BIM BASED ENERGY/SUSTAINABILITY ANALYSIS FOR EDUCATIONAL BUILDINGS – A CASE STUDY

Analysis of HAMK Building Extensions N and S using Autodesk Revit and GBS.

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Clarification of signature

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ABSTRACT

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ABSTRACT

In the AEC industry energy analysis is becoming more and more relevant during the design stage due to the increasing regulation requirements for buildings globally, in the EU as well as in Finland.

Energy calculations are done mostly by traditional hand calculations and spreadsheets and are usually carried out only once, usually at the end of the design process and does not give room for a variety of alternatives. There is a growing need to forecast Energy usage during the design process and consider alternative energy conservative measures (ECM) and design considerations for a more energy efficient building. BIM can provide this possibility.

BIM has been adopted globally as the next trend in building production. Incorporating Energy Analysis is just one way of using BIM to create a seamless work flow. Autodesk as well as other software developers have created faster ways of analyzing energy in a building, and creating near seamless integration with BIM software.

This thesis researched the usability of the Autodesk BIM capabilities to conduct Energy Analysis of Educational buildings during the design phase. The aim is to integrate the use of BIM for energy analysis in the design process and optimize the case building to its possible energy and sustainability potential. The software used were Revit, a BIM software and Green building studio, a cloud based energy analysis program.

The results show that Autodesk Revit in combination with GBS can conduct energy analysis of a structure and analyze design alternatives that can lead to a more energy efficient structure. It can also simulate cost savings as a result of the alternatives. The use of BIM for energy analysis also has its own shortfalls. Accuracy of the energy model and data inputs can greatly affect the result obtained. Energy simulation results can also be affected by the level of complexity and size of the project.

Keywords Energy, Sustainability, Revit, GBS, Green Building Studio. BIM

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BIM	Building Information Modeling
GBS	Green Building Studio
gbXML	Green Building eXtensible Markup Language
EAM	Energy Analytical Model
ECM	Energy Conservative Measures
EUI	Energy Use Intensity
BPA	Building Performance Analysis
IEA	International Energy Association
LPD	Lighting Power Density
EPD	Equipment Power Density
HVAC	Heat Ventilation and Air-Conditioning
COBIM	Common BIM requirements
DOE 2.2	U.S. Department of Energy simulation engine
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
SEER	Seasonal Energy efficiency ratio
Mg	megagram (= 1 metric ton)
NZEB	Net Zero Energy Building

1 INTRODUCTION

The use and operation of Buildings accounts for 40% energy consumption globally and subsequently 36% of CO_2 emissions. Global concern for the environment has necessitated the need to reduce energy demand and consumption in buildings as well as the emission of greenhouse gases especially CO_2.

As a result of the increased awareness of energy consumption and related CO_2 emissions, regulations such as; the Energy Performance of Buildings Directive (EPBD) in Europe, the Act on Energy Certification of Buildings in Finland and programs such as LEED in the USA and BREEAM in the UK have been established over the past few years. Practitioners in the AEC sector are increasingly forced to consider energy consumption and the environmental impact of their building as a result of CO_2 emissions during the design stage. Energy certificates have also become compulsory for new building permits in Finland (Series 10 COBIM 2012 v1.0)

In order to evaluate energy consumption and environmental impact, certain calculations have to be carried out. These calculations are dependent mostly on hand calculations and spreadsheets derived from building codes and national annexes decided by legislation. Normally they are usually carried out only once, usually at the end of the design process mostly for code compliance. This is due to the tedious process involved. This does not give room for consideration of alternative measures for maximum energy efficiency. There is a growing need to forecast Energy usage during the design process and consider alternative energy sources and design considerations for a more energy efficient building. BIM can provide this possibility.

Building information modelling (BIM) is gradually becoming the norm among tools used for design in the AEC industry. The workflow of members of the AEC industry has been largely affected by the development of BIM and its capabilities.

BIM has evolved through the times and is gradually becoming all-inclusive in almost all sectors of the building industry. BIM, seen as multi-dimensional tool for life-cycle management, can be classified into “3DBIM” – parametric building model, as an upgrade to a 2D CAD plan, “4D” addressing time – scheduling and construction stages simulation, “5D” – cost planning and estimation, “6D” sustainability –thermal analysis and environmental assessment, eventually even automated building certification, and finally “7D” as a fully mature, comprehensive model enabling facility management, maintenance and operation (Redmond A et al. 2012), (Georgios G, Et al 2016).

BIM has been adopted globally and also in Finland as the next trend in building production. Incorporating Energy Analysis, is just one way of using BIM to create a seamless work flow. Currently in Finland, BIM software used for energy analysis are few. The main ones are RUISKA, IES VE and IDA ICE.

Autodesk software are popular globally. It is also one of the leading developers of software for the AEC industry. Autodesk Revit is one of the most widely used BIM software. Together with the Autodesk Building Performance Analysis suite they have created near seamless integration for energy Analysis using BIM.

This thesis seeks to explore the potentials of Autodesk Revit and Autodesk Green Building Studio (GBS) for energy/sustainability analysis and its possible adoption in Finland. The method used will be a case study of two HAMK building extensions.

The energy modelling process and the software interface will be evaluated. The suitability for the project location will also be evaluated. The results will be evaluated for code compliance and usability. Using BIM for energy modelling also has its limitations.

2 LITERATURE REVIEW

2.1 Building Information modelling

Building information Modelling can be defined as "a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (Leite, 2010). (Salmon, S. M., 2013)

Building models are approximations of reality. Understanding how to make your building model approximate physical reality can help you create a higher performing building. "All models are wrong, some are useful." (George E.P. Box) This is true for building information models. The key is to make your models as useful as possible. A model is useful if it is able to predict future observations, help control future events, or explain past observations.

In Finland, buildingSMART Finland provides information for the implementation of BIM through its publication series "COBIM (Common BIM Requirements). The Current series is COBIM 2012.

The main advantage of BIM is its ability to integrate different aspects of the AEC and FM workflow through the use of common standards of which IFC and gbXML are examples. This is known as interoperability. This means that information can be shared among members on the same project easily and almost seamlessly.

BIM is becoming widely accepted because of the possibilities it provides. It can be used for architectural design, MEP design, Structural Design, Quality assurance, Quantity take off, Visualization, MEP analysis, Project management, Facility management, Construction, Building supervision and Energy/ Sustainability Analysis.

2.2 Energy/ Sustainability Analysis

For a building to operate and maintain user comfort and functionality, a certain amount of energy is required. In order to estimate the amount of energy that is needed (energy demand), an energy balance has to be set up. It is usually a culmination of energy losses such as transmission and ventilation heat losses of the building envelope. These losses can be fully or partially compensated by the energy gains from appliances and users as well solar gains through openings. Energy gains can diminish the amount of heating required. Additional energy input is needed for lighting, ventilation and for the operation of building systems. Subtracting gains from the overall losses results in the overall energy demand of the building. Figure 1 shows the energy gain and loss in a building (Schlueter A., Thesseling F. 2009).

It is important to know why an energy analysis is needed, what results are expected and then keep this in mind during the energy modelling process so as to meet the project needs The main reasons for energy modelling are usually

- code compliance and/or estimating project energy use
- Early stage model, informing design or providing design assistance.
- Progress models during design to ensure the project remains on track for energy or emission targets
- Model submission for certification (McCarry B., Montague L., 2010)

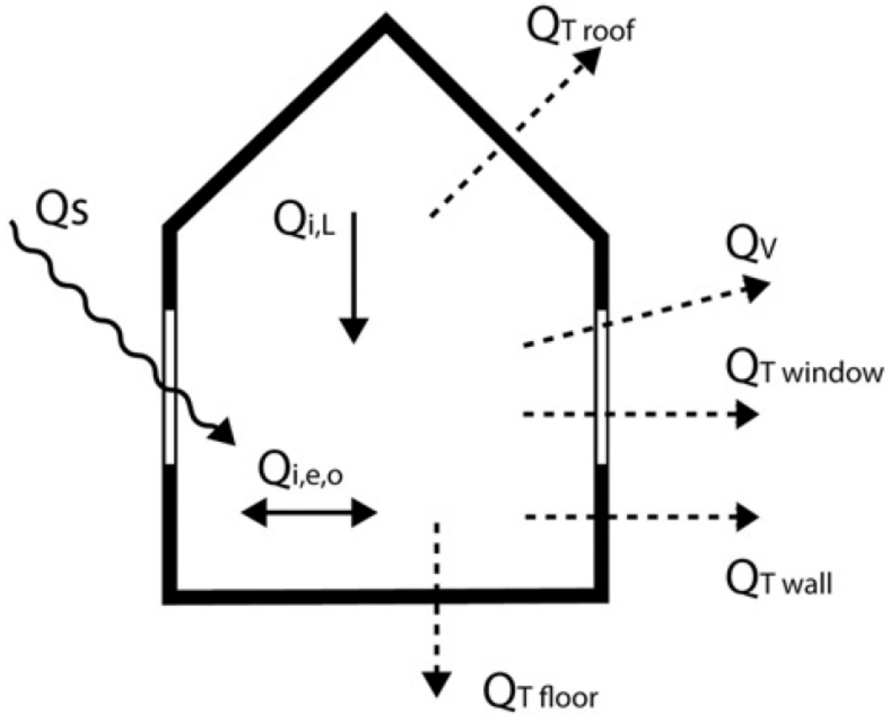


Figure 1 Implemented energy model (Schlueter A., Thesseling F. 2009)

Sustainability with reference to this thesis with focus on cost savings and positive environmental impact as a result of choices and strategies taken to reduce the energy demand and CO_2 emissions.

Sustainability usually has a three pronged approach of economic, social and environmental impact. The social impact is essential and relevant for the success of the sustainability principles, but on the other hand is difficult to analyze using BIM software.

2.3 BIM and Energy/ Sustainability Analysis

BIM is powerful for sustainable design because it can help you iteratively test, analyze, and improve your design. This is called Building Performance Analysis (BPA).

BIM energy analysis tools can predict the energy performance of a building and the thermal comfort of the occupants. In general, they support how a given building operates according to certain criteria and enable comparisons of different design alternatives.

Information required for energy analysis as input data includes:

- building geometry, including the layout and configuration of the space (surfaces and volumes),
- grouping of rooms in thermally homogenous zones,
- building orientation,
- building construction, including the thermal properties of all construction elements,
- building usage including functional use,
- internal loads and schedules for lighting, occupants, and equipment,
- heating, ventilating, and air conditioning (HVAC) system type and operating characteristics,
- space conditioning requirements,
- utility rates, and weather data.

The accuracy of an energy analysis is dependent on the input data. Most energy analysis software are known as simulation engines. See Figure 2. (Nicolle, C. 2013).

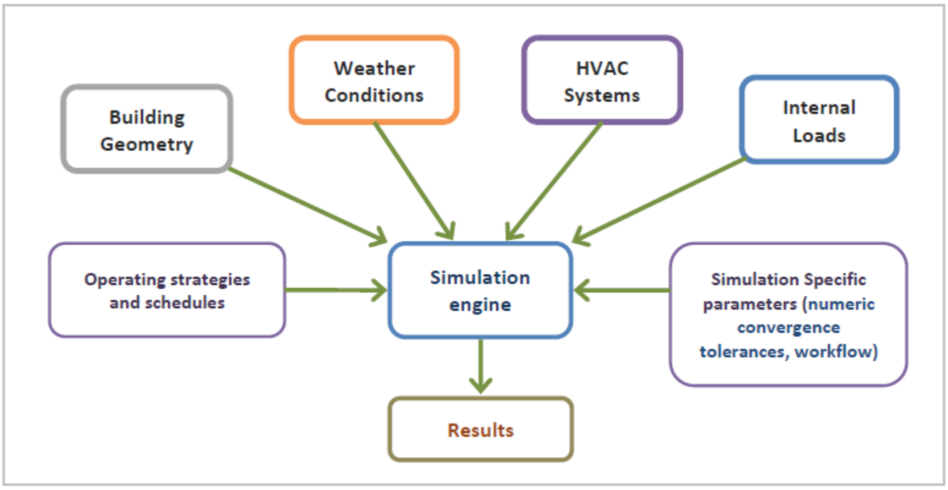


Figure 2 General input data for energy analysis (Nicolle, C. 2013)

BIM bases sustainability calculations generates results faster than the traditional methods and saves substantial resources and time. Currently there are only a handful of BIM based sustainability software used in Finland.

Results from BIM software have to be reviewed as discrepancies may occur periodically.

2.4 Autodesk Building Performance Analysis

Autodesk's core BIM tools with BPA capabilities are: Revit, Vasari, and Green Building Studio. 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: for design studies such as sun path, daylight, wind, airflow. (Le M. K 2014)

The focus will be on whole building analysis using Revit and Green Building Studio. The main structure of Building performance analysis can be seen in Figure 3

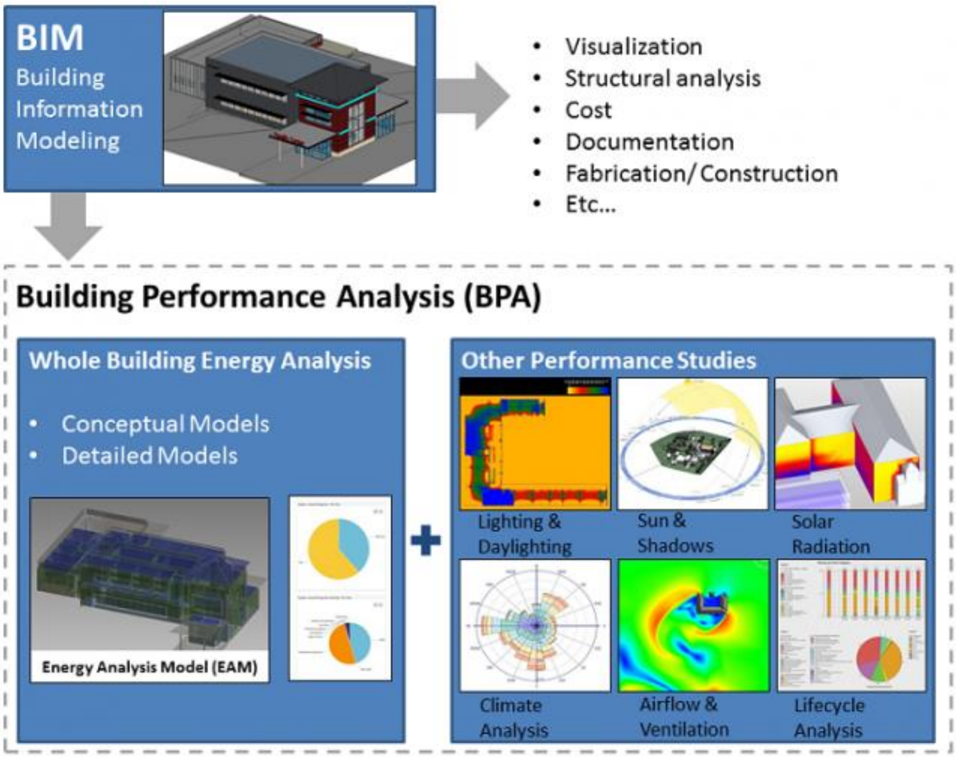


Figure 3 Autodesk Building Performance Analysis

2.4.1 Revit

Revit is a full-featured parametric building information modeling platform for use throughout the design process. Revit models use "Building Elements" like walls, roofs, windows, and floors to create 3D models. There are also conceptual massing capabilities; using basic shapes to model building form and orientation earlier in the design process.

In addition to architectural design, it has tools for MEP design and structural design. (sustainabilityworkshop.autodesk.com). Revit is a very popular design software among members of the AEC industry. It is the modelling end of the Energy simulation workflow.

2.4.2 Green Building Studio

Green Building Studio is a web-based simulation engine for whole building energy analysis. It is based on the DOE-2 simulation engine and powers the whole-building energy analysis tools across Autodesk products: - Revit and Vasari. DOE 2 is a back end to GBS which is more like a user interface that displays the generated data in a readable format.

It can perform analysis on any gbXML file, therefore any software capable of gbXML export can also work with GBS. GBS does not have 3D modeling capabilities. It is solely dependent on external sourced data. (sustainabilityworkshop.autodesk.com). Figure 4 shows the Autodesk whole building analysis workflow.

GBS requires an Autodesk subscription for a full exploration of its capabilities, although it can still work with just an Autodesk registration but certain parameters in the software cannot be edited.

Since it is cloud based, it cannot be installed on a host machine. The advantage is that the results can be viewed anywhere with an internet connection.

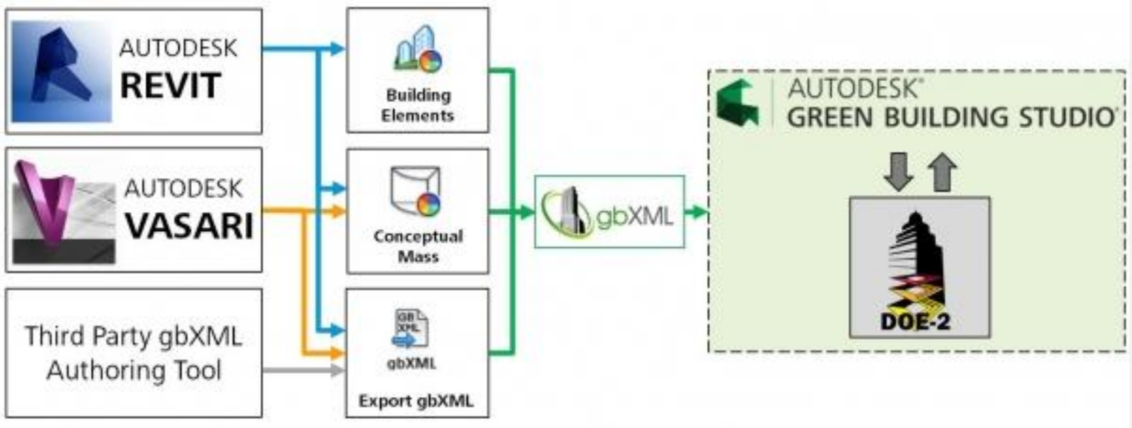


Figure 4 Autodesk Whole Building Energy Analysis.

3 METHODOLOGY

To evaluate the capabilities of Autodesk Revit and GBS a case study methodology was used. The case study involved actual real life design projects for HAMK Visamaki campus. This involved using Building models created in Revit for analysis within Revit and export to GBS for further analysis.

The first stage in Energy simulation is to define the energy target. The proposed target was to;

- simulate code compliance.
- demonstrate reduction in energy demand and its effect on Energy cost, especially the heating cost because of the location.
- reduce CO_2 emission. The final target was to,
- simulate a Net Zero Energy building using software and view the results.

3.1 Case Study

HAMK is in the process of adding two buildings as an extension to its existing building stock in its Visamäki campus located in Hämeenlinna Finland. Table 1 shows the location information of Finland.

The buildings will be referred to as Building Extensions N and S for the purpose of this work. These buildings are new constructions about to be built. For the purpose of the Thesis, we will assume that we are still in the design stage.

Table 1 gives a basic description of the location specific information

Table 1 Finland information

Climatic zone	cold temperate, potentially subarctic	
Energy sources	Black liquor and other concentrated liquors, Wood fuels of industry and energy production, Small combustion of wood (e.g. homes and saunas), Hydro power, Ambient-source heat pumps, Bioliquids in traffic and space heating, Solid recovered fuels (organic fraction), Biogas, Wind power, Other bioenergy, Solar energy.	

3.1.1 Buildings

The Building extension N is a library building with two floors in an open plan. Extension S is a block of offices and classrooms with a basement. It is comprised of four floors. The details of the buildings can be found in Table 2

The building design is basically box shaped with flat roof construction. Library buildings and classroom buildings have different energy demand and therefore will show significant difference in result values. Figures 5 and 6 shows the architectural rendering of the buildings.

Table 2 Basic information of Building extensions N and S.

	Building N	Building S	Note
Building Type	Library	Classrooms and of-fices	
Analytical Area (m^2)	1111	3364	
Total Number of floors including basement	2	4	
Basement	-	1	

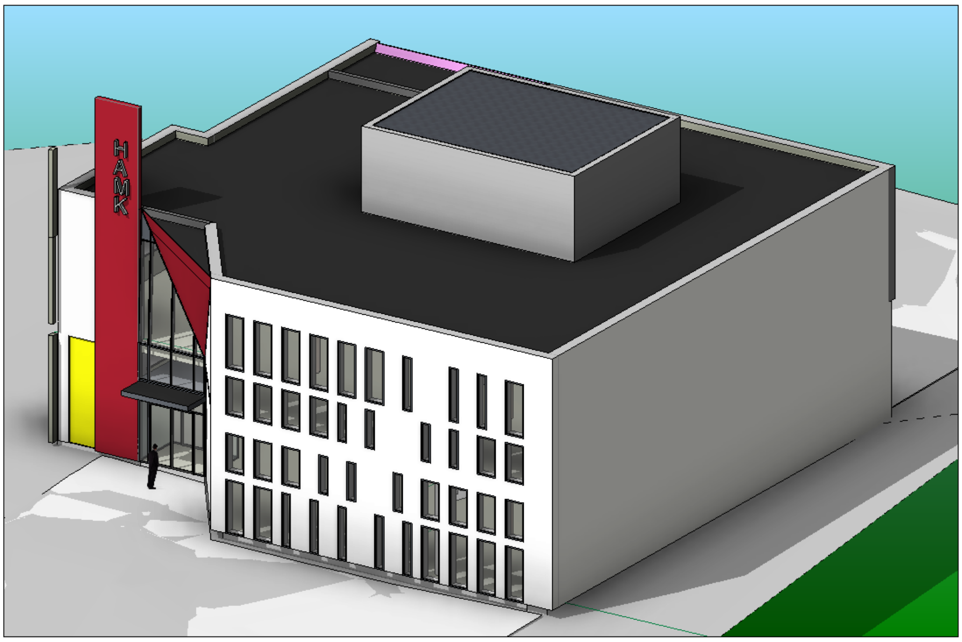


Figure 5 Revit architectural model of Building N.

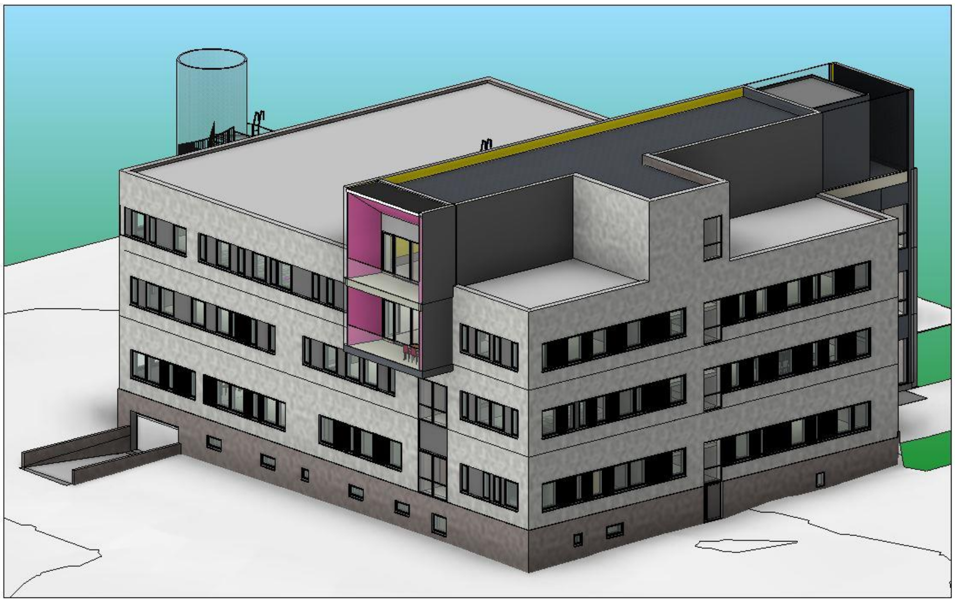


Figure 6 Revit architectural model of Building S.

3.2 Architectural Revit workflow.

The designers of the project supplied the Revit models. The models contained parametric data and descriptions of the building elements.

Since the models were not intended for energy simulation, a few modifications were made to the original model to improve the expected result of the Energy model.

The modifications were made in Autodesk REVIT 2016.

3.2.1 Modifications and data input

The Revit file contained all the buildings in a cluster. The buildings for analysis had to be isolated. Areas adjacent to heated spaces were covered with external wall construction. The reasons for this are as follows;

- Revit computes analytical surfaces based on Elements in the model and their construction status (new or old construction).
- Also energy modelling default values are size dependent; default values for small buildings are different from values for bigger buildings.
- Different building types also have different default values.

Within Revit, there are various options for creating a simulation model for Energy/ sustainability analysis. First is the use of conceptual masses; this enables the designer to conduct analysis at the conceptual stage of the project. The second is by the use of building elements. Due to the availability of a building model the building elements were used.

To use the thermal properties of the building elements in the energy simulation, it is required that the elements in the model contain these thermal properties as part of their parameters. Using the properties palette in Revit the thermal properties were added to the building elements before the energy simulation.

When using building elements there is the option of using Spaces or Rooms. These are software specific terminologies. The rooms or spaces are used to supply additional energy data for the simulation. The data that can be added are as follows;

- Lighting
- Equipment
- Occupancy

These can be specified when using **Spaces** as the export category**,** but the default values are used when **Rooms** is set as the export category. The Rooms category was used for this simulation.

Rooms in Revit are created by bounding objects like walls, floors, ceilings and roof elements. It is important that all walls, roofs, slabs and ceilings be connected. Rooms will not be created if the bounding elements don’t touch. The area and volume calculations are also required for the analysis model and can greatly affect the results. The room elements had to be modified to touch the bounding elements.

The default values for building elements conceptual construction used in the Revit model can are shown in Table 3.

Table 3 Revit default values for conceptual masses

Structure	**Description**	**U value ($W/m^2.K$)**	**Note**
Mass Exterior wall	Lightweight Construction – High Insulation	0.22	Exterior walls
Mass interior wall	Lightweight Construction – No Insulation	2.04	Interior walls
Mass Exterior wall - under-ground	High Mass Construction – High Insulation	0.34	Basement walls
Mass Roof	High Insulation - Cool Roof	0.17	Roof
Mass Floor	Lightweight Construction – No Insulation	1.35	intermediate floor
Mass Slab	High Mass Construction – Frigid Climate Slab Insulation	0.35	Ground floor slab
Mass Glazing	Double Pane Clear – LowE Cold Climate, High SHGC	1.96	Glazing

these values are used when properties of elements are not available the full list, and their R values can be found in Appendix 3

Figure 7 and figure 8 shows the building structure values used for analysis in GBS for the Revit energy simulation. The default values from GBS can be found in Table 5 under section 3.3.

Base Run Construction		
Roofs	R30 over Roof Deck - Cool Roof U-Value: 0.17	395 m^2
Ceilings	Interior Drop Ceiling Tile U-Value: 2.60	13 m^2
Exterior Walls	R30 Wood Frame Wall U-Value: 0.21	581 m^2
	R13 8in Concrete Wall U-Value: 0.42	111 m^2
Interior Walls	Uninsulated Interior Wall U-Value: 2.35	138 m^2
Interior Floors	R0 Wood Frame Carpeted Floor U-Value: 1.16	368 m^2
	Interior Drop Ceiling Tile U-Value: 2.60	338 m^2
	R30 over Roof Deck - Cool Roof U-Value: 0.17	10 m^2
Raised Floors	Concrete slab R15 perim U-Value: 0.07	41 m^2
Slabs On Grade	Concrete slab R15 perim U-Value: 0.07	363 m^2
Nonsliding Doors	R5 Door (1 doors) U-Value: 1.06	3 m^2
Air Openings	Non-North Facing Windows: Single Tint Green U-SI 6.17, U-IP 1.09, SHGC 0.61, VLT 0.75 (2 doors) U-Value: 6.17 W / (m^2-K), SHGC: 0.61 , Vlt: 0.75	13 m^2
Fixed Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (7 windows) U-Value: 1.74 W / (m^2-K), SHGC: 0.40 , Vlt: 0.60	18 m^2
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (16 windows) U-Value: 1.74 W / (m^2-K), SHGC: 0.40 , Vlt: 0.60	37 m^2
Operable Windows	North Facing Windows: Double Low-E Clear U-SI 1.96, U-IP 0.35, SHGC 0.67, VLT 0.72 (35 windows) U-Value: 1.96 W / (m^2-K), SHGC: 0.67 , Vlt: 0.72	47 m^2
	Non-North Facing Windows: Double Low-E Clear U-SI 1.96, U-IP 0.35, SHGC 0.67, VLT 0.72 (40 windows) U-Value: 1.96 W / (m^2-K), SHGC: 0.67 , Vlt: 0.72	38 m^2

Figure 7 Base Run values for Building N

Base Run Construction		
Roofs	Concrete slab R15 perim U-Value: 0.07	475 m^2
	R30 over Roof Deck - Cool Roof U-Value: 0.17	1,412 m^2
Ceilings	Interior Drop Ceiling Tile U-Value: 2.60	153 m^2
Exterior Walls	R13 8in Concrete Wall U-Value: 0.42	557 m^2
	R14.8 8in Concrete Wall U-Value: 0.37	1,350 m^2
Interior Walls	Uninsulated Interior Wall U-Value: 2.35	1,056 m^2
	R15 8in CMU UnderGnd Wall U-Value: 0.08	461 m^2
Interior Floors	Concrete slab R15 perim U-Value: 0.07	244 m^2
	R30 over Roof Deck - Cool Roof U-Value: 0.17	18 m^2
	R30 Wood Frame Floor U-Value: 0.19	517 m^2
	Interior Drop Ceiling Tile U-Value: 2.60	591 m^2
Raised Floors	Concrete slab R15 perim U-Value: 0.07	10 m^2
	R30 over Roof Deck - Cool Roof U-Value: 0.17	53 m^2
	Interior Drop Ceiling Tile U-Value: 2.60	1,077 m^2
Underground Walls	R15 8in CMU UnderGnd Wall U-Value: 0.08	443 m^2
	R7.5 8in CMU UnderGnd Wall U-Value: 0.10	22 m^2
Underground Slabs	R30 Wood Frame Floor U-Value: 0.19	742 m^2
Nonsliding Doors	R5 Door (116 doors) U-Value: 1.06	283 m^2
Fixed Windows	North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (23 windows) U-Value: 3.16 W / (m^2-K), SHGC: 0.69 , Vlt: 0.78	38 m^2
	Non-North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (136 windows) U-Value: 3.16 W / (m^2-K), SHGC: 0.69 , Vlt: 0.78	249 m^2
Operable Windows	North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (4 windows) U-Value: 3.16 W / (m^2-K), SHGC: 0.69 , Vlt: 0.78	7 m^2
	Non-North Facing Windows: Double Clear U-SI 3.16, U-IP 0.56, SHGC 0.69, VLT 0.78 (19 windows) U-Value: 3.16 W / (m^2-K), SHGC: 0.69 , Vlt: 0.78	80 m^2

Figure 8 Base Run values for Building S

3.2.2 Model Validation

When initiating the energy simulation, Revit will display an error message if there are inconsistencies in the model that needs to be modified. This is where model validation comes in.

Model Validation in Revit is an important aspect of the energy analysis process. This is required due to certain limitation inherent in the software and the modelling engine. When creating an energy analytical model (E.A.M.) based on building elements, the following needs to be reviewed

- Model size, complexity and quality - there are limitations that can affect the amount of time taken to generate the EAM
- Energy analytical model form and precision – the appearance of the model may be different from a typical closed shell type geometry. This can lead to a difference in Area/volume values.

Other known issues are;

- Revit design options are not supported when using building elements.
- Revit room and space elements data are independent of the energy model although in some cases data such as room name or space occupancy, lighting and equipment will be used in the energy analysis.
- Revit Room/space separation lines when present do not simulate heat transfer.
- DOE2 the underlying energy simulation engine has limits which can be exceeded by very large, complex models. (Autodesk help pages).

3.2.3 Energy Simulation Modelling

When the models were modified to an acceptable level the Revit inbuilt energy analysis workflow can be initiated. This is connected to GBS so an Autodesk registration is required and then log in to Autodesk 360.

Under the Analyze tab on the Revit ribbon is the Energy analysis panel shown in Figure 9.

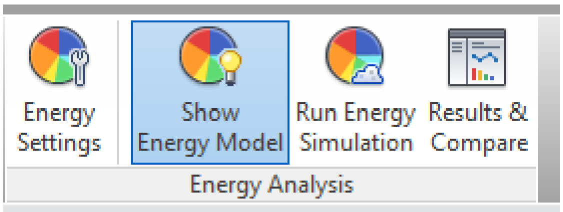


Figure 9 Energy Analysis tab

The first step is to enter the energy settings. The most important basic input parameters using building elements are; building type, location, operation schedule and ground plane. Anything below the ground plane is treated as a basement.

The Energy settings dialogue box is shown in Figure 10. These settings affect the result significantly. Other inputs are dependent on the level of complexity of the model and amount of detail available. The remaining variables including ACH, EPD, LPD, etc. will be added automatically by the software when using **Rooms** category. It will be taken from the spaces data when **Spaces** category is used. Table 4 shows the Energy settings used with notes.

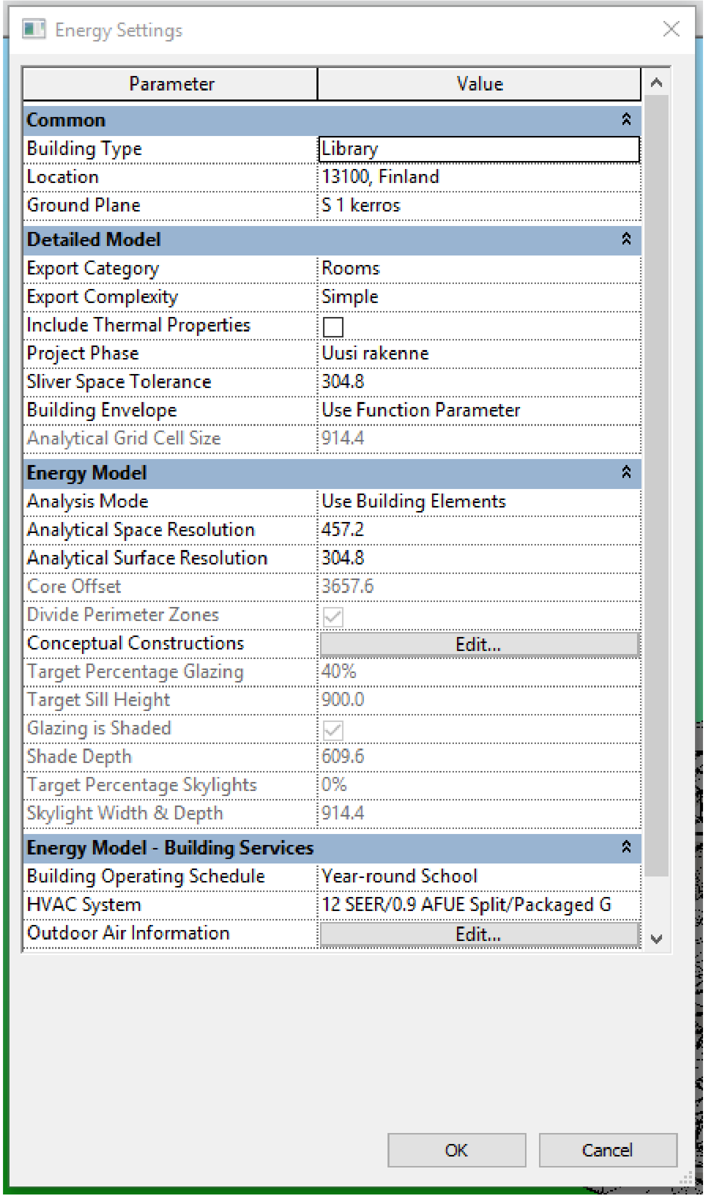


Figure 10 Energy settings dialogue box.

The next step is to Run the energy simulation. The software returns a query asking if you want to use the existing model or to create a new Analytical model. If any change has been made, it is best to create a new analytical model. It is worthy to note that certain aspects of the analysis and inputs can only be done in GBS. Information like currency and energy prices can only be added there. The best practice is to create a new project in Green building studio and then select the project when performing the Energy analysis from Revit.

Using the Results and compare button it is possible to see the results already.

Table 4 Energy settings use for Building N and S

Parameters	Building N	Building S	Note
Building Type	Library	School or university	Affects EPD and LPD

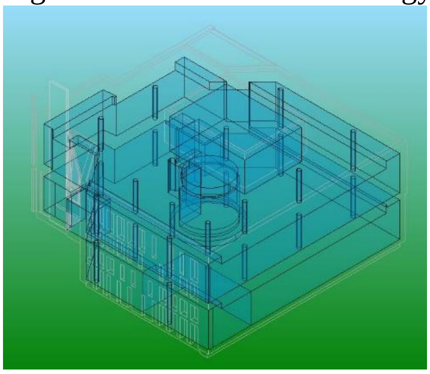
Location	13100, Finland	find location on map
Ground plane	S 1	Building S has a basement S0. S 1 is the ground floor
Export category	Room	enclosed spaces
Export complexity	Simple	This has to do with openings. Simple is faster. Effect on simulation is minimal
Include thermal properties	not checked	when checked returned an error message
Project phase	New construction	All elements to be analyzed should be in the same phase
Silver Space Tolerance (mm)	304.8	default value. minimum gap between spaces that will not be assigned as a room
Building Envelope	Use function parameters	Differentiates between interior and exterior elements. An automatic option is also available
Analysis Mode	Use building elements	
Analytical space resolution (mm)	457.2	Default value. Minimum gap between elements that will be ignored when identifying energy model spaces
Analytical surface Resolution (mm)	304.8	the smallest dimension of any surface to be included in the energy model
Building operation schedule	Year-round School	Has significant effect. This is the times in which the facility is in use
HVAC System	12 SEER/0.9 AFUE Split/Packaged Gas, 5-11 Ton	

3.2.4 Exporting to gbXML

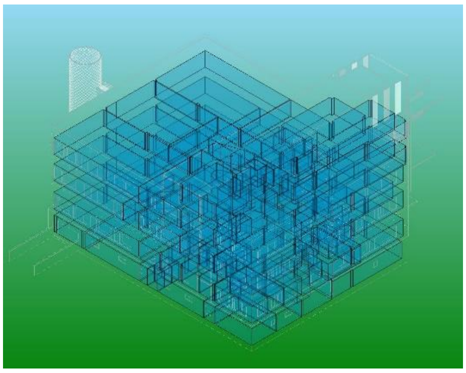
To be able to analyze the energy model for alternatives it needs to be exported to GBS. The file format for GBS is the gbXML file format. Figure 11 a and b shows the energy models.

The export process is straightforward. It will export all the settings made in the Energy settings dialogue box.

Figure 11a & b shows the Energy models



(a)



(b)

Figure 11 Energy model for export to gbXML.(a) Building N, (b) Building S

3.3 Autodesk Green Building Studio workflow.

The first step in GBS is to create a new project. This is important especially in Finland because GBS is an American software and the default inputs are in American nomenclature (units, and currency). This has to be done and necessary inputs added before running the energy analysis because some settings cannot be changed once the runs have been initiated.

The Utility rates used were € 0.10/kWh for Electricity and € 70/MJ for heating (District heating cost. Natural gas was cheaper at €50/ MJ) (Statistics Finland). A little bit of conversion will be necessary at this point because the unit for heating is in “therm”.

In the Project template settings in GBS, it is possible to add custom inputs like,

- Surface settings (Settings for building elements),
- space parameters.
- HVAC equipment and Domestic hot water (DHW)

The climate zone is added automatically based on the location. The code used in GBS is Zone 6A based on the U. S. standard for climates similar to the Finnish climate. Table 5 shows the default values used in GBS for new projects depending on area, climatic zone and building type. This is the same values used for Revit model energy analysis.

Table 5 GBS default values for Energy simulation

	Building N	**Building S**
Building Type	Library	School Or University
Building area (low end range, m^2)	-	2 323
Building area (high end range, m^2)	2 323	10 500 000
Climate Zone of Project Location	ASHRAE Climate Zone 6A	ASHRAE Climate Zone 6A
HVAC System Description (low-rise =<3 floors)	2007-90.1 Baseline System 3: Packaged rooftop air conditioner < 240 kBtu/h Constant volume fan, EER 10.8 DX cooling, AFUE 78% fossil fuel furnace, Economizer (21C limit)	-
HVAC System Description (high-rise >3 floors)	-	2007-90.1 Baseline System 7: VAV HW reheat >150<300 ton 5.55 COP centrifugal chiller, VAV fan, Chilled water loop, 80% thermal eff gas-fired boiler, Economizer (21C limit)
Receptacle Load (W/m^2)	16,14	16,14
Lighting Power Density)	13,99	12,91
Exterior Wall Construction	Ext Wall -R13.3 8" CMU low/R13+7.5ci metal high	Ext Wall -R13.3 8" CMU low/R13+7.5ci metal high
Flat Roof Construction	R20 continuous ins. above deck (U-0.048) cool roof	R20 continuous ins. above deck (U-0.048) cool roof

Pitched Roof Construction	12 inches (R38) of batt or blown in attic/roof ins	12 inches (R38) of batt or blown in attic/roof ins
Ceiling	Typical grid ceiling with lay in place tiles	Typical grid ceiling with lay in place tiles
Underground Ceiling	Interior 4in Slab	Interior 4in Slab
Interior Wall - R0 16" o.c. Metal Frame	Interior Wall - R0 16" o.c. Metal Frame	Interior Wall - R0 16" o.c. Metal Frame
Underground Wall	Underground Wall - R7.5 8" CMU	Underground Wall - R7.5 8" CMU
Raised Floor	Raised Floor - Mass floor w/R12.5 continuous ins.	Raised Floor - Mass floor w/R12.5 continuous ins.
Interior Floor	Interior 4in Slab Floor	Interior 4in Slab Floor
Slab Floor	Concrete slab R10 perim	Concrete slab R10 perim
Underground Slab Floor	Concrete slab R10 perim	Concrete slab R10 perim
Glass Door	Double Low-E Tint U-0.43, SHGC 0.39, Tvis 0.44	Double Low-E Tint U-0.43, SHGC 0.39, Tvis 0.44
Opaque Door	Door - R5 door	Door - R5 door
windows	Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6	Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6
skylights	Triple Low-E Clear U-SI 1.28, U-IP 0.23, SHGC 0.58, VLT 0.70	Triple Low-E Clear U-SI 1.28, U-IP 0.23, SHGC 0.58, VLT 0.70
Outside Air Flow/Person (Liter/second per person)	8,5	6,7
Outside Air Flow/Area (M3/Hour/M^2)	3,657696448	3,657696448
Heat Design Temp °C	22,2	22,2
Cool Design Temp °C	23,3	23,3
Heat Temp On °C [see figure xx for Temperature Setpoints]	21,1	21,1
Heat Temp Off °C	18,3	18,3
Cool Temp On °C	23,9	23,9
Cool Temp Off °C	29,4	29,4
EPD (W/m^2)	10,76	10,76
LPD (W/m^2)	13,99	12,91
Infiltration Flow (ACH)	0,100000001	0,25
Number of People per 100 m^2	10	25
People Heat Gain--Sensible (W/Person)	73,26776886	73,26776886
People Heat Gain--Latent (W/Person)	58,61421585	58,61421585
DHW Load (L/s per person)	0,000294507	0,000361822
Occupancy Schedule Name	Occupancy-Office	Occupancy-School

The setpoints are used for the 24-hour temperature schedules for all of the spaces in each HVAC zone.
For example if the spaces of an HVAC zone are occupied from 7am until 7 pm, a "Cooling On Setpoint" of 24C is the desired temperature of the spaces when the cooling mode is "on", or during the occupied hours of 7am until 7pm.
"Cooling Off Setpoint": This is the temperature a cooling system will try to maintain when the cooling system is "off", or during unoccupied hours. For example if the "Cooling Off Setpoint" is 30C, this will be the desired temperature of the space during the unoccupied hours of the spaces in the HVAC zone.
"Heating On Setpoint": This is the temperature a heating system will try to maintain when the heating system is in heating mode, or during occupied hours.
"Heating Off Setpoint": This is the temperature a heating system will try to maintain during unoccupied hours.
The Zone's throttling range determines the range a space temperature is allowed to fluctuate before an HVAC system is activated. Currently the throttling range is not one of the parameters that can be set in the Project Defaults. The GBS default throttling range for most zones is 2.2C.

Figure 12 Explanation of set points in Table 5(

3.3.1 GBS Base run

After creating a project in GBS, the next step is to upload the gbXML file from Revit to create a base run. When the run is successfully completed, the run displays in the Run List tab.

GBS also creates 154 alternative runs alongside the base run. The automatically created alternatives show the effect of changes to the building elements and application of ECMs to the energy simulation.

GBS base run defaults are based on information gathered from the model imported from Revit and default values inherent in the software. The values used in the base run are presented in Table 6 below.

Table 6 Building structure values for Analysis in GBS base run.

Structure	Description	U value ($W/m^2.K$)	Note
Exterior walls	R13+7.5 Metal Frame Wall	0.4	External wall
Interior walls	Uninsulated Interior Wall	2.35	
Roofs	R20 over Roof Deck - Cool Roof	0.25	Roof
Raised Floors	R12.5 Mass Floor	0.36	raised floor
Underground Slab	Concrete slab R10 perim	0.08	undergroung slab
Mass Glazing	Double Pane Clear – LowE Cold Climate, High SHGC: 0.40 , Vlt: 0.60	1.74	

3.3.2 GBS design alternatives

The design alternative feature in GBS contains capabilities to modify the base assumptions of the Base model and then run a simulation that emulates the impact of the modification on energy efficiency.

In creating the design alternatives, modifications were made to the following

- HVAC equipment
- Roof construction
- Wall construction
- Glazing type

These had the most impact on energy efficiency.

Other possible modifications are;

- Lighting efficiency
- Occupancy control
- Daylighting sensors and controls
- Air tightness

In addition to the 154 design alternatives created by GBS two additional alternatives were created with a combination of modifications to create the best possible simulation.

Table 10 and 11 in the Results chapter show the design alternatives chosen for the energy simulation and their comparison to the base run. The values for the alternative runs are shown in Table 7.

Table 7 Building structure values for Analysis in GBS Alternative runs run.

Structure	Description	U value ($W/m^2.K$)	Note
Exterior wall	Structurally Ins. Panel (SIP) Wall 12.25 in (311mm)	0.15	
interior wall	Uninsulated Interior Wall	2.35	
Roof	R60 Wood Frame Roof	0.08	roof
Raised Floors	R12.5 Mass Floor	0.36	intermediate floor
Underground Slab	Concrete slab R10 perim	0.08	underground slab
Glazing	Triple pane, clear, low-e, SHGC : 0.47, Vlt: 0.64	1.26	windows
Doors	R5 Door	1.06	

3.3.3 GBS work arounds

GBS has a standard approach for building elements and equipment types. A simulation workaround was necessary to be able to create a model that is close to the expected real life situation. This especially had to do with the selection of Equipment and U-value of the building envelope.

Specific elements were chosen for their U-value and not for their structural component. An example is the roof. The roof structure with the best insulation properties is a wooden roof. It was used as substitute for the heavily insulated flat roof system used in the project.

Table 8 shows the main workarounds used in the simulation. The HVAC equipment were chosen for their efficiency rating.

It is also possible in GBS to modify one of the alternative runs automatically created and run it as a separate alternative. An example is when modifying the ACH.

- Select the Alternative run named **Infiltration (ACH)_0.17 ACH**
- modify other parameters like walls, roofs and glazing.
- Add name and run alternative. ACH will be included in the alternative.

Table 8 GBS Alternative runs work-around

Proposed Design	Workaround Description	U value ($W/m^2.K$)	Note
Insulated concrete wall	Structurally Ins. Panel (SIP) Wall 12.25 in (311mm)	0.15	
Insulated concrete Roof	R60 Wood Frame Roof	0.08	
insulated concrete floor slab	R12.5 Mass Floor	0.36	

4 RESULTS

The results contained here were obtained after running several simulations in Revit and Green building studio. Different settings were tried on the base model and on the Energy simulation model. The weather data, spatial data were obtained within the software. Other criteria like construction material of external elements were modified to reduce the energy demand as a result of heating. HVAC equipment was also modified to check for different cost as a result of more efficient equipment. Other changes applied to the base model to create a more sustainable design and the results are presented in the following sections.

The results will be reviewed based on values obtained for,

- Energy use,
- CO_2 emission and
- energy cost.

4.1 Revit Results

The Simulations in Revit/GBS were completed first. Table 8 shows the result obtained from the base models.

Thermal properties were added to the building elements to check its effect on the analysis. This did not produce any results but reported an error message when the “Include Thermal properties” box was checked in the detailed model section of the Energy settings dialogue box.

The possible explanation is that the complexity of the model exceeds the capability of the energy simulation engine. Figure 13 shows the error messages. The building elements were thick and may have exceeded values specified for the simulation.

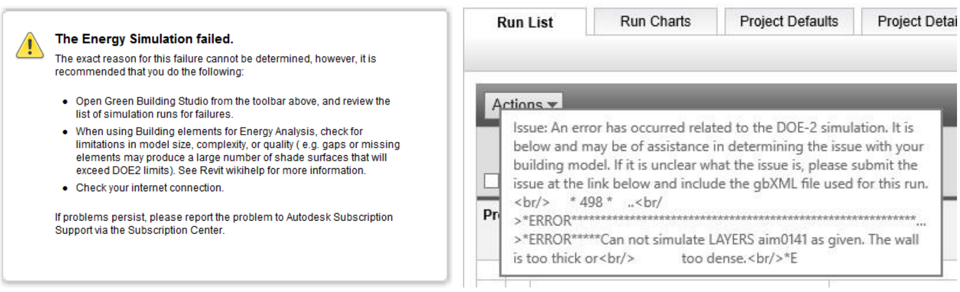
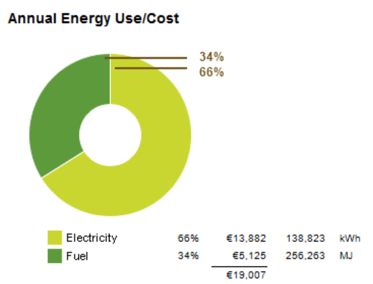
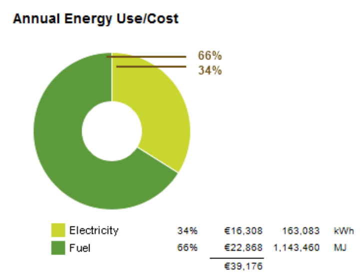
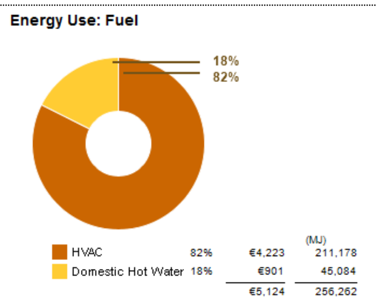
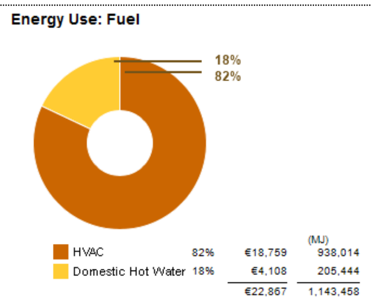
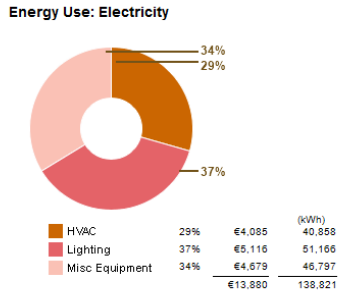
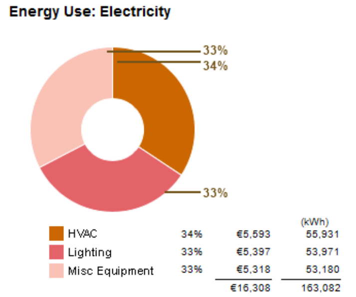


Figure 13 Error message while trying to use thermal properties

The Revit Results displayed on the results page in Revit, showed some discrepancies with the result of the same simulation in GBS. The main error was from the Floor area obtained in the energy model. There was a significant difference between the Floor area indicated in the Result shown in Revit and the result in GBS. Every other result was the same. This is shown in Table 8 and will be discussed further in the next chapter.

The Revit results also shows information for monthly; heating load, cooling load, fuel consumption, electricity consumption and peak energy demand. The full results can be seen in Appendix 1.

Table 9 Revit results showing Building N and S

	Building N	Building S
Area (m²)		
Revit	782	1584
GBS	1111	1498
Analytical area	1111	3364.5
Building Performance Factors		
weather station	171411	
People	78	306
Exterior window ratio	0.25	0.29
Electrical cost (€/kWh)	0.10	
Fuel cost (€/kWh)	0.07	
Energy Use Intensity		
Electricity (kWh/m²/yr)	125	109
Fuel (kWh/m²/yr)	64.17	212
Total (kWh/m²/yr)	189.17	321
Annual energy use/ cost		
Fuel use		
Electricity use		
Life Cycle Energy Use/Cost		

Electricity use (kWh)	4 164 696	4 892 508
Fuel Use (kWh)	2 135 529.20	9 528 841.23
Energy cost (€*10^3)	258.88	533.58
Renewable Energy Potential (kWh/yr)		
Roof Mounted PV System		
(Low efficiency)	13 392	23 341
(Medium efficiency)	26 783	46 681
(High efficiency)	40 175	70 022
Single 4 570mm Wind Turbine Potential	853	

4.2 Results from GBS

The results obtained in GBS were simulated to demonstrate a comparative, based on different ECMs (Energy conservative measures). GBS is like a front end for the DOE 2 engine. It gathers all the data simulated and presents them in an easy to read format as tables and charts.

The Base run is generated once the gbXML file is uploaded into GBS along with 154 design alternatives with modifications based on different aspects of the design that affects the energy modelling. The design alternatives show the effect of

- building orientation at various angles,
- different kinds of glazing,
- different HVAC systems and
- different kinds of external components like walls and roofs.

The simulation then generated a potential energy chart shown in figures 14 for Buildings N and S. These charts show the building features that will have the highest effect on energy savings. They are based on the alternative simulations done alongside the base run. In Building N for example a change in the exterior building envelope and the glazing will have a significant effect on the results obtained. This is a very good pointer and can save time when applying ECMs to generate an energy efficient model.

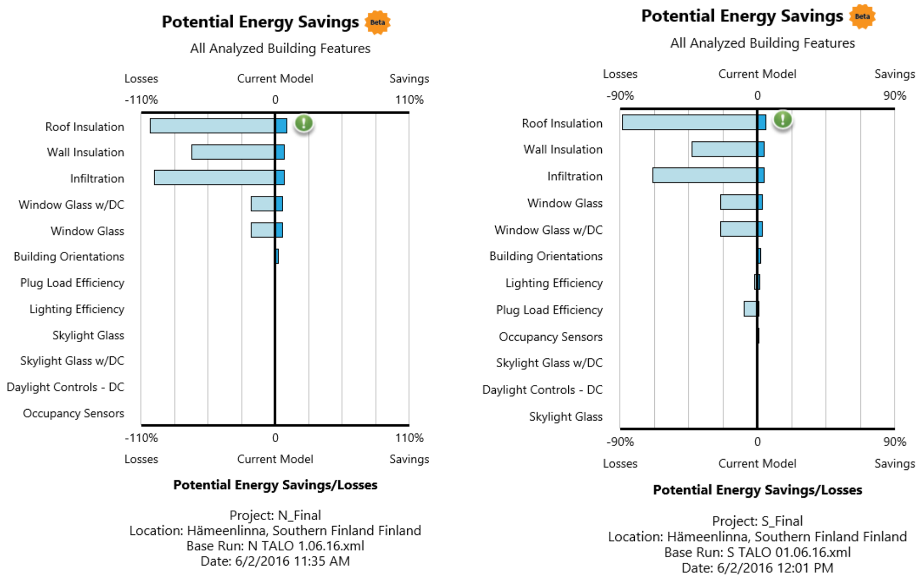


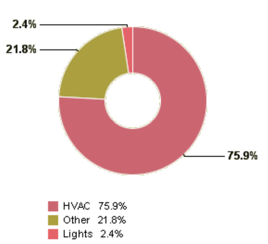
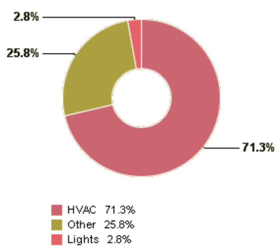
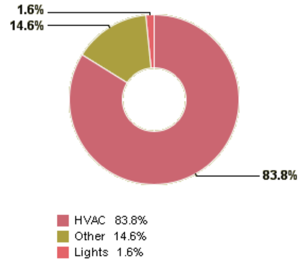
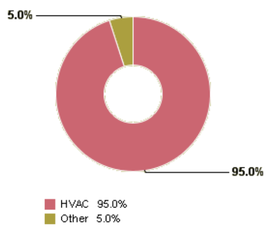
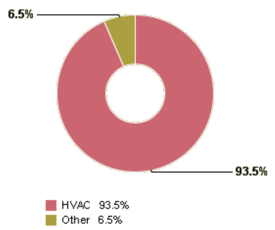
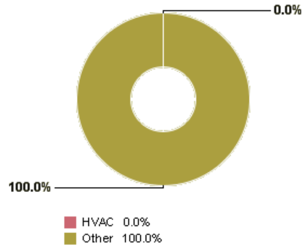
Figure 14 Potential Energy Savings: Building N and Building S.

The results obtained after applying the ECMs and running the simulations are shown in Table 10 and Table 11. The ECMs were focused on reduction of energy demand and CO2 emission. The end game in Energy simulation is to make the Base run as bad as possible and then demonstrate positive measures using alternatives. Two alternatives were applied in this case. They are;

– Improved Insulation.
– Improved HVAC system and Insulation using air source heat pumps.

Table 10 GBS results showing Building N Base Run and Alternatives

	Base Run	Improved Insulation	Improved HVAC and Insulation
Area (m^2)	951		
Building Structure (U-values) W/m^2K			
Exterior walls	0.4	0.15	0.15
Roofs	0.25	0.08	0.08
Underground Slab	0.08	0.08	0.08
Glazing	1.74	1.26	1.26
HVAC	VAV, ASHRAE 90.1-2010, COP 5.55 Chiller, Gas Boiler, 70F economizer	VAV, ASHRAE 90.1-2010, COP 5.55 Chiller, Gas Boiler, 70F economizer	12 SEER/7.7 HSPF Split Packaged Heat Pump
Building Performance Factors			
weather station	171411		
People	88		
Exterior window ratio	0.25		
Electrical cost (€/kWh)	0.10		
Fuel cost (€/kWh)	0.07		
Energy Use Intensity			

Electricity ($kWh/m^2/yr$)	58.03	48.85	86.71
Fuel ($kWh/m^2/yr$)	291	222	14.51
Total ($kWh/m^2/yr$)	349.72	271.11	101
Annual energy use			
Annual energy cost (€*10^3)	25.48	19.85	9.24
Annual Electricity (kWh)	55182	46454	82463
Annual Fuel (kWh)	277199	211142	13802
Annual peak demand(kWh)	21.7	16	99.1
Annual eelectric end use			
Annual Fuel End Use			
Life Cycle Energy Use/Cost			
Electricity use (kWh)	1655457	1393605	2473883
Fuel Use (kWh)	8315973	6334282	414063
Energy cost (€*10^3)	347.03	270.35	125.85
Annual CO2 emissions (Mg) metric tonne			
Electric	12.4	8.8	23.5
Onsite Fuel	49.8	37.9	2.5
Total	62.1	46.7	26
Large SUV equivalent	6.2	4.7	2.6
Renewable Energy Potential (kWh/yr)			
Single 4 570mm Wind Turbine Potential	853		

units in GBS were in MJ and kWh. They are converted to kWh using 1MJ=0.277778kWh

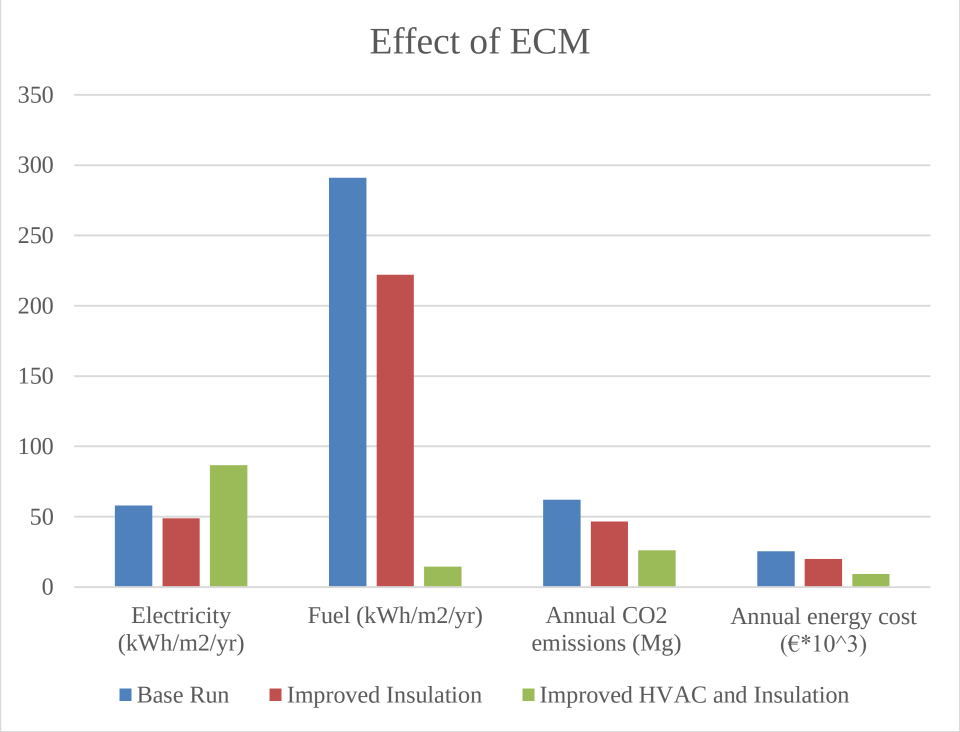
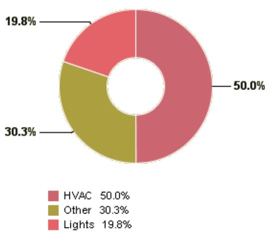
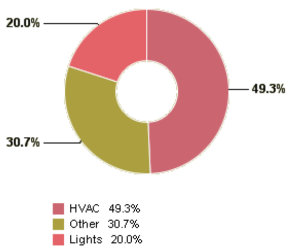
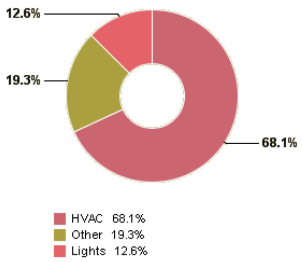
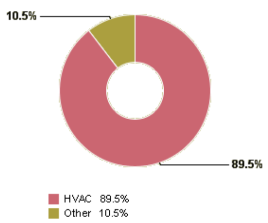
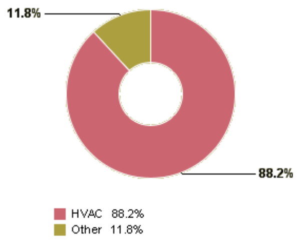
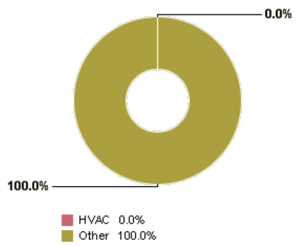


Figure 15 Effect of Energy conservative measures Building N.

Table 11 GBS results showing Building S Base Run and Alternatives

	Base Run	Improved Insulation	Improved HVAC and Insulation
Area (m^2)	3428		
Building Structure (U-values) W/m^2K			
Exterior walls	0.4	0.15	0.15
Roofs	0.25	0.08	0.08
Slab on grade	0.08	0.08	0.08
Underground walls	0.10	0.10	0.10
Underground Slab	0.08	0.08	0.08
Doors	1.06	1.06	1.06
Glazing	1.74	1.26	1.26
HVAC	VAV, ASHRAE 90.1-2010, COP 6.10 Chiller, GasBoiler, 70F economizer	VAV, ASHRAE 90.1-2010, COP 6.10 Chiller, GasBoiler, 70F economizer	12 SEER/7.7 HSPF Split Packaged Heat Pump
Building Performance Factors			
weather station	171411		
People	654		
Exterior window ratio	0.29		
Electrical cost (€/kWh)	0.10		
Fuel cost (€/kWh)	0.07		
Energy Use Intensity			
Electricity ($kWh/m^2/yr$)	109.73	108.31	172.37

Fuel ($kWh/m^2/yr$)	347.24	307.73	36.38
Total ($kWh/m^2/yr$)	456.97	416.04	208.75
Annual energy use			
Annual energy cost (€*10^3)	123.34	113.10	68.07
Annual Electricity (kWh)	376 180	371 281	590 889
Annual Fuel (kWh)	1 190 359	1 054 890	124 724
Annual peak demand(kWh)	126.30	129	762.4
Annual eelectric end use			
Annual Fuel End Use			
Life Cycle Energy Use/Cost			
Electricity use (kWh)	11 285 403	11 138 436	17 726 682
Fuel Use (kWh)	35 710 770	31 646 692	3 741 716
Energy cost (€*10^3)	1 679.83	1 540.30	927.12
Annual CO_2 emissions (Mg) metric tonne			
Electric	84.3	82.3	172
Onsite Fuel	213.7	189.4	22.4
Total	298	271.7	194.4
Large SUV equivalent	29.9	27.2	19.5
Renewable Energy Potential (kWh/yr)			
Single 4 570mm Wind Turbine Potential	853		

units in GBS were in MJ and kWh. They are converted to kWh using 1MJ=0.277778kWh

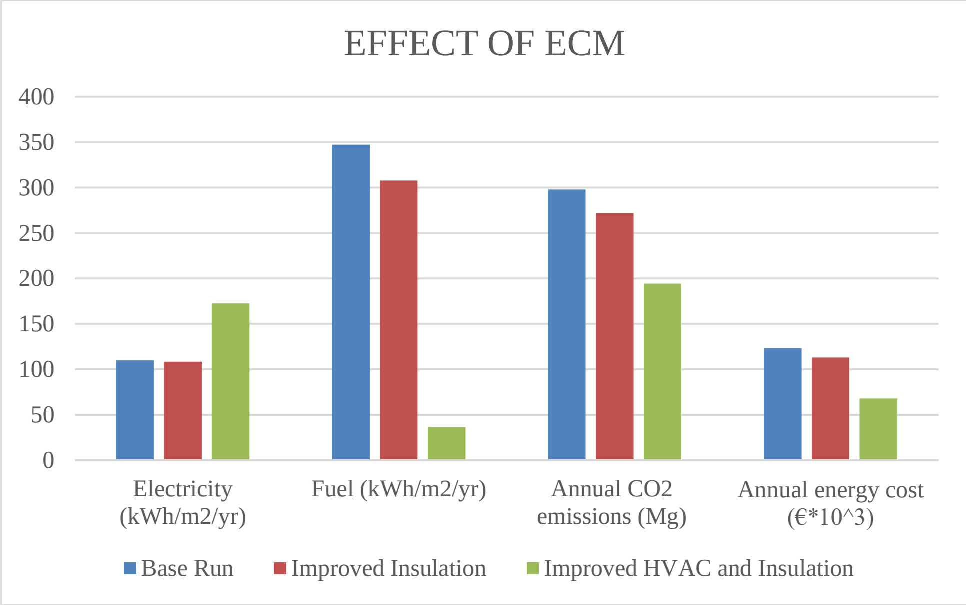


Figure 16 Effect of Energy conservative measures Building S.

The results clearly shows an energy simulation and effect of ECMs that look practical enough.

The results also show the considerable reduction to the energy demand but not low enough to generate NZEBs for the Finnish climate. This is because there is a cap to the default values. This will be discussed further in the recommendations chapter.

5 RECOMMENDATIONS AND DISCUSSION

The results obtained from the simulations shows that Autodesk building simulation software can be used for energy analysis. To obtain a reasonable result it is important to apply the following principles;

- simplified models are better for energy analysis. The simulation engine has certain limitations that can generate error messages.
- Validation of the model as the project advances is very important. It may even be necessary to create a separate model for energy analysis. The more complex the model gets the less likely it is possible to obtain results. Therefore, the energy model should be kept as simple as possible.
- knowledge of HVAC systems and alternative energy systems will help in selection of design alternatives. This is important to get a grasp of the different terminologies used in the software.
- Autodesk software are particularly built for the American market and therefore is based on American standards. The default values are also based on American standards and nomenclature. Although the IEA is working hard to harmonize international guidelines for Energy standards a lot of work still has to be done with regard to countries with uncommon climates like Finland. This is to say that when selecting alternatives in Green building studio, especially on element structure like wall, roof etc. the attention should be on the U-value and not on the kind of structure or the components of the structure. An example is the R60 cool roof of U value of 0.8 $W/m^2.K$, it is a wooden roof but there was no concrete roof that was close to the U-value desired so this had to suffice.
- The software is only customizable to a certain extent unless of course you have access to the API. So there is a limit to the level of alternatives that can be obtained.
- Also the idea of zero energy house or net zero energy houses or passive houses has not caught on with the software. Based on the simulations done during the preparation of this work energy settings for frigid climates were not available or not sufficient especially for conceptual masses. The use of building elements presented some errors based on the complexity of the model, various attempts to work around it did not yield any reasonable result after running over a hundred simulations.
- Use default values as much as possible. They are various options that are close to the desired specifications of most countries.

Using Autodesk BPA reduces the need to source external software for energy analysis. This can save significant cost. The Designer on a project can also easily carryout energy analysis with basic knowledge of Energy simulation.

5.1 Energy modelling with Revit

At the conceptual stage of the design, the use of conceptual masses in Revit to conduct energy analysis can be very helpful. It can show the effect of building orientation and building massing on energy demand.

When modelling with Revit it is possible to add energy specific values when using “Spaces”. Use it for a more accurate result but this will take time and may not affect the result significantly.

It is best to use Revit default values that are close to the values you want than trying to create your own. Energy standards across the globe are currently being harmonized and getting something for your climatic zone won’t be difficult.

Whenever possible conduct your analysis with GBS if you are not the original creator of the model and you want to do something really fast.

5.2 Energy modelling with GBS

Using GBS is probably the best way to conduct energy analysis. Export of gbXML files from Revit using building elements can be quite effective with little errors. The surface settings in GBS can override the settings in the imported file. Changes can easily be made in the simulation to generate something close to the model required.

5.3 Finnish Standards, Autodesk default values and NZEBs.

When trying to simulate a Net Zero Energy Building (NZEB) using the Autodesk Energy software it was difficult to reduce the Energy demand beyond a certain limit.

NZEBs are buildings that generate on site energy as much as they consume. The major alternative sources of energy are solar, wind, geothermal energy. These alternative energy sources all have their drawbacks as a result of natural consequences. Solar energy in Finland is not guaranteed all year round because of the long dark winters in Finland for example.

The idea is usually to reduce the energy demand as much as possible using more insulation in the building envelope and reducing lighting and power consumption using energy conservation principles.

Due to the unique climate of Finland The best default values in Autodesk BPA software is only close to the Finnish 2012 U-values for the building envelope. Table 12 compares the 2012 regulations with Autodesk defaults and values used in Finland for an NZEB building designed by Muuan Studio (Rehva journal 2014)

Table 12 Finnish 2012 regulations compared to Autodesk defaults

	2012 Finnish regulations	Autodesk defaults	NZEB ideas
External wall	0.17	0.15	0.09
Roof	0.09	0.08	0.06
Underground slab	0.09	0.08	0.09
window	1.0	1.26	0.75
door	1.0	1.06	0.6-0.75

If Autodesk can improve the default values or make it possible to use any U-value in the simulation, then the flexibility of the software will know no bounds.

6 CONCLUSIONS AND FURTHER RESEARCH

Autodesk BPA using Revit and GBS can be useful to designers on small projects who can run multiple simulations while using their favorite Revit software without resorting to specialist software. It also requires a shallow learning curve and there is a lot of online resources to help in understanding the software.

Utilizing BIM based energy modelling helps members of a project team discover useful ways to improve the energy efficiency of a building design during the design process. It can enable them make smart decisions concerning energy usage.

Further research by way of comparing estimated simulated results and real energy consumption usage would provide a better understanding and a reflection of the actual performance of the Autodesk BPA with actual real life situation.

The aim of the thesis to perform energy simulation using Revit and GBS was successfully achieved. This can act as a guide to enable future designers in their journey to Energy analysis using BIM.

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Appendix 1

REVIT Results for Building N and S

Results > Compare

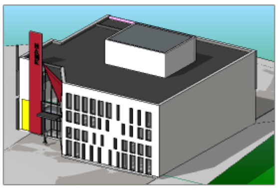
AUTODESK.

Energy Analysis Compare Report

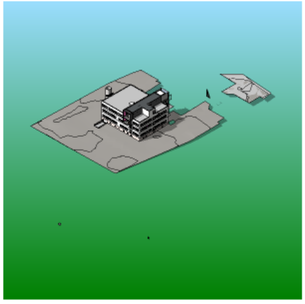
Report created at 2016-06-09 02:33:30 PM

Energy Analysis Result

N_Talo_Thesis
N TALO 1.06.16 Thesis 18_45
Analyzed at 6/1/2016 6:48:54 PM
Version 2016.104.20.54(DOE-2.2-48r)



S_Talo
S TALO 31.05.16 Analysis 18.05
Analyzed at 5/31/2016 4:45:55 PM
Version 2016.104.20.54(DOE-2.2-48r)



Building Performance Factors

	N_Talo_Thesis	S_Talo
Location:	Hämeenlinna, Southern Finland	Hämeenlinna, Southern Finland
Weather Station:	171411	171411
Outdoor Temperature:	Max: 30°C/Min: -23°C	Max: 30°C/Min: -23°C
Floor Area:	782 m²	1,584 m²
Exterior Wall Area:	581 m²	1,350 m²
Average Lighting Power:	12.70 W / m²	10.66 W / m²
People:	78 people	306 people
Exterior Window Ratio:	0.25	0.29
Electrical Cost:	€0.10 / kWh	€0.10 / kWh
Fuel Cost:	€2.11 / Therm	€2.11 / Therm

Energy Use Intensity

	N_Talo_Thesis	S_Talo
Electricity EUI:	125 kWh / sm / yr	109 kWh / sm / yr
Fuel EUI:	231 MJ / sm / yr	763 MJ / sm / yr
Total EUI:	680 MJ / sm / yr	1,155 MJ / sm / yr

Life Cycle Energy Use/Cost

	N_Talo_Thesis	S_Talo
Life Cycle Electricity Use:	4,164,696 kWh	4,892,508 kWh
Life Cycle Fuel Use:	7,687,899 MJ	34,303,801 MJ
Life Cycle Energy Cost:	€258,880	€533,582

*30-year life and 6.1% discount rate for costs (N_Talo_Thesis)

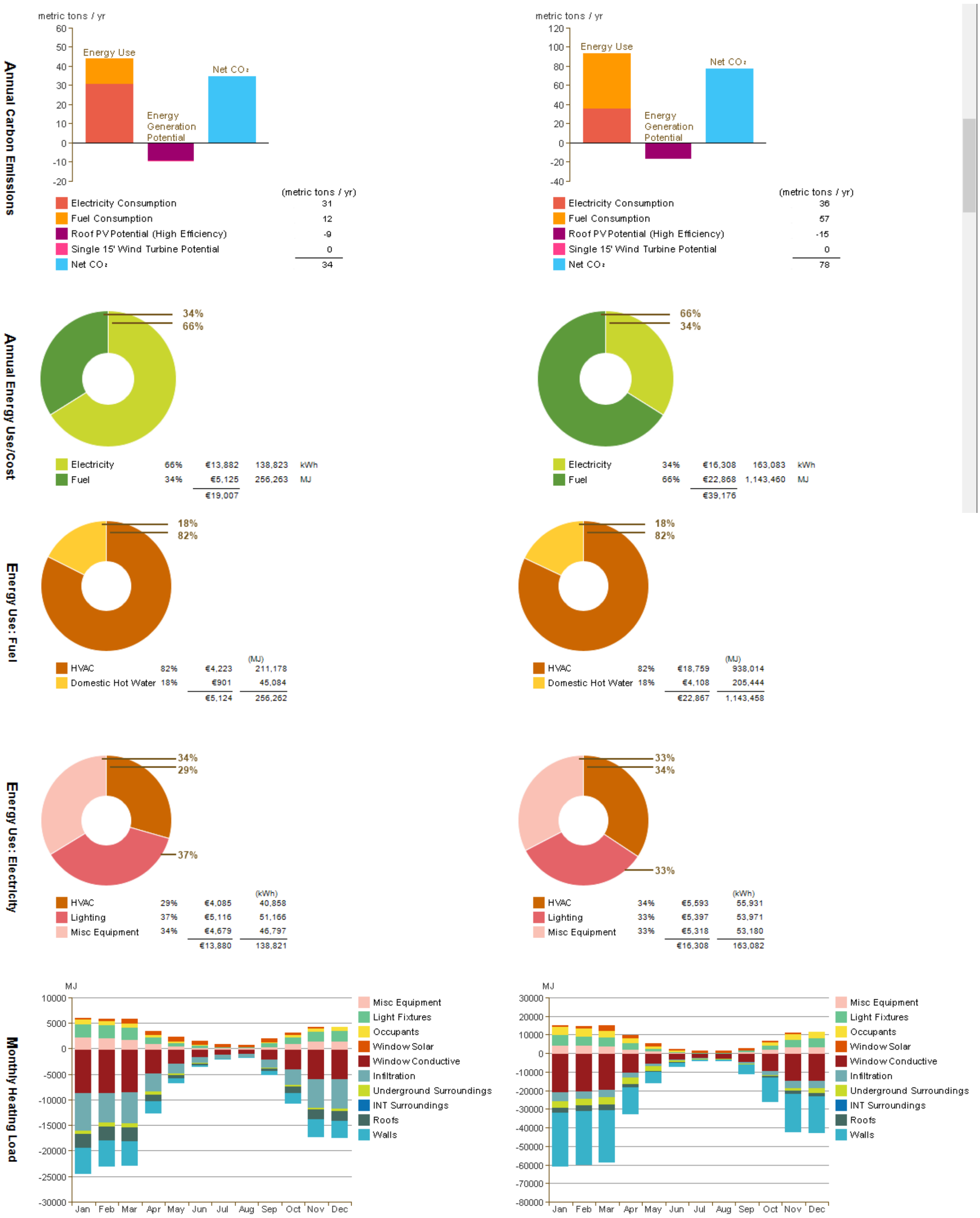
*30-year life and 6.1% discount rate for costs (S_Talo)

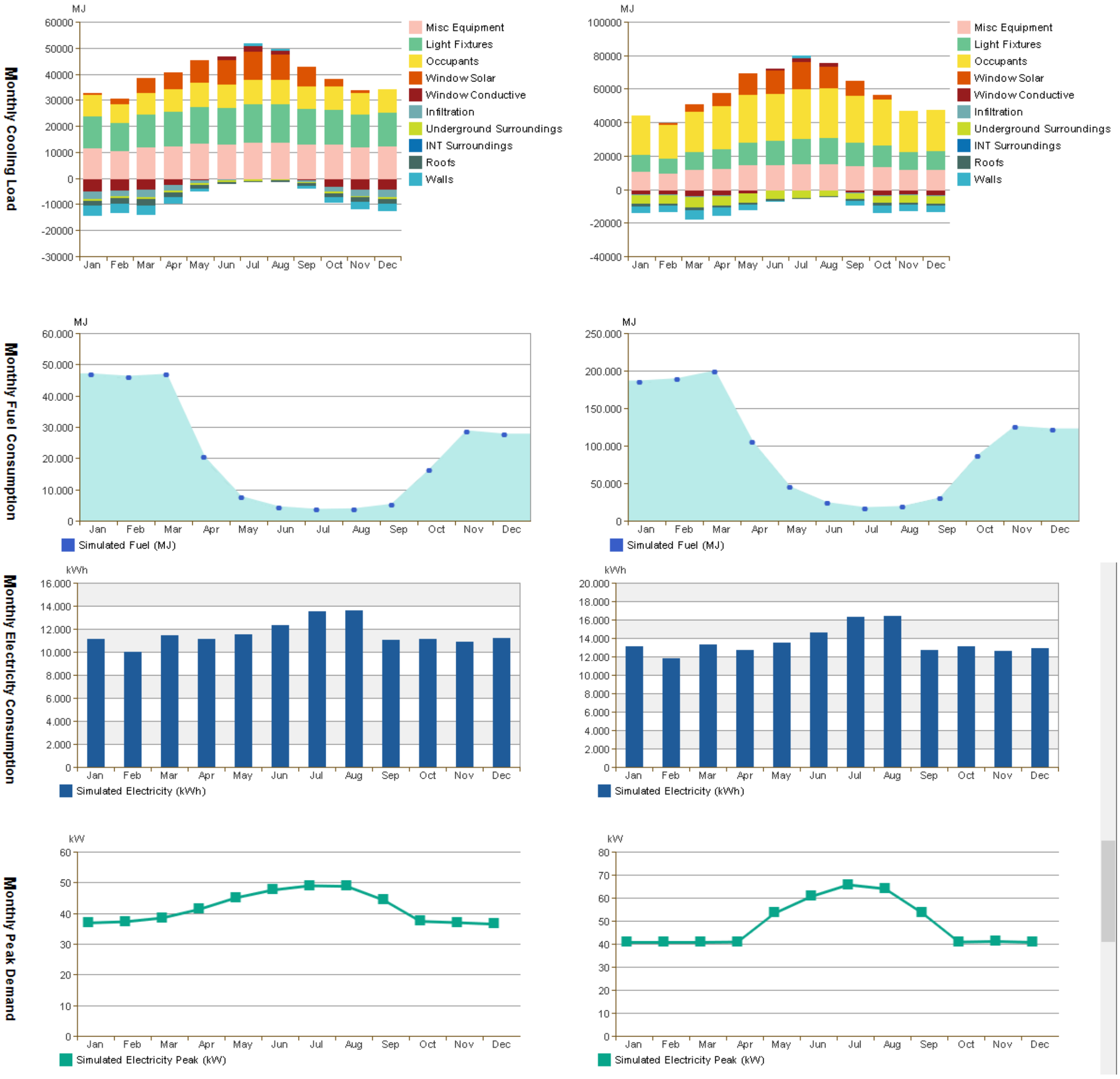
Renewable Energy Potential

	N_Talo_Thesis	S_Talo
Roof Mounted PV System (Low efficiency):	13,392 kWh / yr	23,341 kWh / yr
Roof Mounted PV System (Medium efficiency):	26,783 kWh / yr	46,681 kWh / yr
Roof Mounted PV System (High efficiency):	40,175 kWh / yr	70,022 kWh / yr
Single 15' Wind Turbine Potential:	853 kWh / yr	853 kWh / yr

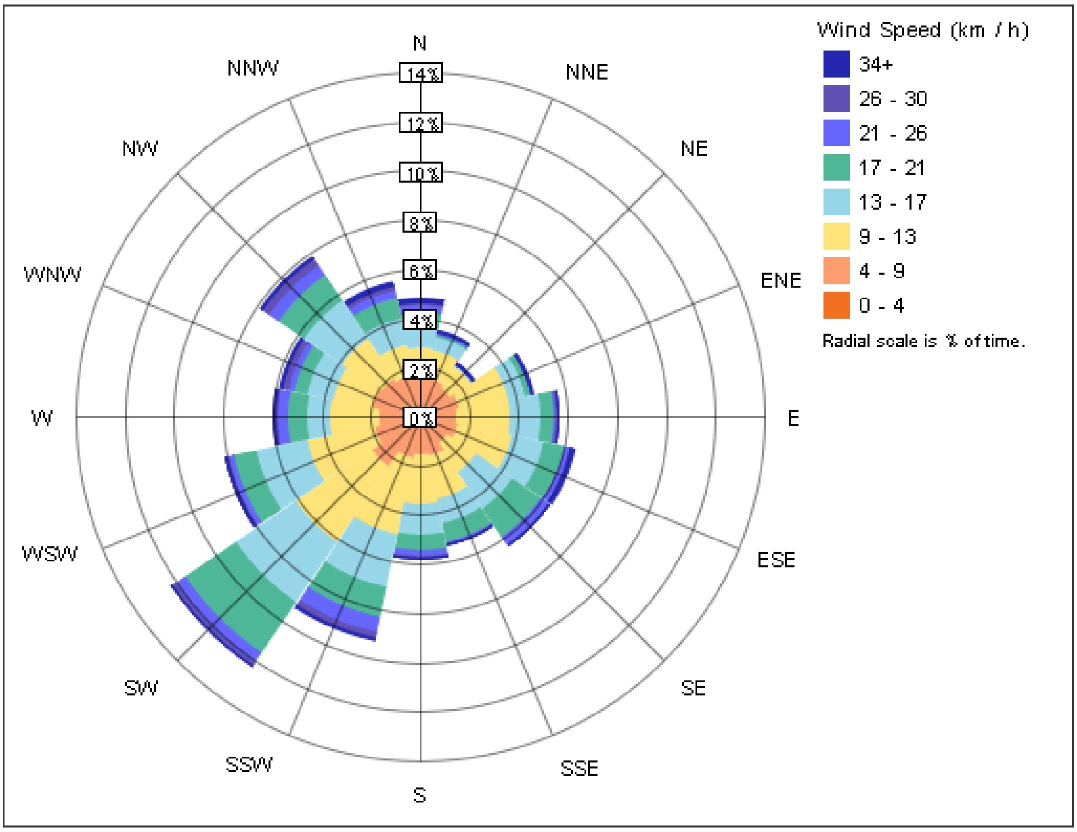
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems (N_Talo_Thesis)

*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high effici systems (S_Talo)

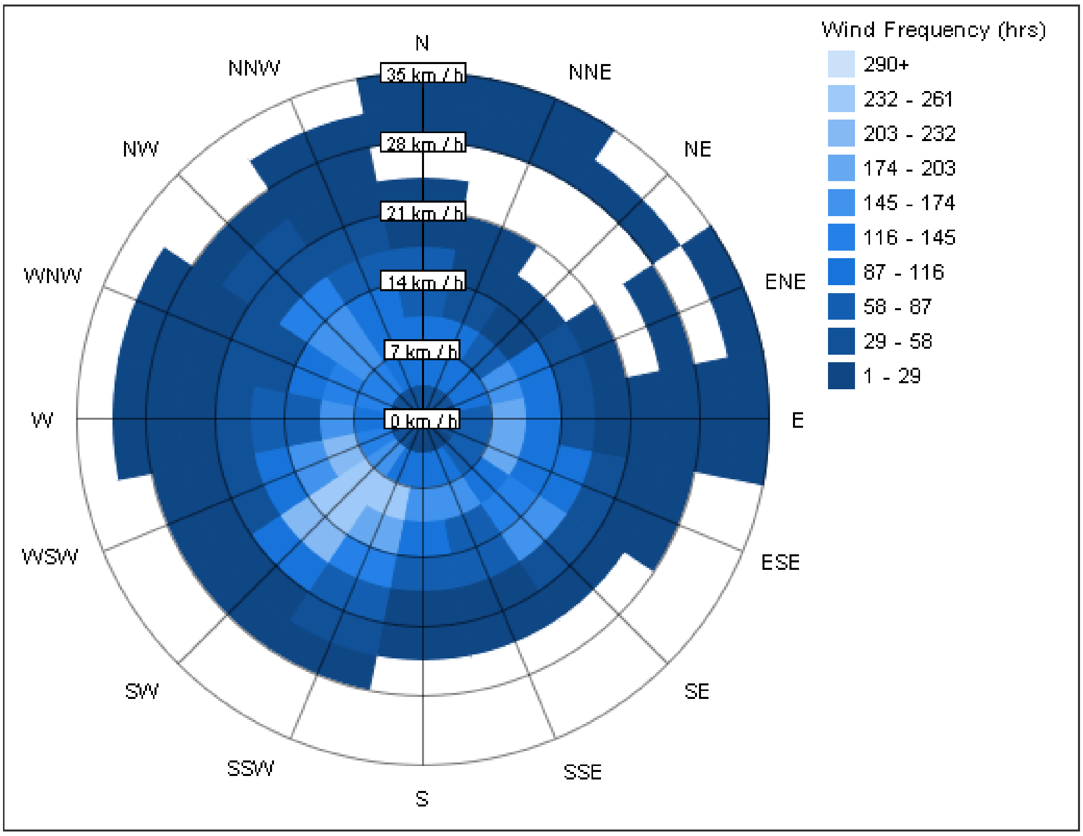

Annual Carbon Emissions
metric tons / yr
Energy Use
Energy Generation Potential
Net CO₂
(metric tons / yr)
Electricity Consumption 31
Fuel Consumption 12
Roof PV Potential (High Efficiency) -9
Single 15' Wind Turbine Potential 0
Net CO₂ 34
Electricity Consumption 36
Fuel Consumption 57
Roof PV Potential (High Efficiency) -15
Single 15' Wind Turbine Potential 0
Net CO₂ 78
Annual Energy Use/Cost
Electricity 66% €13,882 138,823 kWh
Fuel 34% €5,125 256,263 MJ
€19,007
Electricity 34% €16,308 163,083 kWh
Fuel 66% €22,868 1,143,460 MJ
€39,176
Energy Use: Fuel
HVAC 82% €4,223 211,178
Domestic Hot Water 18% €901 45,084
€5,124 256,262
HVAC 82% €18,759 938,014
Domestic Hot Water 18% €4,108 205,444
€22,867 1,143,458
Energy Use: Electricity
HVAC 29% €4,085 40,858
Lighting 37% €5,116 51,166
Misc Equipment 34% €4,679 46,797
€13,880 138,821
HVAC 34% €5,593 55,931
Lighting 33% €5,397 53,971
Misc Equipment 33% €5,318 53,180
€16,308 163,082
Monthly Heating Load
MJ
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Misc Equipment
Light Fixtures
Occupants
Window Solar
Window Conductive
Infiltration
Underground Surroundings
INT Surroundings
Roofs
Walls


Monthly Cooling Load
MJ
Misc Equipment
Light Fixtures
Occupants
Window Solar
Window Conductive
Infiltration
Underground Surroundings
INT Surroundings
Roofs
Walls
Monthly Fuel Consumption
MJ
Simulated Fuel (MJ)
Monthly Electricity Consumption
kWh
Simulated Electricity (kWh)
Monthly Peak Demand
kW
Simulated Electricity Peak (kW)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

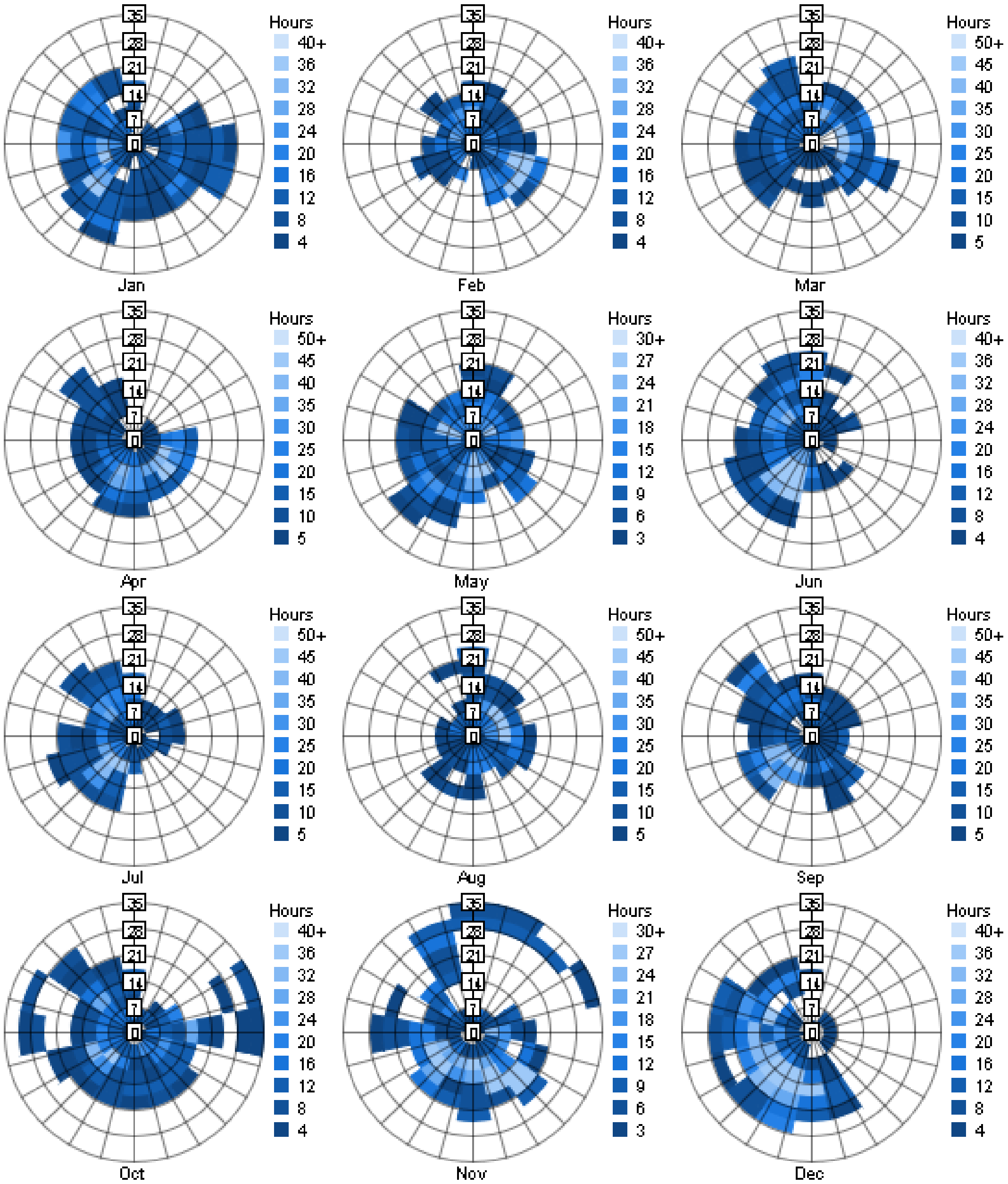
Annual Wind Rose (Speed Distribution)

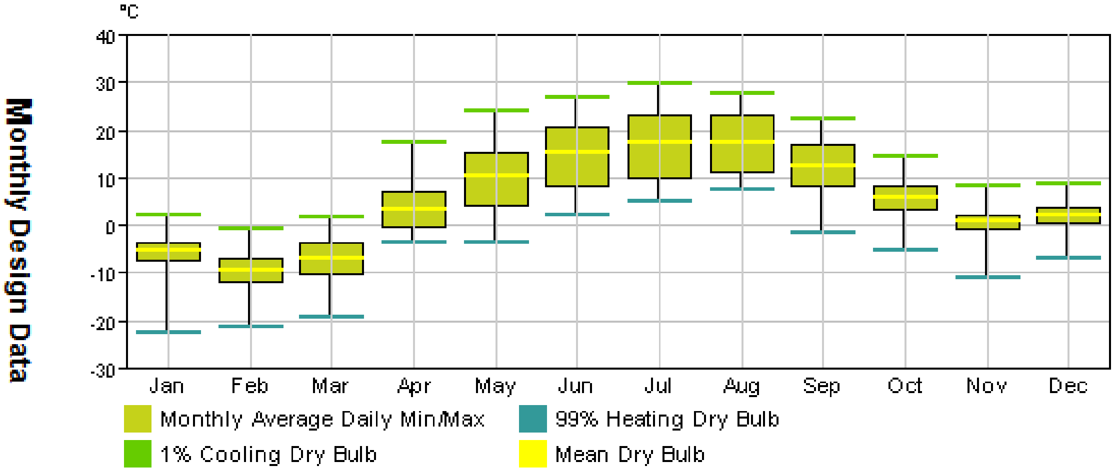


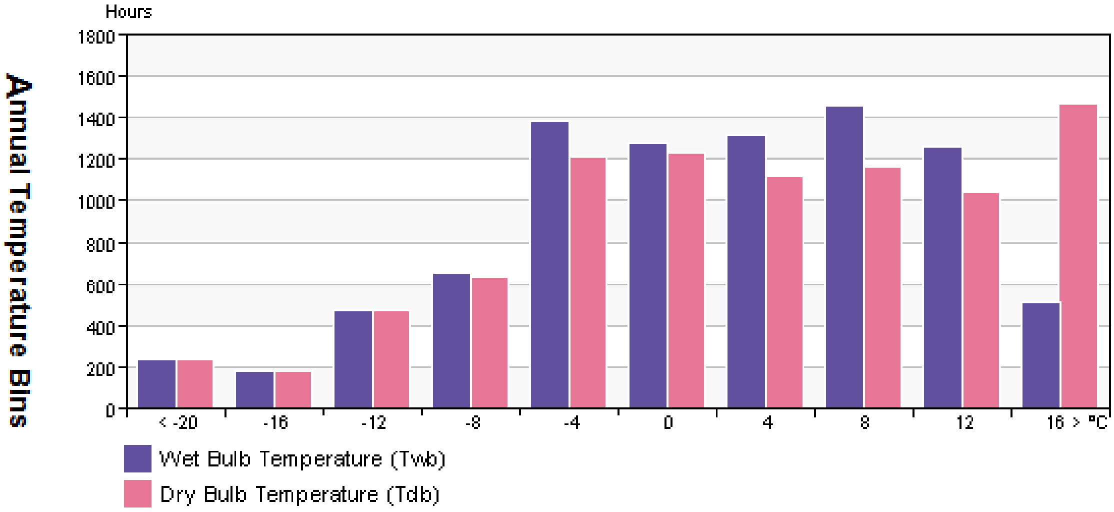
Annual Wind Rose (Frequency Distribution)

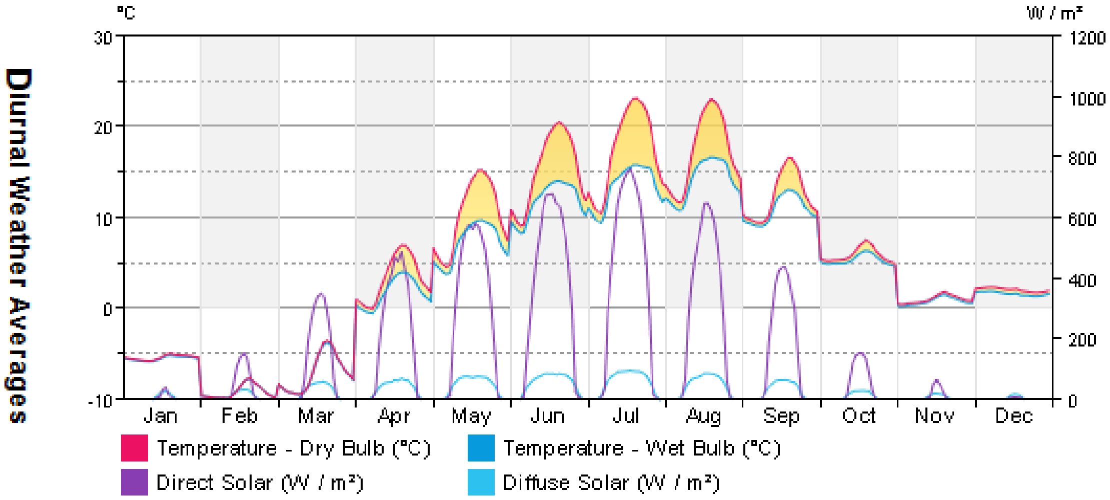


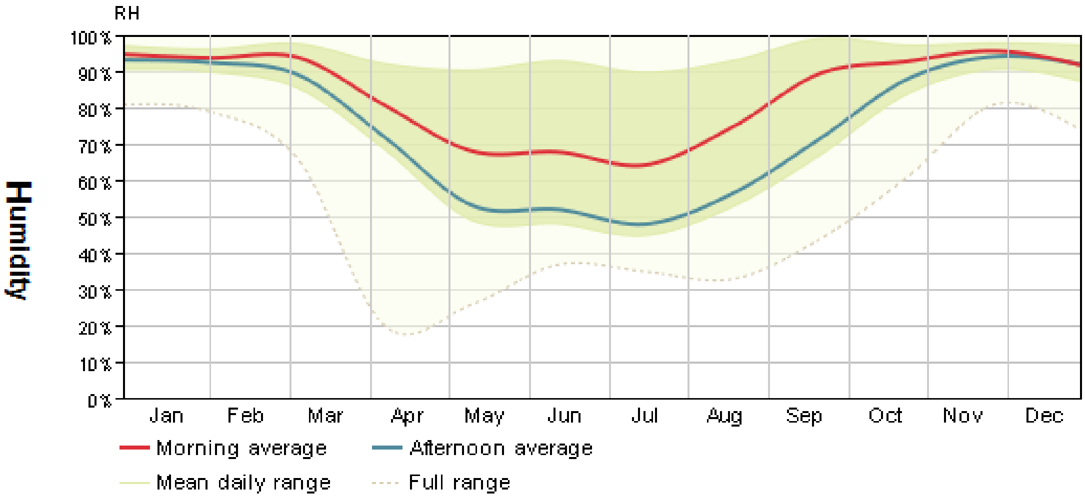
Monthly Wind Roses




Monthly Design Data
°C
40
30
20
10
0
-10
-20
-30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Monthly Average Daily Min/Max
99% Heating Dry Bulb
1% Cooling Dry Bulb
Mean Dry Bulb


Annual Temperature Bins
Hours
1800
1600
1400
1200
1000
800
600
400
200
0
< -20
-16
-12
-8
-4
0
4
8
12
16 > °C
Wet Bulb Temperature (Twb)
Dry Bulb Temperature (Tdb)


Diurnal Weather Averages
°C
W / m²
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Temperature - Dry Bulb (°C)
Temperature - Wet Bulb (°C)
Direct Solar (W / m²)
Diffuse Solar (W / m²)


Humidity
RH
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Morning average
Afternoon average
Mean daily range
Full range