AUTODESK® GREEN BUILDING STUDIO FOR AN ENERGY-EFFICIENT, SUSTAINABLE BUILDING

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Degree Programme in Construction Engineering

Visamäki, spring 2014

Minh Khoi Le

HAMK
UNIVERSITY OF APPLIED SCIENCES

ABSTRACT

VISAMÄKI
Degree Programme in Construction Engineering

Author Minh Khoi Le **Year** 2014

Subject of Bachelor's thesis AutoDesk® Green Building Studio for an energy-efficient, sustainable building

ABSTRACT

The thesis introduced AutoDesk® Green Building Studio (GBS) which is a software for analyzing the whole building. It gives the results of energy consumption such as water usage and costs, natural ventilation potential, carbon emissions based on an actual model, local energy sources and weather data.

The aim of the research was to optimize a plan to achieve an energy-efficient, sustainable building by multiple choices of alternative designs. In addition, the comparison between AutoDesk® Green Building Studio and Graphisoft ArchiCad Ecodesigner Star was done.

An existing design of a residental house was modeled by the parent product: AutoDesk® Revit and was analyzed by the GBS on a web-based analysis service (https://gbs.autodesk.com). The information on typical elements of the building was presented. The web-based service features with all results and alternative designs were also described.

In conclusion, the best energy efficient, sustainable design was recommended to architects for future projects and the software GBS and its functions and features on a web-based service were introduced as a suggestion.

Keywords Energy consumption, sustainable building, carbon emissions, alternative designs, building elements.

Pages 27 p. + Appendices 4 p.

HÄMEEN AMMATTIKORKEAKOULU

PREFACE

This thesis helped me to acquire knowledge of modeling a building to achieve a sustainable and energy efficiency design as well as a deeper understanding of environmental factors such as energy usage, carbon emissions and ventilation potential.

This thesis was accomplished for a Bachelor's degree in construction engineering under the supervision of Senior Lecturer Olli Ilveskoski. I would like to thank him for introducing me a good topic and guiding me with valuable comments during the research work. Additionally, I would like to thank Senior Lecturer Helena Parviainen for the English section. Finally, I would like to give thanks to HAMK's study counselors for all the help and support to finish the thesis.

CONTENTS

ABBREVIATIONS

GBS	AutoDesk®Green Building Studio
BPA	Building Performance Analysis
EAM	Energy Analytical Model
CBECS	Commercial Building Energy Consumption Survey
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineer
EPD	Equipment Power Density
LPD	Lighting Power Density
ACH	Air changes per hour
CFM	Cubic feet per minute
PES	Potential energy savings
CARMA	Carbon Monitoring for Action
LEED	Leadership in Energy and Environment Design
SIP	Structural Insulated Panel
ICF	Insulated concrete form
SHGC	Solar heat gain coefficient
VLT	Visible light transmittance
AES	Archicad Ecodesigner Star

1 INTRODUCTION

Statistics on energy consumption in households are based on the energy used in residential buildings on heating, domestic water and household appliances. According to Energy supply and consumption Statistics of Finland, over 80 % of energy consumption in Finnish households was spent on heating in 2011 and 16 % on household appliances. The consumption of heating energy grew by 11 % to reach about 66,682 gigawatt hours (GWh) in 2012.

The A2 National Building Code of Finland states that an energy economy report is necessary for the building permit. The fact that energy price, the need of energy usage have increased dramatically, and the reduction of natural energy sources supply in the world make the consideration of constructing sustainable, energy efficient building become an essential factor for decision making in the very early design stages.

Autodesk® Green Building Studio® energy-analysis software is a powerful and accurate tool which enables architects and designers to optimize energy consumption and work toward carbon-neutrality. The features of the tool will be introduced such as the whole building energy analysis, detailed weather data, carbon emissions reporting, day lighting, water usage and costs and natural ventilation potential. They were applied to an example which was modelled by Autodesk® Revit 2014.

2 EXPLAINING THE EXAMPLE PROJECT MODELLED BY AUTODESK®REVIT 2014

The building example was modelled by the Autodesk architects as a demonstration for Autodesk® Revit users.

The building was designed on the site of 3315 m^2. It is a two-storey building with the gross internal area of 279 m^2. All the rooms were numbered from 101 to 106 on the 1^{st} floor and 201 to 208 on the 2^{nd} floor. There are also three M_Wind Power Generators nine meters high in front of the villa and two rain water collection tanks, 5000 liters each. The rendering approach view of the villa is shown in Figure 1.

Figure 1 Rendering from approach 3D view

Autodesk® Revit gave the numerical integration report. From the menu – export – reports- room/area report, two options can be chosen to display the area of floor and window inside the building. This data was helpful to calculate and check the heat loss and energy used manually. The tool defines and analyzes room by its name, area and its function by facilities which are installed. It is important to make sure that all the rooms and area have been created properly by Autodesk® Revit tools. Examples of room and window report are shown in Appendix 1.

2.1 Building elements and their properties

All the elements can be chosen from Autodesk® Revit library. The materials available are abundant. Selecting an element is based on many factors such as economical and physical properties. These analytical properties affect the energy usage of the building through the heat transfer coefficient and thermal resistance. It is important to consider and choose the correct types of material for the purpose of saving energy but which are still strong and economical enough. One example of an external wall property is demonstrated below in Figure 2.

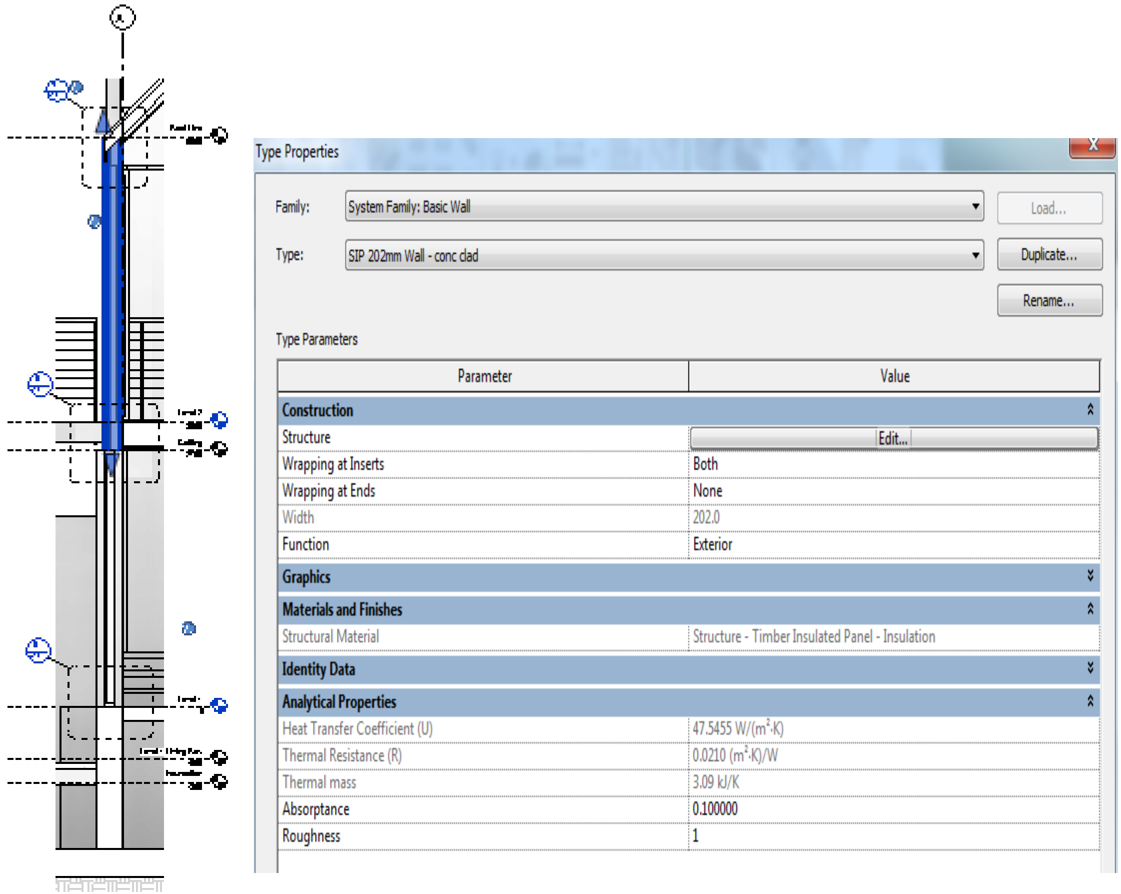


Figure 2 Typical wall section and its properties

The details of the building construction included roofs, ceilings, exterior and interior walls, floors, doors, windows, operable skylight with their properties and U-value which are shown in Table 4, Appendix 2.

2.2 Exporting to gbXML file

Menu – Exporting – gbXML. Revit defines the volume by the area or rooms computation. While computing only areas is faster, it may cause an incorrect result in the analytical model because Revit will approximate the rooms volume. In order to set room computation, the Areas and Volumes option should be chosen in the Area and Volume Computation setting. It is shown in Figure 3 below. The values of some parameters such as the building type, location, export category, export complexity are exposed and can be modified. The 3D view of the model which demonstrates the room separation is also shown on the left. If there is any error or insufficient modelling, a warning board can be found in the Detail section.

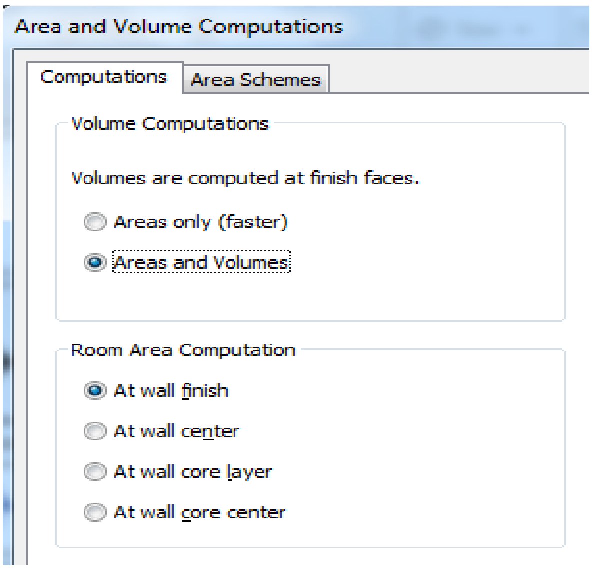


Figure 3 Area and Volume Computations setting

3 INTRODUCTION TO AUTODESK BUILDING PERFORMANCE ANALYSIS WORKFLOW

3.1 Autodesk Building Performance Analysis

Autodesk Building Performance Analysis (BPA) gives help and support to all building performance studies using Autodesk tools. The features of the tools belong to one of the two main categories:

- Whole building energy analysis: Based on building type, geometry, climate, envelope properties, HVAC and lighting, the energy such as fuel and electricity are measured. The building as a whole system is taken into account with all the elements working interdependently.
- Performance-based Design Studies: Autodesk tools (Revit and Vasari) contain some additional function to perform design studies such as sun path, daylight, wind, airflow.

The main structure of BPA is shown below in Figure 4

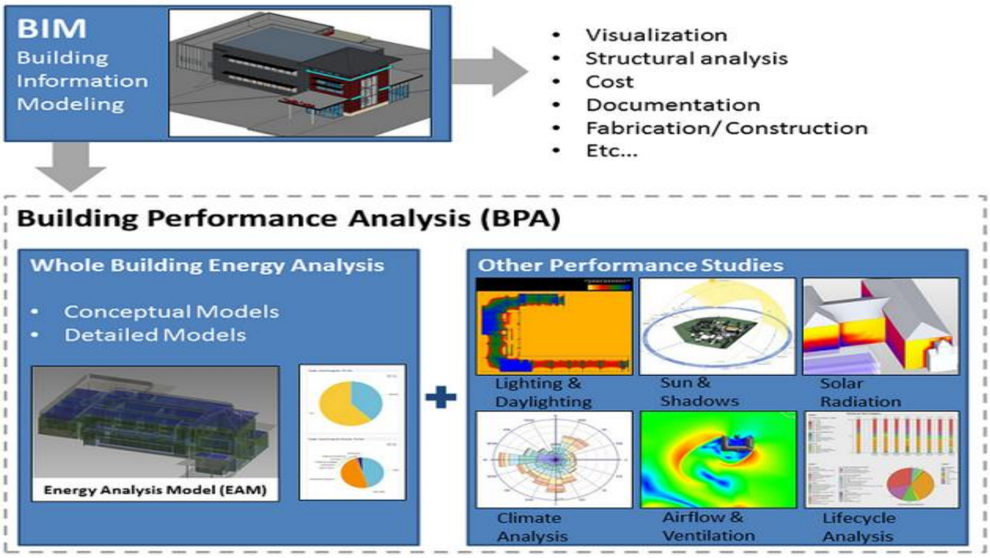


Figure 4 Main structure of BPA

3.2 Energy analysis workflows

The energy used can be analyzed in both conceptual and detailed building information models. The following chart in Figure 5 shows the three main energy simulation workflows from Autodesk tools: building elements, conceptual masses, and gbXMl exports.

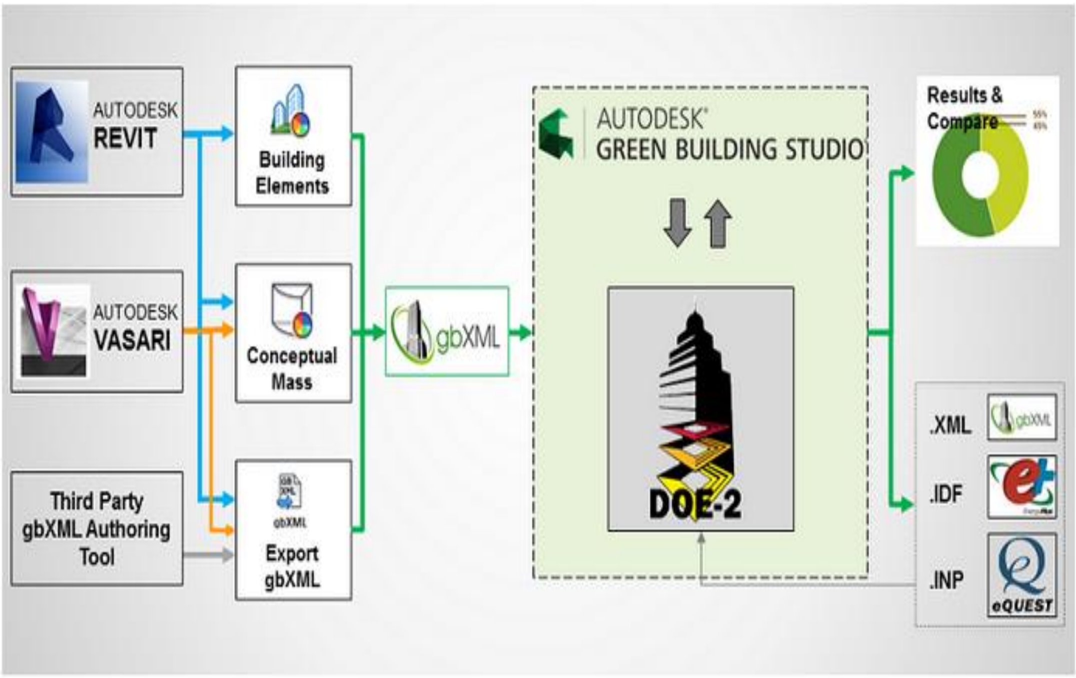


Figure 5 Energy simulation workflows from Autodesk tools

3.2.1 Energy Analysis using Building Elements

This option applies to Revit as a detailed building information model. All building elements (walls, doors, windows, ceilings, roof…) are used to create an Energy Analytical Model (EAM) automatically. This information is then passed to Green Building Studio for energy simulation.

Some steps using Revit to create building elements model are described. In order to use the feature, an account of Autodesk 360 is needed. Firstly, a building element is needed to be set as a basic energy simulation by clicking Building Element Mode from Analyze tab – Energy Analysis panel. Energy setting is used to modify the building type, location and some detailed and energy models. Finally, the energy simulation can be activated by clicking Run Energy Simulation panel. The simulation run needs to be named for results displayed which can be shown in the panel Results & Compare. In Figure 6 below, the Energy Analysis panel where Energy Settings, Run Energy Simulation command and Energy Analysis results symbols display are shown

Figure 6 Energy Analysis panel

3.2.2 GBXML Energy Analysis workflow

Green Building Studio (GBS) can use any gbXML model. It is uploaded to GBS website and can be fulfilled if needed. This means that if any energy parameters have not been defined in the building information model, GBS applies default settings to them. This allows designers to quickly analyze energy use by just simply defining the building type and location.

The detailed instruction for exporting gbXML file from Revit and the notification was shown above in section 2.2. First, it is needed to sign in to Autodesk 360. After that, creating a new project and entering the location of the project are required from the website feature. Once the project has been created, the gbXML file should be uploaded.

4 GREEN BUILDING STUDIO WEB SERVICE

Green Building Studio is a flexible, standalone cloud-based service that allows running building performance simulations to give all energy performance results. Through those reports, energy usage and carbon emissions can be optimized early in the design process. GBS uses the DOE-2 simulation engine for an hourly calculation of the whole building energy usage. It is possible to use GBS with conceptual models from Revit and Vasari, more detailed Revit models or a gbXML file created by other authoring tools. Energy simulation can be displayed on GBS website or with its own models.

4.1 Assumption and default values in GBS

The inputs from Revit and Vasari energy settings are based on standard practices in construction companies and Commercial Building Energy Consumption Survey (CBECS) which is a national sample survey that collects information on the stock of the U.S commercial buildings. It is defined that commercial buildings include all the buildings in which at least half of floor space is used not for residential, industrial or agricultural purposes. By this definition, some other building type can be included, for example schools, hospitals, correctional institutions.(U.S Energy Information Administration - CBECS website, April 2013)

However, this also means that there was no data collected from residential or industrial buildings, so it is quite insufficient information using performance-based design studies from Revit and Vasari for these types of buildings.

Instead of Revit and Vasari Energy settings, other defaults are available upon American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE) standards. ASHRAE is a global society improving human prosperity through sustainable technology for the building environment. It focuses on building systems, energy efficiency, indoor air quality, refrigeration and continuing education. ASHRAE standards are accredited by the American National Standards Institute (ANSI).(ASHRAE website, 18th February 2014)

With all the gbXML files uploaded from any sources, GBS uses default standards based on ASHRAE 90.1, ASHRAE 90.2, ASHRAE 62.1 and CBECS data.

For energy settings where ASHRAE baselines do not exist, regional baselines or survey buildings are applied:

- Schedules: California Non-residential New Construction Baseline Study 1999
- Envelope thermal characteristics, LPD, HVAC efficiency: ASHRAE 90.1 2007 and ASHRAE 90.2 2007
- Equipment power density & DHW loads: California 2005 Title 24 Energy Code
- Occupancy density, ventilation: ASHRAE 62.1-2007

4.1.1 Building type

When performing energy simulation in GBS, the building type should be defined. There are 34 types of building available in the data. GBS applies default values for different types of building. Table 5 in Appendix 3 shows GBS default values of equipment power density (EPD), lighting power density (LPD), outside air flow rates and infiltration rates.

Because the data system is based on the U.S standards, so the values are in the U.S unit system. For example, equipment power density unit is watt per square feet which is equivalent to 0.0929 square meters. The example building is residential single family house, so the values used to analyze energy are:

- 0.43 w/ft^2(watt per square foot) for EPD.
- 0.45 w/ft^2 for LPD.
- The outdoor air flow rate showed the minimum fresh air requirement per person (l/s/person or cfm/person) : not available.
- The outdoor air flow by area showed the minimum fresh air requirement per square feet (l/s/m^2 or cfm/ft^2): 0.06 cfm/ft^2.
- The infiltration flow rate showed the number of interior volume air changes that occur per hour (air changes per hour ACHs).
  ACH can be calculated by multiplying the building’s CFM (cubic feet per minute) by 60 and then dividing by building’s volume.
  (CFM x 60/volume): 0.5 ACHs

4.2 Project in Green Building Studio

When applying the GBS database, a new project creation is needed. The project defined the building type, project operation schedule and the project location. Regardless of the building information model which is used, building elements from Revit, conceptual masses from Vasari or gbXML files from Revit or other third party tools, the information above is compulsory . However, the difference between them is that the definitions of the aspects are mandatory before uploading gbXML files while in Revit and Vasari, all information used for energy analysis and simulation were collected from the project itself automatically.

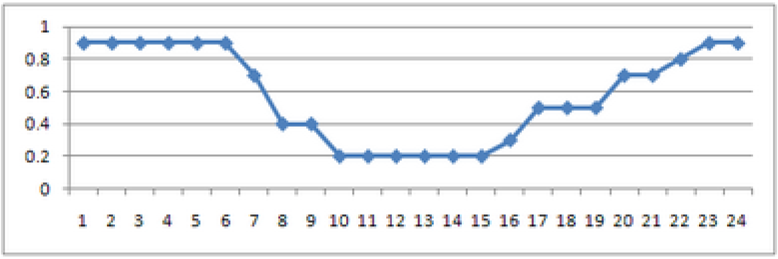
4.2.1 Building operation schedules

The schedule provided occupancy assumption used during energy analysis. These assumptions are accredited from ASHRAE standards.

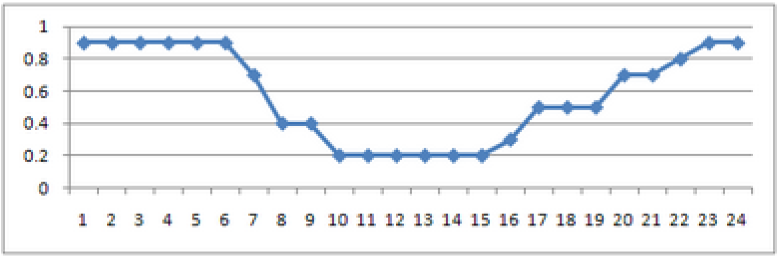
There are several schedule facility defaults in GBS. It can be 24/7 facility, which means that the building is operating at all times throughout the year. The schedule 24/6 is preferred to the operation of the building is from Monday to Saturday and it closes on Sunday. The schedule 12/7 is used for a building that operates every day but is closed at night. A similar deduction is applied to 12/6 where the building is opened all days but at night and Sunday. Schedules for schools and university are K-12 and year-round school. K-12 specifies the operation during school year but the facility is closed in summers and holidays while a year-round school refers to a building which is just closed on holidays. Other schedules such as 24/5, 12/5, theatre/performing arts or worship are also available in GBS defaults.

Figure 7 below illustrates a typical schedule 24/7 facility of a single family building. It provides hourly values for a 24-hour period, starts at midnight (0 to 24 on the x-axis). The values 0 to 1 on the y-axis are the fractional multipliers. For example, if the people in the building are 1000 then

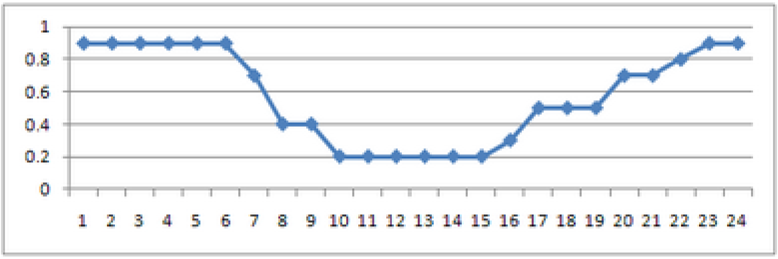
- A value of 1 means that there are 1000 people supposed to be in the building during that hour
- A value of 0 means that no people are assumed to be in the building during the hours
- A value of 0.5 means that there are 0.5*1000 = 500 people supposed to be inside the building at the time.



Residential schedule on weekdays



Residential schedule on Saturday



Residential schedule on Sunday

Figure 7 Building operation 24/7 and residential schedule type

4.2.2 Project location, weather conditions

GBS incorporates $Google^{TM}$ Maps to specify the location and find the appropriate weather station nearby. The project address can be typed directly to the search box. If there is no address, the local city and postal code are enough.

The weather data and geometry are significant inputs in analyzing energy. The weather varies greatly from an area to area, even within a small area. Good weather data provides accurate and quick information so it affects the result of energy analysis greatly . Most weather data comes from physical stations which are located in big airports and so they may not represent the weather in the area of the project.

AutoDesk climate weather data involves 1.6 million virtual weather stations which are simulations based on the data from actual stations. That means it is always possible to find the correct weather conditions of the vicinity within less than 14 km to the project and almost everywhere in the world.

The climate data also works by collecting a period of record of 30 years. It represents typical conditions not only for the detailed recent weather but also for the long period of time. This is helpful for estimating the building weather conditions correctly because it is supposed to be operated not only for one or two year period. So the data collection is a good indicator for the whole building energy simulation. Figure 8 below shows the detailed information when selecting the project location

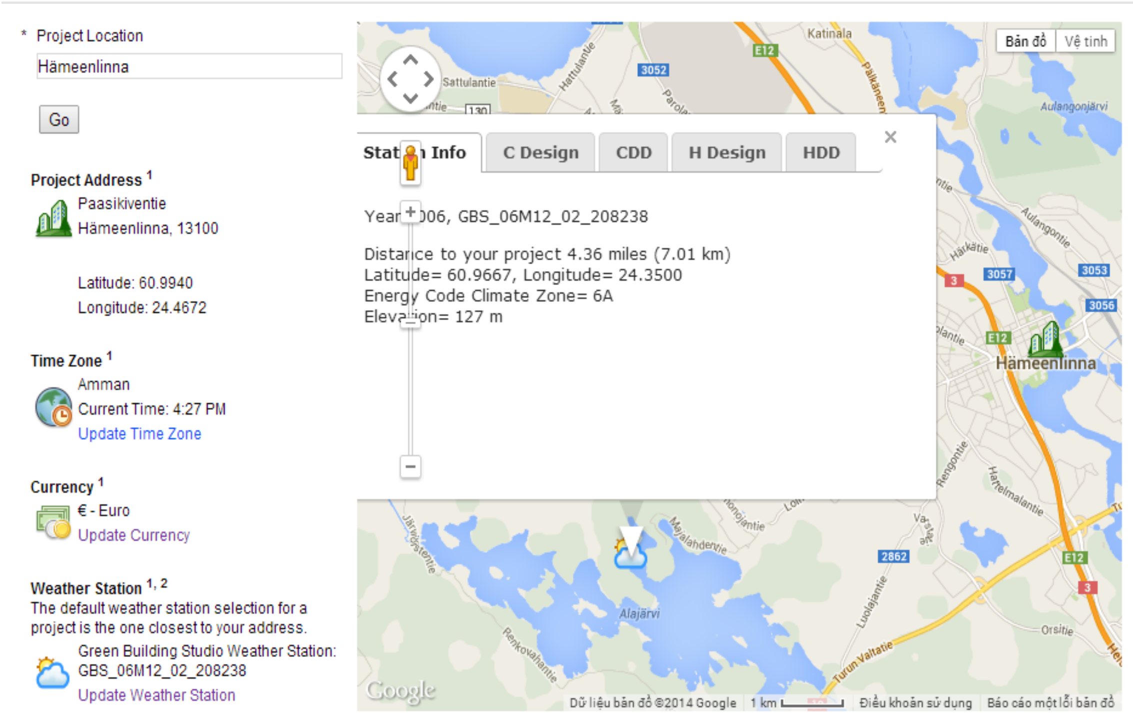


Figure 8 Project location feature

The building was set in Paasikiventie, Hämeenlinna, Finland. It is 7 km to the closest GBS virtual weather station. The station can be changed by update dialog. Local time zone and currency used input are also available.

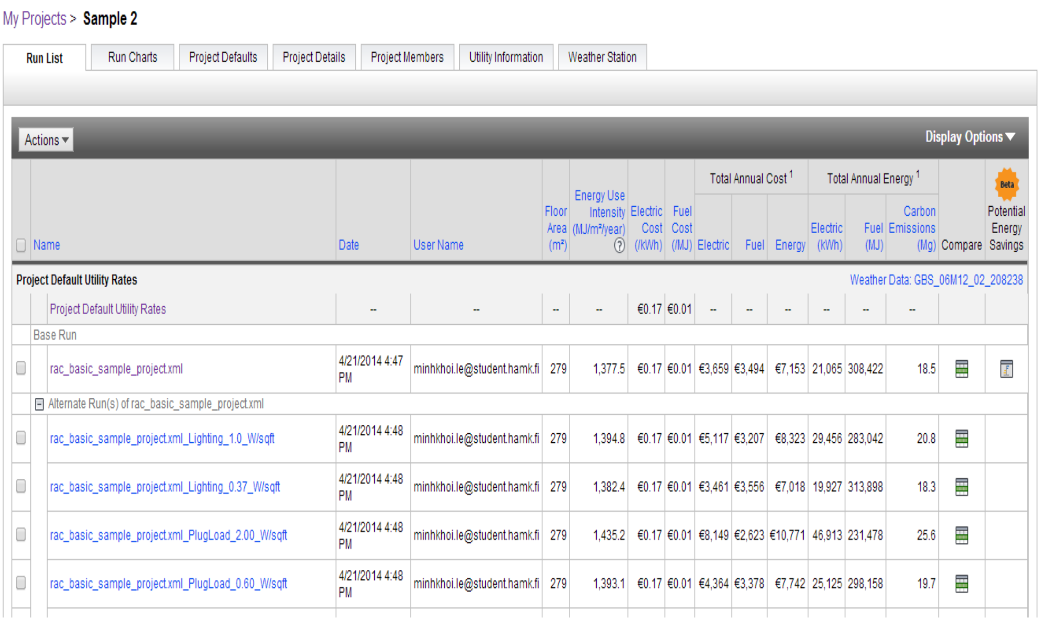
The weather variables are included in GBS's data for each hour of the year:

- Global horizontal radiation (wh/m^2), the amount of energy striking the horizontal surface during the hour
- Direct normal radiation (wh/m^2), perpendicular to the sun's rays
- Diffuse horizontal radiation (wh/m^2)
- Total sky cover (visual estimate of proportion of cloud covering the sky)
- Dry bulb temperature (℃)
- Dew point temperature (℃)
- Relative humidity (%)
- Pressure (mb) 1 millibars = 100 pascals
- Wind direction (°)
- Wind speed (m/s)

4.3 Performance results

4.3.1 Project Run list tab

The table in Figure 9 displays some results running for base run and alternative runs. The results were set under different columns and can be sorted. The principal analysis results included the floor area, energy use intensity, total annual energy cost, total annual electric cost, total annual fuel use, carbon emissions and potential energy saving.



My Projects > Sample 2

Run List | Run Charts | Project Defaults | Project Details | Project Members | Utility Information | Weather Station

Actions | Display Options

Name	Date	User Name	Floor Area (m²)	Energy Use Intensity (MJ/m²/year)	Electric Cost (/kWh)	Fuel Cost (/MJ)	Total Annual Cost[1] Electric	Total Annual Cost[1] Fuel	Total Annual Cost[1] Energy	Total Annual Energy[1] Electric (kWh)	Total Annual Energy[1] Fuel (MJ)	Carbon Emissions (Mg)	Compare	Potential Energy Savings
Project Default Utility Rates												Weather Data: GBS_06M12_02_208238		
Project Default Utility Rates	--	--	--	--	€0.17	€0.01	--	--	--	--	--	--		
Base Run														
rac_basic_sample_project.xml	4/21/2014 4:47 PM	minhkhoi.le@student.hamk.fi	279	1,377.5	€0.17	€0.01	€3,659	€3,494	€7,153	21,065	308,422	18.5		
Alternate Run(s) of rac_basic_sample_project.xml														
rac_basic_sample_project.xml_Lighting_1.0_W/sqft	4/21/2014 4:48 PM	minhkhoi.le@student.hamk.fi	279	1,394.8	€0.17	€0.01	€5,117	€3,207	€8,323	29,456	283,042	20.8		
rac_basic_sample_project.xml_Lighting_0.37_W/sqft	4/21/2014 4:48 PM	minhkhoi.le@student.hamk.fi	279	1,382.4	€0.17	€0.01	€3,461	€3,556	€7,018	19,927	313,898	18.3		
rac_basic_sample_project.xml_PlugLoad_2.00_W/sqft	4/21/2014 4:48 PM	minhkhoi.le@student.hamk.fi	279	1,435.2	€0.17	€0.01	€8,149	€2,623	€10,771	46,913	231,478	25.6		
rac_basic_sample_project.xml_PlugLoad_0.60_W/sqft	4/21/2014 4:48 PM	minhkhoi.le@student.hamk.fi	279	1,393.1	€0.17	€0.01	€4,364	€3,378	€7,742	25,125	298,158	19.7		

Figure 9 Run list tab

The detailed information on each run can be displayed separately. It is also possible to make a comparison between any runs by clicking the symbol of chosen runs in the compare-column.

The energy use intensity measures a combined electricity and fuel used by the project per area. The unit of electricity was converted to MJ from KWH. In the international system,1kwh = 3.6 MJ.

4.3.2 Project run chart tab

Project run chart tab included all the charts that show the proportion of area lights, miscellaneous equipment, space cooling, ventilated fans, pumps auxiliary, space heat and hot water used in the project. There were three different categories which can be shown to display: cost, total energy and energy use intensity. The main run and other alternative runs can be added optionally. The charts were very detailed, showing annually the aspects in comparative visual so that the difference between the run can be seen easily. Figure 10 displays the annual cost of total energy used in the main run and Figure 11 shows the comparative chart of main run and some other alternative runs.

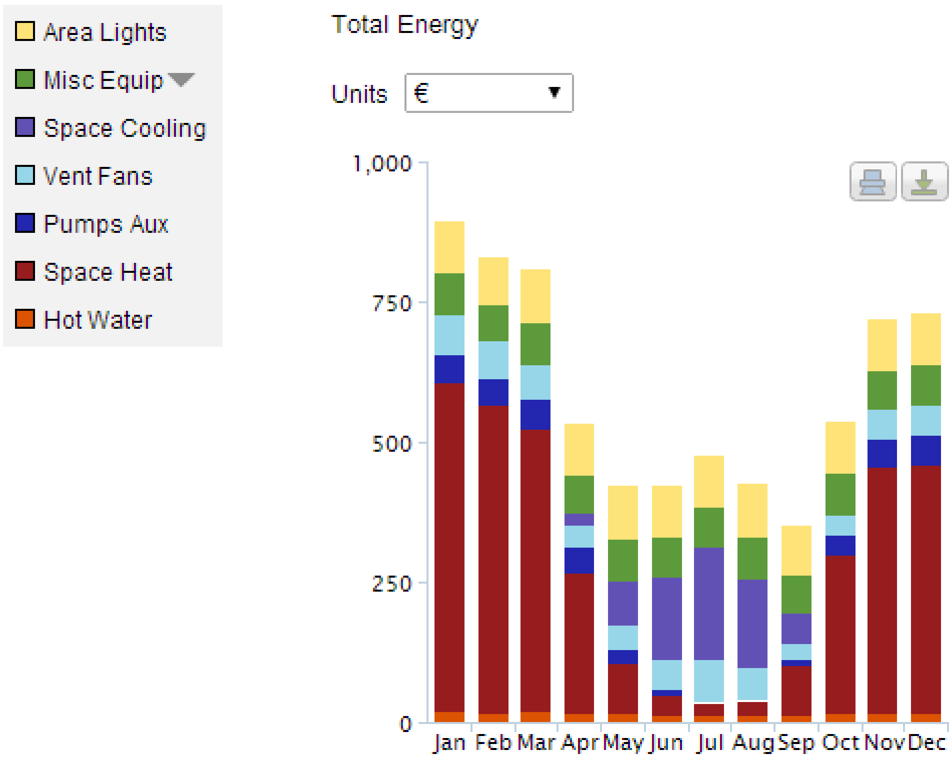
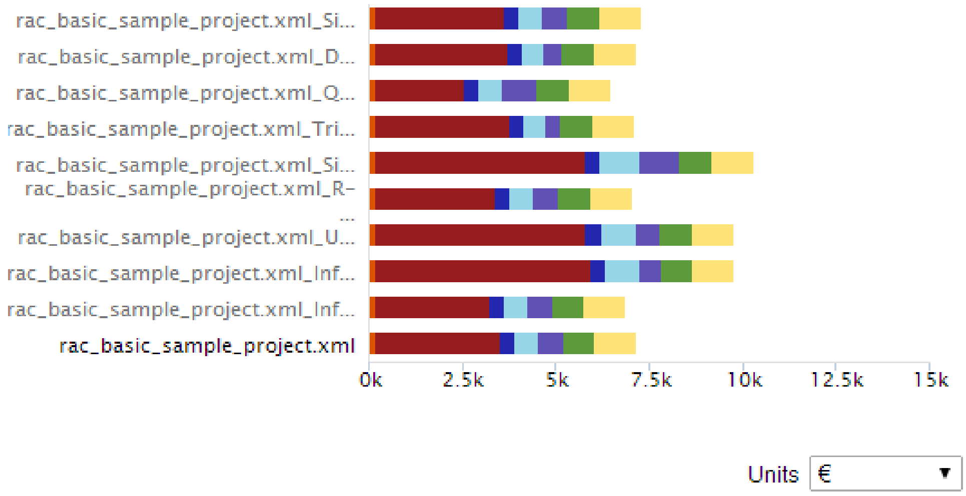


Figure 10 Chart of annual cost of total energy used in main run



r

Figure 11 Chart of annual cost of total energy used in main run and some alternative runs

4.3.3 Potential energy savings (PES) chart

The PES chart includes nine building features like a glazing property, wall and roof insulation, lighting efficiency and infiltration from all the separated energy simulation runs. The chart allows designers to evaluate the sensitive parameter affecting building energy performance through the testing of new and existing designs. The PES chart is shown in Figure 12 below.

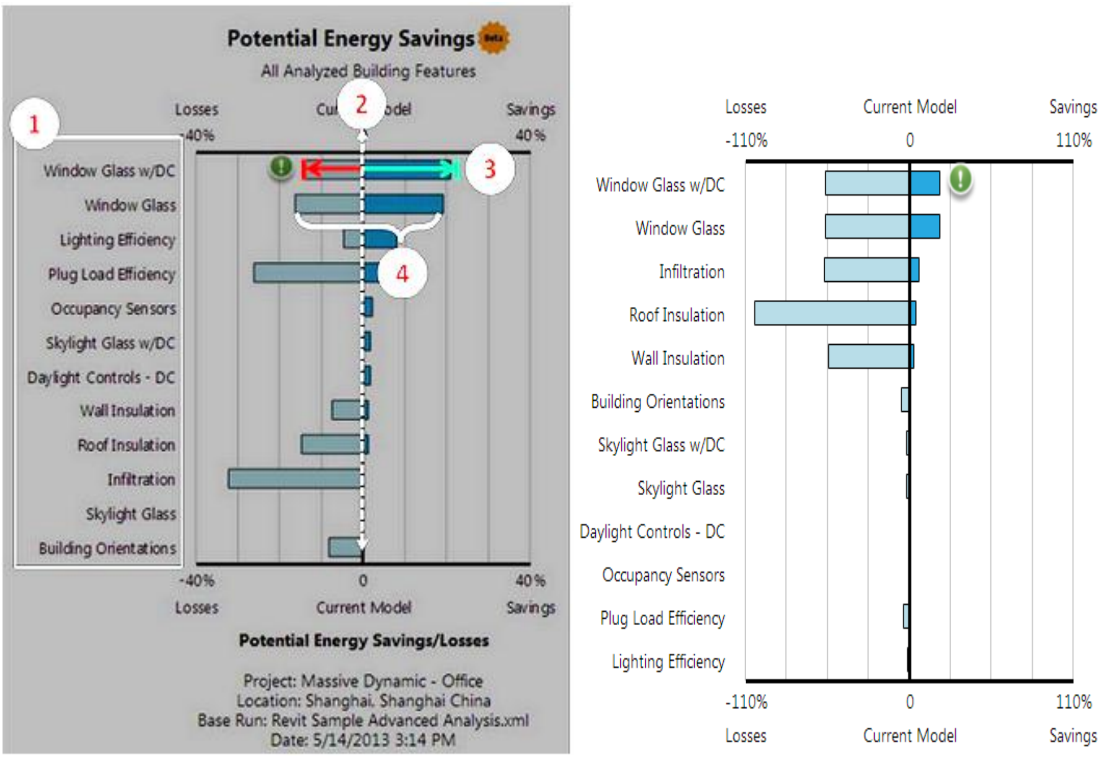


Figure 12 Potential energy savings/losses

The horizontal bars numbered zone 1 in Figure 12 represent the building's elements that determine the importance of their role to building energy performance. Zone 2 is the vertical line that represents the current model baseline which is the original energy simulation. Their value is zero. Zone 3 is the energy savings and losing. The longest bar on the top shows the greatest opportunity for energy savings and the shortest one at the bottom indicates the least potential energy saving. Zone 4 is the sensitivity of the elements. The longer the bar is, the bigger impact it makes on energy performance.

In the sample design, within all simulation of alternative designs, glazing windows may be changed to get the most energy saving. It is possible to save up to 20 % energy efficiency compared to the glazing property from base run by replacing window glasses. The result shows the right selection of roof insulation material of the current designs. Other roof insulation would make the worst energy performance. However, the consideration of other factors like price, material availability etc also affect the final decision.

4.3.4 Understanding Energy and carbon results

Energy and carbon results are put under the project tab. A summary of the information on building energy and resource use, carbon emission, simulation assumption, performance metrics and costs are presented.

Costs were estimated using a default utility rate. The rate was € 0.17/kwh for electric costs and € 0.01/MJ for fuel costs. The rates were updated by the U.S Energy Information Administration (Dec.2011). Therefore, this might not be appropriate for the Finnish market since they use different rates for energy consumption. However, it is possible to add a utility billing data set. The required tools are needed, but it is available to be downloaded on the website. There is also the utility billing data set template in a Microsoft Excel format where users can upload their own bill with the correct local rates.

The energy and carbon results were categorized into small groups to be observed clearly:

- Annual energy costs: estimate total annual costs of electric and fuel use in the project
- Lifecycle costs: electric and fuel costs of the project for the total 30-year period.
- Annual CO2 emissions: carbon emissions were based on the on-site fuel use and the source of fuel to produce electricity in the region.
- Large SUV equivalent: an interesting equivalency building's annual CO2 emissions and amount of emissions from a SUV (sport utility vehicle). The assumptions used are: 24140 km driven annually, 45% highway and 55% city driving; 5.95km/litre city and 7.65km/litre highway.

- Annual energy consumption: amount of energy used during one typical year.
- Lifecycle energy consumption: estimated amount of electricity and fuel the project might consume during a 30 year-period.

Carbon neutral potential measures the annual CO_2 emissions of the project including electricity and on site fuel emission. It is special that GBS can offer a suggestion to change electricity from a local provider which emits emissions by renewable sources such as solar electricity (photovoltaic potential) and wind energy potential. This potential was illustrated by an on site renewable potential value. The value was negative. Another negative value is the natural ventilation potential which represented the amount of carbon possible to remove by using natural ventilation to cool the building rather than a mechanical cooling system, which requires electricity. On site bio fuel provided the carbon removal potential by replacing natural gas, fuel oil or propane obtained from the utility provider by bio fuels.

The CO_2 emissions calculation data and electric power plants sources were used from the U.S Environmental Protection Agency for the United States projects which recorded all historical information about fuel and emissions from all power plants in the United States. With projects outside the United States, the CARMA (Carbon Monitoring for Action) was used. Figure 13 below illustrates the carbon footprint.

Carbon Footprint

Alternate Run Carbon Neutral Potential	
Annual CO_2 Emissions	Mg
1 Base Run	18.5
2 Alternate Run	**14.6**
Onsite Renewable Potential	-13.3
Natural Ventilation Potential	0.0
Onsite Biofuel Use	-11.5
Net CO_2 Emissions	**-10.2**
Net Large SUV Equivalent: -1.0 SUVs / Year	
Assumptions	

Electric Power Plant Sources in Your Region	
Fossil	35 %
Nuclear	34 %
Hydroelectric	19 %
Renewable	12 %
Other	0 %

Figure 13 Carbon neutrality potential and energy power source available

4.3.5 LEED daylight and water efficiency

LEED (Leadership in Energy and Environment Design) is a third-party certification program. It is a U.S accepted organization for the design, construction and operation of high green building performance. In order to receive LEED certification, building projects need to meet the requirements and gain points to achieve different levels of certification.

GBS evaluated and gave LEED points to the project with LEED daylight and water efficiency. LEED a glazing score is the percentage of regularly occupied floor area that has glazing factor higher than 0.02 (2%). The glazing factor is the ratio of interior luminance at a given point on a given plane to the exterior luminance under clouded over sky conditions. So the daylight efficiency is determined by the window size and positions, visible transmittance and floor area. The score needs to achieve 75% to get the LEED credit

LEED Daylight

* Update your glass performance using Design Alternatives.

Percentage of building area with glazing factor over 2%: **98.3% - Qualifies**

LEED requires your project achieve a minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas.

LEED Daylight Space Analysis

Space ID	Space Type	Space Area (m²)	Sidelighting Vision Glazing		Sidelighting Daylight Glazing		Toplighting Sawtooth Monitor		Toplighting Vertical Monitor		Toplighting Horizontal Skylight		Glazing Factor
			Area (m²)	VT	Area (m²)	VT	Area (m²)	VT	Area (m²)	VT	Area (m²)	VT	
sp-101-Kitchen_-_Dining	Unspecified	73	42	0.60	17	0.60	0	N/A	9	0.60	0	N/A	13.2%
sp-106-Living	Unspecified	70	25	0.60	1	0.60	0	N/A	3	0.60	0	N/A	5.7%
sp-201-Entry_Hall	Unspecified	31	15	0.60	9	0.60	0	N/A	0	N/A	0	N/A	9.4%
sp-206-Master_Bedroom	Unspecified	27	14	0.60	16	0.60	0	N/A	0	N/A	0	N/A	13%
sp-105-Hall	Unspecified	24	7	0.60	3	0.60	0	N/A	10	0.60	0	N/A	17.5%
sp-204-Bedroom	Unspecified	14	2	0.60	1	0.60	0	N/A	0	N/A	0	N/A	2.5%
sp-202-Bedroom	Unspecified	14	2	0.60	1	0.60	0	0.70	0	N/A	0	N/A	2.8%
sp-207-Master_Bath	Unspecified	7	2	0.60	1	0.60	0	N/A	0	N/A	0	N/A	4.9%
sp-104-Laundry	Unspecified	5	0	N/A	0	N/A	0	N/A	3	0.60	0	N/A	17.1%
sp-203-Bath	Unspecified	4	0	N/A	0	N/A	1	0.70	0	N/A	0	N/A	16.1%
sp-205-Bath	Unspecified	4	0	N/A	0	N/A	1	0.70	0	N/A	0	N/A	17.5%
sp-103-Bath	Unspecified	3	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0%
sp-102-Mech	Unspecified	2	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0%
sp-208-Linen	Unspecified	1	0	N/A	0	N/A	0	0.70	0	N/A	0	N/A	12.9%

Figure 14 LEED daylight space analysis

Figure 14 above shows the qualification of the project for LEED credits. It was 98.3% LEED glazing score. If the score was less than 75%, more windows would be needed to put or the size of the windows in the occupied area had to be increased.

LEED water efficiency estimated water consumption in the building. It depends on the number of people in the building and the building type. The number of fixtures or the property of fixtures did not affect to the water consumption but only the people who use them. LEED water consumption data used the source of the American Water Works Association 2000 for residential/commercial and institutional end use of water. The values were indicated fully by categorizing into indoor, outdoor, net utility annually. The advantage of GBS is that it is possible to change the input adapting the situations. The information can be replaced on the right included unit water prices, water usage (liter/day), irrigated area. This is shown in Figure 15 below

Water Usage and Costs

Total:	**722,068 L / yr**	**€754 / yr**
Indoor:	278,012 L / yr	€448 / yr
Outdoor:	444,056 L / yr	€306 / yr
Net Utility:	**722,068 L / yr**	€754 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Indoor Water Factors

Number of People: 2

(Typical people for this building type/size: 3)

Percent of Time Occupied (%): 49

Unit Water Prices

Water: 0.69 € / m³ Sewer: 0.92 € / m³

Outdoor Water Factors

Irrigated Area* (m²):	1000	*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers:	Yes	
Pool:	No	
Other Equipment/Fixtures:	No	Usage: 25 L / day

Figure 15 LEED Water Efficiency

GBS analyzed all the exterior surface of the building, from walls, roofs and windows to generate potential electricity using photovoltaic (PV) (solar electricity). The PVs can be installed on vertical or horizontal surfaces. Figure 16 below can tell the results in detail how the building can generate electricity, investment need and time pay back

Photovoltaic Potential (more details)	
Annual Energy Savings:	31,496 kWh
Total Installed Panel Cost:	€359,393
Nominal Rated Power:	45 kW
Total Panel Area:	325 m²
Maximum Payback Period:	42 years @ €0.17 / kWh

Figure 16 Solar electricity potential

4.3.6 Alternative Runs

GBS provided a default of 37 alternative runs besides the base run. It is possible to add or remove alternative runs in Design Alternative tab in Run List feature. The alternative designs gave a good overall picture on how sensitive the parameters are that affect energy usage. By adding a broad range of parameters, it performed the most efficient building and the most inefficient buildings alongside with all the replacement feasible to make the project design become better and more sustainable when it is operated.

Alternative designs work with parameter values which are orientation, wall construction, roof construction, window glass, skylight glass, infiltration, equipment and lighting. The alternative runs chosen from the default section are representative. For example, uninsulated framed walls or uninsulated framed roofs are extremely poor. They have a very high heat loss coefficient U-value. These alternative runs showed the better option the base run had. If the U-value of the basic design is higher than these values, there is definitely wrong material in the wall and roof selection.

Another parameter that should be taken into consideration was orientation. Depending on the geometry, building location, window size and position, changing the direction of the building could make a huge or slight impact on the results. For example, orientation 135- means that the project is rotated counter clockwise 135 degrees so that the north face of the building would be southwest side.

The wall, roof construction and glazing property had extreme impacts on the energy performance. The difference came from the heat loss, solar energy income and natural lighting provided to the building. It is essential to select the correct materials to be used in walls and roofs. In the hot climate, for example, in the summer, the difference is not much but in the cold climate, winter time, the energy used for heating a building is extremely high with a poor insulation system. This is the first and main thing when considering and evaluating project designs in cold climate countries such as Finland. The materials simulated in GBS are metal frame and wood frame, continuous insulation and structural insulated panel (SIPs). While metal is used in construction in tropical regions because of the resistance from moisture, insects, rot, high load and high anti collision property, it has a lower insulation value than wood framed components because of the high conductivity of the metal. SIPs are rigid panels of foam insulation and are used typically in floors, walls and roofs. Another common structural material is insulated concrete form (ICFs) which is a formed or a hollow block. Both are filled with reinforcing bars and concrete. SIPs and ICFs have a quite good insulation value (U = 0.20) and good infiltration/noise reduction ability.

The skylight glass and window glass contributed the most effect on the energy saving potential. There are three factors that determine a good glazing system. The first is the U-value. It is similar to the wall and roof structure. The U value reflects the heat lost during heat transmission. It depends on the material of glass and the amount of glass used in the project. The low U-value glazing confirms a good resistance of moisture and heat lost and saving energy for heating. The U values in the sample project were 1.74 and 1.28 in the windows and skylight glasses which are too high. It is inevitably not suitable in the cold climate. The U value from 0.25 to 0.4 would be more preferable.

The second parameter which represents the property of glazing is the solar heat gain coefficient (SHGC). It measures the ability of a window to hinder warming caused by sunlight. SHGC is a fraction number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits. The quality glass in a hot climate is usually defined by a low SHGC while in a cold climate, a high SHGC glass helps taking more advantage of solar energy for passive heating.

A visible light transmittance (VLT) is the final factor. It measures the amount of visible light that can be transmitted through the glass. Most VLT values are between 0.3 and 0.8. The higher the VLT value, the higher amount of light can get through.

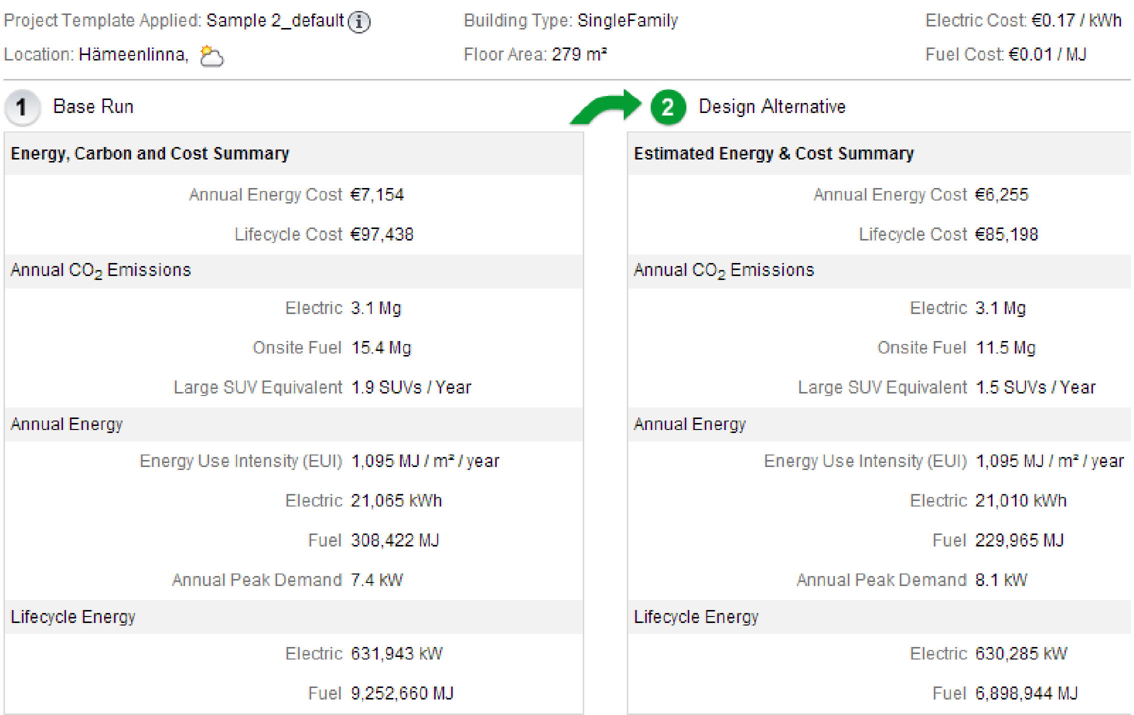
GBS offers four default alternative runs for the window glass and skylight glass. The values of three factors are various to accommodate different climate regions. Energy used in a building in a cold climate like Finland mainly more sensitive to the U-value than other factors so the lowest U-value should be good for insulation. However, high SHGC is also needed for passive heating and high VLT value benefits day lighting. Therefore it reduces the use of light equipment inside.

Because the project location was set in Hämeenlinna, Finland to test the adequacy of GBS tools with Finnish climate and conditions, the result was not appropriate. One alternative design was picked to find a better solution for energy performance. In the potential energy saving, it was found out that the window glass contributed the most potential positive impact. All windows were changed from Pewter Double to Quadruple LoE Films (88) 3mm/8mm Krypton. The comparison in Table 1 below shows the difference between these two

Table 1 Comparison of window types

Window	Pewter Double	Quadruple LoE Films (88) 3mm/8mm Krypton
U-value (w/m^2K)	1.74	0.66
SHGC	0.40	0.45
VLT	0.60	0.62

The new design certainly had a better U-value and VLT. These changes made a big difference in energy performance. The low U-value allows the building use less energy for heating which is the biggest source of energy use in Finland. The results can be found in Figure 17 below.



Project Template Applied: Sample 2_default | Building Type: SingleFamily | Electric Cost: €0.17 / kWh
Location: Hämeenlinna, | Floor Area: 279 m² | Fuel Cost: €0.01 / MJ

1 Base Run		2 Design Alternative	
Energy, Carbon and Cost Summary		**Estimated Energy & Cost Summary**	
Annual Energy Cost	€7,154	Annual Energy Cost	€6,255
Lifecycle Cost	€97,438	Lifecycle Cost	€85,198
Annual CO_2 Emissions		Annual CO_2 Emissions	
Electric	3.1 Mg	Electric	3.1 Mg
Onsite Fuel	15.4 Mg	Onsite Fuel	11.5 Mg
Large SUV Equivalent	1.9 SUVs / Year	Large SUV Equivalent	1.5 SUVs / Year
Annual Energy		Annual Energy	
Energy Use Intensity (EUI)	1,095 MJ / m² / year	Energy Use Intensity (EUI)	1,095 MJ / m² / year
Electric	21,065 kWh	Electric	21,010 kWh
Fuel	308,422 MJ	Fuel	229,965 MJ
Annual Peak Demand	7.4 kW	Annual Peak Demand	8.1 kW
Lifecycle Energy		Lifecycle Energy	
Electric	631,943 kW	Electric	630,285 kW
Fuel	9,252,660 MJ	Fuel	6,898,944 MJ

Figure 17 Base run and alternative run by changing the window glasses

The fuel consumption would be extremely reduced in the alternative design. So, the CO_2 emissions are also cut down almost by 30 %. These factors all together contributed to save energy use about €1000 a year. This was an advanced impact by just changing the window glazing type. The benefit that GBS bring to the designers was significant. The process to choose an appropriate alternative option was clear and easy to follow, from energy saving potential, building location, climate condition understanding to the final decision of picking up a new window glass for saving energy. All could be done in a short time systematically.

Besides 37 default alternative designs provided, GBS contains over 30 options for each parameter to select. This can be found in the design alternative tab. It is should be enough for designers. However, there is always the possibility to have different types of element based on the market outside the United States. In this situation, the selection closest to the designs should be chosen to get the most appropriated results. Figure 18 demonstrates the annual energy use in the alternative run by a pie chart

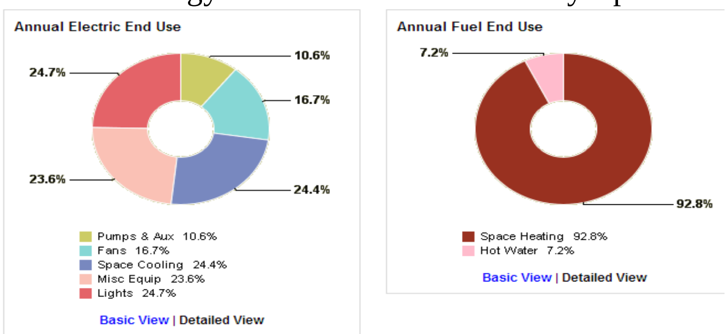


Figure 18 Energy End Use chart

5 COMPARISON OF GBS AND ARCHICAD ECODESIGNER STAR

The thesis did not analyze Archicad Ecodesigner Star (AES) but only made a comparison in some general aspects between these two to get an idea of another tool that has the same function as GBS available in the market.

AES is the program from Graphisoft which performs energy analysis to achieve a sustainable and energy-efficient building. It works based on the ArchiCad 17 as an add-on. While GBS can work separately, AES is like an extension part of ArchiCad in performance energy. Therefore, AES also use the building information model (BIM) to get the energy analysis results through making a building energy model (BEM)(Graphisoft Ecodesigner Star-Archicad extention manual, March 2014). Table 2 below shows a comparison of some points that AES and GBS contain.

Table 2 Comparison of GBS and AES

Unit	GBS	AES
Web-Online service	Yes	No
Input	_ AutoDesk Revit: building elements _ Autodesk Vasari: conceptual mass _ GbXML files from third-party programs	Only ArchiCad 17
Building energy analysis	Whole building energy simulation	Whole building energy simulation + performance-based designs (climate analysis, solar radiation, day lighting, thermal bridge simulation)
Work Flow	BIM – Energy Analytical Model (EAM) – Energy analysis results	BIM – BEM (thermal block) –Energy analysis results
Standards compliance	ASHRAE 90.1, ASHRAE 90.2, ASHRAE 62.1, CBECS	ASHRAE 140-2007, ASHRAE 90.1-2007 (LEED Energy)
Material input	Revit does not offer the option of designing its own design for structures like walls, roofs but providing defaults materials to choose from	Allows to design its own structures whose aspects can be modified (layers, U value etc...)
Comparing energy analysis results	Yes. Visual tables which list all alternative runs are suggested. Very clear	No alternative designs table available. Proposed design is compared with

	and easy to select and predict the results	imported baseline version of the same project before change. Can only do a comparison at a time and have to change designs multiple times without predicting the best energy saving option
Default setting	Relies significantly on default settings. Default values are changeable but not completely.	Mostly defined by designers. Allow user to modify completely the design
Carbon emissions, renewable energy sources and consumption	yes	yes
Export file	Gbxml, vrml, DOE2, Energy plus, weather file	Gbxml, PHPP, iSBEM, VIP-energy

By comparing to a big product like AES, GBS has showed some advantages and disadvantages. The most preferred point from GBS is the friendly features. Visual tables and comparative results are very useful in selecting the best designs and making decisions. It is simple to operate by designers who even do not need to be familiar with Autodesk Revit or Vasari.

On the other hand, AES is an add-on of ArchiCad, so basically it requires ArchiCad skill and allows users to be able to access and modify deeply the results. Both are based on the U.S standards ASHRAE and U.S data collection for foreign countries (AES extention manual, 2014). AES is more complicated on a more professional level. Figure 19 illustrates an example of an annual energy use in a project which is analyzed by AES

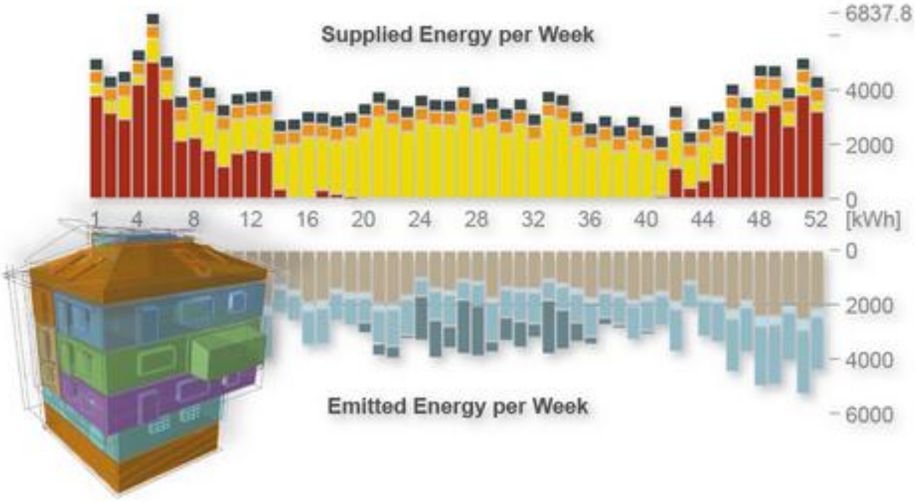


Figure 19 One example of annual energy performance using AES

6 THE DECREE ON IMPROVING THE ENERGY PERFORMANCE OF RENOVATION OR ALTERATION BUILDING IN FINLAND

The memorandum of the decree was made by the Finnish Ministry of the Environment on 27 February 2013. The memorandum indicated that the target of Finland is to reduce greenhouse gases by 20 %, improve energy performance by 20% by 2020 following the European Union climate and energy policy. In 2005, the share of renewable energy in Finland was 28.5%. This needs to be increased by 38 TWh to reach the target of 38% in 2020

In Finland, around 40% of total energy consumption is used for operating buildings. Among 15.5 billion Euros was spent in 2011 on building maintenance activities, heating, electricity, gas, water and waste water contributed 40% of the cost (€ 6.2 billions).

The decree has a connection with renovation and alteration building. The objective is to improve energy performance, reduce energy consumption and carbon dioxide emissions of the existing building by respectively 25% and 45% by 2050. The efficient use of electricity, increasing efficient heat recovery systems or increasing the use of renewable energy sources are recommended in order to save energy and reduce a heat loss. A short term target was set to achieve the reduction of 6% energy consumption in existing buildings by 2020.
(Memorandum of Ministry of The Environment Decree on improving the energy performance of building undergoing renovation or alteration, 25^{th} February 2013)

6.1 Recast European Energy Performance of Buildings Directive

The Finnish decree also takes consideration of recast EU's Energy Performance of Buildings Directive in 2010. Act 958/2012 in the Land Use and Building Act (132/1999) set an obligation to encourage high-efficiency, alternative systems of building technically, functionally and economically under renovation. The buildings that are refurbished are encouraged to stimulate into nearly zero-energy buildings. Land Use and Building Act (488/2007) implemented the minimum energy performance requirements of new and existing buildings. The energy requirements for a new building were also set in the National Building Code of Finland under section C3, D2, D3 and D5. The purpose of the regulation is to ensure meeting the EU energy policy objectives.

In Articles 6 and 7, the recast directive obligates member states to set the minimum energy performance requirements for new and existing buildings. Furthermore, the requirement should be achieved with a view of the optimal cost level and are different between new and existing buildings; different categories of buildings.

The member states must publish the regulations and administrative provisions concerning implementation by 9 July 2012. The provisions must be applied to buildings occupied by public authorities from 9 January 2013 at the latest and to other buildings from 9 July 2013 at the latest. (Memorandum of Ministry of The Environment Decree on improving the energy performance of building undergoing renovation or alteration, 25^{th} February 2013)

6.2 International developments

The short summary of solutions which two member states countries have used for implementing the recast European Energy Performance of Building Directive are presented

6.2.1 Denmark

In Denmark, only major renovation projects require a building permit, small alterations do not need any building permit or notification. The building act was amended to the latest version in 2010. The requirements for a new building are applied to the building elements under renovation. However, each building element must only meet the energy performance level set for a new building only if this is cost-effective. The cost – efficiency is determined by multiplying the annual saving with life cycle and dividing the result by the investment. The results coefficient must be higher than the requirement specified.

The minimum levels of energy performance are determined by equations. One equation is used for dormitories and residential buildings. The other equation is for offices, schools and institutional buildings. Some exemptions are granted to about 9000 protected buildings in Denmark. Single family houses are also involved to some exemption from the requirements.

6.2.2 Finland

The Finnish thermal resistance requirements for a new building have been particularly stricter compared to the rest of Europe. The energy consumption is mainly for heating, generating and distribution of domestic hot water, and lighting. Energy consumed in buildings is highly influenced by Finland's northerly location. Therefore, measurements of decreasing energy need for heating are usually cost-effective.

In Finland, the share of new buildings is small in the building stock (about 1 to 2%). Therefore, the overall energy use cannot be reduced significantly by only applying energy performance requirements to new buildings. The key of energy saving is towards existing building renovation. According to the report from VTT Technical Research Centre of Finland, the potential of energy saving in renovation and maintenance is approximately 6% by 2020.

Alteration and renovation work in existing buildings are variable by the variety of the building stock. Most of the renovations were made because of the declined building elements. The most typical renovation are doors, windows, exterior walls, roofing, water, sewage and ventilation systems.

The large share of the buildings, especially those built in the 1960s, 1970s will fall. (Memorandum of Ministry of The Environment Decree on improving the energy performance of building undergoing renovation or alteration, 25^{th} February 2013)

6.3 Key proposals

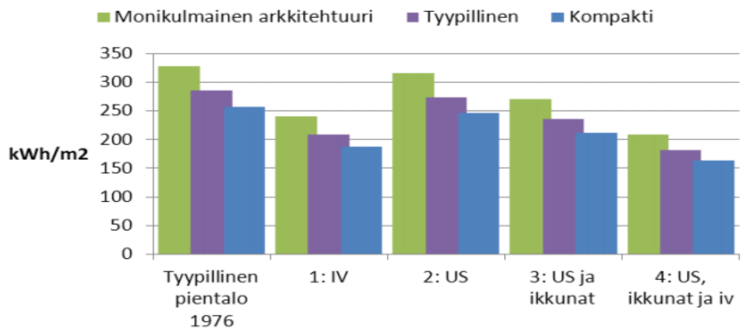
The decree provides the owner of the renovation building three options for determining the level of energy performance improvement:

- The first option is to improve the thermal resistance of building elements so that they meet the required values.
- The second option is to comply with the requirement for the appropriate building type. The requirement is defined as KWh/m^2/year. The calculation of a renovated building can apply calculation instructions to a new building.
- The third option is to calculate the building overall energy use and reduce the energy use by the required amount.

The suitable solution for structures is to reduce the thermal transmittance by at least half of the original level. The cost spent in order to reach the level of a new building is fully feasible and it is often cost-effective.

For window renovations, the most cost-effective solutions is to replace them to reach the level of a new building. The window with a good thermal transmittance can also reduce the solar radiation and prevent overheating in the summer.

The architecture of the building also contributes a major impact on energy use. A building with numerous corners and big windows typically consume more energy than buildings with a more compact architecture. In old buildings the energy use value is normally from 50 to 60 KWh/m^2 while the newer buildings it is 25 to 30 KWh/m^2. This can be shown in Figure 20 below (Memorandum of the Decree, 2013)



A typical single-family house, built in accordance with the 1976 building code.
1: Adoption of mechanical ventilation (SFP: 2 and heat recovery 75%),
2: U-value of external walls from 0.4 to 0.2.
3: External walls and replacement of windows, U from 2.1 to 1.
4: External walls, windows and ventilation

Figure 20 Energy use in polygonal, typical and compact architecture of a single family house

7 CONCLUSION

GBS is a very strong and useful tool working under actual standards and providing high reliable results. The advantage of projects built in the United States is very obvious since all the standards are based on the U.S official energy data. However, with the projects outside the U.S, it is not completely convincing to use the tools if the system and standards were built differently. In addition, even though there is a possibility to change defaults or update separated information in some aspects, it is quite complex and requires a deep understanding of the program. In general, GBS is a great and reliable tool and worth to invest if the U.S energy use information and energy standards are applicable and acceptable.

SOURCES

American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE) standards. Accessed 18^{th} February 2014
https://www.ashrae.org/standards-research--technology/standards--guidelines

AutoDesk® Building Performance Analysis Help manual. Accessed 15^{th} February 2014
http://help.autodesk.com/view/BUILDING_PERFORMANCE_ANALYSIS/ENU/

Energy supply and consumption Statistics of Finland. Accessed March 2014
http://www.stat.fi/til/ehk/index_en.html

Graphisoft Ecodesigner Star – ArchiCad extension manual. Accessed 20^{th} April 2014
http://www.graphisoft.com/archicad/ecodesigner_star/

Memorandum of Ministry of The Environment Decree on improving the energy performance of building undergoing renovation or alteration, 25^{th} February 2013

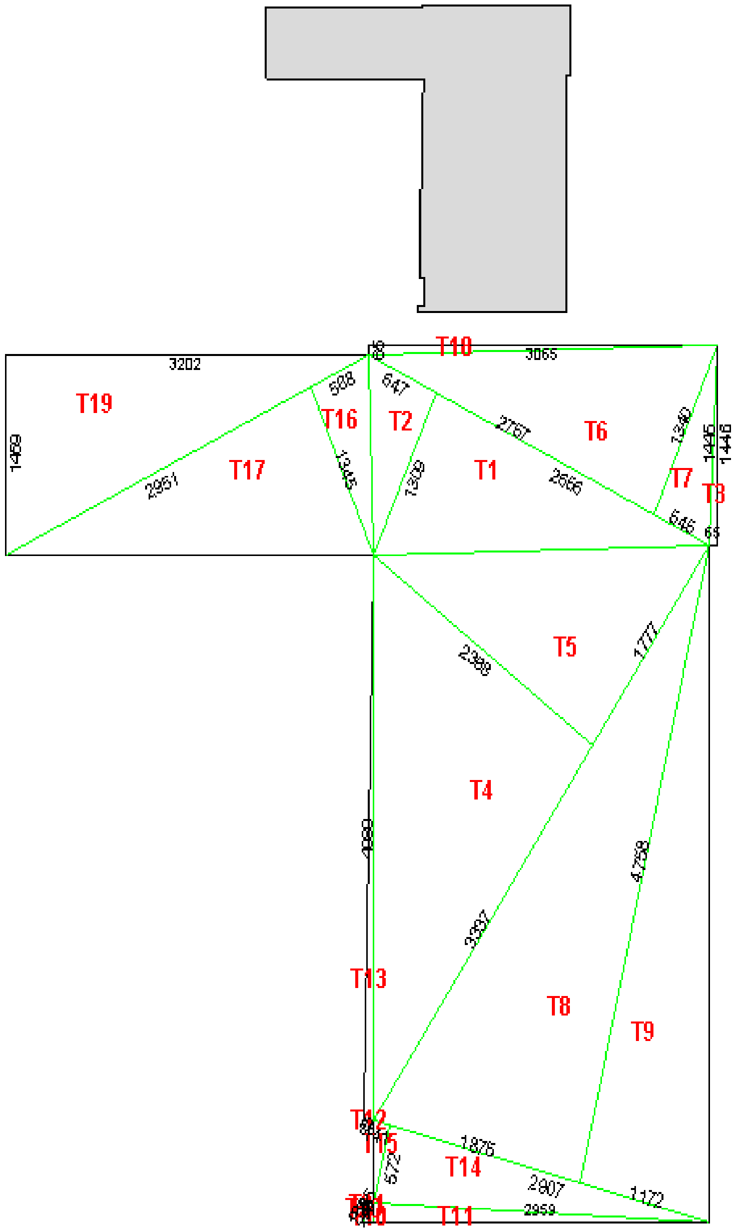
U.S Energy Information Administration – Commercial Building Energy Consumption Surveys (CBECS). Accessed April 2013
http://www.eia.gov/consumption/commercial/about.cfm

Appendix 1

Table 3: Area triangulation for the hall area on the first floor

The figure illustrates area boundaries and triangulation of the area border. All the angles in the triangulation are right angled and the area was calculated as 0.5*c1*c2, where c1 and c2 are the side of the triangle.

#	Calculation	Area
Triangles		
1	½ * 1309 * 2656	2 m²
2	½ * 1309 * 647	0 m²
3	½ * 1445 * 65	0 m²
4	½ * 2368 * 3337	4 m²
5	½ * 2368 * 1777	2 m²
6	½ * 1340 * 2757	2 m²
7	½ * 1340 * 545	0 m²
8	½ * 4758 * 1875	4 m²
9	½ * 4758 * 1172	3 m²
10	½ * 140 * 101	0 m²
11	½ * 140 * 2959	0 m²
12	½ * 86 * 3	0 m²
13	½ * 86 * 4089	0 m²
14	½ * 572 * 2907	1 m²
15	½ * 572 * 141	0 m²
16	½ * 1345 * 568	0 m²
17	½ * 1345 * 2951	2 m²
18	½ * 65 * 3065	0 m²
19	½ * 1459 * 3202	2 m²
20	½ * 81 * 118	0 m²
21	½ * 81 * 55	0 m²
Gross area is 24 m².		



Appendix 2

Table 4: Properties of the building elements (base run)

Unit	Property	Area (m^2)	U-value (W/m^2K)
Roofs	R20 over Roof Deck	144	0.25
	R38 Wood Frame Roof	157	0.13
Ceilings	Interior Drop Ceiling Tile	0	2.6
Exterior walls	R13+7.5 Wood Frame Wall	412	0.28
Interior walls	R0 Metal Frame Wall	282	2.35
Interior floors	R0 Wood Frame Floor	222	1.16
Raised floors	R14.6 Mass Floor	1	0.32
Air walls	Air Surface	128	15.32
Non sliding doors	R2 Default Door (14 doors)	27	2.39
Fixed Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (5 windows)	50	1.74
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (11 windows)	111	1.74
Operable Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (5 windows)	20	1.74
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (11 windows)	48	1.74
Operable skylight	North Facing Windows: Trp LoE (e5=.1) Clr 3mm/13mm Air (4 skylights)	1	1.28
	Non-North Facing Windows: Trp LoE (e5=.1) Clr 3mm/13mm Air (2 skylights)	1	1.28

Appendix 3

Table 5: GBS default values for different building types

GBS building type	EPD (W/ft^2)	LPD (W/ft^2)	Outside Air Flow/Person (cfm/person)	Outside Air Flow/Area (cfm/ft^2)	Infiltration Flow (ACH)
Fire station	1	1.01	18.01	0.2	0.1
Healthcare Clinic	1.18	1.01	16.95	0.2	0.1
Hospital	1.18	1.2	27.55	0.2	0.1
Hotel	0.5	1.01	11.65	0.2	0.1
Library	1	1.3	18.01	0.2	0.1
Manufacturing	1	1.3	16.95	0.2	0.1
Motel	0.5	1.01	11.65	0.2	0.25
Museum	1	1.1	9.75	0.2	0.1
Office	1.34	1.01	18.01	0.2	0.1
Parking Garage	0.3	0.3	N/A	1.5	5
Police station	1	1.01	10.38	0.2	0.1
Arts Theatre	0.54	1.6	11.44	0.2	0.25
School/University	1	1.2	14.2	0.2	0.25
Single Family	0.43	0.45	N/A	0.06	0.5
Sport Arena	1	1.1	8.48	0.2	0.1
Town Hall	1	1.1	6.57	0.2	0.1
Transportation	1	1.01	8.69	0.2	0.1
Warehouse	0.43	0.8	N/A	0.06	0.1
Workshop	1	1.4	20.13	0.2	0.1

Appendix 4

Table 6: Thermal transmittance for different structures, W/m^2K

	Building permit pending in year in Finland					
	1978-	1985-	10/2003-	2008-	2010-	2012-
Heated spaces						
External Wall	0.35	0.28	0.25	0.24	0.17	0.17
Ground-supported floor	0.40	0.36	0.25	0.24	0.16	0.16
Floor with crawl space	0.40	0.40	0.20	0.20	0.17	0.17
Floor butting against outdoor air	0.29	0.22	0.16	0.16	0.09	0.09
Roof	0.29	0.22	0.16	0.15	0.09	0.09
Door	1.4	1.4	1.4	1.4	1.0	1.0
Window	2.1	2.1	1.4	1.4	1.0	1.0
Semi-warm spaces						
External Wall	0.60	0.45	0.40	0.38	0.26	0.26
Ground-supported floor	0.60	0.45	0.36	0.34	0.24	0.24
Floor with crawl space	0.60	0.40	0.30	0.28	0.26	0.26
Floor butting against outdoor air	0.60	0.45	0.30	0.28	0.14	0.14
Roof	0.60	0.45	0.30	0.28	0.14	0.14
Door	2.0	2.0	1.8	1.8	1.4	1.4
Window	3.1	3.1	1.8	1.8	1.4	1.4