CHALMERS
UNIVERSITY OF TECHNOLOGY

Identify Optimal Renovation Packages for Residential Buildings: A State-of-the-Art Computational Model

Citation for the original published paper (version of record):

Kharseh, M., Nägeli, C., Wallbaum, H. (2019)
Identify Optimal Renovation Packages for Residential Buildings: A State-of-the-Art Computational Model
IOP Conference Series: Earth and Environmental Science, 297(1)
http://dx.doi.org/10.1088/1755-1315/297/1/012018

(article starts on next page)

IOP Conf. Series: Earth and Environmental Science **297** (2019) 012018 doi:10.1088/1755-1315/297/1/012018

Identify Optimal Renovation Packages for Residential Buildings: A State-of-the-Art Computational Model

Mohamad Kharseh, Claudio Nägeli, Holger Wallbaum

Chalmers University of Technology, Sweden

The corresponding author's e-mail: mohamad.kharseh@chalmers.se

Abstract. Renovating the existing building stock has a significant potential to achieve the goal of reducing greenhouse gas (GHG) emissions in the European Union. However, a common European renovation project focuses primarily on improving the thermal performance of the building shell by adding insulation to the opaque surfaces and improve the thermal performance of the windows. The potentially positive contribution of renewable energies (RE) in balance with energy efficiency measures is often underestimated. Consequently, a more holistic approach can contribute to a reduction in total net energy demand up to 40-45% for the entire buildings sector. Thus, in order to achieve the goal of GHG emission reduction in an economic most responsible way, the share of RE in a renovation project needs to be increased. However, building renovation projects are becoming - apparently - more complicated if more factors are considered in the planning of a renovation project. Thus, a computational tool for evaluating hundreds of different renovation options, including the implementations of renewable energy resources, to obtain an optimal or nearly optimal set of renovation options is essential. Therefore, a novel planning tool has been developed within the framework of DREEAM project, a project funded by the European Union within the Horizon 2020 research framework. The DREEAM-Tool has been designed in the way that it helps designers and other stakeholders to plan a renovation project of a single building or even on a multi-building scale. The tool was built in the way to optimize the renovation project taking into consideration the most critical factors in planning and decision-making processes, such as the economic or environmental performance. In other words, the tool combines an energy calculation model for a building or multiple building with an economic and environmental assessment to identify and optimize the most beneficial refurbishment solutions. The current study presents the concept of the DREEAM-Tool and shows examples of how the optimal renovation packages of a considered building will be determined and how this will support designers or buildings owners in decision-making processes.

1. Introduction

Because of increasing greenhouse gas emissions and its well-known impact on the climate, reducing energy consumption became an urgent issue. 40% of the total European Union energy use is consumed in buildings [1]. Knowing that about two-thirds of the energy used in the EU-15 buildings goes to space heating, the most significant potential for saving energy lies on renovation and upgrading of the old building to modern energy standard [2,3]. This leads to the fact that 30% of global carbon dioxide emissions come from buildings [4]. Heating and cooling system, which is expected to increase between the year of 2010 and 2050 by 79% in residential buildings and 84% in commercial buildings, account for the majority of energy consumption in building [5].

Unfortunately, 72% of residential dwellings in the EU were built before 1972, namely, were built to the thermal performance standards lower than the current standards which are imposed under current building regulations. In Sweden, for example, 77% of the buildings were built before 1980, while the first Swedish regulation of thermal comfort in buildings was published [3,6]. Thus, refurbishment of the old building is a curtail factor not only to fulfill the target of the EU in reducing the energy consumption but also in reducing the environmental load of the building stock. In other words, the most substantial potential for saving energy toward mitigating the climatic changes lies on renovation and upgrading the old buildings to modern energy standard. The European Commission established a long-term target of reducing the greenhouse gas (GHG) emissions levels for the building sectors by 88-91% up to 2050 compared to 1990 levels [7]. In line with this, the Swedish environmental quality objectives have established a goal of reducing energy consumption by 50% per unit heated area in the built environment in 2050 compared with 1995 [8].

To achieve an economical GHG emissions reduction, the share of RE in buildings renovation projects needs to be increased. However, building renovation projects are becoming - obviously - more complicated if more factors are considered in the planning of a renovation project. Thus, a computational tool for evaluating hundreds of different renovation options, including the implementations of renewable energy resources, to obtain an optimal or nearly optimal set of renovation options is essential.

Several tools are developed to simulate the renovation on the district level to assist designers and stakeholders before deciding on buildings refurbishment. The District ECA that is formed by the EU MODER project, for instance, is available for free as the international version. The D-ECA tool can perform energy efficient strategies and technologies for the energy efficient renovation of districts. However, the calculation is based on the use of pre-defined archetype buildings. This means the geometry and user profile of the archetype buildings specific for the individual country is fixed, which reduce the freedom of the user.

Recently, Fan et al. presented an optimized mathematical model to help decision makers to identify the best combination of retrofit options for buildings to ensure policy compliance in the most cost-effective way in the office sector [9]. The model determines optimal retrofit plans for a whole building in a systematic manner, considering both the envelope components and the indoor facilities. The model also considers the rooftop PV system to reduce the usage of electricity produced from fossil fuels. The model was built based on the dynamic method of calculating heating and cooling load of the building. However, the model can be used for a single building and cannot be used at the district level. Also, the optimization method is a genetic algorithm meaning, taking into consideration a large number of variable, a long computational time.

Wu et al. developed a model using EnergyPlus for the simulation of the energy demands and CPLEX for optimizing [10]. The aim of the model is optimizing both annual costs and GHG emissions. The model considers both retrofits in the building envelope as well as local production of energy with boilers, heat pumps, solar thermal and PV modules. The optimization is posed as an epsilon-constrained mixed integer linear program and takes into consideration a set of previously simulated retrofit scenarios, along with the rest of the local energy production measures. It does not detail how much insulation should be put; it just targets U-values that come from the Swiss regulation. The space heating simulations are thorough, but just a few scenarios are explored.

FASUDIR is another European project [11], which was conducted by industrial and academic parents, has developed FELICITY web-based decision support tool, termed FELICITY, for assessing the condition and energetic performance of large building stocks as well as setting up and comparing retrofitting concepts based on key performance indicators [12].

Finally, designPH EDU was developed specifically with students and universities in mind [13]. The model was developed to help designer and building owner to pan a refurbishment in order to achieve a passive house level. Therefore, the model cannot be used to optimize the retrofitting. Also, it cannot be used at the district level.

Hence, The DREEAM-Tool, which is developed by the Chalmers University of Technology, is the core of the approach to refurbishment concept design taken within the DREEAM-project. The tool considers the possibility of integrating the available renewable energy resource as well as the interaction between the different buildings to define optimal renovation scenario and energy demand reduction. In other words, the developed tool aims at achieving high energy reduction demands by cost-optimally balancing between energy efficiency (EE) and renewable energy supply measures (RES) to optimal energy demand reduction.

2. DREEAM-Tool

In the light of the fact that most renovation projects take place in a multi-building scale accounts for 36% of all EU's residential buildings, innovative approach in which the balances between energy saving measure and implementing of renewable energy on multi buildings scope seems to be the method to increase the saving in energy demand cost-effectively. However, many of the technologies to be considered for cost-effective solutions are available on the market or having been piloted in real-life environments, the integrated approach for the targeted market segment does not exist.
DREEAM-Tool is a computational tool to help in optimizing a building retrofitting project.

2.1. Simulation steps

By taking a multi-building approach to refurbishing their residential building stock, building owners can act more strategically than it is the case when renovating one building at a time and aim to achieve better energy efficiency results.
The overall process can be divided into three necessary steps, see Figure 1:

1) Building Portfolio: The aim here is to give an overview of the status quo of the buildings including, but is not limited to, building type, U-value of different components, occupancy and usage profile.
2) Select what to be renovated: Pre-select what retrofitting measure or technology options to be included based on preferences and pre-assessment. Namely, identify the essential hotspots to be addressed in refurbishment concepts (e.g., windows, wall, roof, install a solar system, or any other renovation option).
3) Optimization Indicators: this step specifies which indicators to be optimized. These can be energetic (i.e., energy demand reduction), economic (i.e., return on investment) or environmental (i.e., greenhouse gas emissions) indicators.

This way the model is ready to run. The energy demand reduction of the concepts is calculated and optimized, based on the indicators selected in step 2. The results visualized on a Pareto-curve allow a building owner to select the most optimal refurbishment concept in an informed way.

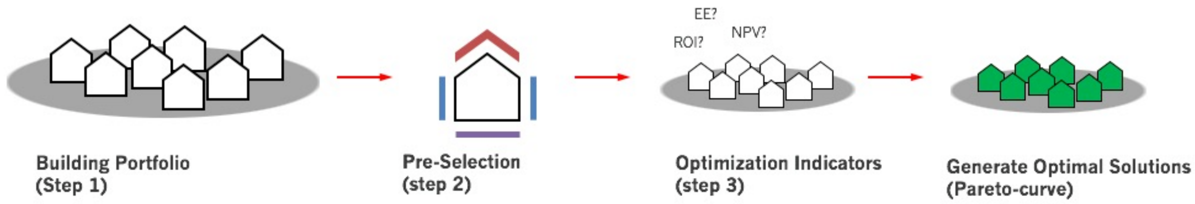

Figure 1. Simulation steps of DREEAM-Tool.

2.2. Concept

The concept of the tool can be broken down into three key parts (see Figure 2). First, the building portfolio and refurbishment database have to be added. In the second part, the energy performance of the building is calculated according to multiple target criteria (e.g., max. energy demand reduction vs. ROI) and then matched with suitable renovation solutions. As a result, selections of optimal renovation scenarios are presented on a Pareto-curve.

The tool combines an energy calculation model for the building with economic and environmental assessments in order to assess and optimize refurbishment concepts. The optimization is done by multidimensional optimization approach, based on an evolutionary algorithm that can automatically find the Pareto-boarder for multiple criteria selected by the user. Thereby, the DREEAM-Tool enables the development of an optimized design of renovation concepts that highlight the trade-offs between the different indicators (e.g., environmental vs. economic benefits) and allows the building owners to select the concept that is most suited to their preference. By doing so, the tool can support building owners in making strategic refurbishment decisions for their portfolio and help them translate those decisions in corresponding refurbishment concepts and select between different refurbishment approaches in line with overarching targets.

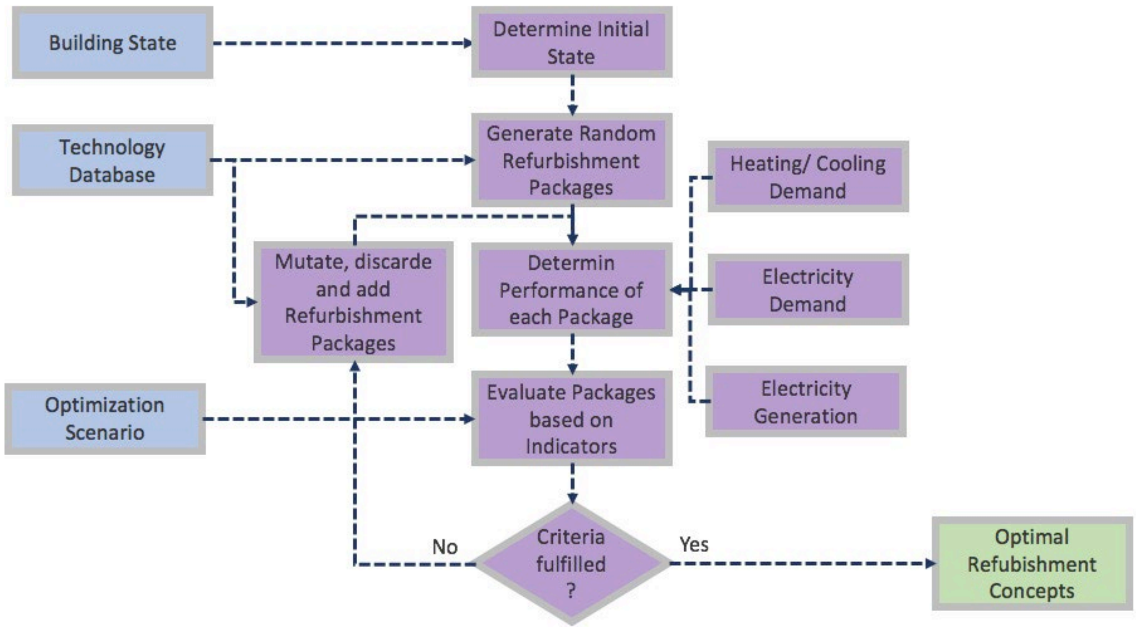

Figure 2. the concept of the DREEAM-Tool.

2.3. *DREEAM-Tool user interface*

The user interface of the DREEAM-Tool has been built to be user-friendly and composed of three sections as follows:

2.3.1. *Building Portfolio*

The user can add and manage the existing building data with an easy-to-use editor. This includes the location, building groups and individual buildings with their properties. The properties include all the technical and geometrical data of the different buildings.

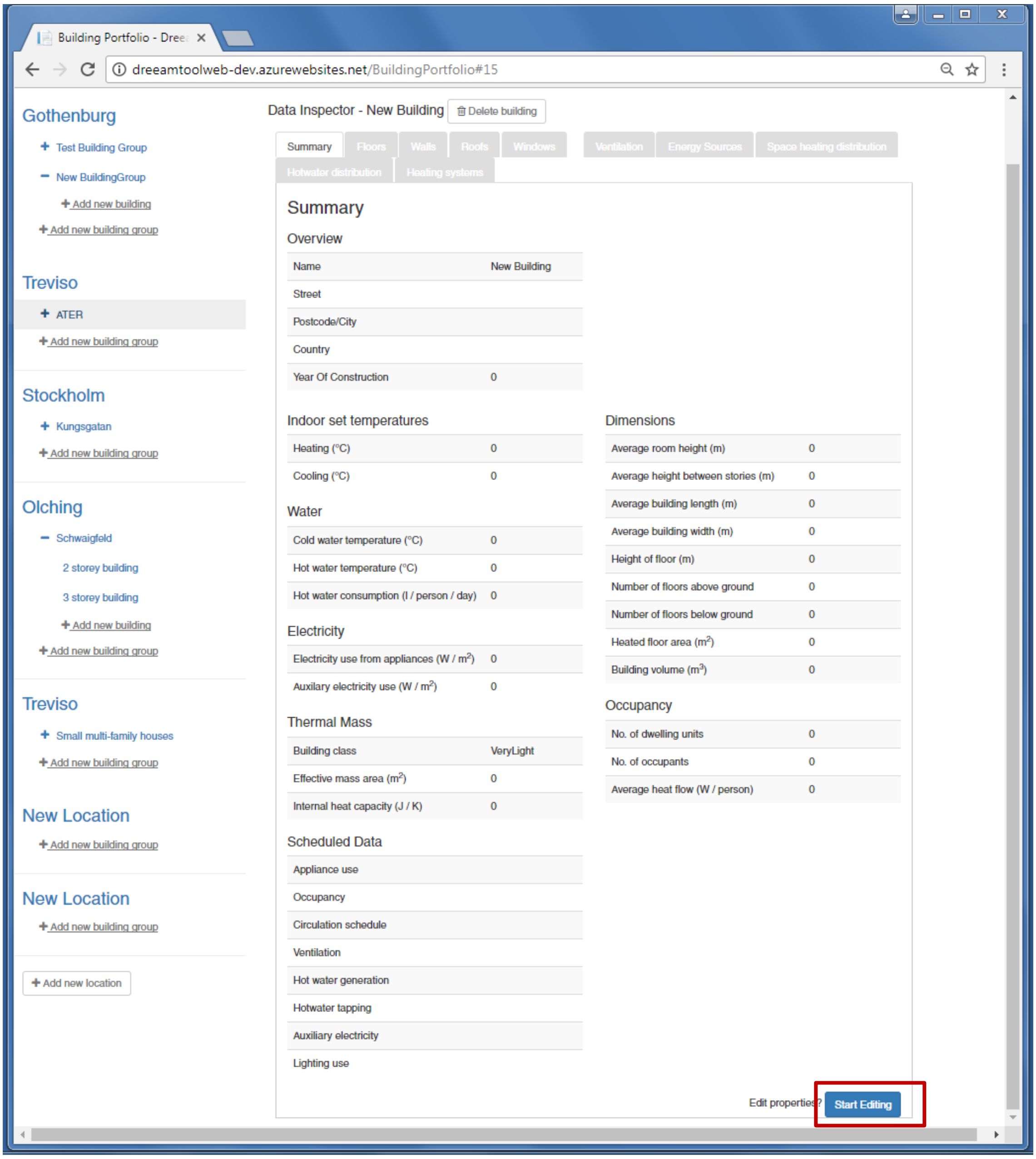

Figure 3: Editing of basic information about the building

2.3.2. Refurbishment Database

The user adds own custom refurbishment options and can edit properties of all the refurbishment options that were added. Those refurbishment packages will be stored in the database, and the user can select later on which are chosen for the calculations.

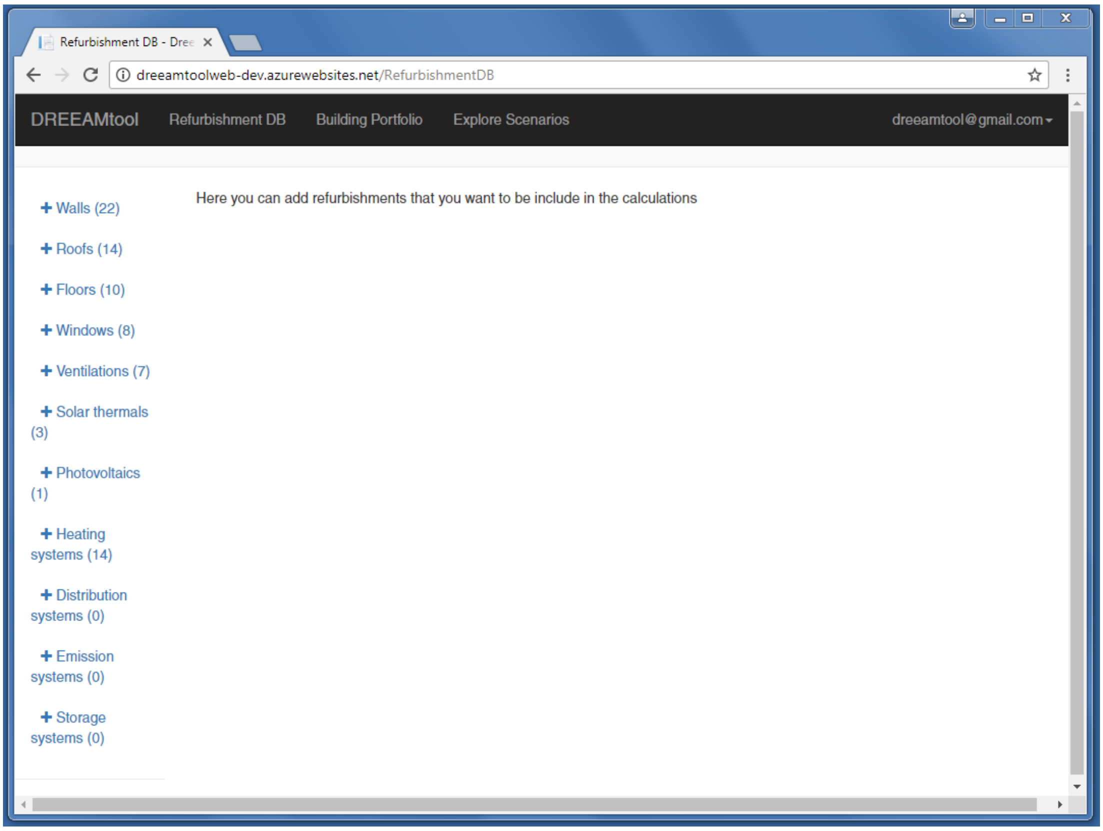

Figure 4: Refurbishment Database Section in the DREEAM-Tool

2.3.3. *Explore Scenarios*

Here new scenario calculations for the building portfolio can be started, and the optimal strategies can be explored when the calculations are done. The different strategies can be selected and exported for external use.

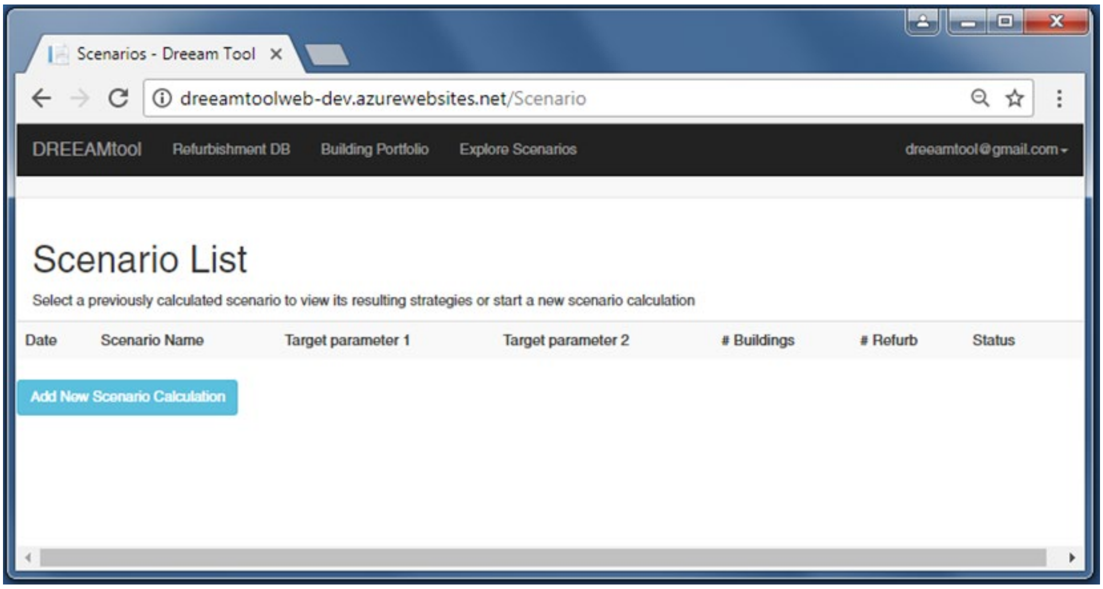

Figure 5: Explore Scenarios in the DREEAM-Tool

After starting the scenario by clicking “Explore Scenarios” it will appear in the scenario list. The status shows how far the calculation has gone. It might take up to 20 min until a calculation reaches 100%.

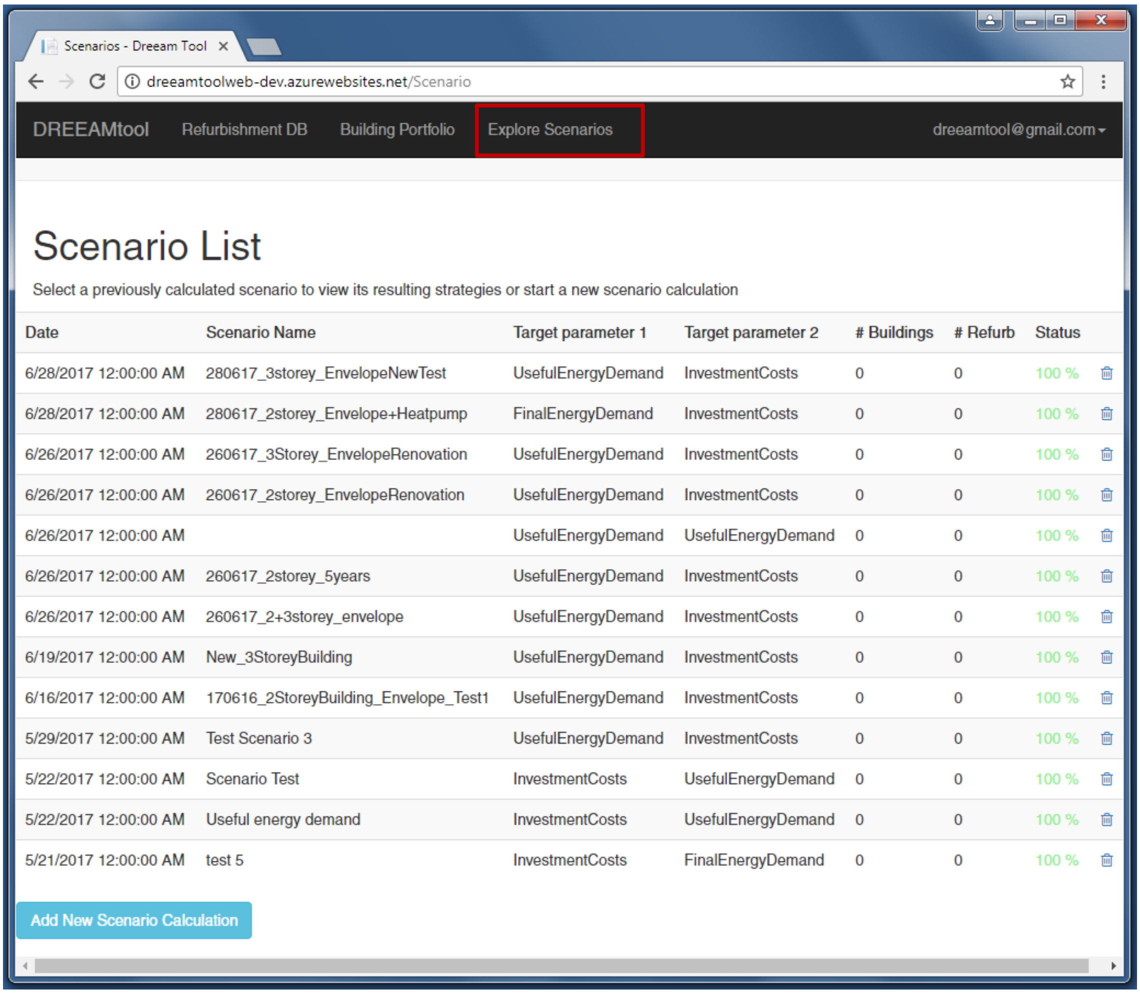

Figure 6: Calculation of the scenario

By clicking on the scenario, a new window opens which shows the results of the calculation between the two chosen target parameters in a graph and table.

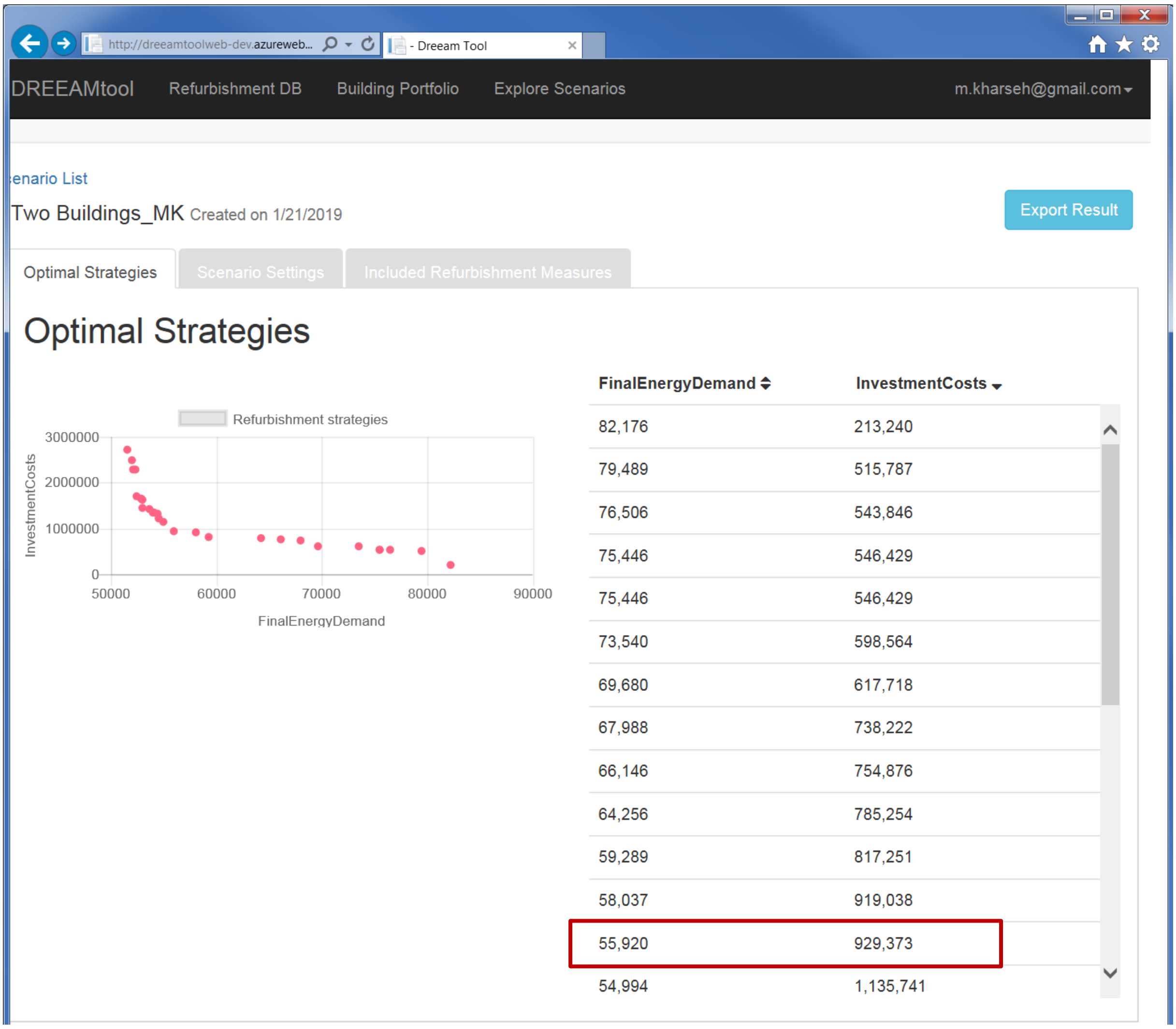

Figure 7: Scenario results

As also shown in Figure 7, one can recall the scenario settings and included refurbishment measures for the specific scenario. By clicking on a specific result in the table or graph, the strategy results are listed in more detail (Figure 8):

- Target parameters
- Costs
- Energy use by energy carrier
- Energy production
- Energy use by type:
- Useful Energy
- Final Energy
- Primary Energy
- GHG Emissions
- Economic indicators

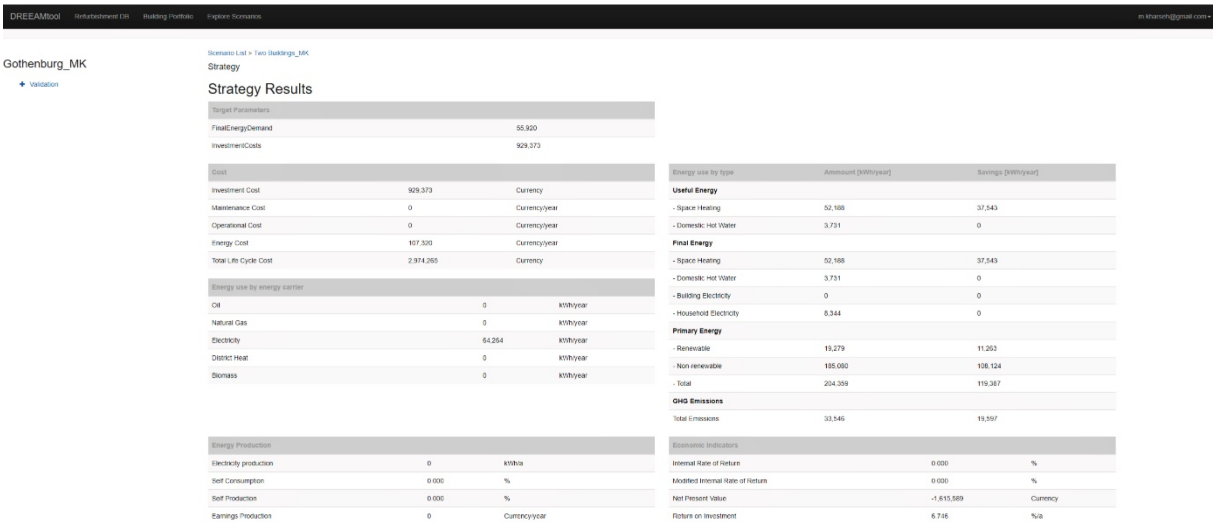

Figure 8: Detailed scenario results

When opening the building on the left side of the interface (here: Validation) one can also see the selected refurbishment solutions for that specific strategy.

3. Conclusion

Renovating the existing building has a significant potential to achieve the goal of reducing GHG emissions in the European Union. However, the main challenges that face the designers and stockholders are the identification of the optimal renovation approach in which the GHG emission in maximized or the economic visibility of the project maximized. To achieve this goal an innovative design DREEAM-too has been developed. DREEAM toll has been developing in a way that helps designers and stockholders to plan a renovation project on a single building or multi-building. The tool was built in the way to optimize the renovation project taking into consideration different criteria, such as economic or environmental criteria. In other words, the tool combines an energy calculation model for the building with economic and environmental assessments to assess and optimize refurbishment concepts.

This work aimed to describe the approach of the DREEAM-Tool to refurbishment, which takes a larger renovation scale (multiple buildings or even portfolio level) as a starting point for renovation planning and design. Taking a multi-building approach to refurbishing the residential building stock, building owners can act more strategically than it is the case when renovating single buildings and aim to achieve better energy efficiency results. The DREEAM-Tool allows an optimized design of renovation concepts that best meet multiple objectives (e.g., energetic, environmental or economic). By doing so, the tool can support building owners in making strategic refurbishment decisions for their portfolio and help them translate those decisions into corresponding refurbishment concepts. A first online version of the tool was developed and can now be tested by potential users.

References

[1] J. Quinten, V. Feldheim, Dynamic modelling of multidimensional thermal bridges in building envelopes: Review of existing methods, application and new mixed method, Energy Build. 110 (2016) 284–293. doi:10.1016/J.ENBUILD.2015.11.003.

[2] M. Gustafsson, G. Dermentzis, J.A. Myhren, C. Bales, F. Ochs, S. Holmberg, W. Feist, Energy performance comparison of three innovative HVAC systems for renovation through dynamic simulation, Energy Build. 82 (2014) 512–519. doi:10.1016/J.ENBUILD.2014.07.059.

[3] L. La Fleur, B. Moshfegh, P. Rohdin, Measured and predicted energy use and indoor climate

before and after a major renovation of an apartment building in Sweden, Energy Build. 146 (2017) 98–110. doi:10.1016/J.ENBUILD.2017.04.042.

[4] E. Antipova, D. Boer, G. Guillén-Gosálbez, L.F. Cabeza, L. Jiménez, Multi-objective optimization coupled with life cycle assessment for retrofitting buildings, Energy Build. 82 (2014) 92–99. doi:10.1016/J.ENBUILD.2014.07.001.

[5] J. Yang, A. Chong, M. Santamouris, D. Kolokotsa, S.E. Lee, K.W. Tham, C. Sekhar, D.K.W. Cheong, Energy utilizability concept as a retrofitting solution selection criterion for buildings, J. Civ. Eng. Manag. 23 (2017) 541–552.

[6] E. Brandsma, J. Valik, Underlag till den andra nationella strategin för energieffektiviserande renovering Ett samarbete mellan Boverket och Energimyndigheten, 2016:15, Boverket, Karlskrona, 2016. https://www.boverket.se/globalassets/publikationer/dokument/2016/forslag-pa-uppdaterad-strategi-for-energieffektiv-renovering_slutversion.pdf.

[7] C. Rodrigues, F. Freire, Environmental impact trade-offs in building envelope retrofit strategies, Int. J. Life Cycle Assess. 22 (2017) 557–570. doi:10.1007/s11367-016-1064-2.

[8] N.W.O. Brown, T. Malmqvist, W. Bai, M. Molinari, Sustainability assessment of renovation packages for increased energy efficiency for multi-family buildings in Sweden, Build. Environ. 61 (2013) 140–148. doi:10.1016/J.BUILDENV.2012.11.019.

[9] Y. Fan, X. Xia, Energy-efficiency building retrofit planning for green building compliance, Build. Environ. 136 (2018) 312–321. doi:10.1016/J.BUILDENV.2018.03.044.

[10] R. Wu, G. Mavromatidis, K. Orehounig, J. Carmeliet, Multiobjective optimisation of energy systems and building envelope retrofit in a residential community, Appl. Energy. 190 (2017) 634–649. doi:10.1016/J.APENERGY.2016.12.161.

[11] FASUDIR, Project partners | FASUDIR, (n.d.). www.fasudir.eu (accessed June 11, 2018).

[12] FeliCity web-based decision support tool, (n.d.). www.felicity.tools (accessed June 11, 2018).

[13] EnerPHit, Passivhaus Institut, (n.d.).
http://www.passivehouse.com/04_phpp/04_phpp.htm (accessed June 11, 2018).