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DIPLOMARBEIT

Integrated building energy analysis in ArchiCAD-17: evaluation, impact and perspectives

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KURZFASSUNG

Die Integration von Energiebewertungs-Software in gängige CAD-Programme des Bauingenieurwesens ist kein grundsätzlich neues Konzept.

Dieser Ansatz wurde in den letzten Jahren schon öfter in verschiedenen Publikationen und Untersuchungen aufgegriffen. Ein entscheidender Vorteil eines solchen Modells liegt in der direkten Einbindung der zuständigen Architekten in Fragen des energieeffizienten Designs. Der Designer wird dahingehend nicht nur beim prinzipiellen Gestaltungsprozess, sondern auch beim Finden von möglichst energieschonenden Konzepten software-seitig unterstützt.

Den zunehmend an Bedeutung gewinnenden Aspekten der Nachhaltigkeit muss bereits in einer sehr frühen Phase der Entwicklung Rechnung getragen werden. Die Planungsphase hat hier schon einen sehr großen Einfluss auf die gesamte Projektentwicklung und in weiterer Folge auf die Gesamtenergie-Effizienz des Gebäudes. Daher ist es umso wichtiger, den ausführenden Architekten ein leistungsstarkes Werkzeug zur Berechnung der Effizienz zur Verfügung zu stellen.

Die Einbindung von Bewertungsinstrumenten direkt in CAD-Programme macht die Energieanalyse aus Sicht des Architekten zu einem transparenten und leichter zu durchschauenden Prozess. Durch die damit verbundene Verringung der notwendigen Software gelingt es außerdem, die vorher strikten Grenzen zwischen Design, Prüfung und Optimierung etwas aufzuweichen.

Diese Diplomarbeit befasst sich mit den Perspektiven und Möglichkeiten, die die weit verbreitete CAD-Software ArchiCAD 17 in Verbindung mit einem integrierten Energiebewertungstool bietet. Diese Fallstudie erlaubt die Bewertung der Leistungsfähigkeit des Software-Pakets sowie die Einschätzung des Potentials für zukünftige Entwicklungen in diesem Bereich.

ABSTRACT

The idea of merging energy evaluation software with design programs is not a new concept; it has been researched by multiple papers and studies during the past few years. Core benefit of the practice is the possibility to provide architects with a better understanding of the way design solutions can influence energy demands. Proper attention should be paid to increasing architects' awareness of sustainability issues and potential consequences of decisions taken during the early design stage. This particular period is considered to have a major influence on whole project's development and further performance of the building.

Integrating evaluation tools directly into program's core became one of the solutions to simplify architects' access to energy analysis by making it a transparent process. The method is supposed to erase border between design, examination and following optimisation by means of excluding import/export routine from a daily workflow of professionals.

This thesis explores scope and perspectives of energy evaluation tool (EcoDesigner) embedded into one of the widespread CAD-platforms, ArchiCAD-17. Case study and scrutiny of program's performance allow making an assessment of its potential, outlining weak points and formulating recommendations for further development.

CONTENTS

1 INTRODUCTION

Despite the availability of sufficient technologies, energy analysis tools tend to show their inconsistency with design process (Morbitzer 2003 and Hensen 2004). Contemporary energy evaluation programs have been developed in research domains by specialists, software developers and product manufacturers to address particular needs of building scientists. Consequently, they often pay little or no attention to the whole building design process, seem too complicated to use or require extensive training. This lack of compatibility between design and evaluation processes may be regarded as an obstacle in the way of architects trying to produce energy-efficient solutions. It emphasizes the necessity of providing relevant building performance information to designers in real time (Mirani and Mahdjoubi 2012).

In May 2012 the Hungarian company Graphisoft has released the 16th version of ArchiCAD. One of the key features of the new edition has become the integrated EcoDesigner - evaluation tool that was supposed to provide architects with a better understanding of energy performance and thus to assist them in optimisation of design solutions. The innovation was expected to bring "informed decisions" into the project's development process (Graphisoft 2011). These attempts to introduce quick and easy to use energy evaluation caused multiple discussions and lead to further evolution of the concept that found its reflection in the newest version of ArchiCAD-17 in July 2013.

There is no clear guidance on best practice in Building Information Modelling (BIM) that could have assisted construction companies in increasing their productivity and efficiency. Therefore they keep facing barriers and challenges in adoption of the concept. In this context the possibility to run quick and accurate evaluations within a familiar interface might become an ultimate solution for situations where price and complexity of stand-alone evaluation tools keep potential users from implementing them on the early design stage.

During years of its presence on the market ArchiCAD gained popularity among CAD-users by positioning itself as a reliable tool with multiple possibilities and stable performance. On the other hand all-in-one packages tend to be treated with a certain amount of scepticism due to possible software failures. The major topic of this thesis will be critical review of the latest EcoDesigner, exploration of its strong and weak sides and speculation on further enhancement.

1.1 Motivation

Project development in architecture is usually regarded as a linear set of activities that leads to delivery of the final result – functioning and operable building. Multiple studies were dedicated to optimisation of both construction and design processes. The papers define Concept Development Stage as a crucial period of project's elaboration. Decisions taken during this short phase might later show a disproportionate impact on resulting performance of the whole building (Domeshek et al. 1994). Bogenstätter claims that 20% of efforts constitute to performance of the 80% resulting parameters thus outlining a certain parallel with the general Pareto principle. He also mentions that the beginning of design process has the highest potential to influence subsequent construction and operation costs (Bogenstätter 2000).

Integration of building performance simulation into design development might be quite challenging for architects as it often involves optimisation of numerous parameters and strategic analysis of possible solutions. This kind of BIM calibration requires certain amount of experience in the building science sphere. A recent study held by Attia (Attia et al., 2012) has shown that architects name intelligence as the most important criteria for simulation tools. In this context "intelligent software" has to provide tips and clear ways of comparison of several design alternatives. According to Attia's paper professionals frequently found it difficult to use the evaluation programs due to their complexity and lack of decision-supporting outcome.

The required performance data of each developed project should be provided to architects on a barrier-free base as emphasises Attia. Therefore, it is essential to ensure the smooth two-way transfer and best guidance available at all steps of design formation (Attia, 2011). One of the obvious solutions here might be merging of drawing and analytical functions within the same interface. Intention to study the effectiveness and potential impact of embedded performance simulation tools leads to evaluation of one of them – namely EcoDesigner for ArchiCAD-17 by Graphisoft.

1.2 Goals and Hypothesis

It is assumed that user-friendly energy evaluation tools integrated into familiar interface might significantly increase building's quality in terms of sustainability and facilitate its further development. Two major questions under discussion are the following: how effective is application of the software and what level of expertise is required to run it. Therefore the goals of this thesis are analysis of EcoDesigner's performance and outlining improvements it could bring into architects' workflow.

1.3 Approach

As the design-elaboration way under discussion implies instant feedback to support the decision making no post-design evaluation tools would suit the task. It is another reason for selecting EcoDesigner as an objective for analysis.

Verification of the hypothesis drawn above requires a practical approach. Existing comparative studies of multiple energy evaluation programs will serve as a background to form of a usability-study method to analyse potential perspectives of EcoDesigner and to define pros and cons of its current version (ArchiCAD-17). General principles of the workflow within the software will be discussed. Modelling conventions will be described and illustrated by series of evaluation examples of architectural projects with varying complexity.

Integration of a one-click analysis, simplification of manoeuvring between designing and evaluating modes is the most direct way of bringing professionals closer to sustainable approach in architecture. Architects should be enabled to run the assessment process parallel to the design one and with minimum of technical barriers such as necessity of recreating geometry or potential file-format conflicts.

Sheer appraisal of possible design combinations and parameters won't suffice as a sole method. Attia names the lack of informed iteration based on design evaluation the second important obstacle towards integration of building performance simulation into architects' workflow (Attia 2011). In other words they need suggestions regarding design improvements based on the analysis results. Thus examination of EcoDesigner's actual impact and possibility to assist decision-making by providing all sorts of recommendations will play a significant role in the tool's assessment process.

1.4 Relevance of work

As the addressed version of ArchiCAD has been released not long ago (July 2013) the lack of critical papers might create a false impression of the software being a sort of a panacea for professionals willing to introduce energy evaluation into architectural process. This fact emphasizes necessity of critical approach and a step-by-step analysis of EcoDesigner's possibilities.

2 BACKGROUND

2.1 Analysis of existing tools

Currently (July 2013) the U.S. Department of Energy website provides information on 396 building software tools for evaluating of potential energy efficiency and sustainability in buildings. A brief analysis of all the software presented on the web-site outlines general tendency in current software development: less than 8% of all the existing programs might provide architects with support during the early-design stage (U.S. Department of Energy 2013).

In the course of evaluation of current situation on the software market three basic parameters have been taken into account. The first parameter was the ability of the program to run a simulation of the whole building and to calculate its energy consumption. Number of programs sufficing the first parameter equals 132 - that constitutes to a third of the primal list. These programs were chosen for further comparison, the full list might be observed in *Table 1*.

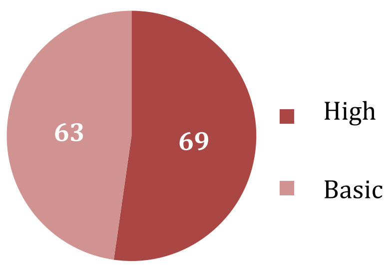
The second parameter was ascertainment weather or not architects are considered a part of the target audience. Description of each program provided by developers allows outlining the picture very clearly: approximately 37% (49 programs) of the 132 selected during the first step name architects among other groups of potential users. That leaves absolute majority to engineers, energy consultants or house-owners.

The third parameter was the level of required expertise - the way it is described by developers. Software expertise demand labelled as "basic" and "minimal" was not considered as a barrier in usability. The results show that more than a half (69 programs) is oriented to users with a rather high experience level, require programming knowledge, profile education in energy evaluation and building systems and don't position themselves as easy-to-use applications.

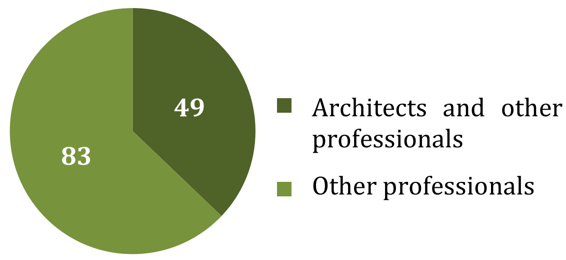
The three parameters combined together provide the following result: the U.S. Department of Energy currently lists 31 programs that enable architects to run energy simulation of the whole building and do not require deep grasp of the subject or any additional knowledge.

The derived number might seem sufficient for the outlined goals. Programs in the list are either add-ons for different CAD-platforms or stand-alone software. They represent a rather wide range of technical parameters, input/output formats and usability levels. To a variable extent they provide feedback on buildings' energy performance and allow evaluation of design alternatives based on energy demands, CO2-footprint and energy balance per month.

Big companies such as Autodesk or Graphisoft don't share information regarding number of users of their energy evaluation packages. As they provide energy evaluation add-ons to CAD-users as a single pack, actual demand remains unclear. At the same time number of users of remaining programs (stand-alone in majority) generally fluctuates between 50 and 2000. This makes a sum of approximately 17000 users including engineers, energy-consultants, students, house-owners and architects.



Expertise requirement level.



Architects as a part of target audience.

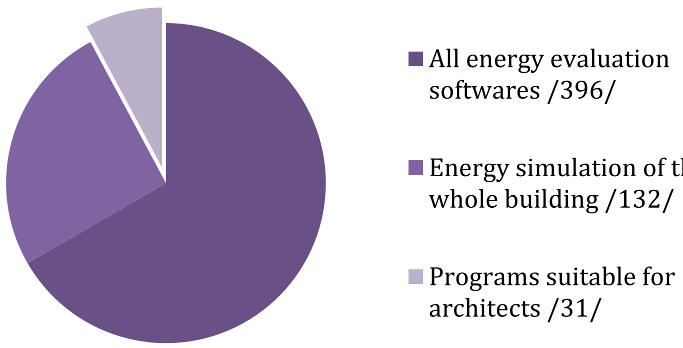


Figure 1: Analysis of the existing design tools in regard of application by architects on early-phases.

It is extremely hard to tell the exact amount of architects using CAD-programs but in the end of 2011 Jon Peddie Research released its "2012 CAD Report," which estimated the whole number of active CAD users worldwide to be 19.3 million (JPR 2012). The number takes into account a wide range of professionals. Compared to the figure outlined earlier (17 000 users) it is possible to get a preliminary impression of the huge gap between the amount of potential and practicing users.

Thus common picture is the following: a very small per cent of existing energy evaluation software might be currently used by architects for evaluation of building concepts. For some reason architects using CAD show a little or no interest towards stand-alone applications that might have assisted them during early-design stages. The same conclusion has been drawn by a number of studies (Lam 2004, Attia et al. 2012) and illustrates that existing simulation tools are inadequate, user hostile or incomplete to be used by architects during the early phases.

Table 1: Comparison of existing programs suitable for energy evaluation of a whole building Part 1.

Software	**Architects as target users**	**Technical expertise required**	**Amount of users worldwide**
1	**2**	**3**	**4**
1D-HAM		✓	
AEPS System Planning	✓	✓	
AFT Mercury		✓	
AkWarm	✓		25
AnTherm	✓		5
AUDIT		✓	
AD Green Building St.	✓		N/A
BEAVER		✓	
Benchmata		✓	
BSim			
Building Design Advisor	✓		8
Building En.Analyzer			
B E M and Simulation			
BuildingAdvice			
BuildingSim	✓		N/A
BUS++		✓	
BV2	✓		3
Cake Systems		✓	
Carbon Estates			
CBE UFAD Cooling Design	✓	✓	
CELLAR		✓	
Cep. Man-t Soft. for Buildings	✓		N/A
CHP Capacity Optimizer		✓	
COMFIE		✓	
COMSOL		✓	
Cymap Mechanical			
CYPE-Building Services	✓	✓	
Czech Nat. Calc. Tool			
D-Gen PRO		✓	
Delphin	✓	✓	
Demand Resp.Quick A.T.			
DEROB-LTH		✓	
DesiCalc			
Design Advisor	✓		14
DesignBuilder	✓		2
DeST		✓	
DOE-2	✓		2
e-Bench		✓	
EA-QUIP			
Easy EnergyPlus		✓	
Eco Designer	✓		N/A
ECOTECT	✓		2
EE4 CBIP			
EE4 CODE		✓	
EED		✓	
EN4M		✓	
ENER-WIN	✓	✓	
EnerCAD	✓		5
Energy Expert			
Energy Profile Tool			6
Energy Scheming	✓		
Energy Usage Forecasts			
EnergyGauge Summit Pr.	✓		35
EnergyGauge USA		✓	
EnergyPlus	✓	✓	
EnergyPro	✓	✓	
EnergySavvy			
ENERPASS		✓	
eQUEST	✓	✓	
eSight			
ESP-r	✓	✓	
EZ Sim			
EZDOE	✓		N/A
FEDS			
flixo			
FLOVENT		✓	

Table 1. Comparison of existing programs suitable for energy evaluation of a whole building Part 2.

1	2	3	4
Flownex		✓	
Frame Simulator	✓		1
FSEC 3.		✓	
Gas Cooling Guide PRO	✓		8
Genability		✓	
Ground Loop Design	✓	✓	
HAMLab		✓	
HAP		✓	
HEAT2		✓	
HEED			
Home Energy Saver			
HomeEnergy Suite			
HOMER		✓	
HOT2 XP	✓		3
HOT2	✓		2
Hydronics Design Studio			
IDA Indoor Climate and Energy			
IES Virtual Environment	✓	✓	
ION Enterprise		✓	
LESOCOOL	✓		5
LESOSAI	✓		2
Market Manager			

1	2	3	4
MC4Suite 29			
Micropas6		✓	
ModEn		✓	
NewQUICK	✓		N/A
OptiMiser		✓	
OptoMizer		✓	
ParaSol	✓		14
PHPP	✓	✓	
Physibel		✓	
Polysun		✓	
Popolo Utility Load Calculation			
PsyChart		✓	
PVcad		✓	
QwickLoad			
Recurve			
REM/Design		✓	
REM/Rate		✓	
Right-Suite Res-l for Windows		✓	
RIUSKA		✓	
Room Air Cond-r Cost Estimator			
scSTREAM		✓	
SIMBAD B-g and HVAC Toolbox		✓	

1	2	3	4
SLAB		✓	
SMILE	✓	✓	
solacalc	✓		3
SOLAR-5	✓		N/A
SolArch	✓	✓	
SolarShoeBox	✓	✓	
SPARK		✓	
SUNDAY		✓	
SUNREL		✓	
System Analyzer			
TAS	✓		N/A
TEK-sjekk	✓		N/A
TOP Energy		✓	
TRACE 7	✓	✓	
TRANSOL		✓	
TREAT		✓	
TRNSYS	✓		7
tsbi3		✓	
VIP+	✓		15
VIPWEB	✓		5
VisualDOE	✓	✓	
ZEBO	✓		2

Comparison results:

overall listing software – 132
architects mentioned as target users – 49
software requiring technical expertise – 69

2.2 EcoDesigner

2.2.1 Appearance and development

Originally EcoDesigner was released in 2008 as add-on for ArchiCAD (starting version 13). Graphisoft intended to provide information on building's energy performance and to give fast feedbacks to architects on efficiency and sustainability of various design alternatives. The feature was supposed to support architects' inclinations towards more energy-efficient and sustainable design. Format-conflict problems were solved as both drawing and simulation processes took place within the same program with the same interface.

Starting ArchiCAD-16 EcoDesigner package ceased being an additional option to purchase and was embedded into the core of the program. The newest version of ArchiCAD-17 that is under examination in this thesis has been released in July 2013 and provides a more elaborated reflection of the same idea: to integrate energy evaluation process and to bind it directly with project development. Graphisoft declares to provide support for sustainable design solutions on every stage of design process. Integrated EcoDesigner package enables users to perform preliminary evaluation process on the Conceptual stage and the stage of Design Development free of charge. For these purposes users don't need to buy or install anything additionally.

The major difference between ArchiCAD versions 16 and 17 in regard of EcoDesigner evolution was providing of both integrated and supplementary (commercial) versions of the tool. The last is substantially enriched with energy evaluation possibilities and exporting options. The add-on named EcoDesigner STAR after installation works on the same platform as the standard EcoDesigner. This Graphisoft tool is considered an extra-feature for energy evaluation; it is not included into the basic set of ArchiCAD-17 and is supposed to be purchased by users separately if they want to cover the last Detailed Design stage of the project. Simulation with EcoDesigner STAR takes place within the same ArchiCAD window and doesn't require any additional export.

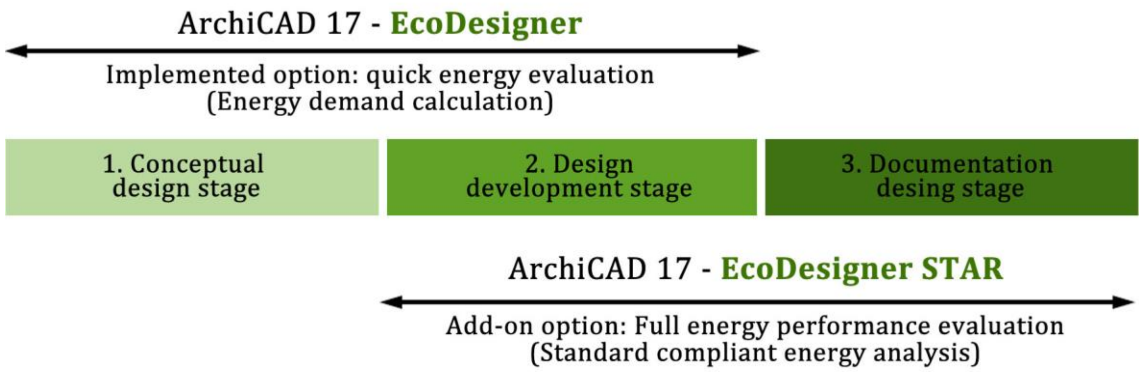


Figure 2: Comparison of free and commercial EcoDesigner editions for ArchiCAD-17

(Graphisoft 2013)

Graphisoft EcoDesigner STAR provides a standard-compliant energy analysis suitable for submission to the local authorities (Graphisoft 2013). It uses dynamic energy analysis and delivers data characteristics on energy demands of the developed building. As the main topic of thesis is energy evaluation on the concept design stage, the add-on will be discussed in a relatively narrow form in the corresponding following part. Brief quality comparison of standard and advanced editions of EcoDesigner features will also be provided.

2.2.2 Technical background

EcoDesigner uses StruSoft VIP-core calculation engine to perform energy evaluation. Results reflect parameters of different thermal blocks of the building as well as physical parameters of defined materials and structures. EcoDesigner also takes into account physical location of the building predefined by user and the corresponding local climate data. Relevant energy prices might be used to obtain the preliminary indicators of heating and cooling costs.

The evaluation results might be exported into the following formats: PDF, XLS and IFC.

Following major parameters represent general characteristics of EcoDesigner (U.S. Department of Energy, 2013).

Validation/Testing: Underlying VIP engine of EcoDesigner by is ASHRAE 90.1-2004 compliant but the program itself (basic version) is positioned just as an assisting tool for architects with no validation.

Expertise Required: None. Any architect familiar with ArchiCAD can run the software.

Users: Starting introduction of EcoDesigner in May 2008 several thousand AEC professionals resorted to use the software.

Audience: Architects and designers

Input: The main source of evaluation is the 3D architectural model. User can establish necessary settings and refine them using graphical interface or through XML system files.

Output: Key values within the report present basic data generated by building geometry analysis (area, volume, etc.) monthly energy balance and CO2-footprint.

Computer Platform: Starting ArchiCAD version 17 a 64-system is required to operate the software. EcoDesigner is supported both by Mac OS X 10.5-10.6 and Windows XP, Vista, 7.

Programming Language: C++

Strengths: EcoDesigner is integrated into the core design software so there is no data exchange needed.

Weaknesses: EcoDesigner does not do energy certification (basic version).

2.2.3 Calculation Engine Specification

EcoDesigner employs the same simulation kernel as the VIP Energy product – an application used for energy performance simulation and calculation of the energy balance. VIP-Energy has been validated with more than 20 years of research and the following tests: EN-15265, IEA-BESTEST, ASHRAE-BESTEST (ANSI/ASHRAE Standard 140-2001) and StruSoft-BESTEST.

The VIP energy simulation software module relies on dynamic simulation where the calculation is repeated every hour. Evaluated model is divided into simplified levels where physical characteristics of the envelope as well as potential external and internal gains are known. Accuracy has been validated on existing buildings under conditions of real usage (Strusoft 2013).

Calculating energy consumption EcoDesigner takes into account measured or user-defined facts on all the parts of the energy flow (Graphisoft 2012). The flow is analysed with consideration of temperature, sun, humidity and wind. Other factors in the simulation include room temperature requirements, air change rate, internal heat gains and application of a range of possible systems (solar panels, ventilation units, heat pumps, cooling systems, etc.).

2.3 Supplementary energy evaluation possibilities in ArchiCAD

Notwithstanding the fact that the embedded energy analysis is the core topic of the thesis it is worthwhile to recall all the existing possibilities of ArchiCAD users in the field of energy evaluation. Brief analysis of available options emphasises advantages of integrated Energy analysis.

Key feature that allows ArchiCAD's interaction with external software is that once model has been created in a way that suffices integrated analysis, it automatically becomes suitable for export to stand-alone applications. Model prepared for simulation includes zones with the recognized openings, bounding surfaces with corresponding U values, exterior shading devices and building location and orientation information. There are two file formats available to export data from ArchiCAD to energy analysis applications: IFC and Excel.

Specialists working with applications based on the IFC- file import option should create a custom IFC translator in ArchiCAD. Settings should be defined the way to satisfy input requirements of each application. The option makes ArchiCAD compatible with, for example, EDSL TAS and EnergyPlus.

Usage the Geometry Data page of the result Excel table enables transferring data into other energy calculation software such as third-party Excel spread sheets that utilize simplified stationary energy calculation algorithms. EcoDesigner Energy Performance Evaluation XLS Report might serve for the same purpose.

Other option of model's recognition within stand-alone energy evaluation software is application of special add-ons that provide export and merge functions. One of them allows cooperation with ArchiPhysik. The picture below illustrates all the currently possible energy evaluation options for models created within ArchiCAD.

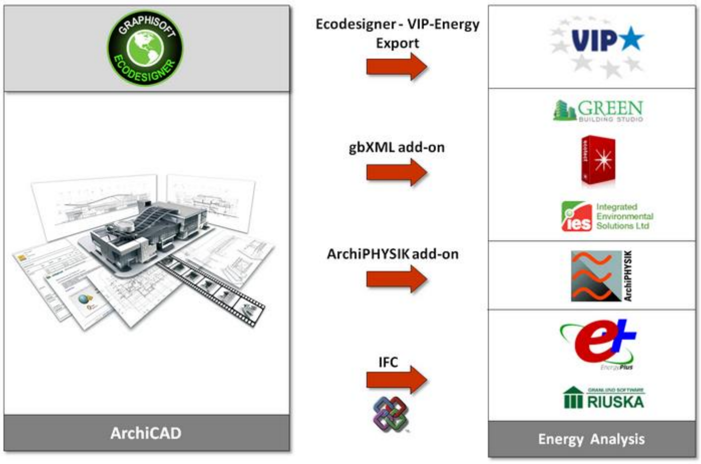


Figure 3: Supported Energy Analysis Applications

(Graphisoft 2013)

It is important to add that possibility to transfer the modelled data might facilitate energy evaluation process but doesn't always guarantee a smooth workflow. Several export methods have been tried out in a course of work on the thesis. For instance, transferring to ArchiPhysik provides a fully recognized building geometry. All the U-values however prove to be lost during the process and need to be reapplied. Export to EDSL TAS by means of saving the file into IFC-format creates multiple geometry failures and in cases with a relatively complicated design leads to almost complete recreation of the model.

3 CRITERIA FOR EVALUATION

Following Attia's methodology for determination of software's potential to assist architects during the process of net-zero energy buildings' development two sets of parameters have been chosen (Attia 2011). Those include Mechanics and Matrix evaluation and are described below.

3.1 Mechanics evaluation

The first set of parameters addresses general mechanics of EcoDesigner. Examination of criterions presented here is essential to evaluate tool's usefulness.

- Usability and information management;
- Intelligence and integration of design knowledge-base;
- Interoperability of building modelling;
- Process adaptability;
- Accuracy and ability to simulate complex building components.

3.2 Matrix evaluation

The second set of evaluation parameters reflects tool's matrix. Those have been determined by the IEA Task 40/ECBCS Annex 52 for the sake of comparing the capabilities of simulation programs (Bourdoukan et al. 2011). Six benchmarks presented below are supposed to cover basic aspects architects address in the beginning of project's development (Attia 2011):

- Metric
- Comfort Level and Climate
- Passive Strategies
- Energy Efficiency
- Renewable Energy Systems
- Innovative Solutions and Technologies

4 SOFTWARE DESCRIPTION

4.1 General principles

In the beginning of simulation process with EcoDesigner user would need a model created within ArchiCAD-17 platform. A model created in earlier versions of the software might be easily recognised and used for further evaluation. The whole process takes place within the same ArchiCAD window where users work on design. Basically speaking, EcoDesigner is represented as a set of toolbars in ArchiCAD interface.

In the first step Zones and Environmental Settings are applied to the building model. Zones define volume of every space and reveal structure types for further analysis – in other words, they might be regarded as a mean for EcoDesigner to “understand” which of the existing structures are walls, slabs etc. and how to divide them into internal and external parts of construction. Afterwards created zones should be assigned to Thermal Blocks – groups of zones characterised with similar orientation, purpose and applied building systems.

Environmental Settings stand for definition of location and thereafter climate. They also supplement the delineation of geometry by defining grade level and thus dividing the recognised structures into those above- and below ground.

At the second step of the process EcoDesigner automatically recognises geometry of the model and divides envelope into structures and openings. Internal structures are also being recognised and are presented in the general listing as adiabatic constructions. They have no impacts on calculation results.

At this phase user assigns physical properties to constructions, windows and doors either choosing among existing ones in a predefined catalogue or creating additional variants manually. The process will be described in details in following chapters. Changes brought into model’s geometry are instantly recognised and find its reflection in project’s evaluation.

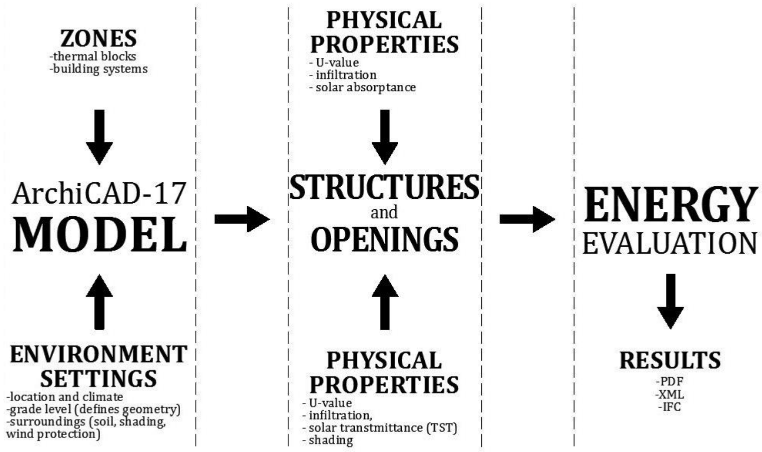


Figure 4: Schematic illustration of EcoDesigner energy evaluation steps.

The third and the last step of the energy evaluation process in EcoDesigner framework is running of the final evaluation and exporting results into one of the available file formats: PDF, or XLS.

4.2 Modelling conventions

Several modelling conventions that will be discussed in this part were either mentioned in the official EcoDesigner tutorial or been experimentally derived during performing calculations for buildings of various complexity levels. Users are strongly advised to follow the guidelines for the sake of accuracy of the following calculation process (Graphisoft 2012).

Energy model review contains only visible elements. All unnecessary building parts such as furniture, lamps should be hidden in the layer panel. The option might also be used to customize evaluation process in case there are several buildings on the site. Thus several buildings modelled within the same file may be evaluated separately if required. In this case zones belonging to different buildings should be assigned to different layers. By turning layers on and off user can include and exclude various volumes to and from calculation. Layers' combinations might be saved in Layers Settings and afterwards accessed within a single click.

User should model the enclosed building structures and openings as well as the major internal structures and partitions that represent heat storage mass to run energy evaluation. ArchiCAD zones must be placed in every conditioned place of the building since the model geometry analysis is based on these 3D-ArchiCAD zones.

There are at least two ways of creating complex building envelope in ArchiCAD. Both are intensively used by professionals on various design stages. One is to use the existing tools (Wall, Slab, and Roof) separately for each layer of the composite structure. During the process each layer is defined with a certain weight, height and building materials' properties that represent physical parameters of the calculated structure.

The second way is assigning composite properties to a single wall element. Thus fills with proper weights will stand for corresponding composite layers within a single wall element. This way allows users easily change composites' parameters in Composite Structures Manager and it is strongly recommended for energy evaluation process (Graphisoft 2012). At least one layer of the existing composite structure should be adjacent to the internal zone boundary.

Empirically it has been established that whenever a composite slab or wall is modelled by means of several slabs put on top of each other instead of using a single ArchiCAD composite structure the results of calculation start to vary significantly. EcoDesigner recognises only the structure directly adjacent to the 3D-Zone. This means that in case when wooden finish on the floor is modelled as a lone slab, EcoDesigner's calculation engine will consider it the only one obstructing surface between the heated space and the ground. All the layers of insulation and concrete will be disregarded in calculation which will lead to significant errors in performance evaluation results.

Starting with ArchiCAD-17 building materials are assigned to the skins of composite structures and construction elements instead of cut fills. The appropriate and consistent use of building materials is crucial for creating accurate energy analysis reports. Building material combines three types of properties: colour (texture) of the material that defines the way it appears in 3D-window, a corresponding cut-fill that defines the way the material is represented in plans and sections and physical properties (thermal conductivity, density and heat capacity). The system allows ensuring correct graphical representation of materials both in drawings and 3D-views and consistent application of thermal properties through the project.

The connection of the ground with the building can be modelled in two different ways. Complex site geometry that divides above- and underground building spaces should be defined using Mesh tool. In cases when the site geometry is planar or the slope is insignificant, ground level might also be set manually by a simplified value input.

As it was mentioned before, 3D-Zones need to be created in every conditioned space of the building. They might be created either manually or automatically. The second way is more preferable as in course of work EcoDesigner tends to display warnings on not updated zones whenever geometry alterations have been applied. In such cases user needs to be able to update zones quickly and automation of this process is possible only with correctly adjusted automatically-built zones. Such an automation of the process will also guarantee the envelope being closed as ArchiCAD doesn't allow building zones automatically in not confined spaces.

4.3 Energy model review

Energy analysis in ArchiCAD-17 does not require any exporting operations or installation of additional software. When the model is ready for further step user is supposed to open a 3D-window and to activate the Energy Model Review menu. The Energy Model Review palette is the main window of ArchiCAD's energy evaluation function. Running evaluation from the 3D-window is optional but it provides users with clear and direct information regarding chosen building elements and geometry errors.

EcoDesigner turns the ArchiCAD building information model (BIM) into a building energy model (BEM). ArchiCAD analyses visible structures and openings according to their orientation and position relative to the zones that represent the internal spaces. The appearing Energy Review Pallet contains separate structural and opening lists in two separate tab-pages. The recognised space boundaries appear in the presented list. All the space boundaries identical in terms of ArchiCAD BEM-data types are aggregated into single structures' list and appear as a sum of their areas within the pallet. Thus, for example, areas of all the external walls facing east that have the same composite structure and position in relate to the ground will be summed up and listed as a one element.

The pallet itself allows users to access basic parameters for energy evaluation (including Environmental Settings, Climate Data, Operation Profiles, Building Systems, Energy Source factors and Energy Costs) via settings button and to navigate through selected items such as walls and windows in 3D. The same pallet contains the Update-Command for zones and for energy model. Those commands ensure that the energy model reflects up-to-date state of the ArchiCAD model. As it has been declared EcoDesigner updates the energy model parallel to design process (Graphisoft 2012). In some cases it has been empirically established that sometimes bugs in the software prevent recognition of the performed changes and user has to update the energy model manually to achieve the full recognition.

4.4 Environment settings definition

Environment settings dialogue box in EcoDesigner contains several groups of parameters. Those allow defining project's location with corresponding climate and various types of surroundings. Presented options comprise predefined data types between which user might choose those that suite the best and thus to create a rather precise picture of project's environment. In the same window, in the External Shading sub-dialog box, user can set up the effect of shadows cast on each elevation of the building by external objects. Those are taken into account while calculating the effect of indirect solar radiation.

Grade level settings influence the output of the Automatic Model Analysis by determining which structures are classified as Shell Element above the grade level (Roofs, Slabs, External Walls) and which belong to Elements in Contact with Ground (Slabs facing Ground, Basement Walls and Floors).

4.4.1 Location and climate settings

Project Location box allows to input Name and Address as well as Latitude and Longitude of the object or to choose a city from the pop-up list. The same window provides a connection with Google Maps for user to observe the established position and to change it when needed. Change of Project Location affects the Sun position. North can be set in the same window. All the settings might be exported to an XML-file or imported from another project.

ArchiCAD downloads the Climate Data from the Strusoft climate server automatically. User can also download climate data manually from other servers and use ASHRAE IWEC, TMY or WTEC2 files for the purpose. Climate Type pop-up window provides a choice between Moist, Dry and Marine options.

In the bottom of the dialog box various charts illustrate the climate fluctuations over the course of one year. User might choose the type of data to observe (temperature of air, relative humidity, solar radiation and wind speed) and the level of details for the climate chart (month, day, week and hour). Wind speed option allows visualising the wind data in wind-rose form. Below the graph maximum, minimum and average values of the chosen data type are listed. Once the weather data is assigned to a certain project, it is stored in the ArchiCAD Cache Library, so the data remain available even if the computer is not online.

ArchiCAD allows creating picturesque data charts and provides an easy access to calibration of corresponding parameters. Nonetheless navigation through the chart itself as well as its export possibilities is extremely poor. For instance graphical representation of such a scale doesn't allow any digging into details. It could have been expected to highlight concrete values for chosen time-periods while navigating through the graph and no such option is accessible. It is also impossible to change scale of the graph or to export it in any other way but by making a screenshot.

4.4.2 Ground level and soil type

There is a possibility to establish the ground level in two different ways in ArchiCAD. Correct definition of terrain contour is necessary for EcoDesigner for recognition of structures' types.

The first method uses defined offset distance that should be input in the Environmental Settings dialogue box. Technically it has a direct connection with pre-established Project Zero and ArchiCAD Storey settings that users set up in the beginning of every project. This method is used for simple buildings with flat sites. The horizontal plane cuts building structures and divides them into those below- and above grade.

The second method uses Mesh Elements to define the grade level. For the purpose the corresponding check-box should be marked in the Environmental Settings dialogue box. In this case EcoDesigner uses geometry of mesh built by user to divide structures and allows precise evaluation of the created construction even with complex slope geometry. Example presented below illustrates the case of automatically recognized above- and below ground structures *(Fig. 5*). Here the mesh element is used as a kind of smart filter.

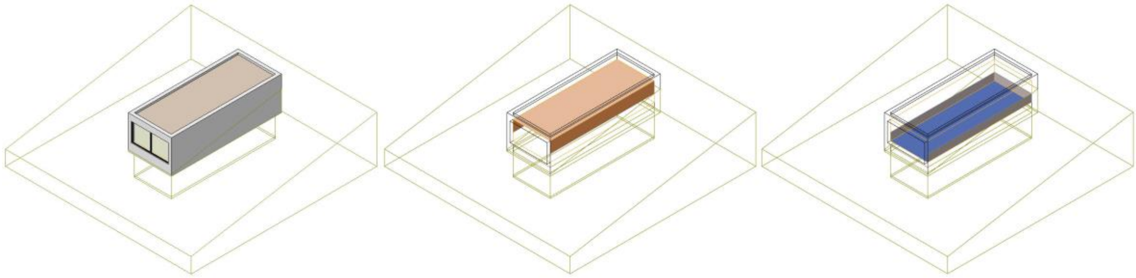


Figure 5: Geometry recognition using mesh element

Initial geometry (left); at- or above grade structures (middle); below grade structures (right).

EcoDesigner provides an opportunity to define a Soil Type. User can choose between gravel, sand, clay, silt, rock etc. Each of the parameters has a corresponding Thermal Conductivity, Density and Heat Capacity levels that are predefined within the software.

4.4.3 Surroundings

User has an opportunity to choose between various surrounding options (Paved, Garden or Waterfront), to set wind protection and to define external shading devices for each side of the building. The settings serve as a basis for calculating heat flow through structures in contact with the ground. During the following energy evaluation these parameters influence outer heat capacity values and thus find their reflection in energy demands and the CO2-emission level.

In the example below the same building geometry has been evaluated with varying soil type, wind protection and external shading settings. Internal conditions also remained unchanged. Objective of the experiment was to find out to which extent changes in surrounding settings may alter the outcome results.

Building chosen for the analysis represents simple geometry with a relatively low glazing ratio (7%). Internal area equals 70 m^2, ventilated volume – 175 m^3. Average U-value of external structures is 0.30 W/m^{2}K. Buildings of the similar complexity with the same physical properties of building materials will be used in the following part (Performance Study) of the thesis as a mean of EcoDesigner's usability evaluation.

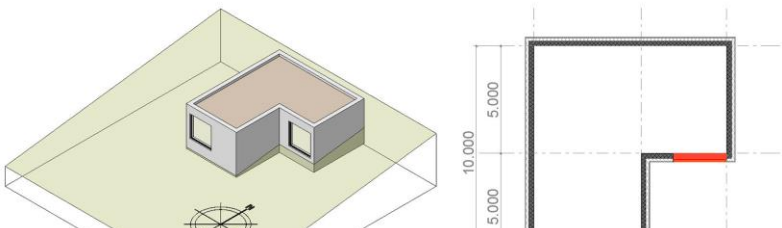
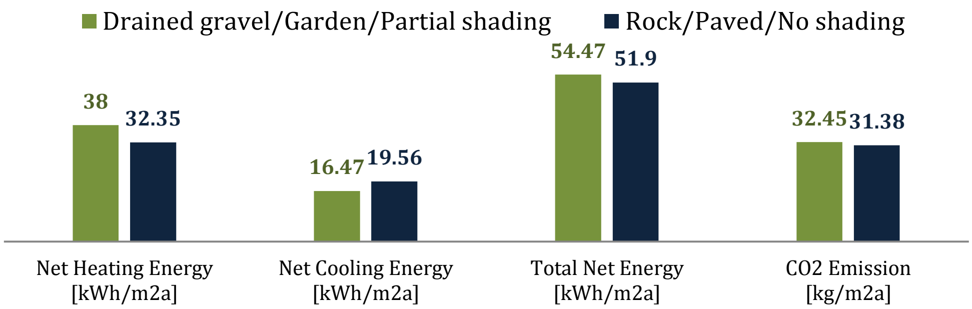


Figure 6: Impact of surroundings' parameters: analysed building geometry.

Case A was defined with a drained gravel terrain, garden surroundings and considerable solar and wind protection. *Case B* represents unprotected building in the paved area with the rock soil type. In comparison with *Case B* the simulation results of the *Case A* illustrate higher energy demands for heating (38 kWh/m²a) and lower (16.47 kWh/m²a) – for cooling. In this particular example lower heating demands of *Case B* lead to better performance results of the unprotected building. Wind protection and shading devices here provide a 5% difference of the resulting parameters. *Table 2* contrasts the resulting values and outlines the impact of surroundings' definition.

Table 2: Difference of evaluation results depending on surrounding definition



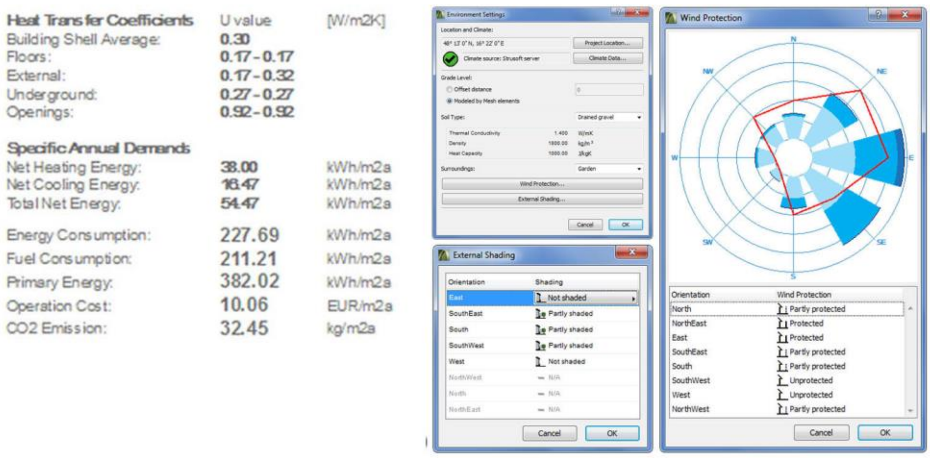


Figure 7: Case A, Surroundings' analysis
Drained gravel terrain, garden surroundings and sufficient solar and wind protection.

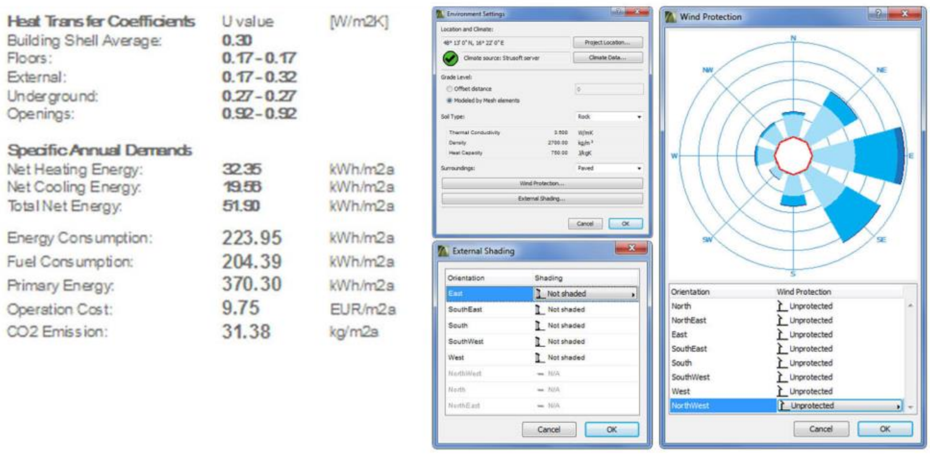


Figure 8: Case B, Surroundings' analysis. Paved area with no solar or wind protection.

4.5 Zones' parameters:

Zones must be adjoining to the surrounding element surfaces. This means that user should manually define the height and level for each zone. Those, unlike zone's contour in plan, cannot be established automatically. Top surface of each zone should touch the inner surface of neighbour slabs but never to intersect them. Intersection will lead to following warnings as the program won't be able to recognise the construction. In case of the complex roof/floor geometry zones might be trimmed in accordance with user's needs. Trimming provides full recognition of the composite structure and correct calculation of the space's volume. It is however essential to adjust separated zones for every separate floor of the building. The same concerns atrium-like spaces which for the sake of accuracy should be modelled with separate zone stamps on the related levels.

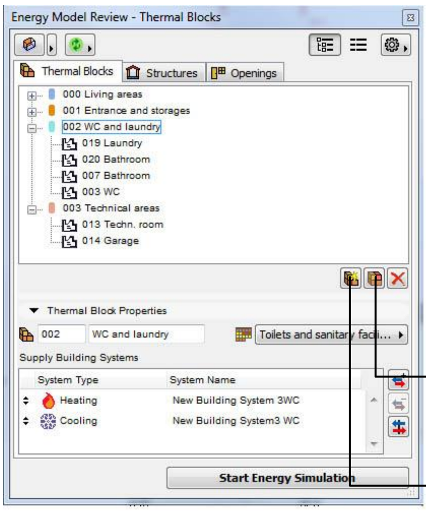
4.5.1 Thermal blocks

Thermal block is a collection of one or more rooms and spaces in a building that have similar cooling and heating conditions predefined by user. These spaces are represented by 3D-zones in the ArchiCAD model and they are grouped together for simulation purposes. Actually no zone with adjacent parts of the envelope is recognised within EcoDesigner before it is added to some thermal block.

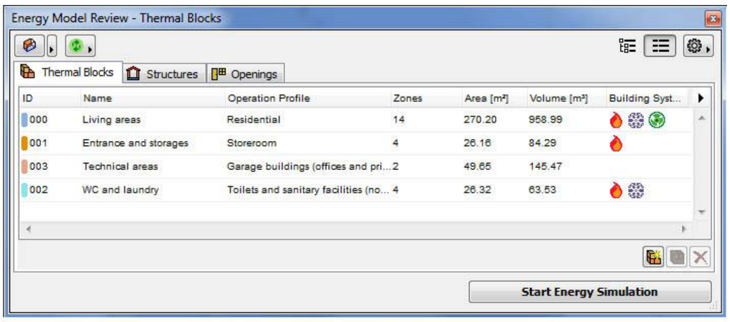
Spaces don't need to be contiguous to be combined within a single thermal block. Amount of thermal blocks is unlimited; users can create new or modify the default one if they are up to a simplified version of simulation with a single thermal block as an input. Properties of Thermal Blocks are defined by the user; their geometry consists of one or more ArchiCAD zones. Each Thermal Block (e.g. Stairwell, Office, Basement, Technical Area) typically has its own energy characteristics.

The energy model list-type review window displays a total amount of thermal blocks with zones assigned to each one of them, sum area and volume of the included zones and specified building systems – this last option is described in the following part of this thesis. Tree-type review pallet presents information about assigned operation timetables, names of all zones. It allows assigning and removing zones to/from thermal blocks as well as between them by drag-and-drop function and provides an opportunity of creating/renaming of thermal blocks.

Tree-type review.



List-type review.



Assigning zones to existing thermal blocks button displays a full listing of zones created within a project and allows to sort out un-assigned ones.

New thermal blocks creation button.

Figure 9: Thermal blocks listing.

3D-view of the building energy model allows navigation through selected thermal blocks and provides an additional mean of maintenance of assigned zones. Zones of the selected thermal block entry are highlighted with a corresponding colour.

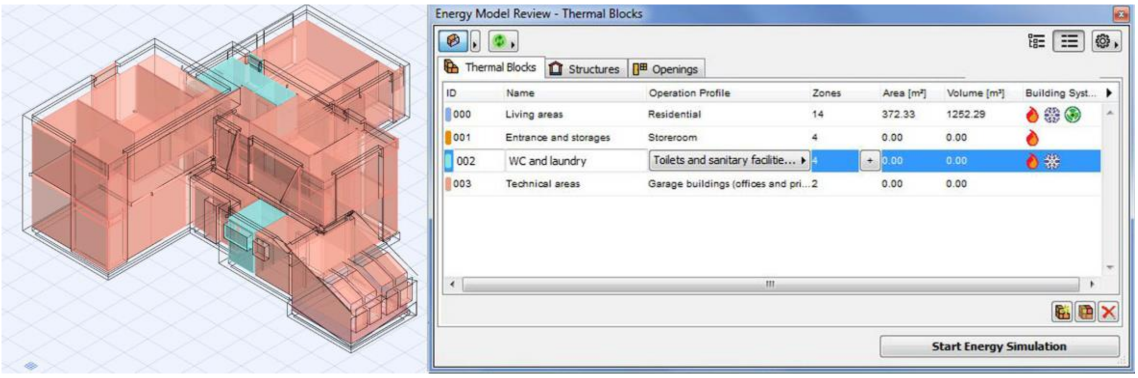


Figure 10: Thermal blocks' representation in 3D-window.

The described option of sorting out zones into logically diverse groups is a newly-appeared option advertised by Graphisoft as one of the ultimate features to simplify energy evaluation within EcoDesigner package. Expanded possibilities are supposed to take advantage of detailed data provided by multiple thermal blocks instead of the single-block method used in ArchiCAD 16 (Graphisoft 2013).

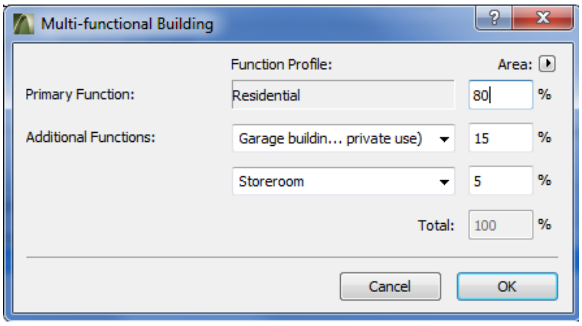
Currently it is possible to exclude areas like ventilating shafts or lifts from general calculation whenever needed. To do this user has to assign them to unconditioned internal spaces. The option proves to be valuable in cases with multi-task projects and complicated technologically-justified planning schemes. In general the feature contributes to the accuracy of model input and thus to the precision of energy evaluation.

4.5.1 Operation Profiles

The Operation Profile is an EcoDesigner attribute, assigned to each thermal block of a building that connects predefined schedules to each Occupancy type, by Hour, for a whole year. Custom Operation Profiles is a new implementation of ArchiCAD version 17. Preceding versions of EcoDesigner didn't support specified timetables with required internal conditions for each thermal block. The only option for ArchiCAD-16 and earlier versions was definition of percentage distribution of all the functions available within the building.

In EcoDesigner assignment of corresponding profiles might be done through the main Energy Model review window. Selecting a certain thermal block with all the zones included user gets information on defined operation profile – it's being displayed in the middle part of the window. Lower part of the window illustrates building systems connected with the same thermal block. Timetable of their work is directly defined by operation profile and its requirements. Building systems' parameters are described in the following chapter.

Operation profiles in AC-16.



Operation profiles in AC-17.

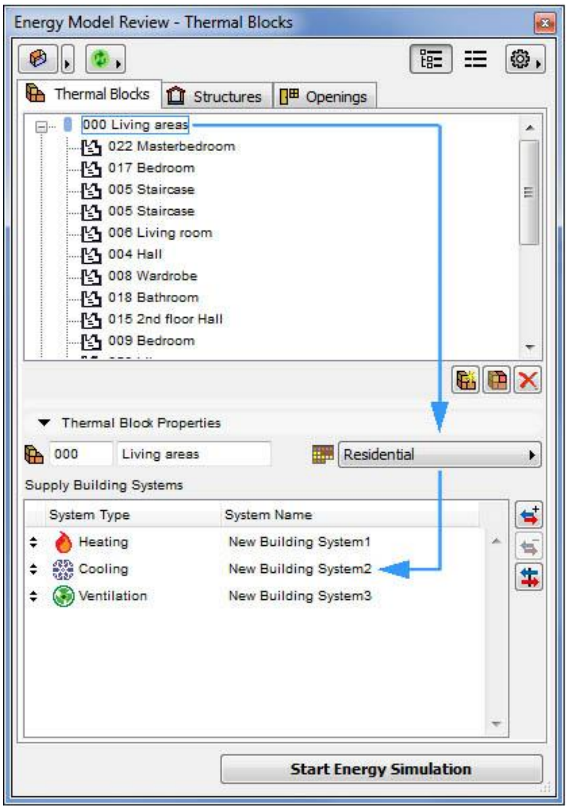


Figure 11: Assignment of operation profiles.

Comparison of possibilities in ArchiCAD versions 16 and 17.

Each Operation Profile is associated with a daily schedule comprising the following data, by hour, for a full year (8760 hours total):

- Required internal temperature range
- Human heat gain
- Hot water needs
- Humidity loads

There is a wide range of predefined Operation Profiles that user can supplement with custom ones whenever needed. Operation Profiles window might be conditionally divided into three parts where the top – the biggest one - contains information on all available profiles, both default and created by user. List of default profiles includes conference halls, auxiliary, canteens, garage, hospital, hotel room, auditoriums, storerooms, unconditioned spaces and many others. In case user decides to resort to existing, he needs to pick the operation profile that best fits the selected thermal block's function from the list of available defaults. These default values reflect the Operation Profile specifications of the DIN 18599 Standard – Energy Efficiency of Buildings.

The Middle part of the window provides data on occupancy for each chosen profile. It can be changed manually both for default and for newly-established profiles. The last part leads to timetable definition and schedules' graph.

Occupancy Data contains information on the occupancy type and various sorts of gains corresponding to the chosen profile. Occupancy type might be defined either as Residential or as Non-residential. Human heat gain stands for the amount of heat produced by the human bodies in the building (W/capita). Service hot-water load represents the amount of hot water necessary per person, as associated to the selected building function (l/day, per capita). Humidity Load is the amount of water vapour that gets into the internal air as a result of the building's operation (l/day). Parameters are taken into account by the engine for calculation of internal heat loads (Graphisoft 2013).

Each operation profile has a corresponding operation timetable. This can consist of one or more daily schedules since the usage data might vary by day of the week and over the course of the year. For each daily schedule user can define Recurrence (days of the week when the particular schedule is in effect) and Date Range (periods of the simulation year). Recurrence and Date Range define the In Use hours - the total number of hours during which the selected Daily Schedule is in effect.

Operation profiles reflect varying parameters of performance (required internal temperature, occupancy count and equipment gains) in dependence on time period. The last column reflects the amount of active (In Use) hours for each schedule. Sum of In Use-hours of all the schedules within operation timetable must be equal 8760 – total amount of hours in a year. Otherwise EcoDesigner will inform user on so-called "uncovered" hours within the calculation. In case user assigns intersecting schedules the notion "Overlapped" will appear as well as the number of overlapping hours that needs to be corrected.

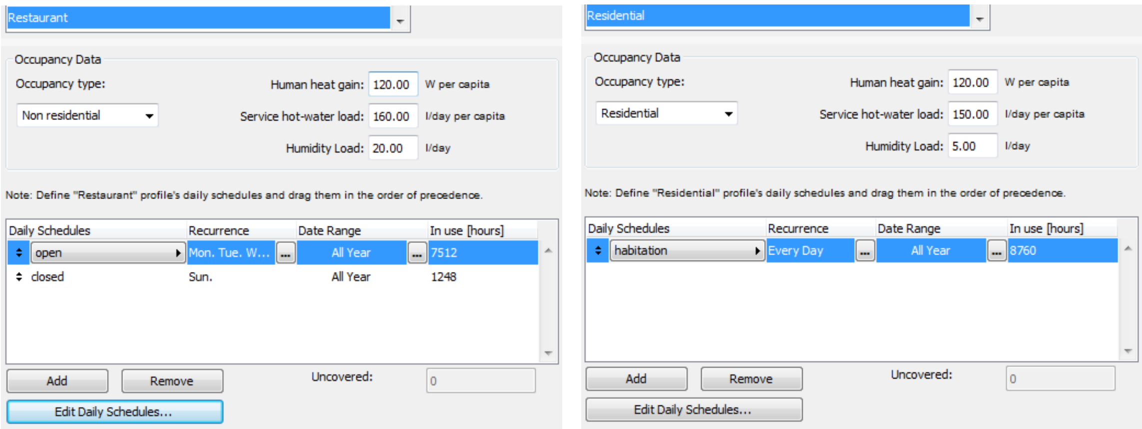


Figure 12: Examples of predefined operation profiles - Restaurant and Residential.

Examples presented above *(Fig. 12)* illustrate combined schedules of two predefined profiles with ultimately opposite functioning types: residential building and a restaurant. "Open"-schedule within a Restaurant profile has its own subdivision into working (11am – 24pm) and non-working hours with corresponding required internal temperature, occupancy count and equipment gains. This information is called Daily Schedules; it has a graphical representation *(Fig. 13)* which can be accessed and edited (Edit Daily Schedules button). The upper part of the graph illustrates the required temperature values while the lower part stands for the combination of internal heat gains. Horizontal axis of each graph is a time line divided into 24 hours.

Residential building has a single schedule assigned to it – obviously because of no need to divide operation profiles into weekdays and weekends. The daily timetable graph illustrates a more complicated approach *(Fig. 14)*. From 23 pm till 6 am no maximum or minimum temperature is established and of all the internal heat gains only the occupancy count is set to 30 m^2 per capita. From 6am to 8am required temperature sets the limit between 20 and 26 C^0 and the lightning gain from compact fluorescent devises (user might choose between several options here) is set to 3 W/m^2. From 8am till 18 pm temperature requirements and occupancy count stay unchangeable while lightning is temporary turned off to reappear in time from 18pm to 23pm.

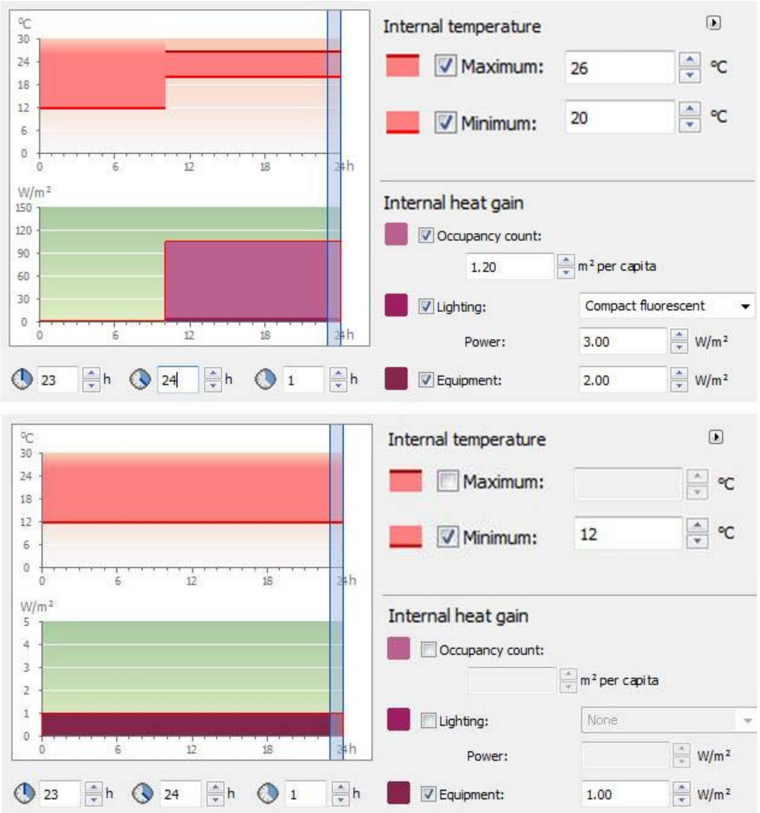


Figure 13: Daily schedules for Restaurant profile.

Open (top) for weekdays and Closed (bottom) for Sundays.

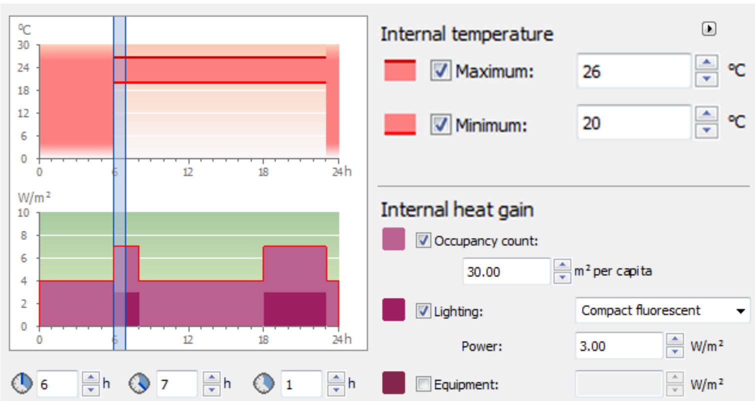


Figure 14: Daily schedule for Residential profile.

Schedule editor dialog box displays two daily occupation profile graphs with corresponding key values to the right of each graph. These are used to specify the required Internal temperature range, Occupancy count, Lighting power density (LPD, in W/m^2) and Equipment power density (LPD, in W/m^2) – parameters necessary to calculate the Internal heat gains. Theoretically, it is possible to define different operation conditions for each hour of the reference year.

Like in majority of energy simulation programs, internal temperature value allows to set the required internal air temperature range (maximum and/or minimum). Internal heat gain defines factors that result in energy emission (internal heat gain) during the day, per m^2 of internal floor area (W/m^2).

User is supposed to refer to local regulations to input the occupancy count value.

The default Power value (W/m^2) for the selected Interior Lighting type appears in the Power field when user selects a lighting type from the dropdown list. One can fine-tune the number manually if the lighting design of the project is available at the time of the evaluation. Equipment gain characterises the density of appliances (E.g.: TVs, Computers, servers) for the selected operation. Entering this value user is also supposed to refer to local regulations.

4.6 Building systems

The Building Systems pallet accessible from the Energy model review table is used to define settings that are supposed to maintain the predefined internal conditions for the thermal blocks of the evaluated model. Parameters of those conditions are specified by the Operation Profiles dialog box.

There are three types of building systems for user to navigate through– these include Heating, Cooling and Ventilation. User can either select from the defaults or to define custom Building Systems and to assign them to each Thermal Block. No more than one type of heating, cooling and ventilation systems can be assigned to a certain thermal block; EcoDesigner will show a warning note in case user tries to allocate several.

The Building Systems dialog box contains two parts – it lists all the Building Systems currently created in the project and the options available for each on them. In this pallet user can edit properties of existing building systems, create new ones and assign them to thermal blocks.

4.6.1 Heating

User has an opportunity to choose between “District Heating” or “On Site Equipment” heating options to describe the building’s heating system. District heating means that hot water or steam is coming through a pipe line from an external place. Here the energy source definition might take place to define the source or multiple sources of energy consumed by the heating system.

On Site Equipment option allows to choose one or more equipment types. Those include:

- Boiler or Furnace. User can fine-tune heater performance (Capacity and System Heat Loss) or use the default values.

- Solar Thermal Collector. In the panel user adds on all the required parameters for further calculation: solar panel type (flat plat or evacuated tube), target (heating, hot water, both heating and hot water), area, tilt angle and angle to south. Remarkable is the fact that notwithstanding the opportunity to insert solar panels into model as a library element EcoDesigner doesn’t recognise them automatically and requires this manual input.

- Water Heat Pump. User can specify system target and priority (by drag-and drop the list items in the desired order) as well as the source (soil, external air, sea, geothermal) and the refrigerant type. Heating output as well as heating factor (coefficient of performance - COP) requires a numerical input and the window provides no references on this option – only predefined values of 5000 W and 4.6 correspondingly.

4.6.2 Cooling

User has two options to define cooling building systems for the project. District cooling implies the possibility accessible in certain countries where the cooled air may be obtained from an external source.

"Cooling Machine" check box means that some type of cooling system is to be installed in the building. Characteristics button here allows editing the performance graph of the cooling system, defining cooling capacity (either in W or in Btu/hr) and dependence of heat factor (COP) on the external temperature.

4.6.3 Ventilation

User can specify the type of ventilation used in the building choosing between "Not Yet Specified or Natural" or "Mechanical Ventilation". Both of the ventilation types could be delineated with Steady Air Change Rate as well as Time Scheduled Air Change Rate.

"Not Yet Specified or Natural Ventilation" option involves no MEP systems: natural air currents drive fresh air into the building and used air out of it.

Mechanical ventilation option provides several variants to choose between: supply-only, exhaust-only and supply and exhaust systems. Heat Recovery feature presented as a check-box as the mechanical ventilation systems may or may not have air-to-air heat recovery units. User is supposed to decide himself (Graphisoft 2013). Air to air energy recovery system can regain a percentage of the heat content of mechanically expelled ventilation air. The feature becomes available if user chooses a ventilation system that involves mechanical exhaust.

As the Air Change Rate depends on national standards and function of the building user can either rely on the default parameters or define the number manually.

4.6.4 Energy Source

In the pallet user is able to specify energy sources (Natural gas, Propane, Oil, Wood, Coal, Electricity or Pellet) from a drop-down menu setting them up in percentage. If more than one energy source is available user may click the + (plus) button and then choose an additional energy source defining the proportion of each. On the figure below, the energy sources used available in EcoDesigner are listed according to their type and with their colours as displayed on the Energy Balance Evaluation report.

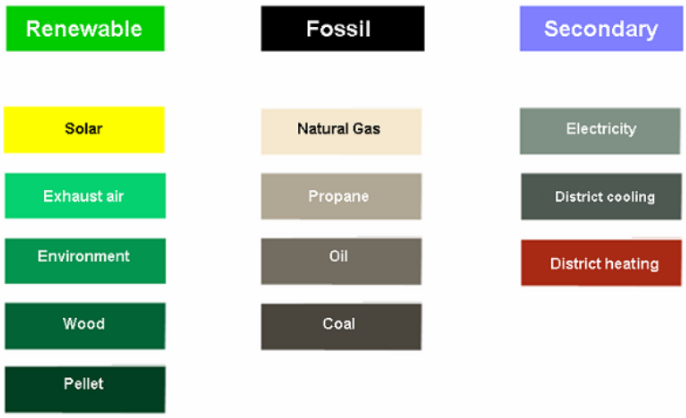


Figure 15: Energy sources types

(Graphisoft 2012)

4.6.5 Energy Source Factors

Definition of the energy source factors is available from the energy model review pallet and should not to be confused with the Energy Source Factors. Using this dialogue user can enter region specific data and thus to define the picture of power generation for a specific country. Here again user can define the building's source or multiple sources of electricity by clicking the + (plus) button and then defining the proportion.

In the pallet each listed energy source (Natural gas, Propane, Oil, Wood, Coal, Nuclear energy, Wind energy, Solar energy, Water energy or Unknown) has a predefined and unchangeable primary energy and CO_2-emission factors. These default values which vary in accordance with location of each project are based on standard DINV-18599.

4.6.6 Energy Costs

Energy Costs option allows specifying financial issues corresponding to each energy type defined in the project. These prices vary by location and therefore must be entered numerically by the user. Currency can also be changed. The input is optional but it allows calculating annual costs for the final review.

4.7 Structures' list:

Structures tab page of the EcoDesigner lists existing space boundaries of the building and defines them as external and internal structures with all the physical properties relevant to the energy simulation. The list is presented in a table-form with two kinds of data-types. The first type is established by the modelled geometry while the second one is defined by user.

4.7.1 Modelled properties

ArchiCAD model data type coming directly from BIM includes:

Orientation: the orientation of the analysed building element according to a predefined by user position of the building. North is supposed to be defined manually in the Environmental Settings pallet.

Thermal Block: assignment of the building element to a particular thermal block. In case the same building element borders several thermal blocks with various indoor-climate parameters it will be subdivided for the calculation automatically.

Space boundary category: building elements are given "false colours" and divided by location and orientation of the space boundaries in respect to the ground level. It consists of the following subcategories:

Walls:

- External (above the ground)
- Underground (shallow)
- Underground (deep)
- Internal

Slabs:

- Upward (valid also for Roof-element)

- Bottom (for example loggias and cantilevers)
- Floor (at or above ground)
- Floor (below ground)
- Internal

Element type: ArchiCAD element type like slab, wall or roof.

Complexity: complexity refers to parameter characteristics for wall-modelling in ArchiCAD. As the software allows creating straight, slanted or profiled walls, EcoDesigner recognises the geometry and highlights it in the table.

Name: the name stands for the composite structure type of the element. In the process of energy evaluation within the EcoDesigner combination of building materials gathered within a certain composite structure defines the general U-value of the building element. Physical properties might be chosen from Materials' Catalogue or established manually - the process is described in the corresponding part below.

Area: net-surface of the modelled element.

Thickness: thickness of the modelled element. Automatically is defined by sum thickness of composite structure.

4.7.2 Assigned properties

The second data-type consists of equivalent of physical parameters that either should be defined by user or might be changed in the course of evaluation.

U-value: the number refers to the heat transmission coefficient. By default it is calculated in accordance with assigned composite structure. The mechanism of U-value automated calculation built in EcoDesigner will be discussed in details below.

Infiltration: air-permeability of the selected structure might be defined manually. In previous versions of EcoDesigner the option was represented by a pop-up menu with four options to choose between. Those were Airtight (0,00 l/sm^2), Low (0,60 l/sm^2), Average (1,10 l/sm^2) and High (1,60 l/sm^2). Starting version ArchiCAD-17 user is supposed to make assumptions by himself. By default parameters for all building elements are set to "Average". EcoDesigner displays air leakage in the key-values section of the energy evaluation report.

4.7.3 Material catalogue

Materials in EcoDesigner are predefined elements with corresponding thermal properties that are supposed to be assigned to structures created in ArchiCAD. Material catalogue in is presented in a form of a table with four columns containing information relevant to energy evaluation. Subdivision within the catalogue is made the way to facilitate users' navigation through various types of building materials. Next to materials' names grouped by type columns with physical properties contain Thermal Conductivity, Density and Heat Capacity *(Fig. 16)*.

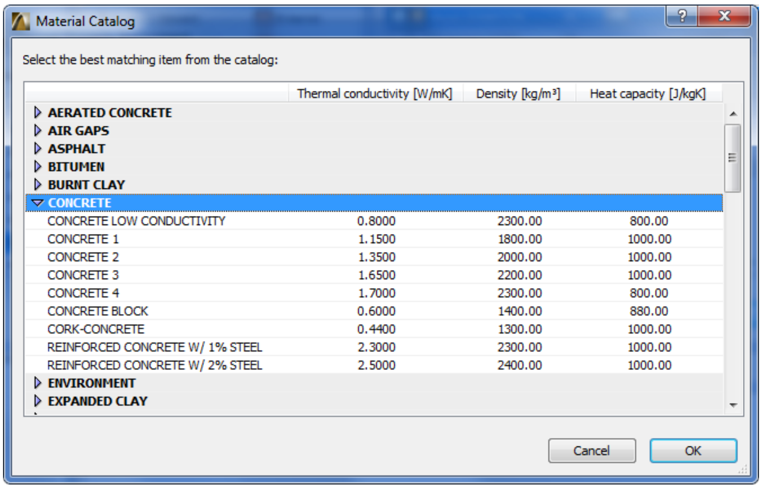


Figure 16: Materials catalogue

As straightforward as navigation trough the catalogue may appear even to inexperienced user, alterations of predefined building materials require access to the system file that defines catalogue's content. The file has an XML-format and is located in the energy evaluation add-on folder. User can access the file and customize it for each project in case the default database proves to be not sufficient. Text presented below is a part of materials' definition from the file:

```
<MaterialCatalog>
 <MaterialGroup Name="AERATED CONCRETE">
  <Material Name="AERATED CONCRETE BLOCK 1" ThermalConduct="0.13" Density="500" HeatCapacity="1290"/>
  <Material Name="AERATED CONCRETE BLOCK 2" ThermalConduct="0.16" Density="600" HeatCapacity="1240"/>
  <Material Name="AERATED CONCRETE BLOCK 3" ThermalConduct="0.18" Density="700" HeatCapacity="1210"/>
  <Material Name="AERATED CONCRETE BLOCK INTERLOCKING 1" ThermalConduct="0.11" Density="400" HeatCapacity="1350"/>
```

There is no possibility to choose one of several Material Catalogue files created while working on series of different projects. In other words it is essential that a single MaterialCatalog.xml file always remains in the folder. For the reason it might be recommended to store a copy of the default file somewhere outside the Add-Ons folder and to change or expand copies whenever it is required. Changes might be carried out through Notepad, WordPad or similar text editors.

4.8 Openings list:

The openings tab page of the energy model review pallet lists building openings with all the physical properties that are relevant to energy simulation. The openings' list is also presented in a table form and just like in the structures' display list each column represents a certain data type. Again data-types might be conditionally divided into parameters coming directly from ArchiCAD BIM and those that should be assigned by user. In this tab the second group is considerably larger and users' input is relatively wide.

4.8.1 Modelled properties

Parameters defined by BIM are the following:

Orientation: orientation of the openings according to a predefined by user position of the building.

Type: type of the ArchiCAD opening might be a window, a door, a curtain-wall or a skylight.

Thermal Block: assignment of the opening to a particular thermal block.

Perimeter: perimeter of the opaque frame.

Glazed area: net-transparent surface of the opening.

Opaque area: net-opaque surface of the opening. Sum of the glazed and opaque surfaces of each opening equals the nominal area. This figure is automatically subtracted from the area of the wall that contains the opening.

In case user needs to define or correct area of the openings, two extra-columns might be activated. **Correction-Glazed area** and **Correction-Opaque area** provide an opportunity of numerical input that will be taken into account instead of the modelled openings.

Solar Analysis: new feature of EcoDesigner that appeared in ArchiCAD-17 enables the model-based solar radiation study. Model-based solar irradiation study monitors annual energy gains through each glazed element individually. During the process engine uses dynamic weather file and geometry of the created model. The analysis determines precise solar gain through each individual opening in the building envelope and provides the graphical solar analysis feedback. Solar analysis calculates shading effects of the building environment (e.g. adjacent objects, other buildings). ArchiCAD plant objects act as intelligent shading devices: their shading capacity is scheduled for the reference year, making it possible to take into account the fact that deciduous species drop their leaves in winter. An example study as well as the detailed overview of the option will be presented below in a corresponding chapter.

4.8.2 Assigned properties

The additional data-types that are assigned to openings' list by user are:

TST: total solar transmittance. The percentage of incident solar radiation transmitted by an object which includes the direct solar transition plus the part of the solar absorption re-radiated inward. TST-value divided by 100 equals solar heat-gain coefficient (g-value).

Glazing U-value: heat transmission coefficient of glass.

Frame U-value: heat transmission coefficient of the frame of the selected opening.

The two U-value parameters might be chosen from the Openings' Catalogue that contains a range of predefined structures with their physical properties. Structure and methods of work within the catalogue are discussed below.

Overall U-value: overall heat transmission coefficient is calculated automatically after glazing and frame parameters were chosen by user from the elements' catalogue.

Perimeter Psi-value: the linear thermal transmittance coefficient is used to calculate the effect of thermal bridges.

Infiltration: air-permeability of the selected opening that typically occurs around the perimeter at the frame-to-wall connection.

Shading device: predefined devices for shading might be applied here by user to a single window or to a group of them. There are two types of Shading Devices on the list:

- Devices whose shading effect is additional to the effect of the model-based Solar Analysis (None, Curtain, Venetian Blind, Roller Blind, Shutter, External Blind, External Louver)
- Devices that disable the effect of model-based Solar Analysis (Canopy, Canopy and Side-Fins, Solar Analysis Off). These settings are mostly used for analytic (scientific) software functionality tests. Users are advised to use Shading Devices from the previous group on architectural projects.

Default properties of shading devices are stored in the ShadingCatalog.xml file located in the energy evaluation add-on folder. Text presented below is a part of shading definition taken from the XML-file of EcoDesigner.


```
<Shading Name="External Blind" ID="105">
<TransmittanceTotal>20</TransmittanceTotal>
<TransmittanceDirect>20</TransmittanceDirect>
<TransmittanceConstrainWindVelocity>true</TransmittanceConstrainWindVelocity>
<TransmittanceMaxWindVelocity>20</TransmittanceMaxWindVelocity>
</TransmittanceMinRoomTemperature>
<TransmittanceConstrainOutdoorTemperature>10</TransmittanceConstrainOutdoorTemperature>
<TransmittanceMinOutdoorTemperature>0</TransmittanceMinOutdoorTemperature>
</Shading>
```


Most shading devices are not fixed; they are activated only when needed. EcoDesigner is capable of taking this dynamic multiple dynamic effects (limited temperature, wind velocity etc.) into consideration. Calculation engine compares the parameters to corresponding entries of the dynamic weather data and includes or excludes the shading devices to/from simulation. Adjustment of the option goes however beyond general user proficiency level. Workflow again transfers to the system XML-files. It requires manual tuning of numerical inputs and, sometimes, re-start of ArchiCAD.

The Total Shade Factor Reduction defines the percentage of total heat energy that reaches the interior while the Direct Shade Factor Reduction outlines the amount of energy that penetrates due to solar irradiation. Horizontal edge angles and vertical fin side angles are used to define the horizontal and vertical borderlines of the shadow masks on the transparent openings list. User may change the numeric values for a more precise description of products used in the project (Graphisoft 2012).

4.8.3 Openings catalogue

Structure of the Opening Catalogue is similar to the one of the Materials'. So are the methods of its extension. The XML-file might be found in the Add-On folder of EcoDesigner and changed in case User is not able to find whatever he needs for a particular project. Text presented below is a part of the openings' definition file from the EcoDesigner system folder.

```
<OpeningCatalog version="2.0">
 <GlazingMaterials>
  <GlazingGroup Name="Glazing - single">
   <GlazingMaterial Name="Clear" TotalSolarTransmittance="87" DirectSolarTransmittance="76"
UValue="5.8"/>
   <GlazingMaterial Name="Tinted" TotalSolarTransmittance="64" DirectSolarTransmittance="52"
UValue="5.8"/>
  </GlazingGroup>
  <GlazingGroup Name="Glazing - double - basic">
   <GlazingMaterial Name="Air fill - clear"  TotalSolarTransmittance="82"
DirectSolarTransmittance="69" UValue="2.8"/>
   <GlazingMaterial Name="Air fill - tinted"  TotalSolarTransmittance="61"
DirectSolarTransmittance="51" UValue="2.8"/>
```


Openings catalogue in EcoDesigner is an extensive database of building physics information relevant to energy calculation. Its interface is presented in a form of a table with two horizontal sections containing possible parameters for transparent and opaque structures *(Fig. 17)*.

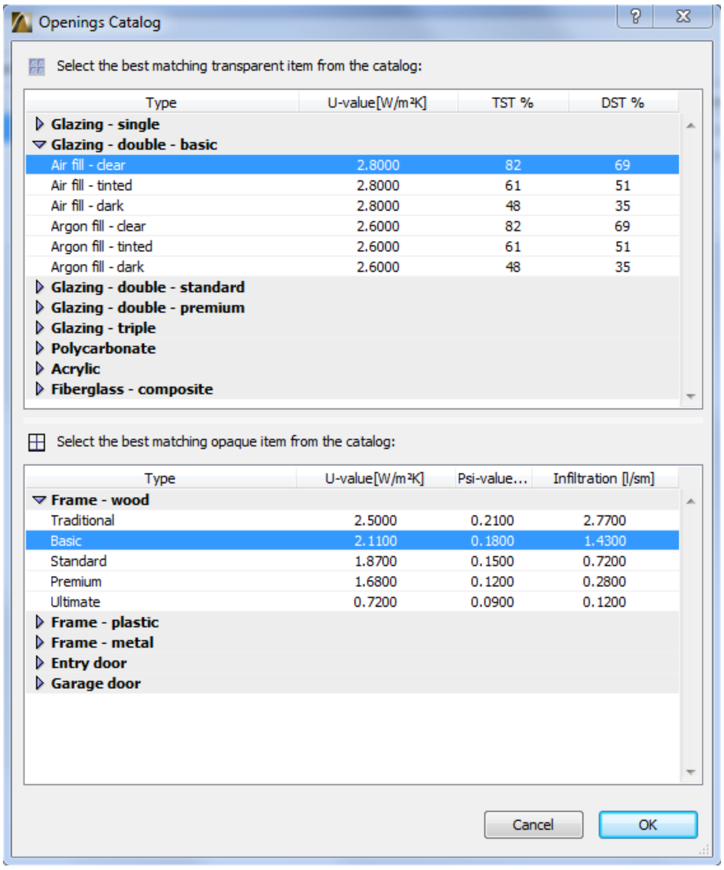


Figure 17: Openings catalogue

In the upper part transparent materials database includes such lists as Glazing, Polycarbonate, Acrylic and Fibreglass types. The lower part contains Frame, Entry door and Garage types. Each transparent item has corresponding U-value, TST and DST parameters as well as each opaque structure U-value, Psi- and Infiltration values. Choosing a required combination leads to definition for the rest of the openings' parameters such as overall U-value, psi-value etc. All of those might be overwritten manually afterwards if such a need occurs.

4.8.4 Solar analysis

ArchiCAD provides model-based solar irradiation study for all the transparent space boundaries. This calculates percentage of the gazed area exposed to direct sun light for every hour of an entire year. Weather data provides a base for the process and enables EcoDesigner to perform calculation. The results are displayed in the solar analysis column of the openings page of the EcoDesigner. Internal openings are automatically excluded from the calculation.

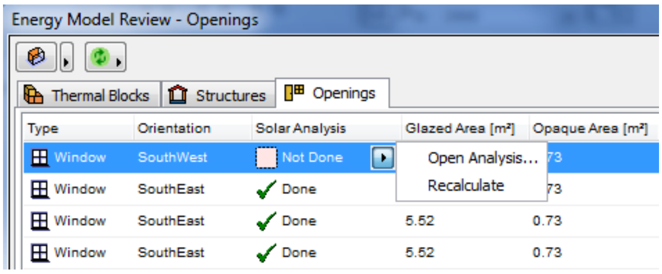


Figure 18: Display of Solar Analysis function in EcoDesigner

As the analysis requires an extensive input of the hard-drive memory it is not being updated automatically and user needs to re-run it (for selected openings or for all of them) every time the modelled geometry is subjected to changes. Presence of a green check-mark in the corresponding column informs on the analysis status *(Fig. 18)*.

Solar analysis dialogue box provides two types of diagrams: one contains information on the percentage of glazed area exposed to sunlight and the other – the direct solar radiation on the glazed surfaces. On both the diagrams the horizontal axis stands for months of the year and the vertical – hours of a certain day. User can hover over the graph with the mouse to display the hourly values throughout the entire year.

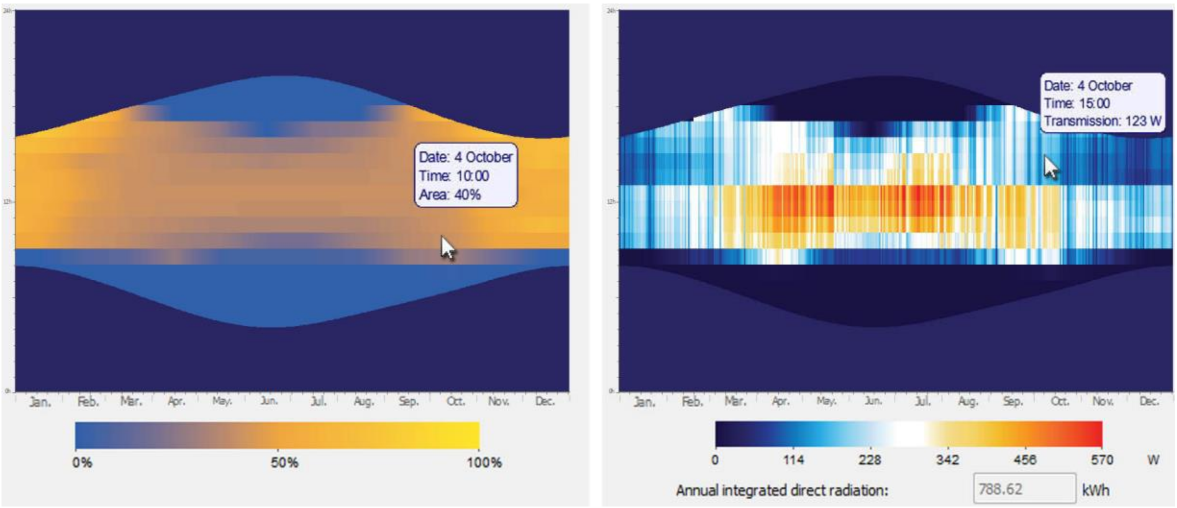


Figure 19: Sun-exposed glazing area (left) and Direct solar radiation (right)

The first diagram is the result of geometry calculation that takes the modelled geometry and the sun path at the relevant location as an input. On the chart the darker yellow colours refer to a lower level of direct sunlight. Therefore the bigger amount of annual integrated direct radiation conforms to a brighter colour on diagram.

On the second diagram only the direct solar radiation is accounted. The amount of annually integrated direct radiation takes into account climate data such as the cloud situation and solar radiation. Other components of solar radiation such as indirect and diffused radiation are not analysed here and handled by the engine on a different level (Graphisoft 2013). The dialog box displays analysis results of one or several openings combined as long as they share the same orientation.

User can insert plants to the ArchiCAD BIM model and these will later be used as intelligent dynamic shading devices. EcoDesigner will calculate the shading impact of inserted plants. The fact that deciduous trees don't have leaves during the cold season of the year and in summer appearing greenery might serve as a natural shading device is reflected in the solar analysis results. User defines surroundings manually in this case by building up a complete model and inserting plants library parts on the site. No additional actions are needed here – as long as trees belong to a visible layer.

An example study of solar analysis is presented below. Base case was evaluated without shading, in Cases 1 and 2 deciduous trees and conifers correspondingly were used as shading casters. The benchmark data for all three cases was identical - a south-east orientated box-type house with a considerably large glazing ratio (16%). Internal area equals 70 m^2, ventilated volume – 175 m^3. Average U-value is 0.30 W/m^2K for the external structures and 0.91 W/m^2K for the openings.

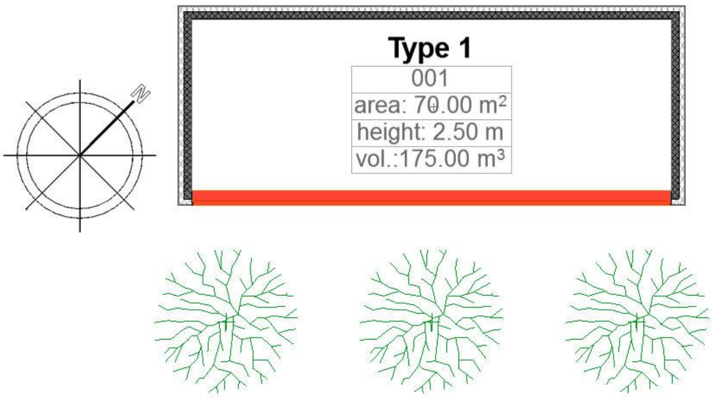


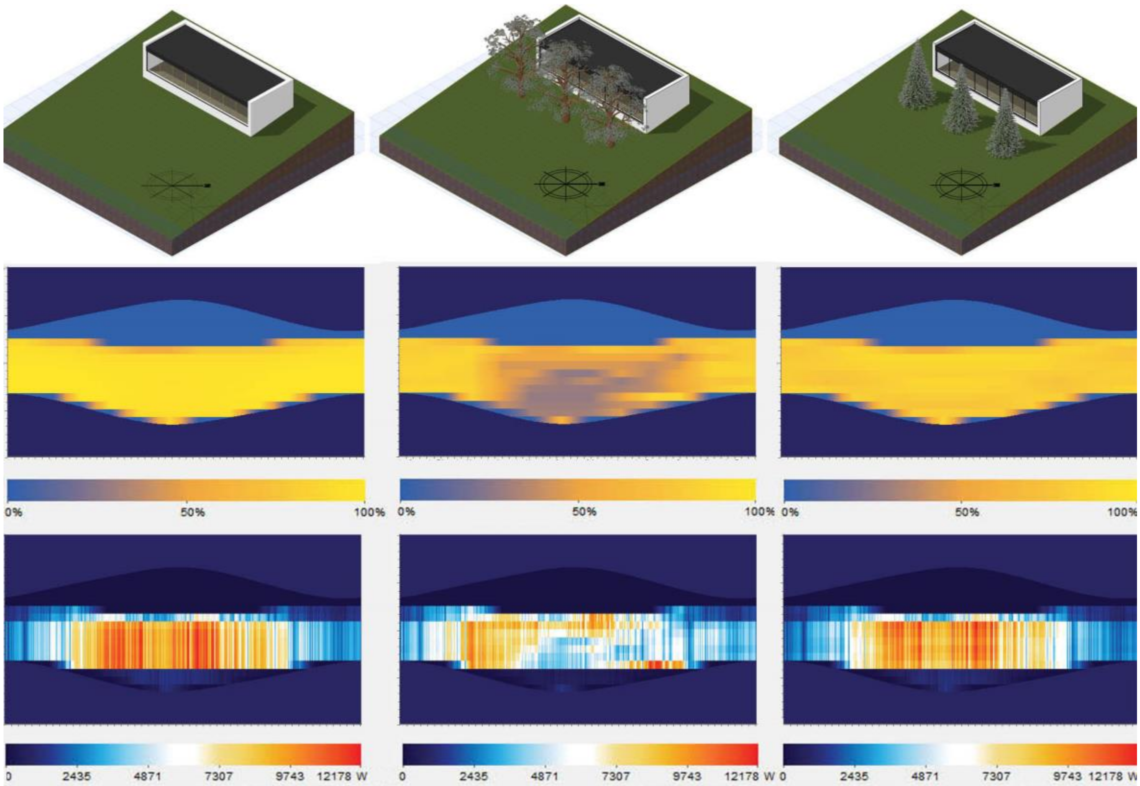
Figure 20: Example study of solar analysis: building geometry

As one can see from the resulting graphs, adding plants in front of the glazed area provides significant decreasing of annual integrated direct radiation. *Base case* shows the result of 16 499 kWh – figure that would most probably lead to overheating of the space of such a scale.

Case 1 illustrates that deciduous plants allow to reduce the index of integrated solar radiation down to 9 511 kWh that corresponds to 57% of the primal value. Secondly the case displays extra-diminution of solar gains in spring/summer months. Thus summer months are displayed by a darker yellow colour (35-45% of glazed area exposed to direct sunlight). Sometimes the amount reaches a rather low "blue" level (10-20%). Winter months are presented by an identical bright yellow (85-99%). This is the result of the different shading cast level caused by a varying leaves' density of deciduous trees.

Case 2 proves the stable qualitative characteristics of conifers through the year. Geometry of the chosen trees however doesn't allow creating shadows of the size comparable to those casted by deciduous plants. This explains such an insufficient improvement (14 401 kWh) of the initial situation in comparison with the *Case 1*. Probable rearrangement of the pine trees on the site and calibration of their size could have allowed reaching a better shading performance in case one needed.

Base case Case 1 Case 2



Annual integrated direct radiation:

16 499.26 kWh 9 511.91 kWh 14 401.81 kWh

Figure 21: Analysis of shadow casting. Performance of pine and deciduous trees

User can completely turn off the solar analysis function from the model review if such a necessity occurs. Shading Devices column in the Openings Panel contains “Solar Analysis off” option that enables the complete exclusion of the analysis results.

4.9 The U-value calculation

In the energy model review pallet structures are displayed with their default U-values. The same pallet provides direct access to the U-value calculation dialogue box. Appearing window contains a list of materials with assigned hatches composing a chosen structure and displays all the relevant properties like thickness, thermal conductivity, density and heat capacity.

Starting ArchiCAD-17 building material is always defined by a combination of Surface (defines outlook in 3D window) and a Fill (defines physical properties). That’s why it is extremely important to use the fills consistently through the project. Building Materials’ properties can be accessed from the U-value calculator in EcoDesigner or from the standard Tool Manager in ArchiCAD. All the changes are automatically reflected in all composite structures that include the edited building material - no matter from which window the alterations have been carried out. User can create new building materials or edit the existing ones. Physical properties of each might either be chosen from the predefined Material Catalogue or put in manually.

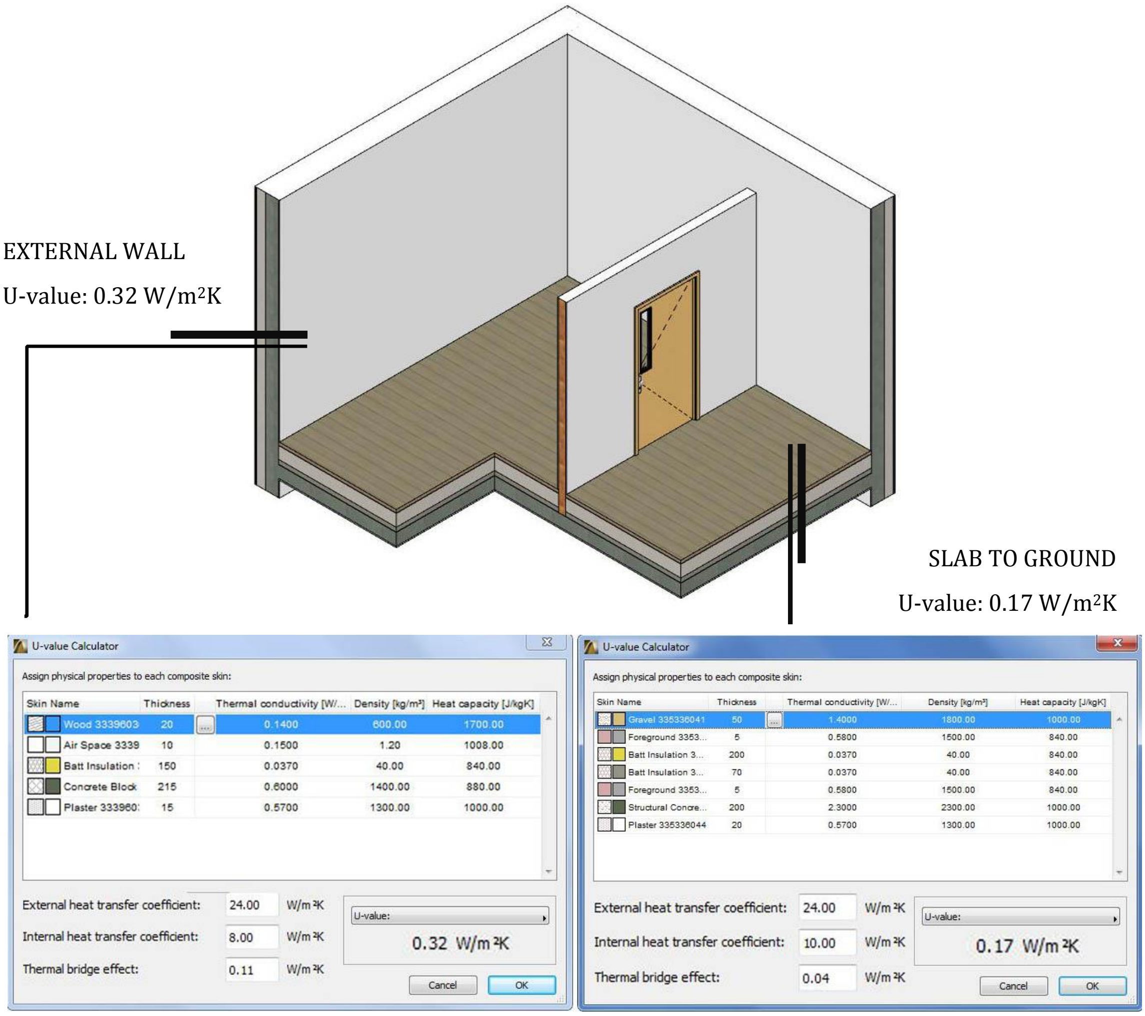


Figure 22: Composite structures' recognition principle

Example presented above illustrates principle of multi-layer composite junctions. All connections were made automatically by ArchiCAD as user defines bearing and finishing layers of a composite structure during the process of its creation. The case refers to the way EcoDesigner recognises constructions. Bearing concrete wall with plaster and insulation is created from basic ArchiCAD building materials, same concerns the slab. U-Value calculator lists all the materials activated within chosen composites and illustrates its thickness with corresponding thermal properties.

Directly from the U-value calculator user can reach Building Materials Properties window and, consequently, Material Catalogue described in the corresponding chapter above. Here one can reapply fill type and surface as well as define material's physical properties. On the illustration given below ArchiCAD building material "Batt Insulation" has the following physical parameters: Thermal Conductivity – 0.04W/mK, Density – 40 kg/m³ and Heat Capacity – 840J/kgK. All of those refer to a material called Mineral Wool Soft in Material Catalogue.

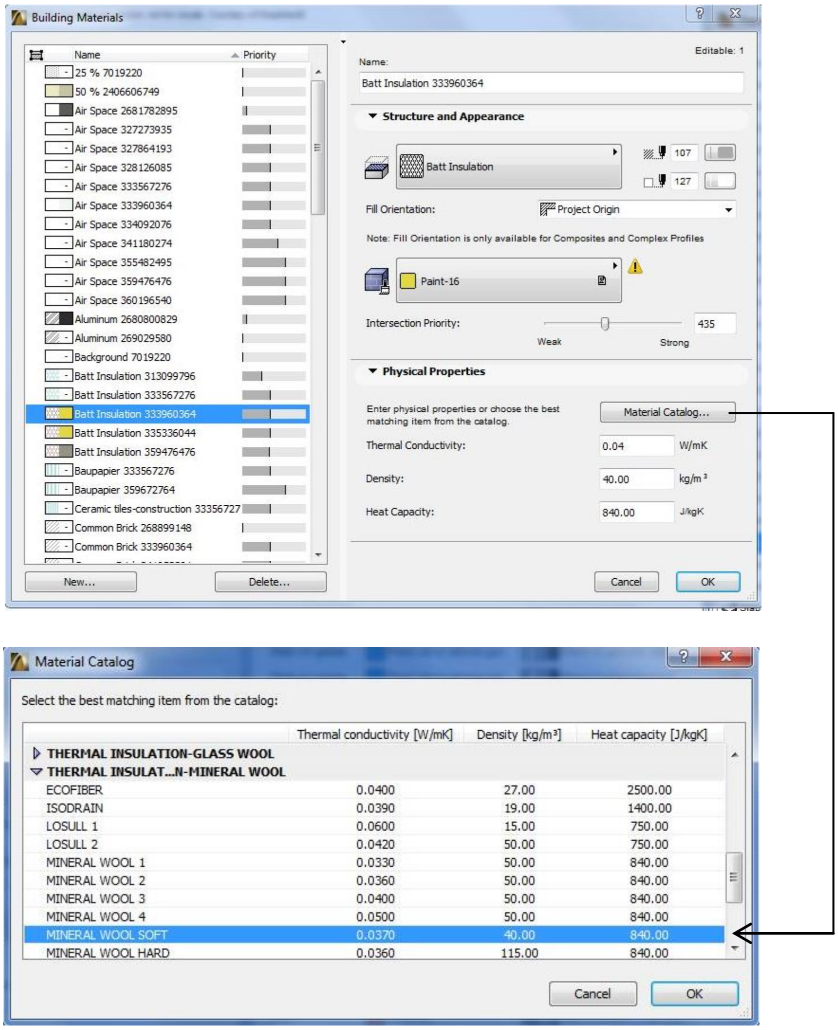


Figure 23: Building materials window in ArchiCAD

If some building material is not defined correctly, for example some value of its physical properties is set to zero (default index for all the newly-created materials), it will be highlighted with red. Also the related structure in the Energy Model review pallet will be marked and an error icon will appear on the place of the U-value.

U-value calculator determines heat transmission coefficient based on a simplified algorithm. The algorithm relies on mentioned properties of each cut fill/building material and three additional static values: external and internal heat transfer coefficients and a thermal bridge effect related to the structural surface area. The parameters are manually-editable and can be accessed from the calculator pallet. Recommended values can be found either in internet or in ArchiCAD Help.

Properties of the composite structures might be changed either from the calculator or from the composite structures manager. The executed changes will be applied through the project to all the walls (slabs, roofs etc.) carrying the same structure name independently from their orientation, area or position. Calculated U-value is displayed in the bottom right corner of the. By default the value is “locked” within the Energy Model review table. This means that the number has been calculated in accordance with all the fills’ parameters and all the additional factors. User is always able to “unlock” the U-value and to override it. In this case Energy Evaluation model of EcoDesigner will take user-defined value as the prior one and disregard the predefined structure. Those kinds of changes might be applied individually for each structure.

4.10 Visualisation of the energy model

3D-window opened together with the Energy Model Review pallet facilitates navigation trough the BEM. User might choose a single building structure or a group that he is interested in (for example all the external slabs facing upwards direction) and those will be instantly highlighted in the 3d-window. The rest model turns to wireless while the selected element is highlighted with the false-colour corresponding to a space-boundary category. Example bellow illustrates possibility of selection of certain building components in 3D.

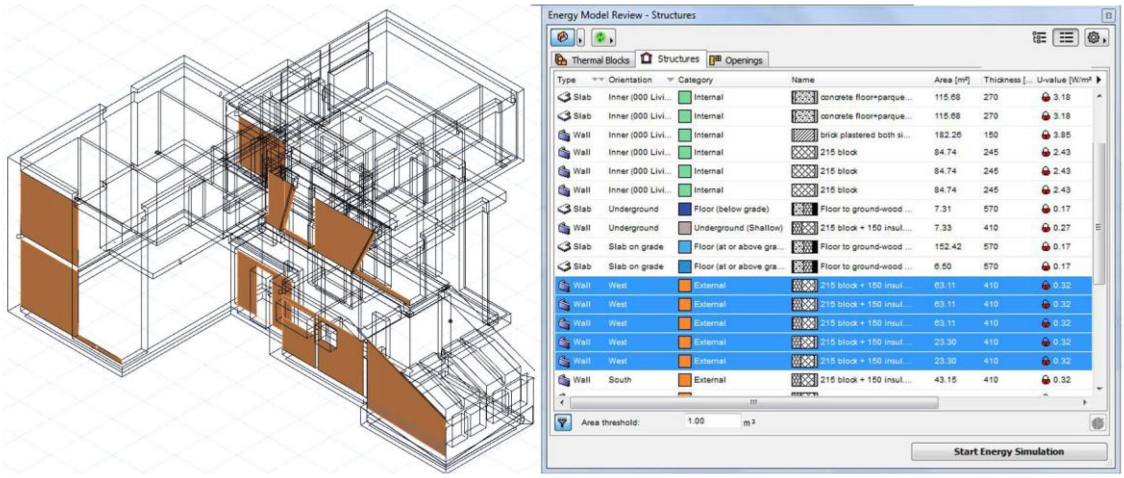


Figure 24: Navigation through BEM in 3D-window

External walls facing west and positioned above ground are highlighted.

A single ArchiCAD element (for instance a wall, positioned both above and below the ground level) can be divided into several elements and thus appear as a part of several different entries with varying orientations in the structures' list. Navigation through the openings list tab is similar. Windows and doors can be selected one by one or in groups to be highlighted in 3D. Right mouse-click on the selected item enables quick access to its U-value calculation window. Thus user can literally assign and reassign physical parameters straight from 3D.

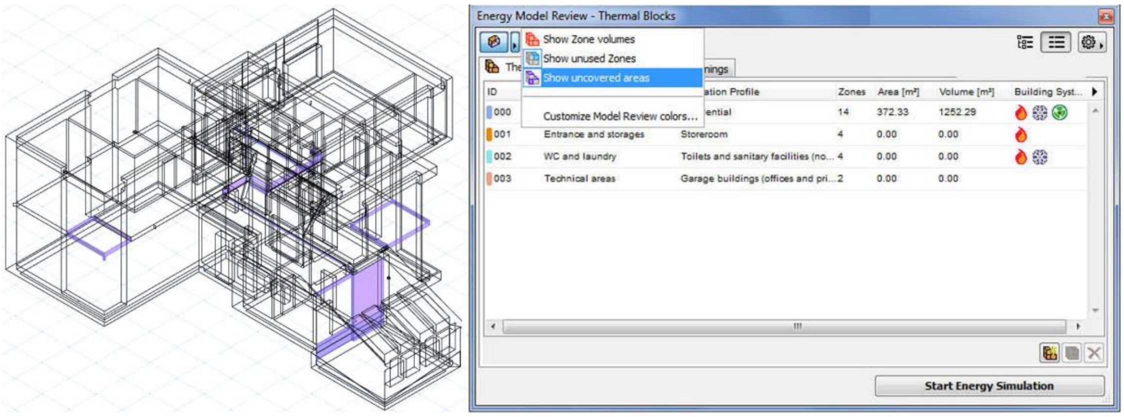


Figure 25: Highlighted uncovered areas in the 3D-window

Button in the top left corner of the Energy Model Review pallet is the major actuator of all possible model control methods available in 3D window. It allows turning on and off all the Zone volumes in 3D in case user needs to check model on presence of some definition gaps. It also provides the possibility to customize model elements' colours and highlights unused zones and uncovered areas. The last two options contribute to general error control and help searching model's defects.

4.11 Error control

As long as EcoDesigner detects any part of the required input data as insufficient, the Start Evaluation button remains inactive. In order to start the energy evaluation, user must first make the necessary corrections.

Automated creation of zones which literally means assigning zones with a single click within a closed perimeter guarantees two important facts for energy evaluation: that zones will be updated whenever the model is changed (thus geometry will be recognised) and that the envelope stays confined. In case when, for example, some walls fail to intersect, a notion on impossibility to update a certain zone appears. With right mouse click user can zoom to the problematic area and correct it.

In the EcoDesigner dialogue box a yellow warning exclamation mark appears next to the entries which contain faulty or missing data. The most common reasons are the following:

- No weather data is available for the specified building location coordinates. This may occur in case weather-file is missing and computer is not connected to the Internet thus unable to obtain the information from the on-line weather database server.
- No building material is assigned to some ArchiCAD fills used in the project so some structures have invalid heat transmission coefficients. In this case an error sign appears next to the affected entry of the Building elements list.
- Some openings have not been assigned with building physics data from the Openings Catalogue. In this case an error sign appears next to the problematic opening in the elements list.
- Building shell is not closed because external wall contains an empty opening (window or door without glass or any other filling). In this case a yellow warning exclamation mark appears next to those entries which contain faulty or missing data and the empty opening itself is highlighted in pink.

All changes that ArchiCAD detects in geometry require zones' update. The message informing on all the existing inaccuracies appears when user presses "Start Energy Simulation" button in the Energy model review (Fig. 26).

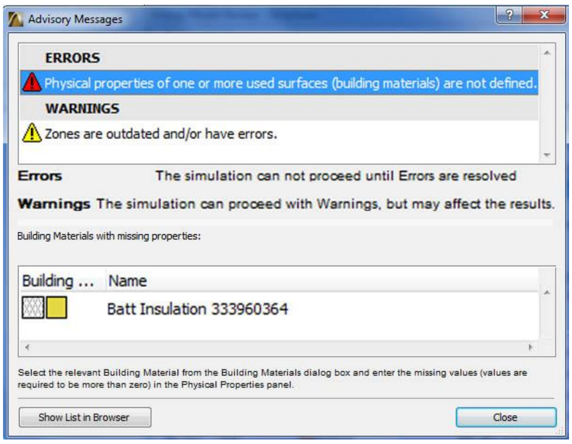


Figure 26: Detected errors preventing Energy evaluation.

Outdated zones and missing physical properties.

User can check the errors in browser which contains a full description of detected inaccuracies with recommended solutions. For example missing physical properties have the following description (Table 3):

Table 3: Advisory messages table: missing physical properties.

Error	**Related items**	**Suggestions / Notes**
Physical properties of one or more used surfaces (building materials) are not defined.	Batt Insulation 359476476	Select the relevant Building Material from the Building Materials dialog box and enter the missing values (values are required to be more than zero) in the Physical Properties panel.
	Foreground 200325501	

In cases when ArchiCAD fails to recognise geometry because of its complexity (discussed in chapter "Detected Inaccuracies") user is still able to influence software's performance and achieve more accurate results. For instance user can manually correct areas of all recognised building elements. Column called "Correction Area" in the Energy Model review pallet allows numerical input of correct parameters for each structural unit.

Another input that can be defined manually is the Area Threshold. The value by default is set to 0 m^2. Setting the parameter for instance to 0,5 m^2 allows excluding all the building elements with a smaller area from the calculation. On practice it means that all the walls that might have been "broken" in the course of modelling won't be taken into account. The option makes sense only in cases with a complicated geometry and should be applied after preceding visual analysis of all the recognised structures.

User is able to ignore warning messages but not the errors. Evaluation report exported to XLS will contain a line with advisory messages generated by the program. It will list the total amount of warnings even if a user decides to disregard them.

4.12 Energy performance evaluation

Once EcoDesigner gets necessary data user may run the energy performance evaluation. "Start Energy Simulation" button in the Energy Model review window launches the simulation process. Time required for the calculation depends on computer possibilities and on complexity of the model. Result displayed afterwards is the Evaluation Report.

4.12.1 Report format

EcoDesigner runs simulation of the energy performance of the building for a period of one year. The final review file represents itself a document of three pages covering six blocks: Key Values, Energy Consumption by Sources, Energy Consumption by Targets, Project energy balance, Thermal Blocks and Environmental impact.

The first chapter containing Key values (Fig. 27) displays the most important project data. This part includes general project description with factors like location, area and glazing ratio. "Building Shell Performance" and "Heat Transfer Coefficients" sections correspondingly provide information on infiltration, outer heat capacity and building elements' U-value. The last part lists Specific Annual Demands on net heating, cooling and total energy, fuel consumption (and costs if a corresponding input has been done) and CO2 emission.

Key Values

General Project Data		
Project Name:	Private House	
City Location:		
Climate Data Source:	-2007	
Evaluation Date:	02/08/2013 18:12:16	
Building Geometry Data		
Gross Floor Area:	**432.86**	m²
Treated Floor Area:	**372.33**	m²
External Envelope Area:	**791.71**	m²
Ventilated Volume:	**1252.29**	m³
Glazing Ratio:	**14**	%
Building Shell Performance Data		
Infiltration at 50Pa:	**1.79**	ACH
Outer Heat Capacity:	**90.21**	J/m²K

Heat Transfer Coefficients	U value	[W/m²K]
Building Shell Average:	**0.37**	
Floors:	**0.17 - 0.23**	
External:	**0.17 - 0.32**	
Underground:	**0.27 - 0.27**	
Openings:	**0.72 - 1.74**	
Specific Annual Demands		
Net Heating Energy:	**86.36**	kWh/m²a
Net Cooling Energy:	**22.25**	kWh/m²a
Total Net Energy:	**108.61**	kWh/m²a
Energy Consumption:	**315.68**	kWh/m²a
Fuel Consumption:	**315.68**	kWh/m²a
Primary Energy:	**461.29**	kWh/m²a
Fuel Cost:	--	EUR/m²a
CO_2 Emission:	**66.18**	kg/m²a

Figure 27: Energy report. Key Values

The second chapter is called Energy Consumption by Sources. It consists of one table and several charts. Left corner of the table contains Energy Sources separated by type (Renewable, Fossil and Secondary) with their tags and colour codes. The Quantity column provides information on corresponding magnitudes while the Cost column shows the price of each energy source consumed per year. Right column of the table displays the CO2-footprint associated with listed energy sources. The Source Energy Quantities by Primary Sources bar chart allows users to compare the scale of energy consumption with the primary energy consumption (Graphisoft 2013).

Energy Consumption by Sources

Source Type	Energy Source Name	Quantity kWh/a	Primary kWh/a	Cost EUR/a	CO_2 Emission kg/a
Secondary	Electricity	27107	81323	--	3156
	District Heating	90427	90427	--	21485
	Total:	**117535**	**171751**	Not Applicable	**24641***

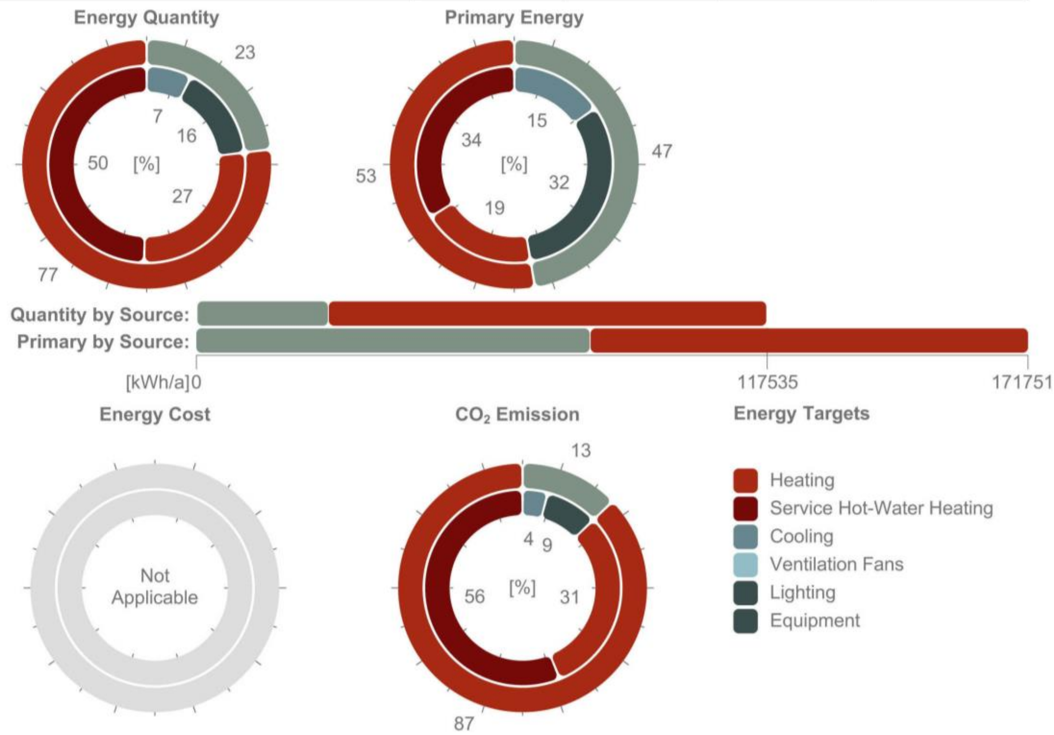


Figure 28: Energy report. Energy Consumption by Sources

Energy Consumption by Targets chapter has in principle the same structure as the preceding part. Here the table lists energy targets with their colour codes used in the pie chart. The Quantity column displays magnitude while the Cost column provides information on calculated price of energy spent on each target per year. Following far right column of the table demonstrates the CO2-footprints associated with each of the analysed energy targets.

Energy Consumption by Targets

Target Name	Energy Quantity kWh/a	Primary kWh/a	Cost EUR/a	CO_2 Emission kg/a
Heating	32153	32153	0	7639
Cooling	8768	26305	0	1020
Service Hot-Water	58274	58274	0	13846
Ventilation Fans	0	0	0	0
Lighting & Appliances	18339	55018	0	2135
Total:	**117535**	**171751**	**NA**	**24641**

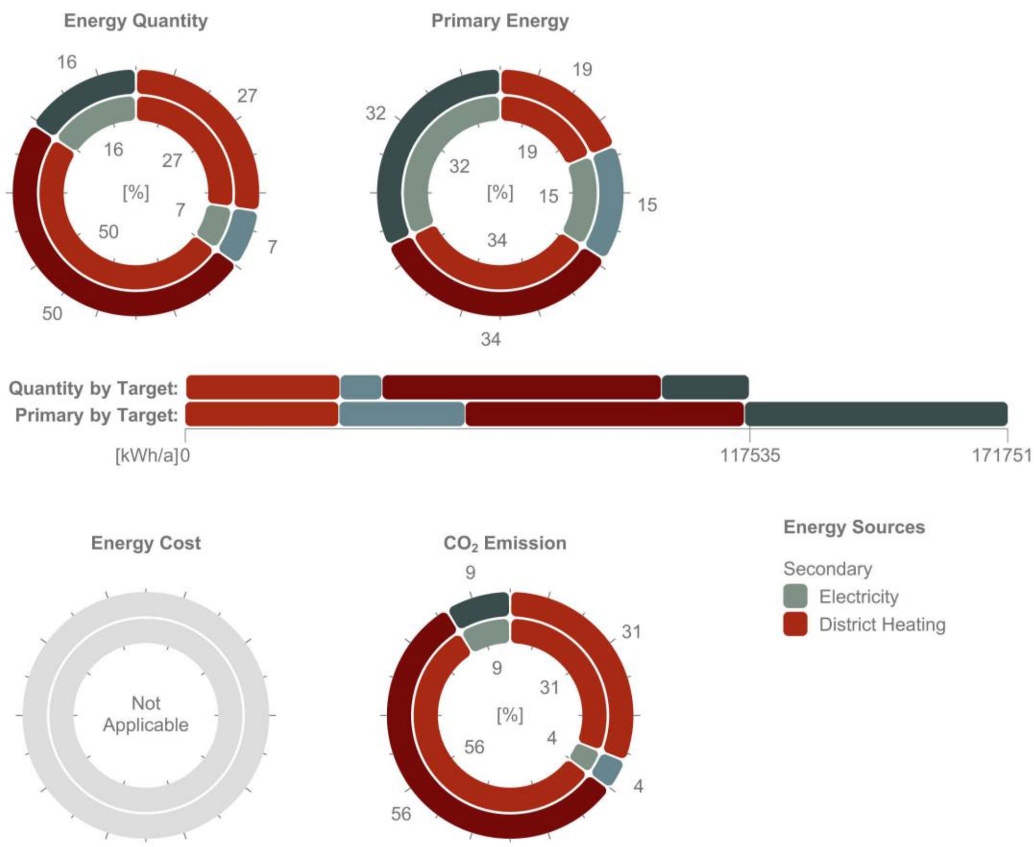


Figure 29: Energy report. Energy Consumption by Targets

Project Energy Balance chapter contains the Monthly Energy Balance bar chart as an illustration of the amount of energy that building emits (lower part of chart) and the one that needs to be supplied (Fig. 30). Amount of energy the evaluated building is supposed to absorb both from environment and its own internal heat sources is presented in the upper part of chart. Horizontal axis divides values tabled by month or week depending on settings defined by user.

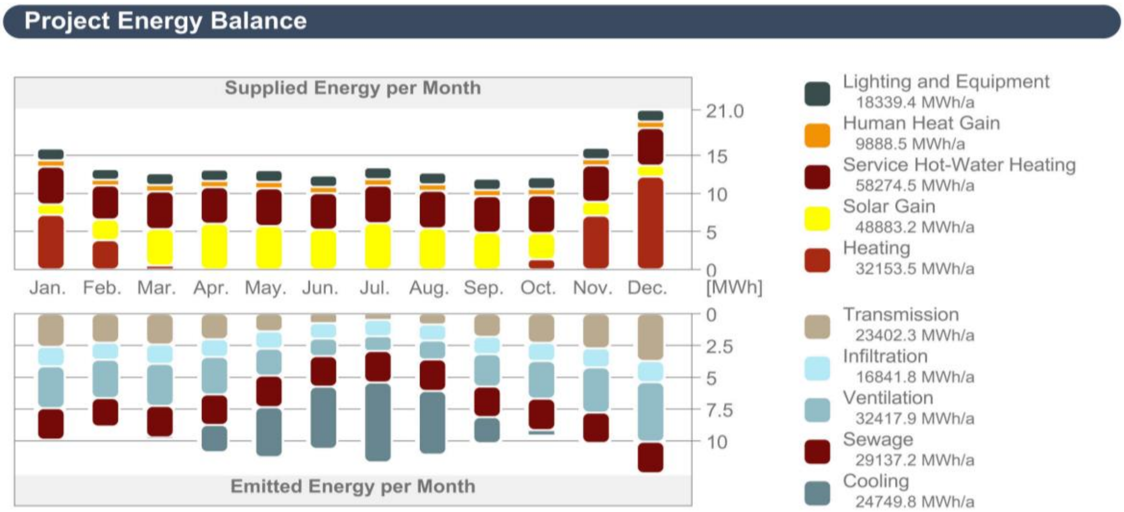


Figure 30: Energy report. Projects Energy Balance

In accordance energy balance equation emitted and supplied energy have to be equal every month – thus bars on the top and bottom parts of the chart are also equal. Vertical axis indicates energy scale. The Monthly Energy Balance Bar Chart illustrates the collective results of derived energy balance calculations (Graphisoft 2013). Thermal Blocks part lists a total amount of thermal blocks with their recognised geometry data and Operation Profiles (Fig. 31).

Thermal Blocks

Thermal Block	Zones Assigned	Operation Profile	Gross Floor Area m²	Volume m³
000 Living areas	14	Residential	309.68	958.99
001 Entrance and storages	4	Storeroom	34.01	84.29
002 WC and laundry	4	Toilets and sanitar...	33.28	63.53
003 Technical areas	2	Garage buildings ...	55.90	145.47
Total:	**24**		**432.86**	**1252.29**

Figure 31: Energy report. Thermal Blocks

Environmental Impact chapter summarizes the environmental impact of the building's operation displaying Carbon Footprint and Primary Energy, according to Energy Sources (Fig. 32).

Environmental Impact

Source Type	Source Name	Primary Energy kWh/a	CO_2 emission kg/a
Secondary	Electricity	81323	3156
	District Heating	90427	21485
	Total:	**171751**	**24641**

Figure 32: Energy report. Environmental Impact

Evaluation window allows including and excluding different blocks to/from the final report before exporting it to the PDF-format. It also provides a possibility to change outlook of certain parts. For instance user can alter time intervals for project energy balance (weekly or monthly) and units displayed, set legend colours, choose between pie and bar charts.

4.12.2 Export possibilities

The integrated (free) version of EcoDesigner allows exporting final evaluation report into two different formats: PDF and XLS. Earlier versions (till ArchiCAD-15) also provided an opportunity to export results into PHPP. The option was seized in version 16 and re-integrated for the commercial version of EcoDesigner Star in ArchiCAD-17.

PDF-report has basically the same structure as the one appearing in the ArchiCAD window. Its frame and outlook reflect the adjustments (contents, charts' preferences, etc.) that user applies before saving the final PDF-file.

XLS-report is a detailed energy balance data-export. EcoDesigner automatically creates a number of different XLS-files. The first one contains simulation information for the whole project while the rest correspond to each of the defined thermal blocks separately. The common project report has pages with Project Key Values and Monthly Detailed Results. Thermal blocks files also include a page called "Detailed Inputs" - building geometry description with all the areas and U-values. User can utilize this data as an input for some Excel-based stationary energy calculation software.

Content of the Project Key Values section is similar to the one of the PDF report, yet it provides extra material on Climate Data, Design Loads and Advisory Messages (Errors and Warnings).

In general the XLS-file contains more details than the PDF and the table format of the monthly report constitutes to its readability *(Table 4).* Heating and Cooling are split in accordance with specific targets (Space heating, Hot water generation). Auxiliary energies necessary to operate the systems appear separately; so do the values for Lighting and Appliance Electricity consumptions.

Option of defining Local Heating and Cooling systems is accessible only for the commercial version of EcoDesigner STAR. In the table below the section illustrates zero-value for this reason.

Table 4: Evaluation Report in XLS-format. Detailed Results per month

Monthly Values

Energy flows	MEP System typ Target	January	February	December	Annual Total [kWh]	Annual Absolute [kWh]	Annual Specific [kWh/m²]
All numbers are in [kWh]							
Transmission		-2610.94	-2287.80	-3719.55	-23402.34	23402.34138	62.85
Infiltration		-1530.34	-1334.74	-1669.39	-16841.78	16841.78	45.23
Human heat gain		839.80	758.53	840.26	9888.45	9888.45	26.56
Solar gain		1379.08	2731.02	1428.59	48883.17	48883.17	131.29
Heating		7177.86	3838.32	12210.26	32153.48	32153.48	86.36
	Central	7177.86	3838.32	12210.26	32153.48	32153.48	86.36
	Boiler	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Solar thermal collector	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Heat pump	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Auxiliary systems	0.00	0.00	0.00	0.00	0.00	0.00
	District	7177.86	3838.32	12210.26	32153.48	32153.48	86.36
	Space heating	7177.86	3838.32	12210.26	32153.48	32153.48	86.36
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Local	0.00	0.00	0.00	0.00	0.00	0.00
	Boiler	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Solar thermal collector	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Heat pump	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Auxiliary systems	0.00	0.00	0.00	0.00	0.00	0.00
	Dx heater	0.00	0.00	0.00	0.00	0.00	0.00
	Space heating	0.00	0.00	0.00	0.00	0.00	0.00
	Auxiliary systems	0.00	0.00	0.00	0.00	0.00	0.00
	Not yet specified	0.00	0.00	0.00	0.00	0.00	0.00
Service hot-water heating		4949.24	4470.28	4950.36	58274.47	58274.47	156.51
	Boiler	0.00	0.00	0.00	0.00	0.00	0.00
	Service hot-water heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Solar thermal collector	0.00	0.00	0.00	0.00	0.00	0.00
	Service hot-water heating	0.00	0.00	0.00	0.00	0.00	0.00
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Heat pump	0.00	0.00	0.00	0.00	0.00	0.00
	Service hot-water heating	0.00	0.00	0.00	0.00	0.00	0.00
	Auxiliary systems	0.00	0.00	0.00	0.00	0.00	0.00
	District	4949.24	4470.28	4950.36	58274.47	58274.47	156.51
	Service hot-water heating	4949.24	4470.28	4950.36	58274.47	58274.47	156.51
	Circulation pump	0.00	0.00	0.00	0.00	0.00	0.00
	Sewer recovery	0.00	0.00	0.00	0.00	0.00	0.00
Cooling		0.00	0.00	0.00	-24749.77	24749.77	66.47
	Central	0.00	0.00	0.00	-8285.29	8285.29	22.25
	Mechanical	0.00	0.00	0.00	-8285.29	8285.29	22.25
	District	0.00	0.00	0.00	0.00	0.00	0.00
	Local	0.00	0.00	0.00	0.00	0.00	0.00
	Mechanical	0.00	0.00	0.00	0.00	0.00	0.00
	DX Cooling	0.00	0.00	0.00	0.00	0.00	0.00
	Not yet specified	0.00	0.00	0.00	-16464.48	16464.48	44.22
Ventilation		-3288.91	-3014.24	-4676.58	-32417.87	32417.87	87.07
	Mechanical	0.00	0.00	0.00	0.00	0.00	0.00
	Not yet specified or Natural	-3288.91	-3014.24	-4676.58	-32417.87	32417.87	87.07
	Air to air recovery	0.00	0.00	0.00	0.00	0.00	0.00
Lighting and Equipment		1561.79	1406.75	1551.71	18339.41	18339.41	49.26
	Lighting	291.78	259.64	281.70	3386.03	3386.03	9.09
	Equipments	1270.01	1147.11	1270.01	14953.38	14953.38	40.16
Service hot-water		-2474.62	-2235.14	-2475.18	-29137.23	29137.23	78.26
Supplied energy		15907.78	13204.90	20981.19	167538.97	167538.97	449.97
Emitted energy		-9904.81	-8871.92	-12540.70	-126549.00	126549.00	339.88
Difference		6002.96	4332.98	8440.49	40989.98	40989.98	110.09
Auxiliary systems		0.00	0.00	0.00	241.63	241.629401	0.65
On-site electricity		0.00	0.00	0.00	0.00		
	Solar photovoltaic	0.00	0.00	0.00	0.00		
	Wind energy	0.00	0.00	0.00	0.00		
	Potential production	0.00	0.00	0.00	0.00		
	Solar photovoltaic	0.00	0.00	0.00	0.00		
	Wind energy	0.00	0.00	0.00	0.00		

5 PERFORMANCE STUDY

5.1 Introduction

Multiple studies claim that development of energy-efficient housing is not intuitive, thus energy simulation should be taken into account in the beginning of each project (Hayter, et al. 2001, Athienitis, et al. 2010 and Donn et al., 2009). Subsequently the performance-based approach illustrates powerful implication towards usage of simulation tools integrated or tightly bound with the CAD-environment familiar to architects. Implied workflow is a dynamic process where all the input parameters (geometry, materials and building systems) find their reflection and may influence design optimisation.

Practical application method has been chosen to evaluate EcoDesigner in the capacity of decision-support tool. It has been assumed that the major interest of architects on the early design stage might be delineation of an optimal geometry and effective shading. EcoDesigner's suitability for exactly this sort of tasks is to be examined in the following part of the thesis. Monitoring of the workflow and time demands will allow making certain conclusions on EcoDesigner usability.

5.2 Simplified geometry evaluation

In this chapter relatively primitive buildings are subjected to performance analysis. Taken morphological types provide examples of the way EcoDesigner evaluates basic concepts in architecture. Cases have been taken randomly to outline potential advantages and disadvantages of different solutions in design: building's positioning in relate to north, its shape and proportions, glazing arrangement.

All building systems in provided examples were set in an absolutely identical way and will be described below. U-values were also matching. The approach of making physical parameters a common denominator allowed putting the task of materials' and systems' optimisation outside the brackets in the study. Thus evaluation of created geometry became a priority.

Sample projects' location was defined as Vienna, Austria and the corresponding climate file was downloaded from the Strusoft server. Figure below provides visualisation of the weather data.

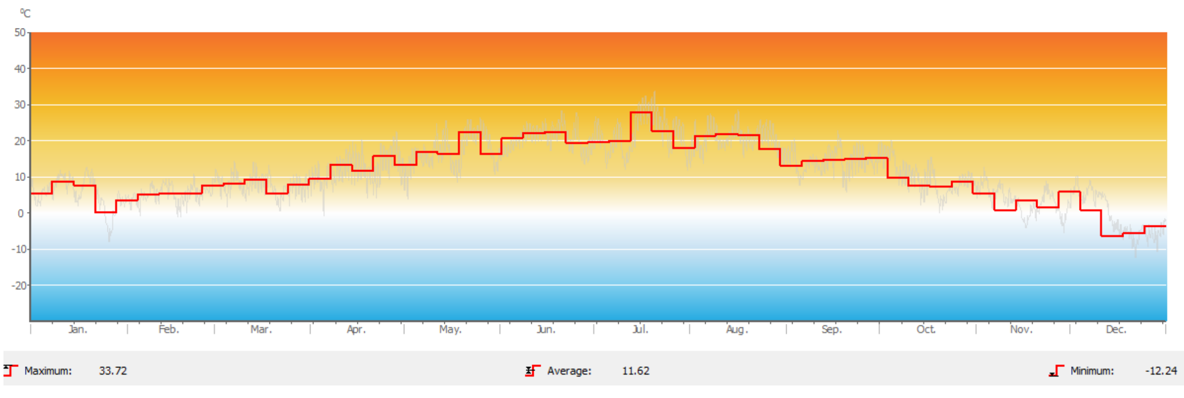


Figure 33: Climate data visualisation graph for Vienna. Strusoft Server

Parts of building envelope for all the evaluated houses were combined exclusively from default building materials catalogue in the following way:

Table 5: Materials used for simplified geometry evaluation

External walls (410mm)	**Slab to ground** (570mm)	**Roof slab** (550mm)	**Slab to air** (570mm)
U-value: 0,32 W/m²K	U-value: 0,17 W/m²K	U-value: 0,17 W/m²K	U-value: 0,17 W/m²K
- Plaster 15 mm 0,57 W/mK	- Parquet 20 mm 0,14 W/mK	- Gravel 50 mm 1,407 W/mK	- Parquet 20 mm 0,14 W/mK
- Insulation: mineral wool soft 150 mm 0,037 W/mK	- Air space 30 mm 0,15 W/mK	- Lightweight concrete 20 mm 0,60 W/mK	- Air space 30 mm 0,15 W/mK
- Concrete blocks 215 mm 0,60 W/mK	- Lightweight concrete 20 mm 0,60 W/mK	- Vapour seal 10 mm 0,50 W/mK	- Lightweight concrete 20 mm 0,60 W/mK
- Gypsum plaster 15 mm 0,57 W/mK	- Vapour seal 10 mm 0,50 W/mK	- Insulation: mineral wool 270 mm 0,037 W/mK	- Structural concrete 220 mm 2,30 W/mK
	- Insulation: XPS 200 mm 0,035 W/mK	- Vapour seal 10 mm 0,50 W/mK	- Insulation: EPS 200 mm 0,035 W/mK
	- Structural concrete 220 mm 2,30 W/mK	- Structural concrete 220 mm 2,30 W/mK	- Plaster 15 mm 0,57 W/mK
	- Lightweight concrete 25 mm 0,60 W/mK	- Plaster 15 mm 0,57 W/mK	
	- Drained gravel 100 mm 1,40 W/mK		

U-value for the openings was defined as 1,45 W/m²K with triple argon filled glazing (0.60 W/m²K) and plastic frame (1.60 W/m²K).

To simplify the timetable, operation profile has been set to "residential" with year-round occupancy (8760 hours). Heating sources for all the created building types were defined as a combination of a compact heat recovery system and a fireplace with external air supply. Heating system was characterised with 85% efficiency. Hot water generation limits were set in a range of 10 and 60 °C. Cooling machine with default characteristics provided a capacity of 1500W. Ventilation system settings were defined as mechanical; target – supply and exhaust. Energy source factors were described with the following proportion corresponding to data provided by Wien Energie (Wien Energie 2013):

- Water energy – 47%
- Natural gas – 45%
- Wind energy – 4%
- Unknown – 4%

Energy prices were also taken from Wien Energie. No solar thermal collectors or photovoltaic panels were taken into account during the simulation.

5.2.1 Case 1: optimisation of windows' orientation

The study case provides a simple building template with a south-orientation. Floor area as well as building envelope area and glazing ratio remain the same. The impact of glazing orientation is evaluated.

Common building geometry data:
Gross floor area – 70 m^2
Building envelope area 177.37 m^2
Ventilated volume – 175 m^3
Glazed area – 11.04 m^2
Glazing ratio – 6%

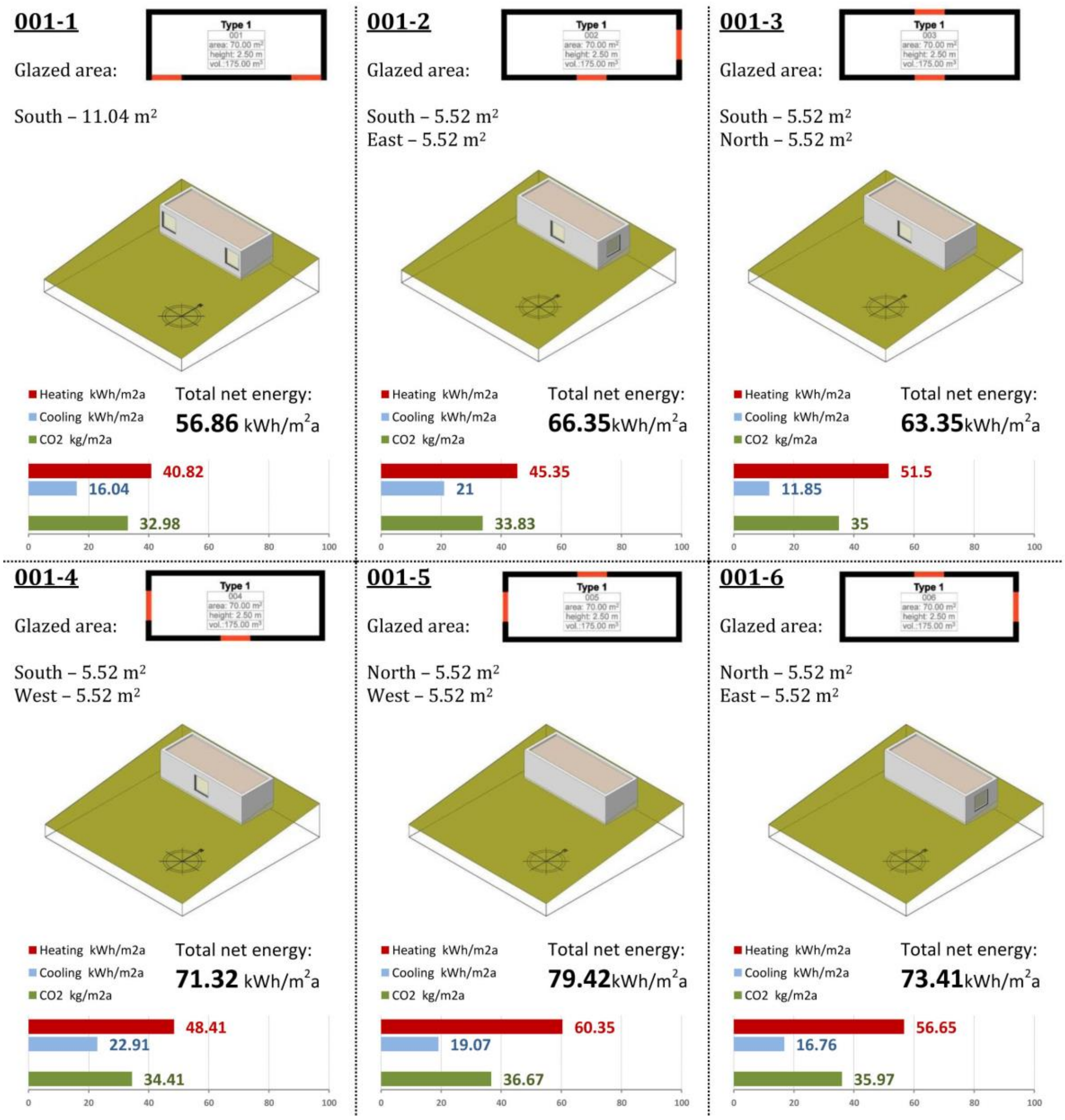


Figure 34: Case 1. Optimisation of windows' orientation

Case illustrates a range of evaluation results changing in dependence of windows' position. Two openings of the same size are allocated on different sides of the building to analyse how their orientation might influence building performance.

In the given case evaluation results show that south-orientated glazing (001-1) tends to be the most effective one. Strictly north-orientated case has been eliminated from the study analysis as an obvious outliner. The worst results have been detected in the case when half of the glazing was positioned on the north side and another half - on the west (001-5).

According to EcoDesigner simulation, user may come to conclusion that it could be more reasonable either to concentrate glazing on south-orientated side of the building or to spread it the way that also allows catching early sun hours. Program outlines that west-orientated openings tend to lead to overheating a bit more than those with east orientation. This might be explained with the fact that lower angle of the west sun is more difficult to block with overhanging, thus sun rays strike already pre-heated internal spaces.

South-facing windows are often considered a vital component for a passive design (Green Passive Solar Magazine 2011). Due to the fact that southern side potentially receives sunlight throughout the day, many passive solar buildings feature glass dominating the southern side. Evaluation results, obtained from EcoDesigner enable user to compare a range of possible scenarios and calibrate glazing percentage in accordance with required floor area.

Workflow of the study case included preparation of the initial building and following input of standard-library windows and took approximately 15 minutes for the initial case and extra 2-3 minutes for each variant. This included modelling itself, preparation of building materials, assignment of zones and establishing building systems. Calculation time took less than one minute.

5.2.2 Case 2: optimisation of building's orientation

Building templates of the same area, glazed area and ventilated volume are positioned on a slope. Differentiation in energy consumption is caused both by orientation and by varying building envelope area situated above the ground level.

Common building geometry data:
Gross floor area – 70 m^2
Ventilated volume – 175 m^3
Glazed area – 11.04 m^2

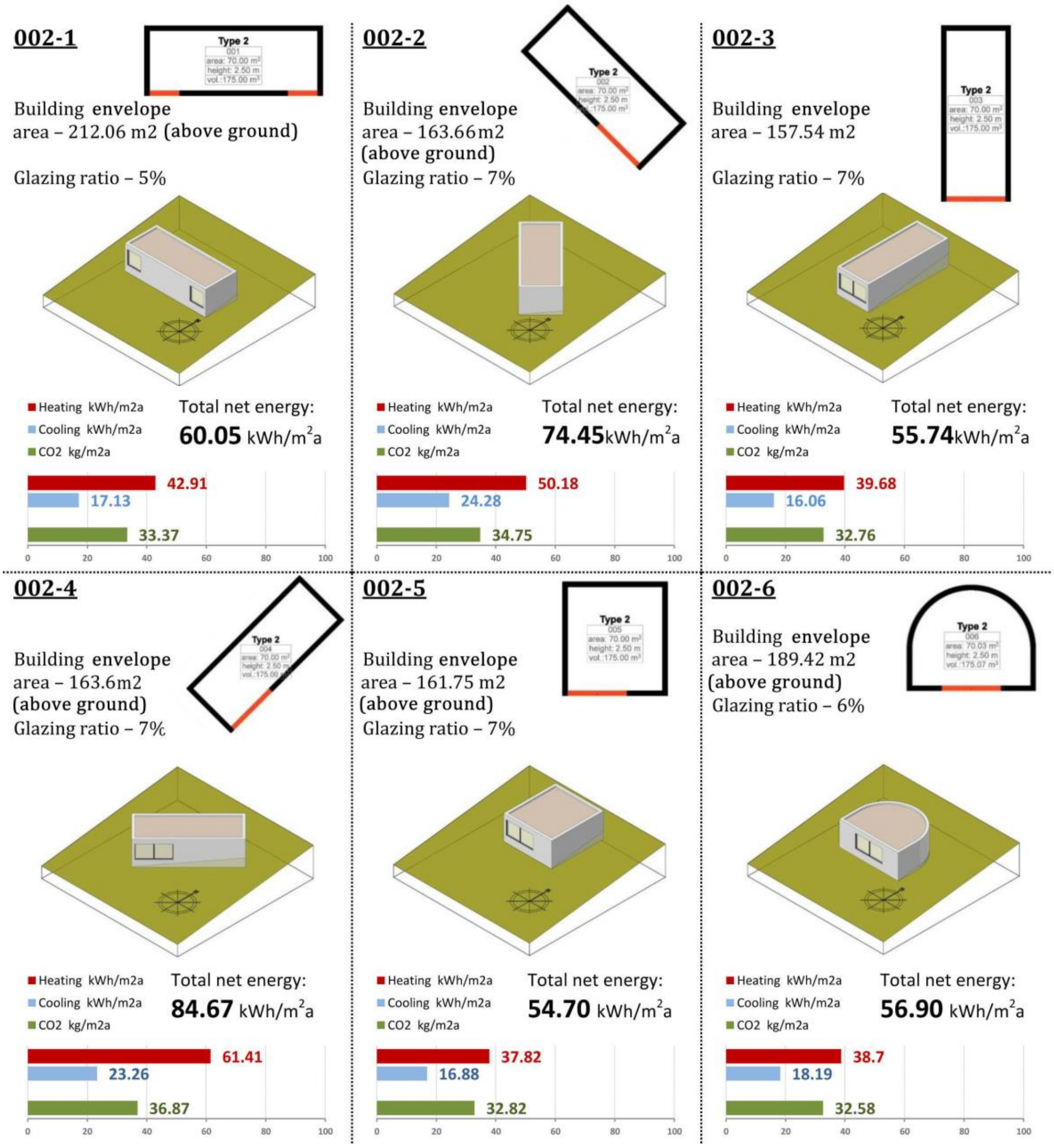


Figure 35: Case 2. Optimisation of building orientation

According to simulation the worst performance results are illustrated by buildings with their long axis set up diagonally in nw-se (002-2) and ne-sw (002-4) directions. They tend to show the highest heating demands. Case with a long axis in n-s direction (002-3) has approximately the same proportion of building envelope structures positioned above- and below ground as the previous two; nevertheless EcoDesigner depicts it as one of the most effective solutions.

Orientation of a building has the potential to make a considerable difference in resulting energy performance. There are numerous elements to be taken into account during placing building on a site and the derived study results may help user to outline those factors.

Passive solar buildings are typically rectangular with the long side of the building facing south – this way they absorb more sun heat energy (Green Passive Solar Magazine 2011). South-orientated elevations tend to provoke overheating but summer sun can be mitigated with horizontal shading devices due to its higher angle. South-facing elevations might be considered optimal for passive solar heating design solutions, which may involve a significant amount of glazed area.

In the study Case 002-1 served as a starting point for all the other model modifications. This helped to reduce general preparation time. Like in previous case building materials and structures were multiplied for every building type. Calculation of the simple geometry took less than one minute including solar analysis. No errors or warnings have been detected.

5.2.3 Case 3: optimisation of roof geometry

Study case provides evaluation of various types of roof geometry. Building templates of the same area, glazing area and glazing orientation are positioned on a slope. Differentiation in energy consumption is caused by varying of ventilated volume, roof orientation, building envelope area and glazing ratio.

Common building geometry data:
Gross floor area – 70 m²
Glazed area – 11.04 m²

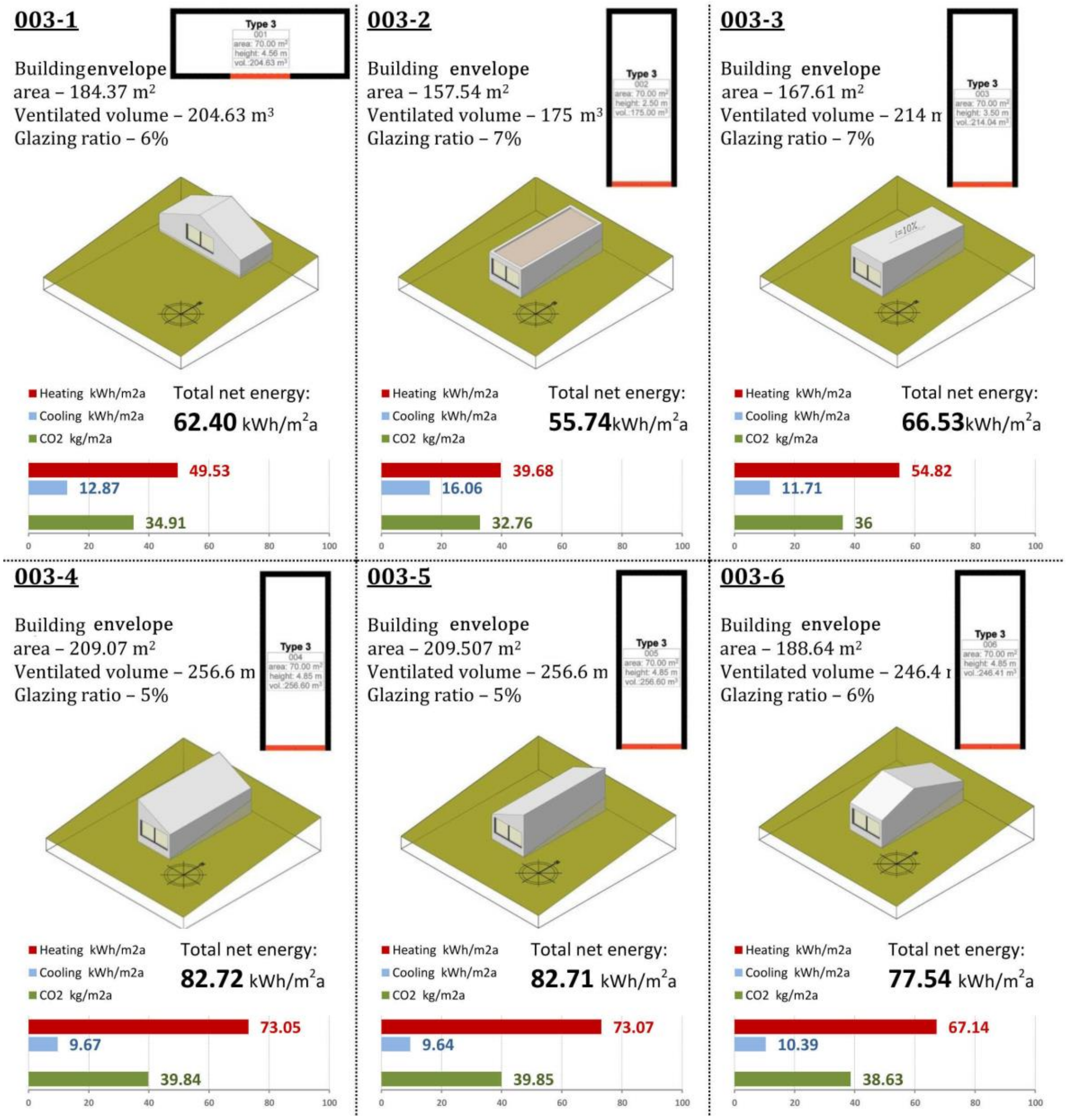


Figure 36: Case 3. Optimisation of roof geometry

The study case provides a better look on EcoDesigner modelling possibilities. Analysis of the presented building types might help user to find connection between size of a potential building and its energy demands. In other words, program may help to delineate such factors as the optimal envelope area, volume and compactness of the building.

Five buildings out of six have strict south-north orientation. The one with east-west orientation (003-1) is the building proving second-best performance results. Cases 003-2 and 003-6 have different roof geometry but share the same area and orientation. Total energy demands of the Case 003-2 are nevertheless almost 30% lower than those of the Case 003-6.

Here EcoDesigner tends to outline the most compact form of a building as the most effective one. Examples show how calibration of the roof form and following change of the ventilated volume within the house of the same area might significantly influence performance.

Workflow timetable shows that evaluation and modelling of buildings with pitched roof geometry might require a slightly more amount of time. This can be explained with the fact that zones don't "recognize" this type of roofs automatically and should be manually subtracted to fit the implied form. Case 003-5 presents itself a mirrored copy of the Case 003-4; thus time for the modelling has been reduced to minimal. Preparation of other models took between 12 and 20 minutes.

5.2.4 Case 4.1: optimisation of building geometry

Study case provides evaluation of various types of building geometry. Templates represent the same area, glazing area and certain differentiations of the ventilated volume. Fluctuations of energy consumption are caused by varying orientation, geometry, building envelope area and glazing ratio.

Building geometry data:
Gross floor area – 70 m^2
Glazed area – 11.04 m^2

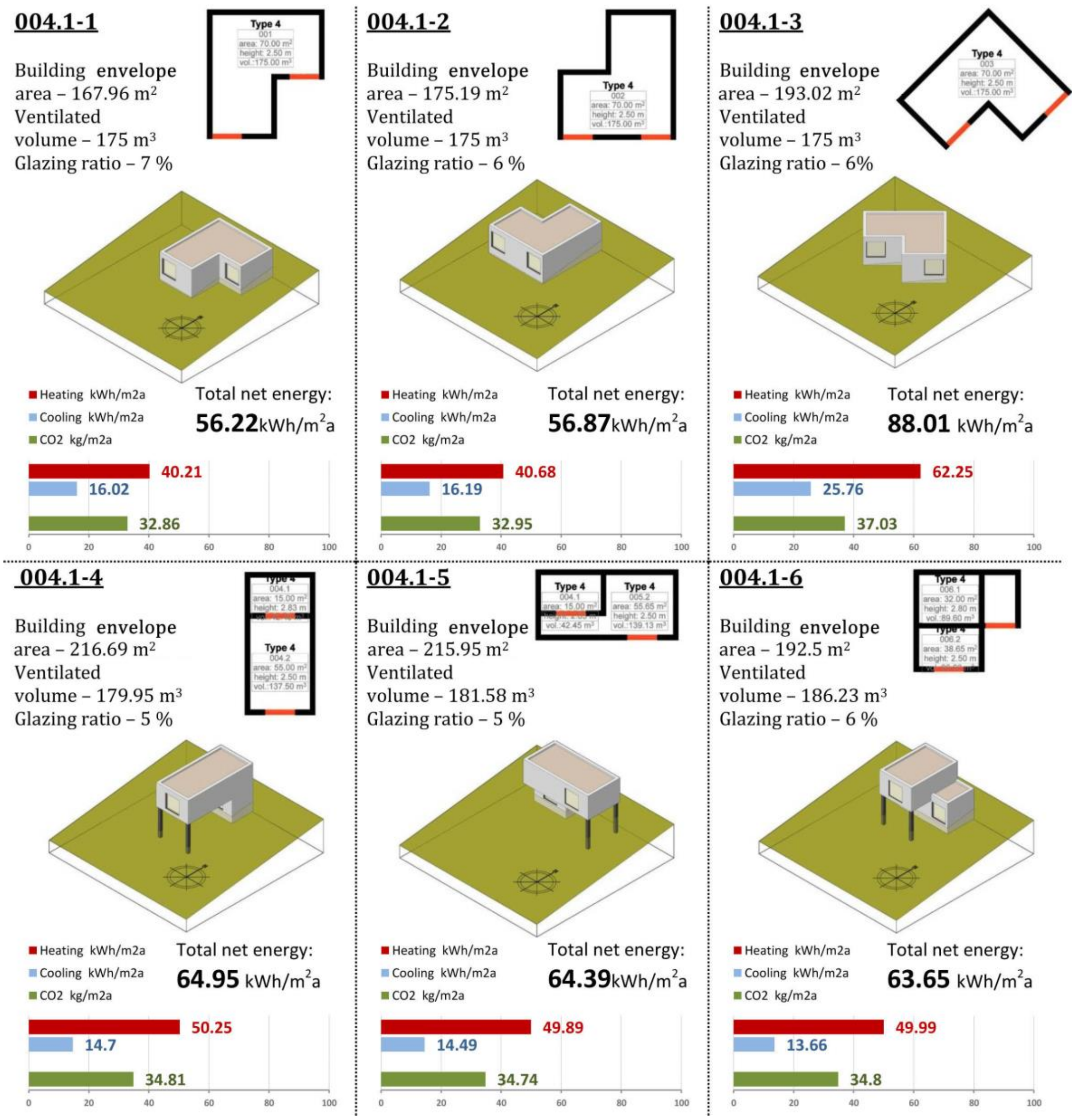


Figure 37: Case 4.1. Optimisation of building geometry

EcoDesigner shows that irregularly-shaped homes are less efficient than compact houses of a simple design. Following evaluation results, one might call Case 004.1-3 a clear outliner. Here a fairly large envelope area is exposed to north-east and north-west direction which might have found its reflection in comparatively large heating demands.

Simulation shows that two-storey houses prove to be quite effective and to illustrate lower cooling demands. This might be explained with reduced footprint and roof area as well as with the fact that during summer sun is higher in the sky and a smaller area of building envelope is exposed to direct sun.

In the example workflow proved to be less smooth and more time-demanding due to the presence of two-storey buildings. Extra-type of building structure had to be defined for slabs facing downward direction. In Case 004.1-4 the inner space in between two blocks was defined as a multi-level one. Established design created an unrecognised envelope area that belonged to the slab edge. Following calibration of zones solved the problem but consumed some extra time. Same concerned Case 004.1-6 that required additional zone calibration and didn't allow full recognition until two overlapping zones were not assigned to the same level.

5.2.5 Case 4.2: optimisation of building geometry

Extended version of the Study Case 4.1 provides evaluation more complicated types of building geometry. Templates represent the same area and glazing area. Fluctuations of energy consumption are caused by varying ventilated volume, orientation, roof-geometry and building envelope area.

Building geometry data:
Gross floor area – 140 m^2
Glazed area – 11.04 m^2

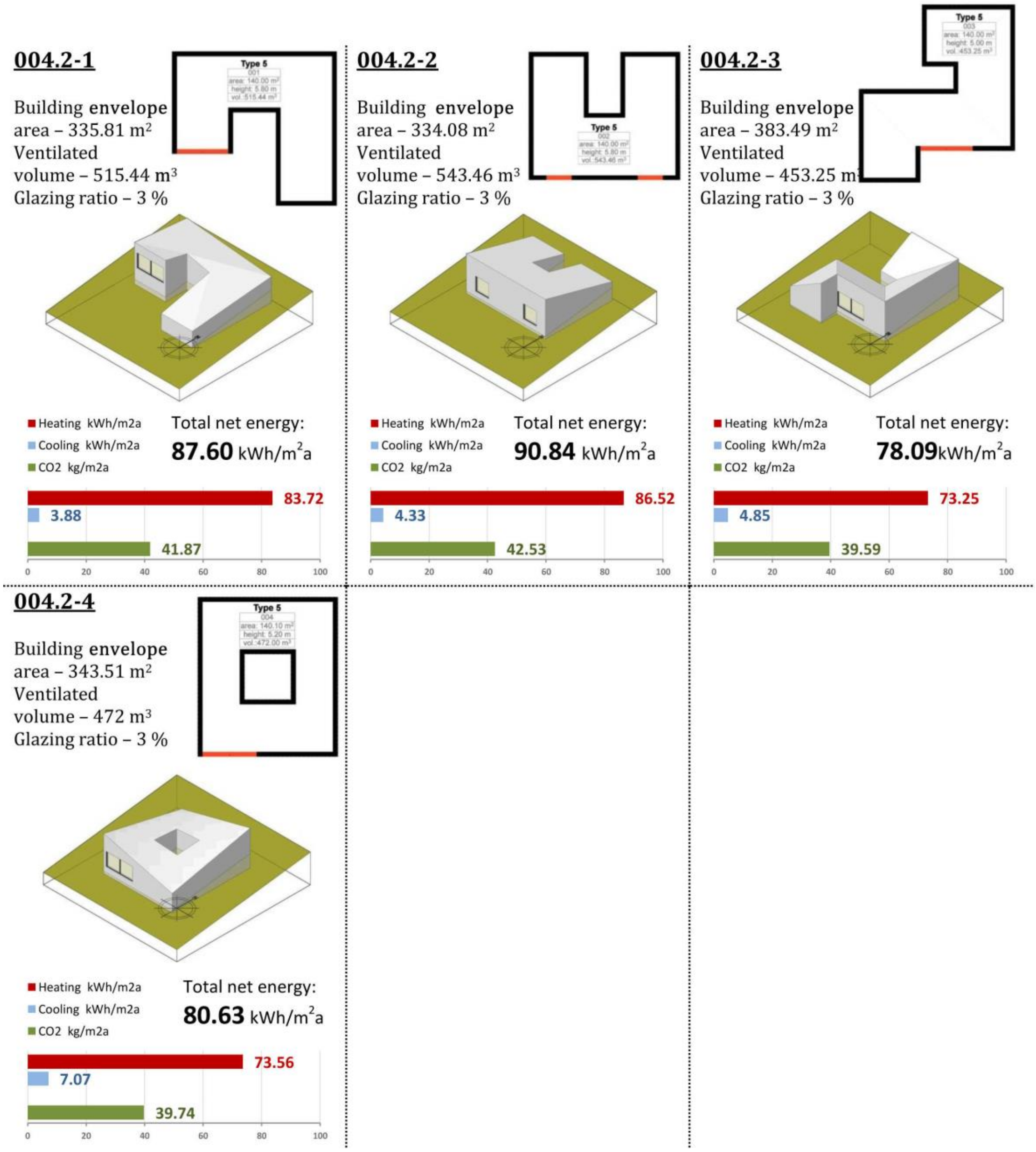


Figure 38: Case 4.2. Optimisation of building geometry

The key task of this part was testing of EcoDesigner's modelling possibilities. It is very important to keep outline of the building as simple and straight as possible to escape unnecessary junctions and to reduce the building envelope area. Thus it could have been anticipated that provided examples would illustrate sufficient heat loses leading to high heating demands. According to simulation results user might again outline advantages of compact architectural solutions.

The set of building types here represents itself a vivid example of program's geometry recognition potential. Preparation time took between 12 (Case 004.2-2) and 30 (Case 004.2.1) minutes in dependence on model's complexity. Case 004.2-4 might be regarded as the one of particular interest because of its hyperbolic roof form. Composite materials assigned to the structure allowed full recognition as soon as the corresponding zone had been assigned and "trimmed" to fit the inner contour. Time-demands just insignificantly exceeded those from the previous chapter.

5.2.6 Case 5: glazing ratio impact study

The study case evaluates influence of glazing ratio on energy performance. Gross area and ventilated volume remained constant; no shading devices were applied.

Building geometry data:
Gross floor area – 70 m^2
Building envelope area 161.75 m^2
Ventilated volume – 175 m^3

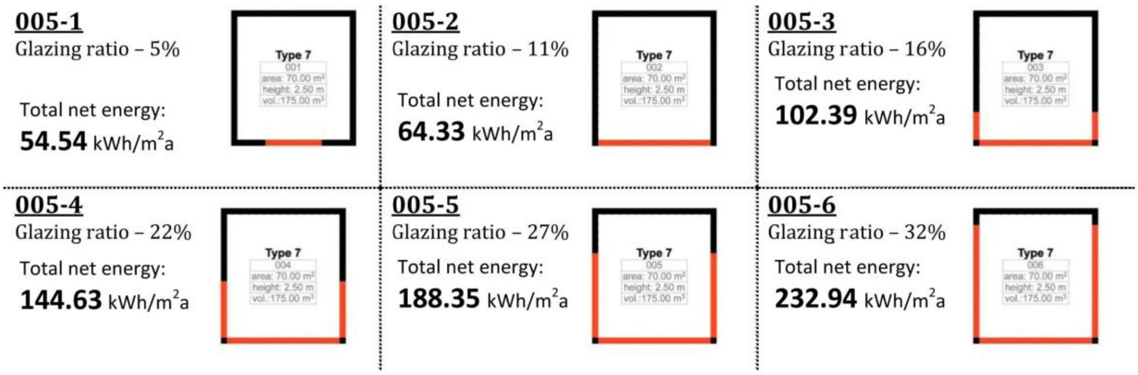
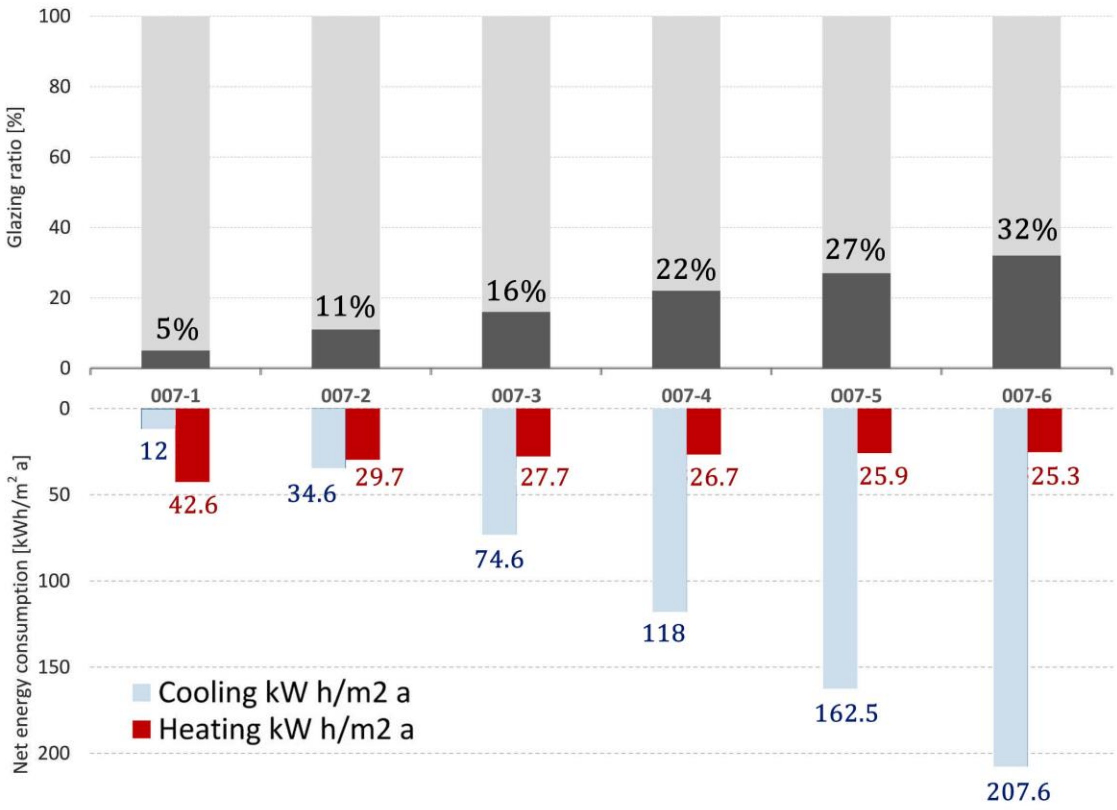


Figure 39: Case 5. Glazing ratio analysis

The first two cases show south-orientated glazing; in following examples new windows were added symmetrically on Eastern and Western sides of the building. Percentage of glazed area was gradually increased through series of steps from 5% to 32%. Major goal was to establish the amount of windows that according to EcoDesigner might create a balance between heating and cooling demands. In other words, task of a hypothetical user was to outline optimal glazing percentage that provides enough solar gains during winter days and doesn't lead to overheating during summer.

Table 6: Case 5. Influence of glazed area percentage on energy demands



On the graph above one can see that according to this simplified simulation balance of heating and cooling demands might be provided with 10 - 12% of glazed area. Percentage higher than that leads to over-heating during the day an excessive heat loss at night.

Workflow of this example resembles the one of Case 1. Solar analysis nonetheless proved that calculation time increases in a direct proportion to glazing percentage. Due to a rather primitive geometry no warnings have been detected. This particular case also emphasises the necessity to introduce alternatives' comparison into evaluation report. Currently every simulation has to be saved separately to derive key values and to analyse them afterwards by means of other software.

5.2.7 Output analysis

Review of the workflow description and analysis results allows making following conclusion: EcoDesigner may quite successfully assist in comparison of possible design solutions. The program illustrates easy model recognition and fast calculation. Time demands for simulation increase in accordance with complexity and size of the model. Minimal changes, whose effect was to be evaluated, may be applied, analysed and compared in rather brief time.

In general EcoDesigner tends to highlight compact buildings with south orientation as the effective ones. The tool provides means for easy calculation and optimisation of geometry compactness. Sheer analysis of building forms might lead to further evolution of design once architects compare developed options. Nevertheless, just like with stand-alone simulation tools, interpretation of the results requires certain experience, critical attitude and comprehension of program's logic.

5.3 Advanced geometry evaluation

Two examples presented in this chapter are supposed to illustrate possibilities of EcoDesigner to evaluate more complicated geometry. Main goal of the study was intention to try program in a field close to real design development. Two different scenarios were to be scrutinised. The first case is represented by a project of a private house. The second one – by a building originally erected 1909 and currently occupied by an office.

5.3.1 Case 1. Private house

Project taken for evaluation in this chapter is a two-storey private house with an area of 372 m². Main feature that made this particular design interesting for EcoDesigner evaluation was its relative geometrical complexity. The house has two types of roofs (pitched and flat), predefined shading devises on the facades, big glazed areas, two-storeyed spaces within the building, differential of levels and presence of structures below the ground level. The combination allowed having a better look in EcoDesigner's usability, modelling issues and program bugs.

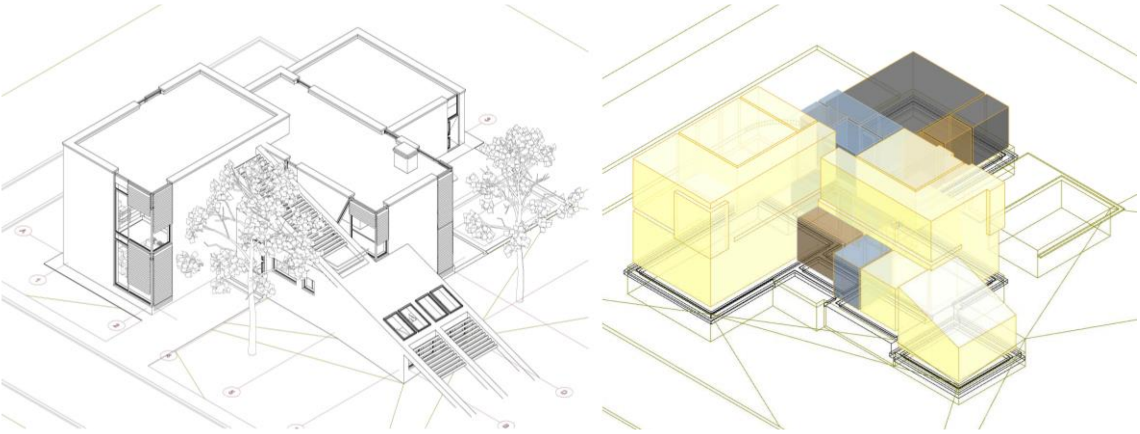


Figure 40: Advanced geometry, Case1. 3D-view. Defined zones and thermal blocks

Location of the house was set to Vienna; climate file was downloaded from Strusoft Server. Soil type was defined as gravel, surroundings – as garden. House was partly protected from wind – mostly from the eastern side. Horizontal shading was set to a low level from east and south-east.

All the zones of the house were divided between four thermal blocks with varying building systems. The first thermal block called "Living areas" included all the dwelling spaces. Overall the thermal block included 14 zones with a total area of 270 m². Residential type of the operation profile was applied. Human heat gain was set automatically to 120 W per capita, service hot water loads – to 150 l/day per capita and humidity load to 5 l/day. Building systems for the block included heating and cooling. The second thermal block contained lobby, several corridors and all the storerooms thus presenting an area of 26 m². The block operation profile was also set to a dwelling type though it was characterised with lower internal gains. Spaces were calculated without cooling. Bathrooms and laundry were combined to a separate block with a total area of 27 m². Corresponding operation profile supplied the rooms with heating. Technical areas such as garage and furnace room were defined as unheated and formed the last thermal block with an area of 50 m².

Heating source was a combination of a compact heat recovery system and a fireplace with external air supply. Cooling capacity of the machine was set to 1500 W. Ventilation profile was set to natural. Operation costs were calculated in accordance with prices of WienEnergie (www.wienenergie.at).

Operation profile defined work of the building systems in a following way: night period (from 0 am till 6 am) was characterised with a minimal temperature set to 20^{o}C. From 6 am till 23 pm maximal temperature was set to 26 ^{o}C. Fluorescent lights with a power of 3 W/m^2 were turned on in the periods of 6-8am and 18-23pm. Occupancy count remained at the level of 30 m^2 per capita. No equipment gains were included into evaluation.

Materials used for the evaluation mostly resemble those in the previous chapter. Two additions were external wall to the ground for parts below earth level and a pitched roof.

Table 7: Materials used for Case 1, advanced geometry evaluation

External walls (410mm)	**Wall to ground** (410mm)	**Slab to ground** (570mm)	**Roof slab** (550mm)	**Pitched roof** (435mm)
U-value: 0,32 W/m^{2}K	U-value: 0,27 W/m^{2}K	U-value: 0,17 W/m^{2}K	U-value: 0,17 W/m^{2}K	U-value: 0,19 W/m^{2}K
- Plaster 15 mm 0,57 W/mK - Insulation: mineral wool soft 150 mm 0,037 W/mK - Concrete blocks 215 mm 0,60 W/mK - Gypsum plaster 15 mm 0,57 W/mK	- Plaster 15 mm 0,57 W/mK - Insulation: mineral wool soft 150 mm 0,037 W/mK - Concrete blocks 215 mm 0,60 W/mK - Gypsum plaster 15 mm 0,57 W/mK	- Parquet 20 mm 0,14 W/mK - Air space 30 mm 0,15 W/mK - Lightweight concrete 20 mm 0,60 W/mK - Vapour seal 10 mm 0,50 W/mK - Insulation: XPS 200 mm 0,035 W/mK - Structural concrete 220 mm 2,30 W/mK - Lightweight concrete 25 mm 0,60 W/mK - Drained gravel 100 mm 1,40 W/mK	- Gravel 50 mm 1,407 W/mK - Lightweight concrete 20 mm 0,60 W/mK - Vapour seal 10 mm 0,50 W/mK - Insulation: mineral wool 270 mm 0,037 W/mK - Vapour seal 10 mm 0,50 W/mK - Structural concrete 220 mm 2,30 W/mK - Plaster 15 mm 0,57 W/mK	- Water-proof cover 20 mm 0,57 W/mK - Air space 25 mm 0,15 W/mK - Lightweight concrete 20 mm 0,58 W/mK - Insulation: EPS 200 mm 0,037 W/mK - Wooden construction 150 mm 1,40 W/mK - Plaster 20 mm 0,57 W/mK

Glazing overall U-value was fluctuating between 1,29 and 1,86 W/m^{2}K with double glazing, argon filled, low E (1.30 W/m^{2}K) and premium plastic frame (1.60 W/m^{2}K). Frames' U-value was put to 1,70 W/m^{2}K. Thus building shell average was defined by EcoDesigner as 0,48 W/m^{2}K.

Glazing ratio of the building was relatively high – 14%. As the architecture of the building predefines external blinds and overhangs, the corresponding shading devices were applied to windows where necessary.

General workflow started with an existing ArchiCAD model and converting it to a state applicable for EcoDesigner evaluation. The process included redefining existing simple walls (solid fills with no developed structures) into wall composites with a certain U-value. The same issue concerned slabs and roofs. As the next step, 3D-zones were created and their heights were established to recognize the envelope. Subsequently to series of error analysis certain calibration of geometry has been applied. Major problem was definition of spaces with varying height. In general preparation of the existing model initially created in ArchiCAD-12 took approximately 6-8 working hours. Resulting model still had minor unrecognised areas that were excluded from the calculation manually.

Following evaluation report was produced by EcoDesigner as a result of energy evaluation.

Key Values

General Project Data
Location:
Primary Operation Profile: Residential (100%)
Evaluation Date: 22/08/2013 23:18

Building Geometry Data

Gross Floor Area:	447.73	m^2
Building Shell Area:	802.05	m^2
Ventilated Volume:	1252.29	m^3
Glazing Ratio:	14	%

Building Shell Performance Data

Air Leakage:	0.80	ACH
Outer Heat Capacity:	139.09	J/m^2K

Heat Transfer Coefficients	U value	$[W/m^2K]$
Building Shell Average:	0.48	
Floors:	0.17 - 0.23	
External:	0.17 - 0.32	
Underground:	0.27 - 0.27	
Openings:	1.29 - 1.86	

Specific Annual Demands

Net Heating Energy:	80.31	kWh/m^2a
Net Cooling Energy:	18.56	kWh/m^2a
Total Net Energy:	98.87	kWh/m^2a
Energy Consumption:	285.10	kWh/m^2a
Fuel Consumption:	266.54	kWh/m^2a
Primary Energy:	482.53	kWh/m^2a
Operation Cost:	12.70	EUR/m^2a
CO_2 Emission:	40.93	kg/m^2a

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity MWh/a	Energy Cost EUR/a	CO_2 Emission kg/a
Renewable	Environment	7	NA	0
	Wood	13	349	349
Fossil	Natural Gas	51	1538	11074
Secondary	Electricity	37	3023	4399
	Total:	110	4910	15823*

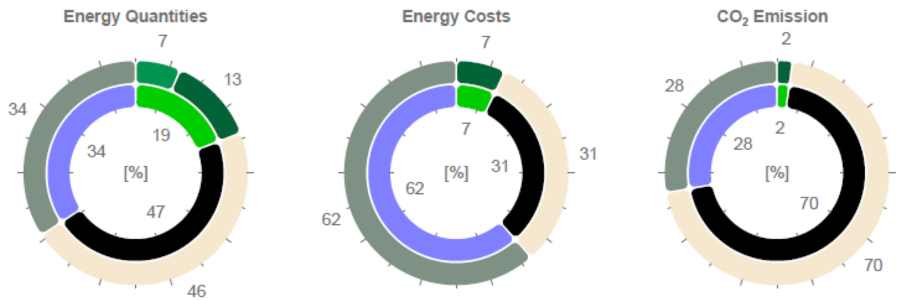


Figure 41: Advanced geometry, Case 1. Evaluation results

Derived results left a wide range of potential improvements. Energy demand indexes were distributed in a way where major part of required resources was supposed to cover heating needs (over 80 kWh/m^2a). Less than a fifth (18.56 kWh/m^2a) was supposed to sustain cooling demands. Theoretically those could have been regulated or even utterly voided by means of shading devices.

Optimization that was performed shortly after evaluation of the initial case included increasing of the insulation thickness in external walls (from 150 to 200 mm) and in slabs facing ground (from 200 to 250 mm). This time solar panels were supposed to be placed on the area of $15m^2$ facing south. Blinds' performance was also slightly tuned. Execution of described calibration took approximately 20 minutes. Figure below illustrates the results.

Key Values

General Project Data		
Location:		
Primary Operation Profile:	Residential (100%)	
Evaluation Date:	28/08/2013 08:11	
Building Geometry Data		
Gross Floor Area:	479.29	m^2
Building Shell Area:	787.24	m^2
Ventilated Volume:	1252.29	m^3
Glazing Ratio:	13	%
Building Shell Performance Data		
Air Leakage:	0.76	ACH
Outer Heat Capacity:	150.16	J/m^2K

Heat Transfer Coefficients	U value	$[W/m^2K]$
Building Shell Average:	0.43	
Floors:	0.14 - 0.14	
External:	0.14 - 0.34	
Underground:	0.19 - 0.19	
Openings:	1.29 - 1.86	
Specific Annual Demands		
Net Heating Energy:	73.43	kWh/m^2a
Net Cooling Energy:	16.23	kWh/m^2a
Total Net Energy:	89.66	kWh/m^2a
Energy Consumption:	264.26	kWh/m^2a
Fuel Consumption:	194.43	kWh/m^2a
Primary Energy:	363.93	kWh/m^2a
Operation Cost:	9.59	EUR/m^2a
CO_2 Emission:	29.48	kg/m^2a

Energy Consumption by Sources

Source Type	Source Name	Energy Quantity MWh/a	Energy Cost EUR/a	CO_2 Emission kg/a
Renewable	Solar Collector	21	NA	0
	Environment	6		0
	Wood	10	253	253
Fossil	Natural Gas	37	1117	8046
Secondary	Electricity	31	2522	3671
	Total:	**107**	**3894**	**11971***

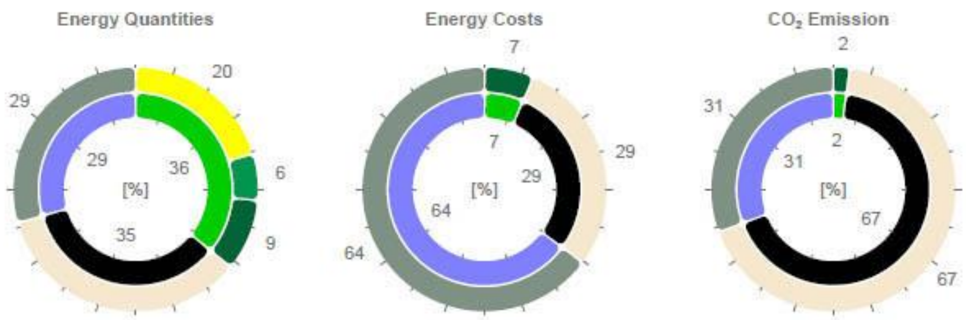
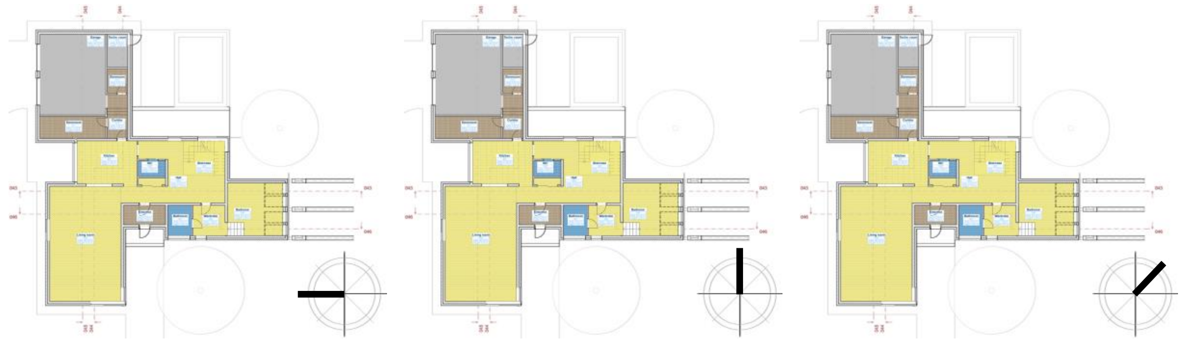


Figure 42: Evaluation results. Optimized case

Resulting parameters illustrated a reduction both in heating and cooling demands and a 24% decrease of the operation costs (from 12.7 to 9.6 eur/m²a). Solar panels covered more than a fifth of energy quantities. According to EcoDesigner applied changes caused a significant drop down in the CO2 footprint level (from 40.93 to 29.48 kg/m²a).

Another sort of experiment has been performed to analyse the way EcoDesigner evaluates orientation of complex buildings. Geometry and building materials' parameters remained untouched.



Initial case	*Case 1*	*Case 2*
Heating: 80.31 kWh/m^{2}a	Heating: 70.64 kWh/m^{2}a	Heating: 82.78 kWh/m^{2}a
Cooling: 18.56 kWh/m^{2}a	Cooling: 15.47 kWh/m^{2}a	Cooling: 21.41 kWh/m^{2}a
Total: 98.87 kWh/m^{2}a	Total: 86.12 kWh/m^{2}a	Total: 104.19 kWh/m^{2}a

Figure 43: Optimisation of building's orientation

Case 1 could be explained with the fact that after re-establishing north west-facing parts of the building envelope became dominating. That might have led to a slight increase of the amount of absorbed solar energy. Putting the house on the slope diagonally (Case 2) would have increased the percentage of north-facing structures. Observed performance fluctuations might draw attention to potentially problematic solutions, serve a source for alternatives' analysis and provide certain support in further project development.

5.3.2 Case 2. Office building

The building is situated in Moscow and belongs to a tramway depot complex, first established in the end of the 19th century. Currently the space is occupied by administration of the tram-park. Characteristic feature of the architecture is the thickness of external brick walls - 70 cm. House has two occupied floors and a warm attic – construction of the roof has been renovated in the middle of 70-s. Total are of the building – 1490m^2, ventilated volume – 3172m^3. Glazing ratio – 17%.

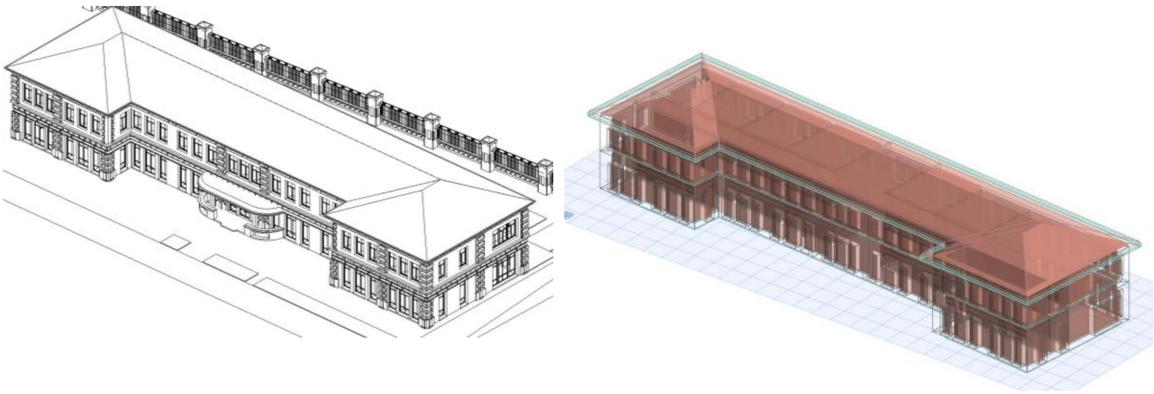


Figure 44: Advanced geometry, Case2. 3D-view and thermal blocks

Location was defined as Moscow; soil type - gravel, surroundings – paved. North and north-west sides are protected from the wind by neighbour buildings. Zones were separated into three groups: one for the offices, the second - for the communication areas (corridors, staircases) and the third one for unconditioned roof-space. Operation timetable has been divided between working days and holydays. Heating type was defined as “District”. Cooling machine was set to capacity of 3000W.

External walls made exclusively from brick provided a U-value of 0.79 W/m^{2}K according to EcoDesigner. Mean U-value of the materials used through the whole project was 0.70 W/m^{2}K. This rough approximation was conditioned by the lack of accurate data on real constructions. U-value of the openings fluctuated between 1.4 and 1.52 W/m^{2}K.

Workflow started with the preparation of the existing model. Presented walls and slabs were created earlier in ArchiCAD version 11 but lacked assigned construction types. Overall the process took approximately 3 hours. That included re-establishment of the envelope, creation of zones, ascribing of the operation profile and of the building systems. Detected problems included unrecognized area of the slab between the attic and the 1st floor. It occurred in places of intersection between slab, external wall and the lower part of the pitched roof. After several unsuccessful attempts to fix the issue in model, the area has been excluded from the calculation manually. Worthwhile to mention is that all the windows coming originally from ArchiCAD library version 11 were instantly recognized and evaluated.

Resulting total energy demands were equal 78,49 kWh/m^2. Alternative evaluation for this example included variations of daily time schedules. Working hours (7am – 18pm) in initial case were characterized by minimal temperature 20 and maximal 26. Rest of the time minimal and maximal limits were turned off. During weekend minimal temperature stayed at 15 degrees C. One of alternative evaluations implied narrowing of the acceptable temperature limit during working hours to 22 till 24 degrees C. Here EcoDesigner illustrated an expectable escalation of energy demands. The second one excluded temperature limit for weekend. Here program quite predictably showed decreasing energy consumption. According to EcoDesigner calculation, potential of energy saving with such scenario may reach almost 20 %. Key values of resulting files are presented below.

Key Values

General Project Data			**Heat Transfer Coefficients**	U value	[W/m²K]
Project Name:	AC 17_Buro		Building Shell Average:	**0.70**	
City Location:			Floors:	**0.13 - 0.13**	
Climate Data Source:	D_IWEC.epw		External:	**0.19 - 0.79**	
Evaluation Date:	19/11/2013 21:55:37		Underground:	--	
			Openings:	**1.44 - 1.52**	
Building Geometry Data					
Gross Floor Area:	**1489.24**	m²	**Specific Annual Demands**		
Treated Floor Area:	**1338.09**	m²	Net Heating Energy:	**75.50**	kWh/m²a
External Envelope Area:	**1341.56**	m²	Net Cooling Energy:	**2.99**	kWh/m²a
Ventilated Volume:	**3172.49**	m³	Total Net Energy:	**78.49**	kWh/m²a
Glazing Ratio:	**17**	%	Energy Consumption:	**186.72**	kWh/m²a
			Fuel Consumption:	**186.72**	kWh/m²a
Building Shell Performance Data			Primary Energy:	**293.76**	kWh/m²a
Infiltration at 50Pa:	**1.69**	ACH	Fuel Cost:	--	GBP/m²a
Outer Heat Capacity:	**126.16**	J/m²K	CO_2 Emission:	**11.06**	kg/m²a

Initial evaluation: Temperature limit during working hours 20-26 degrees C

Key Values

General Project Data			**Heat Transfer Coefficients**	U value	[W/m²K]
Project Name:	AC 17_Buro		Building Shell Average:	**0.70**	
City Location:			Floors:	**0.13 - 0.13**	
Climate Data Source:			External:	**0.19 - 0.79**	
Evaluation Date:			Underground:	--	
			Openings:	**1.44 - 1.52**	
Building Geometry Data					
Gross Floor Area:	**1489.24**	m²	**Specific Annual Demands**		
Treated Floor Area:	**1338.09**	m²	Net Heating Energy:	**106.36**	kWh/m²a
External Envelope Area:	**1341.56**	m²	Net Cooling Energy:	**5.84**	kWh/m²a
Ventilated Volume:	**3172.49**	m³	Total Net Energy:	**112.20**	kWh/m²a
Glazing Ratio:	**17**	%	Energy Consumption:	**221.93**	kWh/m²a
			Fuel Consumption:	**221.93**	kWh/m²a
Building Shell Performance Data			Primary Energy:	**337.67**	kWh/m²a
Infiltration at 50Pa:	**1.69**	ACH	Fuel Cost:	--	GBP/m²a
Outer Heat Capacity:	**126.16**	J/m²K	CO_2 Emission:	**11.96**	kg/m²a

Evaluation Case A: Temperature limit during working hours 22-24 degrees C

Key Values

General Project Data			**Heat Transfer Coefficients**	U value	[W/m²K]
Project Name:	AC 17_Buro		Building Shell Average:	**0.70**	
City Location:			Floors:	**0.13 - 0.13**	
Climate Data Source:			External:	**0.19 - 0.79**	
Evaluation Date:			Underground:	--	
			Openings:	**1.44 - 1.52**	
Building Geometry Data					
Gross Floor Area:	**1489.24**	m²	**Specific Annual Demands**		
Treated Floor Area:	**1338.09**	m²	Net Heating Energy:	**60.68**	kWh/m²a
External Envelope Area:	**1341.56**	m²	Net Cooling Energy:	**1.46**	kWh/m²a
Ventilated Volume:	**3172.49**	m³	Total Net Energy:	**62.14**	kWh/m²a
Glazing Ratio:	**17**	%	Energy Consumption:	**169.49**	kWh/m²a
			Fuel Consumption:	**169.49**	kWh/m²a
Building Shell Performance Data			Primary Energy:	**271.70**	kWh/m²a
Infiltration at 50Pa:	**1.69**	ACH	Fuel Cost:	--	GBP/m²a
Outer Heat Capacity:	**126.16**	J/m²K	CO_2 Emission:	**10.57**	kg/m²a

Evaluation Case B: Exclusion of internal temperature minimum for weekend

Figure 45: Advanced geometry, Case 2. Evaluation results

6 DISCUSSION

6.1 EcoDesigner Mechanics

The section presents analysis of EcoDesigner mechanics parameters. They are supposed to outline main features of the software that have direct impact on user's efficiency. Set of the chosen criteria allows describing capabilities, requirements and functionality of the tool

Evaluation method reflects the one chosen by Attia (Attia 2011). Rank marks were assigned in accordance with corresponding characteristics of the programs he had analysed in his survey.

6.1.1 Usability and Information Management

(Medium)

Adoption of working methods of every program takes time and experience. Therefore presence of built-in tutorials is a remarkable advantage of EcoDesigner. The same concerns wide and vibrant on-line community. Graphisoft has established an on-line Help Centre that unites user guide, official channel with video-tutorials and users' forum. The recourse can be accessed directly from the ArchiCAD window. In cases of software's unexpected failures, it also has a ticketing system to support requests. In general EcoDesigner user guide provides a clear and structured description of the workflow. Negative side is that Graphisoft does not define the type of user or the level of expertise required.

EcoDesigner may be considered a rather powerful visual analysis instrument. It supports modelling and evaluation of a relatively complicated geometry. Work with the tool, however, requires not just the basic knowledge of ArchiCAD but an advanced grasp of the program. An indispensable condition of any analysis conducted in EcoDesigner would be accurately established geometry with strictly assigned zones and composite structures. Correctly-generated model can be afterwards changed infinite amount of times. That contributes to a high interoperability level. Errors detected by EcoDesigner are highlighted in a vivid way.

EcoDesigner's interface is organized around the only Energy Evaluation Model window. All the input blocks including climate, materials and building systems are concentrated in the top right corner and might be accessed by clicking on drop-down menus. The same sub-menus can be reached from the ArchiCAD itself.

Process of assigning building systems and operating profiles follows the wizard approach and may be considered intuitive. Materials, system's components and surroundings are supposed to be selected from predefined lists. Customization of those is possible but might be performed exclusively through XML system files. General workflow in EcoDesigner corresponds to the one of ArchiCAD. This might sufficiently increase usability level for experienced ArchiCAD users.

EcoDesigner provides no opportunity to compare several simulated cases. User is forced to run one evaluation after another. Key values can be found and analysed easily. Report is structured in a user-friendly way to be intuitively understandable. Nevertheless graphs are inflexible and might be hard to read. The only two options of their adjustment (choosing between pie- and table chart forms) don't suffice the task. Scale of the graphs and their presentation in PDF-report might be considered illegible and hard to analyse for a person first time working in EcoDesigner. Monthly-based reports in XLS-format provide a better picture allowing users themselves to visualise sectors of their particular interest.

All the mentioned characteristics allow putting EcoDesigner to a medium usability level. Main reason is the fact that common ArchiCAD user doesn't usually resort to the great amount of model refinements essential for the simulation. Sometimes EcoDesigner input requirements conflict with common ArchiCAD workflow. For instance it has been empirically proven that simulation of big projects with varying interior levels runs with fewer detected errors when ArchiCAD storey-dividing system is neglected. In these cases working space is set to a single floor of an infinite altitude. Problem does not have a constant character. Ways of solving it depend on user's proficiency, skills and modelling habits. In general work in EcoDesigner may not require wide expertise in energy simulation but advanced grasp of ArchiCAD remains an important condition to facilitate the process.

6.1.2 Intelligence and Integration of design Knowledge-Base

(Low)

EcoDesigner has a large database that covers climate, materials' library, HVAC systems and operation profiles. Users can choose from a wide range of predefined characteristics, calibrate them or create new. Approach depends on the level of user's expertise and required accuracy. Table presented below illustrates comparison of predefined EcoDesigner values for Human Heat Gains and Occupancy Count with those from ASHRAE.

Table 8: Comparison of predefined values.

	Human heat gain (W per capita)		Occupancy count (m^2 per capita)	
	EcoDesigner	ASHRAE	EcoDesigner	ASHRAE
Residential	120	120	30	18-55
Office	120	130	10	10
Classroom	100	100	3	2

As was already mentioned, EcoDesigner doesn't support comparison of several design solutions. It also doesn't inform users on energy codes requirements in their particular region. A possibility of storing design alternatives within the same report might have facilitated decision making. The same concerns lacking pre-design advices. Currently simulation results do not sufficiently support architects and leave design evolution to the old trial and error method. User is supposed to analyse the report himself and afterwards to produce a new modified design. Ranking of several design strategies might have also been a valuable feature to be implemented.

Due to complete absence of advisory functions EcoDesigner might only be characterized with a low level of intelligence.

6.1.3 Interoperability of Building Modelling

(Medium)

EcoDesigner supports relatively wide freedom of modelling: it recognises curved structures and irregularly-shaped windows. Graphisoft also provides a rich database of various building elements and library parts created either within the company or by users. Should be, however mentioned that several building elements (windows, for instance) that were downloaded from the official resource to be tested were not recognised by EcoDesigner. The defect puts under question achievable level of model refinement.

Export of the created model can only be rated as average. ArchiCAD itself provides a wide spectrum of transfer possibilities to a number of different energy evaluation programs. Those include EDSL TAS (through IFC–format) and AchiPhysik. Mentioned options were implemented into ArchiCAD long before integration of EcoDesigner. Software itself, at least its non-commercial release, allows saving reports exclusively into PDF and XLS formats. The feature characterises EcoDesigner as a quite comprehensible but a rather superficial tool. Users are not supposed to achieve with its help anything else but preliminary evaluation.

6.1.4 Process Adaptability

(Medium)

EcoDesigner doesn't support various levels of data input for different stages. Required elaboration level is rather high even for preliminary simulations. In general EcoDesigner may be considered suitable for early design phases. It provides everything required for site, solar and geometry analysis. Created model might be smoothly transferred to commercial version for further work and certification.

6.1.5 Accuracy and Ability to simulate Complex building Components

(Medium)

Underlying VIP-calculation engine of EcoDesigner is ASHRAE 90.1-2004 compliant but the program itself is still just a design-assisting tool for architects. The question of accuracy has been raised straight after Graphisoft announcing its intentions to integrate EcoDesigner into ArchiCAD (Pickering 2012). No official statement concerning the margin of error has been made by far. Nevertheless there were several attempts by Graphisoft collaborators to cover the gap. One of the studies ran by Miklos Sved included evaluation of Hadlow College (Sved 2011). In order to verify EcoDesigner's calculation accuracy Sved compared the most important resulting data generated by EcoDesigner with the one generated for the by PHPP. Results are presented below:

PHPP Energy Calculation Results

Specific Demands with Reference to the Treated Floor Area		
Treated Floor Area:	242.1	m^2
	Applied:	Monthly Method
Specific Space Heat Demand:	14	$kWh/(m^2a)$
Pressurization Test Result:	0.4	h^{-1}
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	87	$kWh/(m^2a)$
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	45	$kWh/(m^2a)$
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		$kWh/(m^2a)$
Heating Load:	13	W/m^2
Frequency of Overheating:	8	%
Specific Useful Cooling Energy Demand:	8	$kWh/(m^2a)$
Cooling Load:	11	W/m^2

EcoDesigner Energy Calculation Results

Specific annual demands		
Net heating energy:	14.40	kWh/m^2a
Net cooling energy:	7.98	kWh/m^2a
Primary energy:	88.45	kWh/m^2a

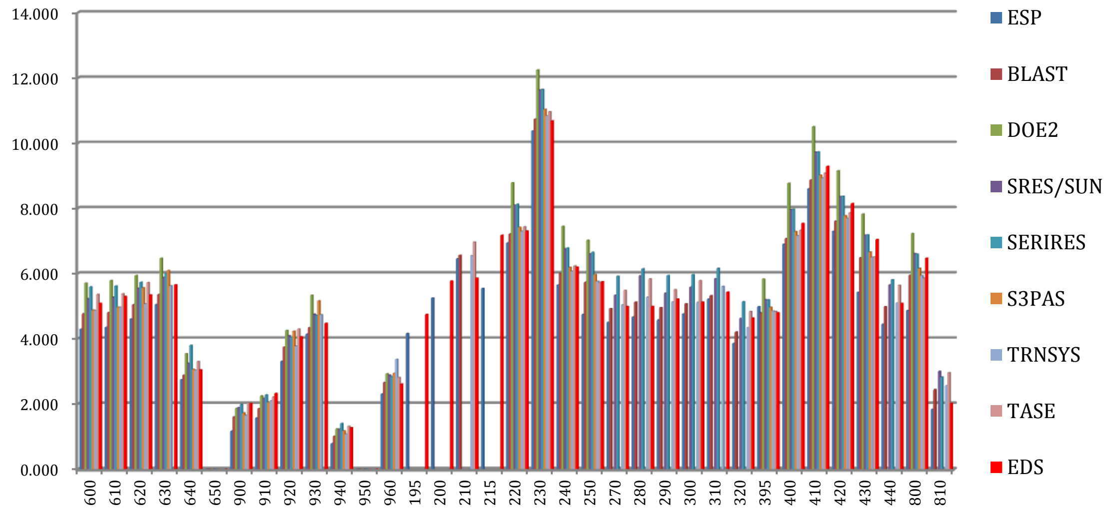
Figure 46: Comparison of EcoDesigner and PHPP energy calculation results

(Sved 2011)

In the case EcoDesigner calculation results were almost identical to those by PHPP. Detected difference was in +-5% frame.

A wider comparative analysis of EcoDesigner performance has been officially provided by Graphisoft in February 2013. Thus the latest update of EcoDesigner is announced to comply with the Building Thermal Envelope, Fabric Load Tests and all the three sections of the ANSI/ASHRAE Standard 140-2007. The study is supposed to technically prove that the existing version of EcoDesigner is able to produce similar accuracy as high-end analysis software.

Table 9: Comparison of results provided by various energy evaluation tools and EcoDesigner STAR (Graphisoft 2013)



EcoDesigner illustrates a rather high level of complex geometry recognition but its ability to simulate detailed building components leaves several questions. For example Pickering claims software's support of thermal bridges' recognition to be essential for a genuine Building Information Model (Pickering 2012). In EcoDesigner thermal bridge effect should be assigned to structures manually.

Another questionable issue is solar analysis function. The option is supposed to increase work efficiency and accuracy of the outcome. Generated results are, however, excluded from the final report in standard version. The only option is to establish shading level for each window manually using corresponding pop-up menus. The method leads to a duplicated workload: first users model shading devices and afterwards attach shading parameters in Energy Model Review table.

6.2 EcoDesigner Matrix

Following table has been elaborated during the process of work in EcoDesigner. It illustrates coverage of the aspects that architects would presumably address in the beginning of project's development.

Table 10: EcoDesigner Matrix analysis

	Graphisoft EcoDesigner
Metrics	
Energy	●
Environmental (CO2)	●
Economic	●
Embodied Energy	
Urban Scale	
Comfort & Climate	
Climate Analysis	●
Static	●
Adaptive	○
Comfort Visualisation	
Passive Strategies	
Geometry, Massing	●
Day lighting	●
Natural Ventilation	●
Window/wall ratio	●
Thermal Mass	
Shading Devices	●
Energy Efficiency	
Envelope Insulation	●
Glazing Performance	●
Envelope Air Tightness	●
Artificial lighting	●
Plug Loads	●
Infiltration rate	●
Mechanical Ventilation	●
Cooling System	●
Heating system	●
Renewable ES	
Photovoltaic (PV)	●
Building Integrated PV	
Solar Therm. Collectors	●
Innovative Solution & Technologies	
Mixed Mode Ventilation	○
Advanced Fenestration	
Green Roofs	
Cool Roofs	
Double Skin Facade	●
Solar Tubes	
Phase change materials	

Energy, environmental and economic indexes define the level of building performance. Therefor it is essential for a program to cover a wide spectrum of simulation metrics. EcoDesigner evaluates energy demands, CO2-footprint and potential costs. Implementation of urban scale evaluation might have been a valuable improvement.

Climate analysis in EcoDesigner can be supported with several possible sources (StruSoft, ASHRAE IWEC, TM, WTEC2). Definition of adaptive or static inner conditions within the software in unclear. User is able to apply different operation profiles to infinite amount of thermal blocks within one building. Developed system might become quite sophisticated and cover various hours, days of week and months of year. Nevertheless EcoDesigner doesn't allow establishing maximum and minimum temperature limits to activate certain profiles.

The only genuinely dynamic feature of the program is the possibility to activate shading elements in accordance with external and internal conditions. Adjustment of the activation parameters is, however, accessible exclusively through XML-files. The opportunity itself brings clear benefits to EcoDesigner's performance. Processing is far from obvious and thus may confuse an inexperienced user.

Most of the fundamental passive strategies are accessible in EcoDesigner. Some of them (shading devices) require manual input that confronts the idea of BIM/BEM automated workflow.

Energy efficiency factors are also generally covered in EcoDesigner. Those provide an opportunity to define envelope insulation, HVAC systems and to calculate electricity loads and glazing performance.

Number of available renewable energy sources that user can include into project is relatively narrow. It includes Photovoltaic Panels and Solar Thermal Collectors. Collector should be defined manually and might be assigned to heating and to hot water generation.

The weakest side of EcoDesigner concerns application of innovative solutions and. Double skin façade can be modelled and recognised unlike, for example, cool roofs. Mixed mode ventilation might be sublimated by adjusting several ventilation profiles to the same thermal block and defining timetable of their operation. But just like in the case of adaptive climate control, the option doesn't include any sort of optimisation or automation in the calculation process.

6.3 Detected inaccuracies

Issues presented below illustrate a range of drawbacks and bugs that common user may face developing project and evaluation it with EcoDesigner. The list may vary in dependence on operator's expertise and the task set.

Dealing with adiabatic walls in EcoDesigner proved to be quite problematic in cases when just one of two neighbouring buildings is a subject for evaluation. ArchiCAD modelling allows defining a concrete structure with insulation where the one is needed. On picture below red highlights concrete wall between two adjacent buildings and blue shows insulation.

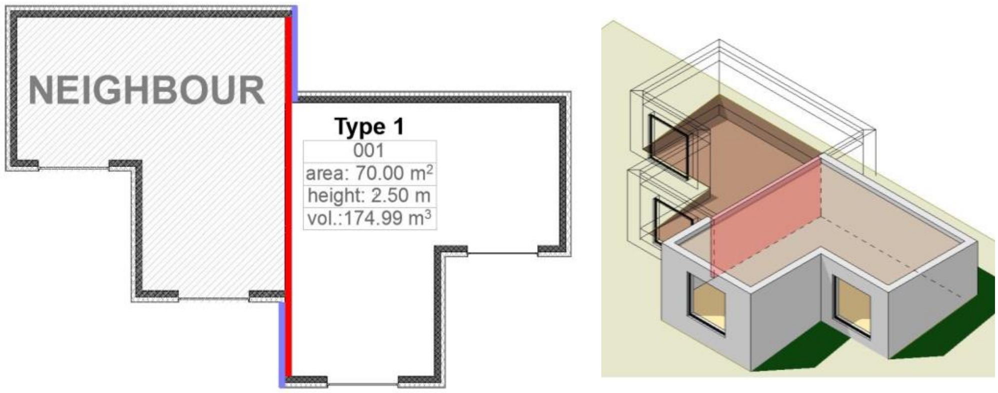


Figure 47: Adiabatic walls in EcoDesigner

If no zone is defined to identify the neighbour as a heated space, ArchiCAD will take the bare concrete wall (U-value 2.01 W/m^{2}K) as an external wall that in its turn will lead to significant inaccuracy in calculation results. If one creates a zone with a special thermal block to define the neighbouring house as a conditioned space, it will be taken into account as a part of volume to be calculated for the report. In previous versions of EcoDesigner it was possible to assign adiabatic qualities to walls; no such possibility has been detected in the current version. The easiest way to overcome the problem is to manually exclude "external" part of the concrete wall from the calculation.

Another discovered issue was lack of possibility to tune the amount of occupants manually. The number is predefined by profile and finds its reflection in internal heat gains. Figure itself isn't displayed anywhere in the review panel and cannot be changed.

By default "Show Uncovered Areas" command highlights surfaces that don't have space boundaries associated to them. This indicates model inaccuracies and ideally there should be none. During the course of work on projects of different scale it has been noticed that appearance of "uncovered areas" is basically inevitable whenever the model grows relatively complex. In most cases they appear when zones defining neighbouring inner spaces belong to different ArchiCAD levels or have different height. Even though the error doesn't appear constantly, it is extremely hard to deal with: alteration of zones' geometry leads to the change of the unrecognized area's location but not to its full disappearance.

Another problem can be caused by using not-standard ArchiCAD library elements for windows. Elements downloaded from official Graphisoft database tend to disappear from the Energy Model Review – even if they were recognised in the beginning. Thus usage of these elements might only be advised at user's own risk and for projects of a small scale when it's easy to track all the presented openings before launching the calculation.

6.4 Comparison with commercial version (EcoDesigner-STAR)

Several weak or missing points in EcoDesigner workflow have been detected during elaborating study cases. The short list of features that might affect the quality and the easiness of preliminary energy evaluation within the software looks the following way:

- Missing import to PHPP. The option available for EcoDesigner till ArchiCAD version 15.
- EcoDesigner doesn't recognise the geometry of building itself as a source of shading. Notwithstanding integrated solar analysis, all the shading units have to be defined manually.
- Program doesn't recognise thermal bridges.

Mentioned points are covered within the frame of commercial edition of EcoDesigner; beta-version was announced and made available by Graphisoft in February 2013. Brief analysis of the software's possibilities has been run for the sake of revealing its potential advantages in comparison with basic edition.

According to Graphisoft, EcoDesigner-STAR addresses detailed design and documentation design stages (Graphisoft 2013). In other words the add-on is supposed to cover advanced levels of project development that are in general outside the scope of this thesis. It is assumed that several features available only in EcoDesigner-STAR could find its use on the early design stage. Following part includes contrasting of the two versions.

6.4.1 Standard compliance

Basic version of EcoDesigner is not validated according to any international standard. The only validated technical background is the usage of the same simulation kernel as VIP Energy product. The one is certified with EN-15265, IEA-BESTEST, ASHRAE-BESTEST (ANSI/ASHRAE Standard 140-2001) and StruSoft-BESTEST.

EcoDesigner STAR in its turn fully complies with all three sections of the ANSI/ASHRAE Standard 140-2007. As it has been declared by Graphisoft on the step of EcoDesigner STAR-beta release, the software also satisfies Energy Star, Architecture 2030 Goal, Green Star, BCA Section J, NatHERS, NABERS, Building Thermal Envelope and Fabric Load Tests (Graphisoft 2013).

6.4.2 Thermal bridge analysis

In standard edition of EcoDesigner thermal bridge effect is assigned to structures manually and is represented by the value-input box. For windows, for example, the index is identified with Psi-value that stands for the linear thermal transmittance coefficient. U-value calculation includes thermal bridge effect into common algorithm leaving definition of the number itself to users. Recommendations concerning those inputs might be found either in internet or in ArchiCAD Help. Some default delta U-values taken from ArchiCAD Help file are presented below:

- External wall - 0,11
- Roof – 0,04
- Basement wall - 0
- Slab above unheated attic – 0,09
- Wall between heated and unheated internal spaces – 0,04

It is however advised by official EcoDesigner user guide to review and manually override these predefined values if the structural situation demands (Graphisoft 2012). Recommendation provides user with no official database and implies sheer internet surfing.

Detailed approach to thermal bridge analysis in EcoDesigner STAR was one of the major features announced as a difference between basic and commercial versions. Simulation is done by means of standard ArchiCAD tool called "Detail" and the workflow looks the following way:

1. Detail originally taken from a 3D-section or drawn in 2D is defined with the same building elements/fills used throughout the project.
2. User indicates external, internal and underground area of the drawing thus specifying geometry.
3. User assigns internal and external air temperature, heat transfer coefficient and soil type, if required, and runs simulation. It is also possible to re-write U-value parameters of used fills in simulation window.
4. After simulation results have been derived and a Psi-value of a certain junction has been established, user can connect the evaluated detail to corresponding thermal blocks. The only numerical input required is length.

Even though the option might be considered a valuable expansion of program's possibilities, its presence on preliminary evaluation stages might hardly be considered mandatory.

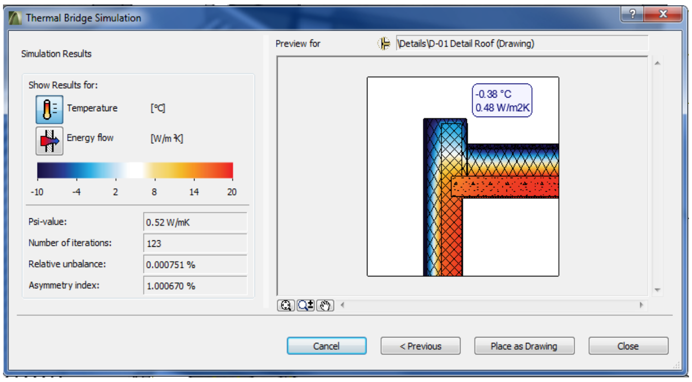


Figure 48: Thermal bridge simulation

6.4.3 Solar/shading analysis

Model-based Solar Irradiation Study has been implemented to ArchiCAD starting version 17. Simulation might be considered quite intuitive and easy to generate. Results of the analysis itself however are not taken into account when a "Monthly Energy Balance" is calculated in standard edition of EcoDesigner. Thus 3D model does not provide any effect on solar shading analysis. All the settings of shading devices have to be set up manually. Performing this user has to choose from a comparatively narrow amount of options.

In the commercial version Solar Irradiation Study finds its reflection in simulation results. That allows users to accurately model green environment of the project or optimise designed geometry of the building in accordance with simulation results. Additional refinement such as manual input of shading devices is still possible but the list is enlarged with predefined shades defined in accordance with ASHRAE.

6.4.4 Output results

EcoDesigner is positioned as an actual dynamic energy simulator (Graphisoft 2013). Simulated energy demands either for one year or for a month might be accessed from PDF-report or - in a more extended way - from the exported XLS-file. What lacks in the basic version output is the possibility to take a look on a daily temperature profile separately for each day. There is also no possibility to identify the coldest or the hottest room in the analysed building. The feature that might not be ultimately necessary on the early design stage but useful for better understanding of building's geometry.

STAR-version produces more detailed performance reports and a wider spectrum for optimization of its appearance. Add-on allows executing separate thermal blocks and to run evaluation of daily profiles thus establishing temperature in- and outside the building for each particular day of the year. Another newly-established feature of STAR-version is integration of the "Energy consumption and savings" chapter into report that is supposed to help optimizing building energy demands by generating a baseline building.

6.4.5 Export options

Export into a PHPP format has been derived from the standard EcoDesigner package starting ArchiCAD version 16. Only remaining export options are to the IFC-format – from the common ArchiCAD export window – and the regular PDF and XLS saving possibilities for the EcoDesigner reports.

Besides standard IFS, PDF and XLS reports, commercial version in its turn can export thermal block geometry and material property data into a number of external energy calculation apps and compliance tools. Direct export channels are available for PHPP, VIP-Energy, iSBEM and the gbXML.

7 CONCLUSION AND RECOMMENDATIONS

In the course of study EcoDesigner proved itself a relatively quick and easy-to-comprehend tool for energy evaluation. Workflow within the program might be structured in a very coherent way. The software can be applied for projects of a different scale but the number of model errors increases with increasing complexity of buildings. Errors that may influence accuracy of the simulation are recognised and highlighted by EcoDesigner. Elimination of them, however, requires a rather wide grasp of ArchiCAD.

Program provides a wide spectrum of predefined values and characteristics to facilitate the performance analysis. Still, it is necessary to remember that EcoDesigner is not an energy-compliance tool but a preliminary simulation instrument. If an advanced approach to energy performance becomes essential, user should either address its commercial version or other evaluation tools.

EcoDesigner is not standard-compliant or verified. As the major topic of this thesis concerns early design stages, obtaining energy certificates has not been considered as an indispensable condition. Nevertheless the tool should be able to provide reasonable evaluation results. Brief analysis illustrates that in general EcoDesigner is capable to recognize advantages of different design solutions with regard to energy performance. Interpretation of the simulation results depends exclusively on user's expertise.

EcoDesigner toolbar is located next to all the basic functions in the ArchiCAD window and thus can be easily found. This might stimulate users towards performing energy evaluation simultaneously to design development. Preliminary modelling, preparation of construction documentation and energy evaluation can be conducted within the same interface. Therefore simplicity and accessibility of performance simulation may inspire more professionals for creation of a sustainable environment.

Although Graphisoft has to a certain degree succeeded in eliminating borders between different sides of project development, EcoDesigner still requires substantial refinements. The first issue concerns a very low intelligence level of the program. Format of informing architects on sustainability potential of their design is currently quite shallow and needs a considerable enhancement.

Program lacks possibility of comparison between different evaluation cases. It also doesn't provide any recommendations on potential improvements. References to regional requirements should be made accessible directly from the evaluation window. Fully-functioning shading recognition needs to be implemented thus to replace the manual input.

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8.2 Figures

8.3 Tables