alternative through a details simulation and analysis of the main factors that affect energy building performance. This type of multi-criteria analysis provides architects with the option to select the most suitable design alternative.

Since energy modeling is typically done early in design development, there is potential to influence projects extensively.

Using DesignBuilder to perform several simulations has unveiled information regarding the performance of the building envelope and the most significant architecture component that influence Háskolatorg building energy balance. DesignBuilder was very efficient in conducting range of simulations to help sort out the suitable alternative in cooling and heating strategy that was undertaken for Háskolatorg building.

Further, building simulation tools such as DesignBuilder not only benefit architects and designers for quality decision making and proof of concept but also, the building owner for better performance, the facility manager with troubleshooting tools .

5.1.5 Survey

The results in this report underscore a number of issues currently effecting Háskolatorg building, its presents an opportunity to look for improvement. Energy simulation and physical measurements can be valuable, but by themselves they also need to be interpreted in terms of how they impact occupants (Brager & Baker, 2008). Building occupants themselves are a rich yet underutilized source of direct information about how well buildings are working, and without occupants viewpoints a complete picture of a building's performance cannot be assembled (Huizenga, Laeser, & Arens, 2002).

Looking at the results of the survey, the low level of participation is disappointing. Of over 9000 students that received the survey questions just over 3% participated, about 270 completed the survey over a 3 weeks time frame.

With respect to the results on thermal comfort in Háskolatorg shown in figure 75, only 47,8% of the respondents were satisfied with the thermal comfort, which fall short of ISO standard 7730:1994 recommended acceptable condition in which at least 90% of people are satisfied with their thermal environment (ISO 7730, 1994).

Regarding the visual comfort (Figure 77), about 58% of respondents confirmed that they were satisfied with the visual comfort in Háskolatorg. When asked about the performance of the Háskolatorg building energy usage, about 35% have confirmed that they were not informed, as shown on figure 78.

Occupant's responsiveness is crucial; they influence lighting, computer equipments and indoor temperature, while lack of awareness and pertinent information is leading to energy efficiency and effective opportunities being ignored (Jaber, 2002).

Figure 76 shows the results of the air quality satisfaction in Háskolatorg building. 76,4% of respondents voiced that they were satisfied with the air quality. ASHRAE standard 62.1-2004 however defines acceptable air quality as a condition in which more than 80% of occupants do express satisfaction (ASHRAE, 2004). Here again, Háskolatorg fails to reach this standard.

In the subject of overall building satisfaction, almost 68% responded satisfied and about 6% claimed their dissatisfaction with the building, while 25% stated being indifferent of the building overall performance.

One of the main finding of this survey is the high number of women that completed the survey at 78% of participants. Even though some studies reported that no statistical relationship between respondents gender and building energy efficiency (Poortinga, Steg, Vlek, & Wiersman, 2003), studies as well have shown that gender might influence environmental behaviour and women were reported to show more pro-environmental behaviour than men (Zelezny, Chua, & Aldrich, 2000).

Other findings

This study has uncovered occupants' frustration regarding both the lack of seating during lunch time and the shortage of electricity plugs at many tables at Háskolatorg. Some occupants voiced the narrowness of the place and the absence of plants. Additionally, there are complaints about the interference of sun glare and the fact that the curtain was not lowered every time.

With respect to the white colour of walls, some students voiced their dissatisfaction and compared the building to a hospital or train station. The smell of food and cold temperature close to the revolving door are part of the complaints.

Survey intentions

The survey results provide general lessons learned from occupants and are intended to improve the indoor environment for occupants in the building; they may also, through educating the institutions, improve IEQ in their future building projects. In addition, the results could be used as research tools, developing knowledge of certain building technologies and how they affect occupants. Furthermore they could be used to benchmark building quality (Huizenga, Laeser, & Arens, 2002).

Improving the quality of buildings critically depends on accountability and learning from experience; what works, what does not, and what choices about building design or operation can make a big difference (Brager & Baker, 2008). Thus the voices of occupants are a very useful component of the assessment. Moving toward building energy efficiency, Post Occupancy Evaluation (POE) should be a natural part of the process, since everyone benefits from learning how a building performs in practice.

Sadly, very few architects or other members of the design team are likely to know how well their building is working after it is completed and occupied. The fees were paid and they are on other project. Without learning from experience in an objective way, building industry professionals are less likely to make design that will truly enhance energy performance of buildings.

Conducting a survey could have a direct effect on improving the comfort of occupants by ensuring that the building is performing as designed, especially as this survey was

conducted at POE. Because designers and architects want occupants to benefit from the full potential of the building features, makes the results of such survey are helpful for the researchers and the building community at large in promoting understanding of the needs of occupants, the building potential and possible flaws (Brager & Baker, 2008).

5.2 Limitations

Energy simulation

Single energy prediction software is not necessary enough to architects for provide inclusive advice for buildings energy performance.

Because small changes make significant differences, questions such as, how clean are the window? How big a swing in indoor temperature will the occupants accept? Is one large screen TV monotor or one automatic beverage vendor matter?

Doing energy modeling requires lots of time of honing the model and collecting as accurate data as possible. Complaining about the time spend on simulation, question is asked if effort and costs of collecting detailed data and using complicated models compare to benefits?

Some studies have reveled that energy modeling is doing poor job predicting energy use and not accurate especially for older buildings, but because newer home tend to have lower rate of air leakage and higher R-values than older homes, energy models usually do a better job of predicting energy use in newer homes

Further, some energy modeling requires too many inputs which are not necessary improve the outputs of the simulation. The existing model asks for inputs that are difficult to assess, such, heat generated by people, light, and many other sources (Holladay, 2012).

Despite the energy simulation software developments, having objective to facilitate the use of the software, very limited guidance is available to architects for understanding and integrating simulation as a design tool in the early design stage (Poerschke & Bambardekar, 2009).

Human factors

In many case architects will not exactly find a real definition of building occupants during design, they will only come to an approximate assumption on clothing, activities behaviour , culture and other human factors.

Climatic factors

One of the limitations that might prevent energy prediction accuracy is climatic factor. The Icelandic Meteorology station is about 1km of Háskolatorg building (shown in figure 6), since there are many factors that can affect design site such as urban density, street, parks and traffics which are not accountable in the model. Further, building site surrounding elements such as materials, colours, green spaces etc, could have considerable effect, creating small microclimates that are hard to define. Thus it is not easy to obtain climatic condition near the building.

5.3 Problem encountered

- DesignBuilder manual claims its capability to import 3D architectural models created in Revit and other 3D CAD system supporting gbXML data exchange. After several tries, it was proven that the gbXML capability was not living up its promises. Its outcome was the model losing part of its feature and making it impossible to simulate with DesignBuilder.
- Even though DesignBuilder tools is considered to be mature product, but practically it doesn't offer a flexible complex geometry (free form), and activity table schedule inputs.
- To run the simulation model requires very rigorous input information about the building geometry and materials that often made the modelling such a tiresome task that requires building energy specialists.
- DesignBuilder is relatively complicate to master, consequently consuming hours of computations before delivering results.

6 Conclusion

DesignBuilder was designed for architects and engineers to use, particularly early in design, when crucial decision about form and orientation are made. It analyses the reaction of a building's skin and geometry in response to internal loads and external climate conditions.

The Building envelope determines the energy exchange between outdoor environment and indoor spaces and hence governs the overall energy performance of the building. The objective is to limit thermal losses during winter and thermal gains during summer. It is undoubtedly clear that an external glazed shell such as the one found in the University Square zone has greatly influence the HVAC loads of Háskolatorg building and requires thorough design consideration to design it.

This study shows that precise design of the building envelop of Háskolatorg building can significantly help achieve the heating and cooling objective and improve energy efficiency.

Moreover, this study demonstrates that appropriate thermal insulation, glazing type and shading elements can reduce the heat conducted through the building envelope. Both cooling and heating strategy, such as use of shading, have proven to be crucial and significantly influenced Háskolatorg building energy balance and energy usage.

DesignBuilder energy simulations benefit architects for quality decision making and proof of concept but also provides tools to recognize the relevant factors affecting the performance of building envelope and to analyze systematically as to their probable performance in respect to their varied requirements. With such capability, architects may begin to discriminate between various designs for particular uses, and even more importantly to provide a basis for the development of improved design.

It is clear that DesignBuilder is an energy simulation tool that can be used for building energy usage prediction and early design help tool for decision process, but in order to use such tool efficiently, user must have sufficient knowledge to understand the basic principles of the energy simulation software. This contains the basic knowledge of building

heat transfer, thermal properties and behavior of materials, and basic load calculation. Without this there is a possibility that either the simulator would enter unrealistic input to the programme or it produces impracticable results.

This study has shown that when architects begin to work with integrating environmental climate, building energy, and comfort related factors in the design process, the balancing of these demands can be expected to result in new, broader paradigms for low-energy architecture.

Conducting a survey could have a direct effect on improving the comfort of occupants by ensuring that the building is performing as design. Energy simulation and physical measurements can be valuable, but by themselves they also need to be interpreted in terms of how they impact occupants. Occupants are building end-users, and are themselves a rich yet underutilized source of direct information about how well buildings are working, and without occupants viewpoints a complete picture of a building's performance cannot be assembled.

While a generic conclusion cannot be drawn from a single case study, it is hoped that this framework will inspire and enable other researchers and architects and designers to perform similar studies in local or other climatic areas, thus helping to disseminate building energy simulation tool such as DesignBuilder simulation tool as an effective instrument to assess energy prediction performance of buildings and also to be translated into building construction practices.

6.1 Recommendations and further studies

- New public buildings should require building energy simulations.
- In the Icelandic climate, energy prediction simulation are recommended for fully glazed buildings
- Conduct survey inquiring about occupant's point of view at post occupancy evaluation.
- Further study is recommended on fully glazed buildings' energy balance in Icelandic climate.

Bibliography

- Al-Hamoud, M. S. (2000). Computer-aided building energy analysis techniques. *Building and Environment* , 421-433.
- Almenna verkfræðistofan hf. (2005). *Háskolatorg HÍ: Hönnunarforsendur fyrir lagnir*. Reykjavík: Almenna verkfræðistofan hf.
- Andresen, I., Kleiven, T., Knudstrup, M. A., & Heiselberg, P. (2011). *State of the art review Vol. 2B. Methods and Tools for designing Integrated Building Concepts*. International Energy Agency, Energy conservation in Buildings and Community Systems programme.
- Andresen, I., Thomsen, K. E., & Wahlstrom, Å. (2010). *Nordic Analysis of Climate Friendly*. Nordic council of Ministers.
- Arasteh, D., Selkowitz, S., Apte, J., & LaFrance, M. (2006). Zero energy windows. *American Council for an Energy-Efficient Economy(ACEEE)* , 1-14.
- Aschehoug, Ö., & Andresen, I. (2011). *State-of-the-Art Report Vol!: Integrating environmentally responsive Elements in Buildings*. International Energy Agency, Energy Conservation in Building and Community System programme.
- ASHRAE. (2004). *American Society of heating, Refrigerating, and Air conditioning Engineers. Standard 62.1-2004-Ventilation for Acceptable Indoor Air Quality(ANSI Approved)*. ASHRAE.
- Attia, S., Beltran, L., Herde, A. D., & Hensen, J. (2009). Architect Friendly: a comparison of ten different building performance simulation tools. *Eleventh International IBPSA* (pp. 204-211). Glasgow: Building simulation 2009.
- Augenbroe, G. (2002). Trends in building simulation. *Building and Environment* , 1-4.
- Autodesk. (2011). *Sustainability workshop* . Retrieved 01. March 2012 from Glazing property: <http://sustainabilityworkshop.autodesk.com/fundamentals/glazing-properties>
- Björnsson, S., Guðmundsdóttir, I. D., & Ketilsson, J. (February 2010). *Geothermal development and research in iceland*. Retrieved 12. February 2012 from Orkustofnun:The National Energy Authority: http://www.nea.is/media/utgafa/GD_loka.pdf
- Brager, G., & Baker, L. (2008). Occupant satisfaction in Mixed-Mode Buildings. *Air Conditioning and the Low Carbon Cooling Challenge*. Windsor: Network for Comfort and Energy Use in Buildings.
- Chwieduk, D. A. (2008). Some aspects of modelling the energy balance of a room in regard to the impact of solar energy. *Solar Energy* , 872.

- City of Reykjavik. (2011). *Reykjavík's baseline Emission Inventory and sustainable Energy Action Plan*. Retrieved 2. April 2012 from Covenant of Mayors: http://helpdesk.eumayors.eu/docs/seap/1842_1825_1309467054.pdf
- DesignBuilder. (2005). *Building Simulation made easy*. Retrieved February 21, 2012, from DesignBuilder Simulation: <http://www.designbuilder.co.uk/content/view/43/64/>
- Einarsson, M. Á. (1984). Climate of Iceland. In H. Van loon, *World Survey of Climatology 15: Climate of the Oceans* (pp. 673-697). Amsterdam: Elsevier.
- Energy Studies in buildings Laboratory. (18. May 2006). *Rethinking the Design Process*. Retrieved 21. April 2012 from Better Bricks: http://www.betterbricks.com/graphics/assets/documents/IED-Rethinking_Design.pdf
- Erdim, B., & Manioglu, G. (2011). Impact of building form on energy efficient heat pump application. *Proceedings of the Eleventh International Conference Enhanced building operation* (pp. 1-2). New York: ICEBO.
- Ferrante, A., & Cascella, T. M. (2011). Zero energy balance and zero on-site CO2 emission housing development in the mediterranean climate. *Energy and Buildings*, 2002-2010.
- Goldstein, R., Tessier, A., & Khan, A. (2010). Customizing the Behavior of Interacting Occupants using personas. *SimBuild 2010 Conferences*. New York: IBPSA-USA SimBuild Conference.
- Goulding, J. R., Lewis, J. O., & Steemers, T. C. (1992). *Energy Conscious Design: A prime for Architects*. London: B.T. Batsford Ltd.
- Goulding, J. R., Lewis, J. O., & Steemers, T. C. (1992). *Energy in architecture*. European Communities: Batsford.
- Goulding, J., & Lewis, O. J. (1997). *Bioclimatic Architecture*. Hoeilaart, Belgium: European Comussion: Directorate General for Energy.
- Gut, P., & Ackerknecht, D. (1993). *Climate responsive building*. St. Paul, Switzerland: SKAT.
- Holladay, M. (30. Mars 2012). *Energy modeling isn't very accurate*. Retrieved 11. May 2012 from Musings of an Energy nerd: contemplating residential energy use: <http://www.greenbuildingadvisor.com/book/export/html/23759>
- Hong, T., Zhang, J., & Jiang, Y. (1996). IISABRE: An Integrated building Simulation Environment. *Building and Environment*, 1-4.
- Hornsteinn and Ingimundur Sveinsson . (2006). *Háskola Íslands- Háskolatorg1, Sæmundargata 4: Teikningar*. Reykjavik: Byggingafulltrúi.
- Huizenga, C., Laeser, K., & Arens, E. (2002). A Web-based Occupant satisfaction Survey For Benchmarking Building Quality. *Indoor Air*, 1-6.

Icelandic Met Office. (e.d.). *the weather of Iceland: Climate summary*. Retrieved 21. February 2012 from Vedurstofa Íslands: <http://www.vedur.is>

International Energy Agency (IEA). (2000). *Daylight in Buildings: A source book on Daylighting Systems and Components*. Berkeley, California: Lawrence Berkeley National Laboratory.

ISO 7730. (1994). *Moderate thermal environments- determination of the PMV and PPD indices and speculation of the conditions for thermal comfort*. Geneva: International Organization for Standardization.

Jaber, J. O. (2002). Prospects of energy savings in residential space heating. *Energy and Buildings* , 318.

John R. Goulding, J. O. (1997). *Bioclimatic Architecture*. Hoeilaart: Lior E.E.I.G.

John, G., Croome, D. C., & Jeronimidis, G. (2005). Sustainable building solutions: a review of lessons from the natural world. *Building and Environment* , 319-328.

Kim, B. S., & Degelman, L. O. (1998). An interface system for computerized energy analyses for building designers. *Energy and Building* , 97-107.

Klein, L., Kavulya, G., Jazizadeh, F., Kwak, J.-y., Gerber, B. B., Varakantham, P., et al. (2012). *Towards Optimization Of Building energy and Occupant Comfort Using multi-Agent Simulation*. Retrieved February 15, 2012, from TEAMCORE Research Group: <http://teamcore.usc.edu/papers/2011/ISARC.pdf>

Kuhn, T. E., Herkel, S., Frontini, F., Strachan, P., & Kokogiannakis, G. (2011). Solar control: general method for modelling of solar gains through complex facades in building simulation programs. *Energy and Buildings* , 19-27.

Laustsen, J. (2008). *Energy Efficiency Requirements in building Codes, Energy Efficiency Policies For New Buildings*. OECD: International Energy Agency(IEA).

Lehar, M. A., & Glicksman, L. R. (2003). *A simulation tool for predicting the energy implication of advanced facades*. Retrieved May 19, 2012, from MIT design advisor: http://designadvisor.mit.edu/Design/papers/Lehar_Glicksman_RIBP_2003.pdf

Lomanowski, B. A., & Wright, J. L. (2009). Modeling fenestration with shading devices in building energy simulation: A practical approach. *Eleventh International IBPSA* (p. 976). Glasgow, Scotland: Building Simulation 2009.

Maile, T., Fischer, M., & Vladimir, B. (December 2007). Building Energy Performance simulation Tools: a Life-Cycle and Interoperable Perspective. *CIFE, Centre for Integrated Facility Engineering* , bls. 1-8.

Mannvirkjastofnun. (24. January 2012). *Ný byggingarreglugerð*. Retrieved 01. March 2012 from Mannvirkjastofnun: <http://www.mannvirkjastofnun.is/byggingarmal/ny-byggingarreglugerd/>

- Marteinsson, B. (2002). *Efnis- og orkunotkun vegna fjölbýlis í Reykjavík*. Reykjavík: Háskoli Íslands.
- McDonough, W., & Braungart, M. (2003). Towards a sustaining architecture for the 21st century: promise of cradle-to-cradle design. *UNEP Industry and Environment* , 13-14.
- McMullan, R. (1998). *Environmental Science in Building*. London: McMillan Press Ltd.
- Meek, C., & Breshears, J. (2010). Dynamic solar shading and glare control for human comfort and energy efficiency at UCSD: integrated design and simulation strategies. *American Solar Energy Society* .
- Moore, F. (1993). *Environmental Control System: Heating, Cooling, Lighting*. New York: McGraw-Hill International Edition.
- Nasrollahi, F. (2009). *Climate and Energy Responsive Housing in continental climate*. Berlin: Universitätsverlag der TU Berlin.
- Olgyay, V. (1992). *Design with climate: a bioclimatic to architectural regionalism*. New York: Van Nostrand Reinhold.
- Oliveira, A. C., & Marrero, A. P. (2006). Evaluation of solar thermal system using building louvre shading devices. *Solar Energy* , 545-546.
- Oral, G. K., & Yilmaz, Z. (2003). Building form for cold climatic zones related to building envelope from heating energy conservation point of view. *Energy and Building* , 383-388.
- Persónuvernd. (e.d.). *Myndir úr eftirlitsmyndavelum má aðeins senda lögreglu*. Retrieved 21. February 2012 from Persónuvernd: <http://www.personuvernd.is/>
- Poerschke, U., & Bambardekar, S. (2009). The architect as performer of energy simulation in the early design stage. *Eleventh International IBPSA* (p. 1306). Glasgow: Building simulation 2009.
- Poirazis, H., Blomsterberg, Å., & Wall, M. (2008). Energy simulation for glazed office buildings in Sweden. *Energy and Building* , 1161-1170.
- Poortinga, W., Steg, L., Vlek, C., & Wiersman, G. (2003). Household preferences for energy saving measures: a conjoint analysis. *Journal of Economic Psychology* , 24,49-64.
- QuestionPro. (2012). *QuestionPro: online research made Easy*. Retrieved 21. February 2012 from QuestionPro: <http://www.questionpro.com/>
- Rekstrarstjóri fasteigna. (2011). *Hot, cold water and electricity usage and cost*. Reykjavík: Rekstrarstjóri fasteigna.
- Reykjavíkborg. (2012). *Reykjavíkborg*. Retrieved 4. June 2012 from Borgarvefsjá: http://www.reykjavik.is/desktopdefault.aspx/tabid-3546/5704_view-1139
- Roulet, A. C. (2006). Architecture education for sustainable design: A proposal for improving indoor environmental quality. *the 23rd Conference on Passive and Low Energy*

Architecture. Geneva, Switzerland: LESO-PB, École Polytechnique Federale de lausanne, Switzerland.

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews* , 3617-3631.

Shameri, M. A., Alghoul, M. A., Sopian, K., Zain, M. F., & Elayeb, O. (2011). Perspective of double skin facade system in buildings and energy saving. *Renewable and Sustainable Energy Reviews* , 1468-1475.

Silvia, S. M., & Almeida, M. G. (2011). Achieving Sustainable Energy Efficiency while Assuring Indoor Environmental Quality. *Portugal SB 10: Sustainable building for all* .

Smith, P. F. (2005). *Architecture in a Climate of Change*. Burlington: Architectural Press Elsevier.

Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. *Building and Environment* , 2581-2593.

Stack, A., Goulding, J., & Lewis, J. O. (2000). *Shading system: Solar Shading for the European climates*. Dublin: ENERGIE Programme of the European Commission.

Straube, J. (2006). The thermal control in a building. *Buildind Science Digest 011* , 3-4.

The Energy Research Group, School of Architecture, University College of Dublin. (1993). *Energy in Architecture: The European Passive Solar Handbook*. London: B.T. Batsford Limited.

U.S. Department of Energy. (2012, January 12). *Energy Efficiency*. Retrieved February 21, 2012, from EnergyPlus Energy Simulation Software: <http://www.eere.energy.gov/>

UNEP-SBCI. (2009). *Building and Climate Change, summary for decision-maker*. Paris: United Nations Environmental Programme -Sustainable Building & Climate Initiative.

University of Iceland. (2011). *University of Iceland map - Vatnsmýri.svg*. Retrieved 10. June 2012 from Wikimedia: http://commons.wikimedia.org/wiki/File:University_of_Iceland_map_-_Vatnsm%C3%BDri.svg

Urban, B., & Glicksman, L. (2007). A Rapid building energy model and interface for non-technical users. *Building X conference, ASHRAE*. Clearwater FL: MIT.

Waddell, C., Kaserekar, S., Arup, & Ten, A. (2010). Solar Gain and Cooling Load Comparison Using Energy Modeling Software. *Fourth National Conference if IBPSA-USA* (p. 150). New york: SimBuild.

Wang, L., Gwilliam, J., & Jones, P. (2009). Case Study pf Zero energy design. *Energy and Buildings* , 1215-1222.

WBDG. (10. October 2010). *Engage the Integrated Design process*. Retrieved 21. April 2012 from WBDG: a program of the national Institute of Building Sciences: http://www.wbdg.org/design/engage_process.php

White, T., Dec, M., Troy, D., & Thornton, B. (2008). Effective Early Collaboration Between Engineers and Architects For Successful Energy-Efficient Design. *Third National Conference of IBPSA-USA* (pp. 184-186). Berkeley, California: SimBuild 2008.

World Weather and climate Information. (2011). *World Weather and climate Information*. Retrieved 21. February 2012 from Average weather and climate in Iceland: <http://www.weather-and-climate.com/>

Wymelenberg, K. V., & Meek, C. (2011). *Daylighting design*. Retrieved 3. April 2012 from University of Washington: http://www.idlseattle.com/Documents/BS2011_SimBasedDaylightingEd&Tech.pdf

Zagreus, L., Huizenga, C., Arens, E., & Lehrer, D. (2004). Listening to the occupants: a web-based indoor environmental quality survey. *Indoor Air* , 65-74.

Zelezny, L. C., Chua, P. P., & Aldrich, C. (2000). Elaborating on gender differences in environmentalism. *Journal of social Issues* , 56, 443-457.

Zhai, Z. (2006). Application of Computational Fluid Dynamics in Building design: Aspects and Trends. *Indoor and Built Environment* , 305-306.

Appendix A: survey

Introduction

This survey is conduct as part of the Master thesis on building design and the prospect of energy use.

Highly glazed facade buildings are claimed to be particularly sensitive to the outdoor condition, orientation and occupancy for its performance. In order to assess the indoor comfort quality of building occupants, it is therefore important to examine “Háskolatorg” user’s perception.

Background

1. Are you...?

student

Staff

Faculty

Others_____

2. What is your gender?

Female

Male

3. In typical week, how long time do you spend in Háskolatorg

10 minutes or less

11-30 minutes

More than 30 minutes

other_____

4. If you spend time in Háskolatorg, what do you do normally there?

Eating

Meeting friends

Reading

Studding

Just passing

Other_____

5. If you spend time seating in Háskolatorg, do you use your laptop?

Yes

No

Thermal comfort

6. How satisfied are you with the temperature in Háskolatorg during winter time

(1) Very satisfied, (2), (3), (4), (5) very dissatisfied

Other_____

7. How satisfied are you with the temperature in Háskolatorg during summer time

(2) Very satisfied, (2), (3), (4), (5) very dissatisfied

Other_____

8. If you are dissatisfied with the temperature at Háskolatorg

Cold

Cool

Neutral

Warm

Hot

9. If you have to choose a seat in Háskolatorg, do you prefer to be near the exterior gazing wall (within half meter)?

Yes

No

10. If you do not prefer to seat within half meter, How far do you want to seat from the exterior gazing wall? _____m (meter)

11. Overall, does your thermal comfort in Háskolatorg interfere with the place you would like to seat there?

Yes

No

Other_____

Air quality

12. How satisfied are you with the air quality in Háskolatorg?

(1) Very satisfied, (2), (3), (4), (5) very dissatisfied

13. You have said that you are dissatisfied with the air quality in Háskolatorg, is it because

Air is stuffy

Air is not clean

Air smell bad

Other issues_____

Lighting

14. How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?

(1) Very satisfied, (2), (3), (4), (5) very dissatisfied

15. Overall, does the lighting quality enhance or interfere in your comfort quality in Háskolatorg?

(1) enhance, (2), (3), (4), (5) interfere

Building

16. Considering energy use, how efficient is this building performance in your opinion?

(1) Outstanding, (2) Excellent, (3) good, (4) average, (5) Poor, (6) not informed

17. Please indicate how satisfied are you with the effectiveness of the window blinds of Háskolatorg?

(1) Outstanding, (2) Excellent, (3) good, (4) average, (5) Poor, (6) not informed
Other_____

18. How satisfied are you with the building overall?

(1) Very satisfied, (2), (3), (4), (5) very dissatisfied

19. Any additional comments or recommendations about Háskolatorg overall, please describe?

Appendix B: Háskolatorg building energy demand data collection and calculation

The energy demanded for heating and ventilation has been calculated using the general formula $P=Q_{\text{netto}}*dT$

Where: Q_{netto} is the average of Q_{in} and Q_{out}

Q_{in} is the flow of in-water temperature

Q_{out} is the flow of out-water temperature

Average in temperature: 77,5 °C, with density of 995,7 kg/m³

Average out temperature 30 °C, with density of 971,8 kg/m³

$C(\text{water})=4,184 \text{ J/g}^{\circ}\text{C}$

It comes to the result Q_{netto} daily every m³ of water at 53,73 kWh. Further multiply with water amount each day, giving the energy load provided by the hot water each day:

Table 60: Háskolatorg building energy demand from 20th until 26th of March tabulation results

Date(day of week)	Outdoor Average temperature (°C)	Hot water for Heating and ventilation (m ³)	Energy demanded heating/ventilation (kWh)	Electricity consumption (kWh)	Total Energy demand(kWh)
20 th Mar. (Tue.)	3,2	65	3492,45	15,78	3508,2

21 st Mar.(Wed.)	3	54	2901,42	13,22	2914,6
22 nd Mar. (Thu.)	5,5	62	3331,26	14,51	3345,8
23 rd March (Fri.)	8	41	2201,93	16,06	2219
24 th Mar.(Sat.)	8	52	2793,96	15,87	2809,8
25 th Mar. (Sun.)	8,3	31	1665,63	8,51	1674,1
26 th Mar. (Mon.)	7,7	46	2471,58	12,17	2483,8

Appendix C: Master thesis poster presentation

Study aims

The aim of this study is to assess energy balance of a building by use of an energy simulation tool, as a prelude to improve decision making related to design building envelope. This process is driven by commitment to study of the potential building low energy usage goal, while identifying building design potential improvement. For this study, Háskolatorg building has been chosen as a case study.



Figure 1: Háskolatorg building perspective. Christopher Lund ©

Introduction

Buildings have substantial share of the energy consumption all over the world. Over 80% of its energy used, takes place during the operation phase of a building, when energy is used for heating and cooling, ventilating, lighting, appliance and other application (UNEP-SBCI, 2009).

Energy use and environmental degradation has been linked because of the main emphasis of building design to solve climate related heating, cooling and lighting problems induced by inadequate building design approach. Poor design of buildings and systems not only wastes resources and energy, and cause adverse impacts to the environment, but also creates uncomfortable and unhealthy indoor environment. Efforts toward designing and operating energy efficient building have been enhanced; by shifting resource allocation such as reducing the space air-conditioning load by design and using climate responsive buildings and materials, both meets the occupants needs for thermal and visual comfort and requires less energy to run and subsequently has a reduced impact on the environment.

Significant energy consumption, however, can be reduced in building operation during earlier phase of architectural design, if design improvement, selected with the aid of decision support simulation software will be undertaken. It has been suggested that it could reduce energy use by 75% in new buildings (Goldstein, Tessier, & Khan, 2010).

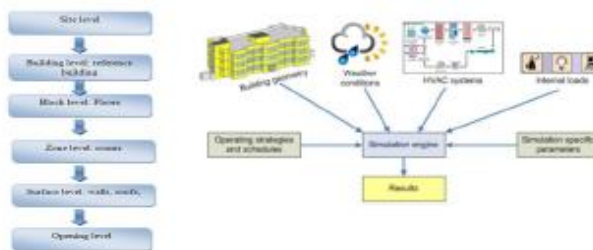


Figure 2: DesignBuilder model hierarchy and data inheritance

For this case study the simulation possibilities in the software DesignBuilder® have been used for different aspects such as: energy usage prediction, building energy balance and performance

Goldstein, R., Tessier, A., & Khan, A. (2010). Customizing the behavior of interacting occupants using personas. SimBuild 2010. New York: IBPSA-USA SimBuild Conference.

UNEP-SBCI. (2009). Building and Climate Change, summary for decision-makers. United Nations Environment Programme (UNEP), Sustainable Building & Climate Initiative. Paris: United Nations Environmental Programme.

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Figure 4: All year Háskolatorg building internal gains

All year Háskolatorg building internal gains

As exhibited on Figure 4, DesignBuilder® energy simulation results show that solar gains were the most significant of Háskolatorg building all year internal energy gains, followed by general lighting and zone sensible heating

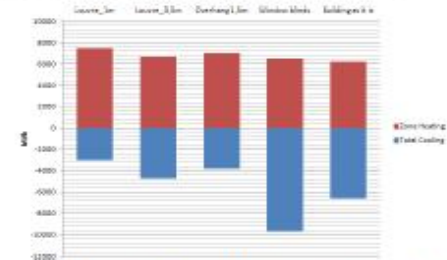


Figure 5: All summer Háskolatorg building shading devices analysis

All summer shading devices analysis

As indicated on Figure 5, simulation individually installation of 0.5 m and 1.5 m Louvre, 1.5 m overhang and adjustable scheduled device window blinds have significant impacts on Háskolatorg building all summer system loads

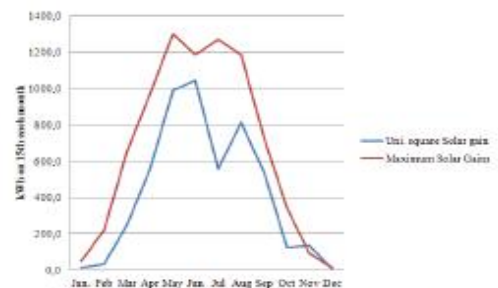


Figure 6: University square solar gains simulation results and calculated maximum solar radiation on 15th of each month comparison

Conclusion

DesignBuilder® was designed for architects and engineers like ways to use, particularly early in design, when crucial decision about form and orientation are made. It analyzes the reaction of a building's skin and geometry in response to internal loads and external climate conditions. This study shows that careful design of the building envelope of Háskolatorg building can significantly help achieve the heating and cooling objective and improve energy efficiency.

Further, this study has shown that when architects begin to work with integrating environmental climate, building energy, and comfort related factors in the design process, the balancing of these demands can be expected to result in new, broader paradigms for low-energy architecture.