A product-centric approach for assessing the energy performance of solution for building renovations

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Abstract: Considering that 35% of the buildings in the EU are over 50 years old, the renovation of buildings represents a substantial potential for energy savings. The EU estimates that improvements in the energy efficiency of buildings could lead to a reduction of energy consumption in the order of 5 - 6% and a reduction of CO2 emissions of 5% (European Commission, 2019). Building energy performance is the basis to make any decision to enhance the energy efficiency of a building. Unfortunately, building energy performance models are rarely used in building design, commission and operation. The process is very time consuming, costly and labor intensive. Furthermore, the delivery of the results takes too long. Within our approach, we present a method how to build energy models only by changing elements of existing building energy models. This paper presents an energy simulation approach that allows designers to evaluate the performance of a combination of different energy savings products that are available on the market

Keywords: Building Energy Model (BIM), Product-centric simulation, Building renovation, energy-efficient buildings

Introduction

According to Buildings Performance Institute Europe, 40% of the energy consumed and 36% of CO2 emissions in the European Union are related to buildings (European Commission, 2019). Considering that 35% of the buildings in the EU are over 50 years old, the renovation of buildings represents a substantial potential for energy savings. The EU estimates that improvements in the energy efficiency of buildings could lead to a reduction of energy consumption in the order of 5 - 6% and a reduction of CO2 emissions of 5% (European Commission, 2019). Moreover, the renovation of the building stock is the most viable solution to reduce energy consumption and CO2 emissions (Nägeli, Camarasa, Jakob, Catenazzi, & Ostermeyer, 2018, p. 444).
Renovation strategies are required to find existing energy saving products that can be installed to achieve energy efficient renovation. The energy use of buildings depends to a significant extent on how the various elements of a building work together as systems, rather than depending on efficiencies of the individual devices (Harvey, 2009, p. 140). To obtain a good renovation strategy in terms of improving the energetic values of the building, models for analyzing and predicting the energy balance are suitable.
Unfortunately, building energy performance models are rarely used in building design, commission and operation. The process is very time consuming, costly and labor intensive. Furthermore, the delivery of the results takes too long. Also, the quantitative results are difficult to reproduce or to compare to each other (Vollaro, et al., 2014, p. 87). Most of the time, building energy models are generated based on building information models. These generated models are often inaccurate and difficult to make established statements. Nevertheless, building energy performance assessment is necessary to ascertain the efficiency of energy use in buildings. Moreover, it is the basis to make any decision to enhance the buildings energy efficiency.
In our approach, we want to present a method how to build energy models by changing elements of the building model. Based on Building Energy Models from real construction projects, we want to show the energetic effects by changing the elements for renovation within the model. As input variables, we use weather conditions, building description and building component descriptions. The inputs for

component description include the elements of the building, for example façade elements or windows. Within our approach, we take these building elements as the basis for the simulation. The improvement of the building elements has the advantage of being simple to model. Moreover, it provides important information to support development of energy efficiency buildings or to justify investments (Borgstein, Lamberts, & Hensen, 2016, p. 477). Laying the focus on the renovation products, we present the different energy performances for building renovations. Accounting the properties of the structures can allow an accurate modelling procedure that reflects the building energy consumption based on the different product values. Analysis of buildings can lead to correctly estimate the building energy performance. However, this type of analysis is often limited to simple technological upgrades and assume, that the environmental conditions were identical before and after renovation.
We want to show a proceeding to simulate the whole building energy changes based on different design strategies. To overcome the uncertainties with respect to building renovation, this paper presents an energy simulation approach that allows designers to evaluate the performance of a combination of different energy savings products that are available on the market.
We do the energetic simulation with the help of EnergyPlus. This software simulates almost all types of buildings with there elements. In addition to that, EnergyPlus runs building energy simulations based on their components. The Building Energy Data will come from real demonstration cases, which are in three different countries in European Communion. We will start with three Energy Models to test our approach.
These results are then employed to point possible energy saving potentials, and to benefit the decision-making process leading to more sustainable and cost-effective projects. This paper refers to the EU collaborative research project called P2Endure. This project focused the practical development and implementation of Plug-and-Play solutions and tools for deep renovation projects of residential as well as public building (P2Endure, 2019).

1. Optimization and energy model in construction projects

Determining and predicting the energy consumption is a critical and equally important input for planning and controlling the energy performance of a building (Xiaoshu, Tao, Charles J., & Martti, 2015). A detailed and accurate building energy model thus provides an outlook on the expected energy values of the building (Arayici, et al., 2011). These energy values are the basis for the selection and use of various building elements in accordance with the requirement to achieve energy target values. Various design options can be compared against each other during the planning phase in order to find the optimal solution for the construction of a building. Creating building energy models requires significant effort. However, the need for such models is increasing (Giannakis, Lilis, Kontes, & García-Fuentes, 2015). There are also numerous publications in the literature that focus on the creation of building energy models. The focus, then as now, is the generation of energy models from existing building models. One of the first efforts for a transformation into energy models are already more than two decades old. Earlier applications of the Lawrence Berkeley National Laboratory (LBNL) started to extract rudimentary geometries of building elements from instances of building information models and converting them into an Input Data File (IDF) for EnergyPlus (Hitchcock & Wong, 2011). Olof Granlund Oy, a building service company from Finland, developed middleware software more than 20 years ago, which can convert elements from a building model to an IDF format without requiring the user to have detailed knowledge of the elements (Karola, et al., 2001). The Architecture, Engineering, Construction, Owner Operator, Phase 1 (AECOO-1) Years later, Testbed started the attempt to optimize the data exchange during the development phase of a building in order to reduce costs and improve the Building Performance Energy Analysis (BPEA). The BPEA thread focused on defining and documenting data exchange requirements for early design energy analysis (Hitchcock & Wong, 2011). New applications, such as the Green Building Web Services, convert special gbXML descriptions of the building into data formats that can be loaded by the EnergyPlus software, among others. Object-oriented frameworks for the optimization of green buildings have been developed (Wang, Jing, Zhang,

& Zhao, 2009) and also optimization processes to develop a collaborative design framework (Bleiberg & Shaviv, 2007). Component-oriented frameworks were presented to facilitate multi-disciplinary design optimization (Geyer, 2009).

At the European level, various research projects have devoted themselves over the past few years to optimizing the planning, implementation and control of construction projects. Holisteec, a H2020 funded research project, developed a Building Information Model (BIM) based collaborative software platform with the aim of designing, implementing and controlling building plans after completion of the construction project. Holisteec aims to improve the overall process efficiency, cooperation and conflict resolution of all participants. At the same time, life cycle costs and errors in planning and execution are to be reduced. Another research project, which should be mentioned, is eeEmbedded. This project was also funded by the European Commission within the framework of H2020. Similar to Holisteec, a cooperative BIM-based simulation platform was developed. In addition to that, a holistic building design methodology, an energy system information model and an integrated information management concept for the design of energy-efficient buildings were presented. Within the project, knowledge-based templates were presented, which enable energy simulations already in the early project phases. Finally, Design4Energy, also a H2020 project, should be mentioned. The aim of this project was to develop methods to simulate future energy values of buildings. The baseline of this procedure are energy attributes of buildings, neighborhood energy systems, result-related parameters, Energy simulation tools as well as current consumer usage parameters.

The process of product-centered representation for evaluating the energy efficiency of buildings has common features regarding this research. The present work is also focusing on optimizing the existing process for the evaluation and controlling of energy values. Our proposal also uses defined building model values or values of the building elements contained therein. On the other hand, our process, focuses on the exchange of elements from existing building models. We show a procedure with the help of which the simulation of different renovation options with one and the same building model.

2. Case study

In this section, we present the process of the product centric approach for assessing the energy performance of building renovations. We describe the structure of the buildings elements as well as the exchange of elements between the building energy models. Before we discuss the product centric approach, we start with a brief introduction about the demonstration case, which we use within this paper.

The case study for testing and demonstrating our approach, is a real existing building located in Warsaw, Poland. The case study is a two storey kindergarten, which was constructed in 1965. The building volume is 2712 m^3. Through a deep retrofitting procedure, the energy consumption of the building, especially for heating, are to be reduced. Therefore, the plan is to install new windows as well as a new Plug-and-play façade. To monitor the renovation process, a building energy model was created. Within this paper, we use this energy model to demonstrate the aim of our approach.

Based on the demonstration project in Warsaw, the design exchange was performed by two entity classes and parameters, windows and panels. First, the old windows of the kindergarten will be replaced by new windows in the course of the renovation project. The new windows have values specified by the manufacturer. The size and number of the windows will remain the same after the renovation. The old windows had single glazing. The new windows will be double or triple glazed. The windows can also be rotated around their own axis. The interior and exterior glazing have different parameters in terms of light transmittance. By rotating the windows, the amount of light entering the room can be reduced, thus reducing the amount of light in summer. Table 2 presents the values of the old window, while table 3 demonstrate the new windows, that will be integrate as part of the renovation process.

Table 1: Window objects from the original building energy model

Field	Units	Obj. 1	Obj. 2	Obj. 3	Obj. 4
Name		V06_ Window_PVC	V07_ Window_PVC	V08_ Window_PVC	V09_ Window_PVC
U-Factor	W/ m²K	1,5	1,5	1,5	1,5
Solar Heat Gain coefficient		0,7	0,7	0,7	0,7

Table 2: New values of the windows, which will be integrate into the original building energy model

Field	Units	Obj. 1	Obj. 2	Obj. 3	Obj. 4
Name		V09_ Window_PVC	V10_ Window_PVC	V03_BGTec	V08_ Window_PVC
U-Factor	W/ m²K	0,9	0,9	0,9	0,9
Solar Heat Gain coefficient		0,53	0,53	0,27	0,53

Second, Plug-and-Play external façade panels will be installed. The façade values are also specified by the manufacturer. Table 3 presents the values of the external panel according to the manufacture. The façade consists of several elements with different characteristics. The left side on figure 1 indicates the installation of the new façade. A panel installation shaft connects the whole panel with the external wall. The right side of figure 1 presents a schematic illustration of the façade with the individual elements described in Table 3.

Table 3: Attributes and values of the new panel

Material	Density [kg/m³]	Thickness s[mm]	Λ [W/mK	R [m²K/W]	Diff.-Wid
Structure of the field area Air passage warm side Rsi 0.13					
Mineral wool 04	20	50	0.040	1.250	1
Fermacell gipsum fibre	1150	Dez 50	0.320	0.039	13
Vapour break	1100	0.2	0.2	0.1	100000
Mineral wool 035	50	200	0.035	5.714	1
Fermacell Powerpanel	950	15	0.3	0.05	40
Light mortar LM 21	700	10	0.21	0.048	15/35
Air passage cold side Rse 0.04					

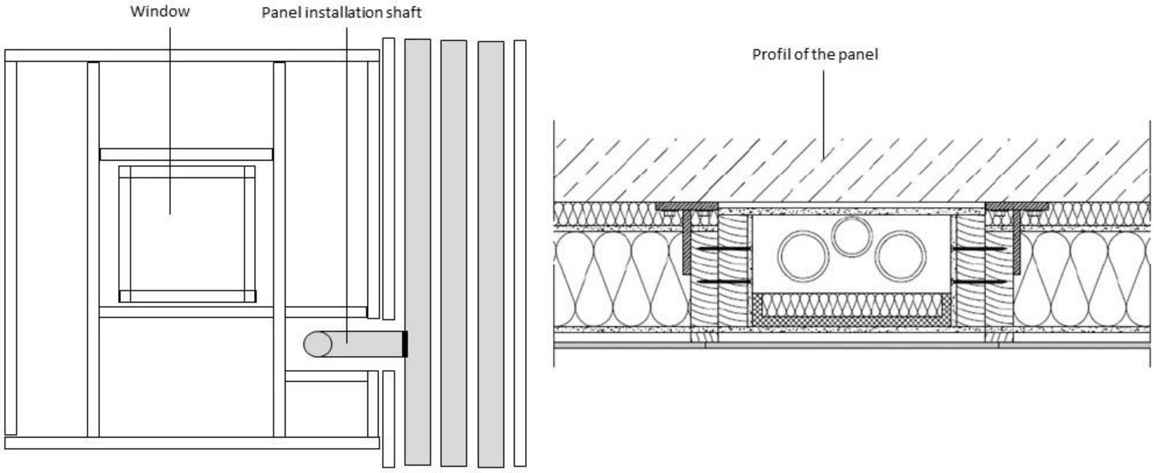


Figure 1: Construction plan of the external facade

In our approach, we use EnergyPlus to perform the simulation of the buildings energic values. EnergyPlus is an energy simulation code with a modular structure. It uses the IDF data format for input data. IDF consists of architectural- and mechanical design elements. Space boundaries, shading and thermal view are part of the architectural design. These design features are important to build to geometry for the IDF file. The architectural design consists of thermal properties of construction material. These construction properties are also needed for the IDF file to run the energetic simulation (National Renewable Energy Laboratory (NREL), 2019).

3. Product centric assessement process

We classify our process into three overall process phases. At the end of a process step, results are generated that serve as input parameters for the following sections. Within the first phase, we define the building elements. Each element is defined by attributes. These attributes are product specific. Based on these specific attributes for describing the building classes, we can build types of products. We then classify these product types into product classes in the product class layer. The sum of the elements of all product classes is the description of the building energy model.

In the second phase, the simulation of the building energy model takes place. The outcome of the second process step are the simulated energetic values based on the chosen renovation options. These values are the input for the third and last phase. Here, the visualization of the energetic values takes place. Within this paper, we want to focus on the process steps one and two. The third phase is not part of the scope. Below, we describe the process steps 1 and 2 in more detail. Figure 2 presents the overall process with the three internal process steps.

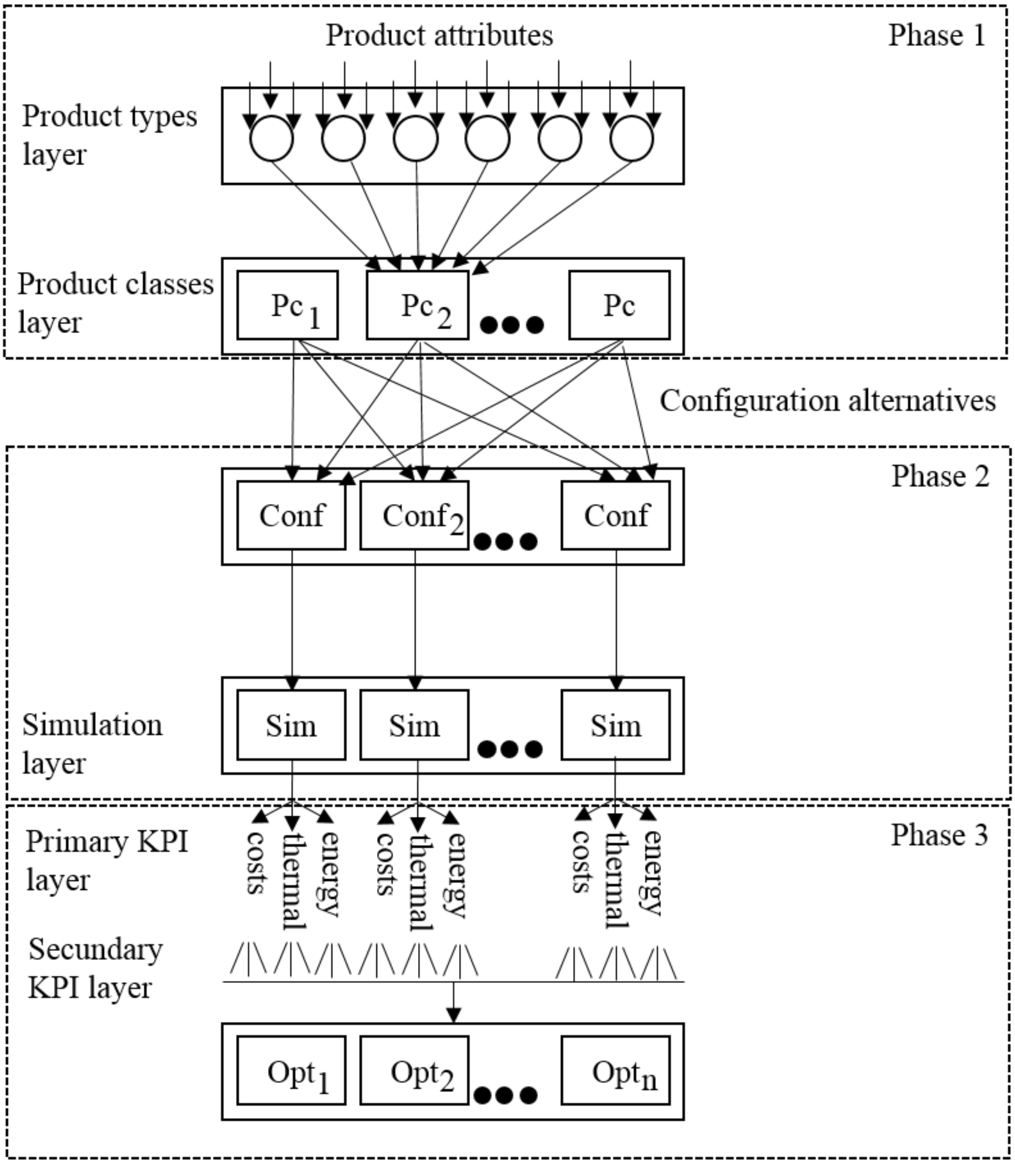


Figure 2: Overall process where we build product classes based on attributes (phase 1), run the simulation based on the chosen renovation option (phase 2) and present the results (phase 3).

As shown in Figure 2, multiple simulations are required to determine the best selection of design options. In the traditional approach, different energy models with integrated renovation elements must be created and then tested through an energy simulation program (e.g. EnergyPlus). Our approach preserves the existing energy model. Only the elements to be renovated are replaced by new components. This replacement does not take place in EnergyPlus. For this we use an algorithm developed by us, which changes the file of the energy model according to the design options. Components that need to be renovated are replaced by the same types.

Process step 1

In the first process step we define the classes of products. Following our case study, we describe the class definition using the example of windows and facades. To define product classes, attributes are required to describe the properties of the class. Here, we adapt the respective class descriptions for building elements of EnergyPlus. Figures 3 illustrate the structure of the product classes façade and window.

```
Material:[
 {
   "Name" :"",
   "Roughness":" ",
   "Thickness":"",
   "Conductivity":"",
   "Density":"",
   "Specific_Heat":"",
   "Thermal_Absorptance":" ",
   "Solar_Absorptance":" ",
   "Visible_Absorptance":" "
 },
]
```

```
[
  {
   "Window":{
   "U-Factor":" ",
   "Solar Heat Gain Coefficient":" ",
   "VisibleTransmittance":" "
},
"WindowMaterial:GlazingSystem":{
   "Name":" ",
   "Optical Data Type":" ",
   "Window Glass Spectral Data Set Name": " ",
   "Thickness":" ",
   "VisibleTransmittance (*)":" ",
   "Incidence":" ",
   "Conductivity":" "
  },
 }
]
```


Figure 3: Description of the attributes for the renovation product class Material and Window

According to figure 3, we illustrate the groups of parameters necessary for the creation of the facade and window classes. On the left of figure 3, a façade element is shown. A facade consists of one or more material elements. In figure 3, an example of a facade panel with only one material is shown. Accordingly, a parameter group is sufficient to describe the material of the facade. If the facade consists of several elements, a parameter group is used for each element to describe it. This n-number of the describing parameter groups are combined in the entire façade element class. The Windows class consists of two parameter groups. The first group describes the properties of the window. The second group describes the glazing system.

The parameters shown in Figure 3, are without values. These values will be added according to the properties of the respective facades or windows. The parametric description of the classes completes the first phase of the process. At the same time, the product classes describe also the interface for the second phase of the process.

Process step 2

This second phase of the process is characterized by three internal process steps. In the first process step, the as-is building energy model is analyzed regarding the building elements to be renovated. According to the renovation plan described in chapter 3, all windows are replaced by new double-glazed windows. For the analysis, we developed a context-dependent algorithm to examine the building energy model according to the classes to be replaced.

```
! ======================  GAP - MATERIAL GLASS ======================
WindowMaterial:SimpleGlazingSystem,
 V07_Window_PVC_2350x2250_Win (10mm), ! Name
 1.5,          ! U-Factor
 0.7,          ! Solar Heat Gain Coefficient
 ;              ! Visible Transmittance (*)

! ======================  GAP - MATERIAL FRAME ======================

! ========================  GAP - CONSTRUCION ========================
 Construction,
  H06_Window,     ! Name
  V07_Window_PVC_2350x2250_Win (10mm); ! Outside Layer
```

Figure 4: Presentation of the class window within the building energy model. To cut out the old window, construction parameters also needs to be included

Figure 4 shows an excerpt from the energy model. In order to completely remove the old windows, the construction feature must also be removed. Figure 4 shows the properties required to replace the windows. “GAP-MATERIAL-GLASS” describes the properties of the glass used in the existing building. In addition to these parameters, the “GAP-CONSTRUCTION” properties must also be considered and adapted or replaced. The parameters for “GAP-MATERIAL FRAME” are not considered within our model.

After the data has been removed from the model, the second internal process step starts. The instances of the new windows are inserted. At the moment we arrange the new values at the end of the building energy model. The placement of these elements is not decisive for EnergyPlus. After the new elements have been inserted, the third process step, the new simulation of the energy model, can start. The results of this simulation are the input values for the third phase of our proposed process.

4. Results and outlook

Section 5 presents the method behind the product centric exchange of elements in building energy models and describes the process of finding, adding or replacing construction objects in the model. Within this section, we describe the outcome of our product centric approach. Therefore, we compare the energic consumptions of the different renovation options.

Table 4 shows the outcome of the energy simulation based on the performance parameter “Total Site Energy”, “End Uses” and “Energy Use Summary”. We compare these parameters with four different renovation option. The baseline for further considerations is the building energy model of the demonstration project in Warsaw. The energetic values of the performance parameters describe the situation before any kind renovation activity takes place. Our product centric approach allows use, to add and remove building elements within the as-is building energy model. Within table 4, we present the energetic values of the building energy model with a) additional external facades, b) new window, c) external façade as well as new window. To compare the different design options, we also present the energetic values of the as-is building energy model.

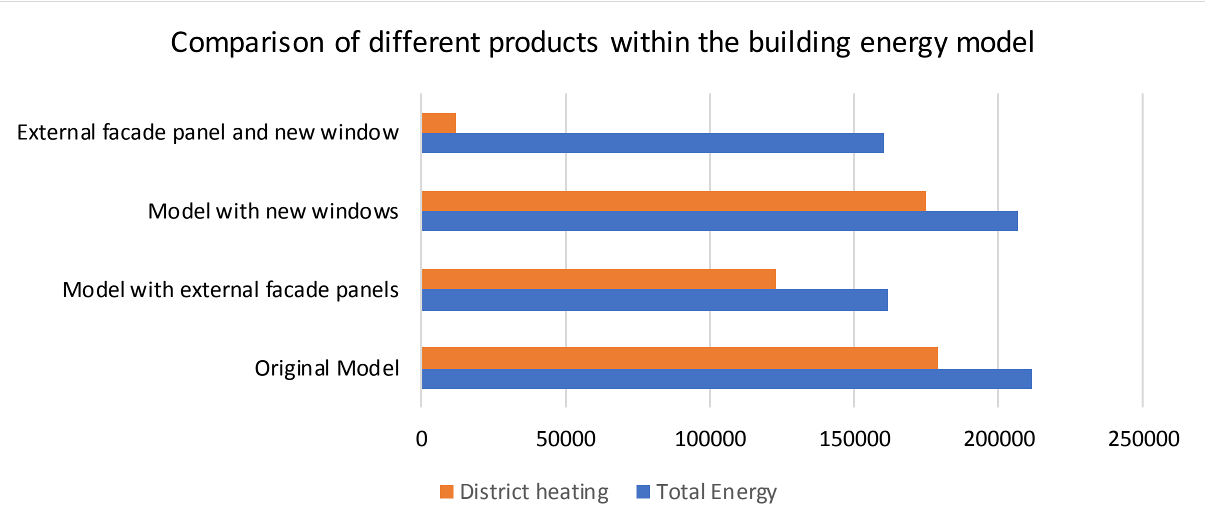
The first renovation option describes the integration of an external façade element. The energetic values are significantly improved by adding the new construction element. For example, the value for Total Energy decreases from 211325.3 to 161776.79. In option b) we replaced the old windows of the building with new ones. The panels from option a) are not integrated. A significant reduction in energy consumption is also noticeable. In option c) we added the external panels as well as the new windows. Compared to the renovation options a), b) and the as-is building energy model, Option c) is the best solution for renovation in terms of energy consumption.

Table 4: Comparison the energetic results bases on different products (renovation options) within the building energy model

Performance parameters		As-is building energy model	a) Model with external facade panels	b) Model with new windows	c) Model with new window and external facade panels
Total Site Energy	Total Energy in [kWh]	211325.30	161776.79	206728.27	151861.20
	Energy Per Total Building Area [kWh/m2]	154,05	91,53	150,70	85,92
	Energy Per Conditioned Building Area [kWh/m2]	166.22	97.05	162.60	91.10
End Uses	District heating [kWh]	179243.29	123207.33	174646.26	113291.74
Energy Use Summary	Total [kWh]	211325.47	161776.92	206728.43	151861.32

Table 5 visualize the energetic outcome of the three renovation options as well as the energy values of the as-is building energy model.

Table 5: Visualisation of the energetic comsumption based on different products within the energy model



Based on the results, we can demonstrate the benefits of our approach. With the process of our approach, we only change elements of the energy model, not the whole model. Therefore, we enable a fast and comparable way of simulating and displaying energy data. The as-is energy model serves as the baseline for the further simulation of the different renovation options.

Within this paper, only windows and panels are considered as renovation options. Based on Tables 4 and 5, however, we demonstrate the benefits of our approach. The exchange of individual elements of an energy model under the assumption that all other elements of the building energy model, which are not affected by the exchange, remain unconsidered, enables a precise prediction of the energetic results of different renovation options.

Using a short application example, we want to propose a possible outlook of our approach.

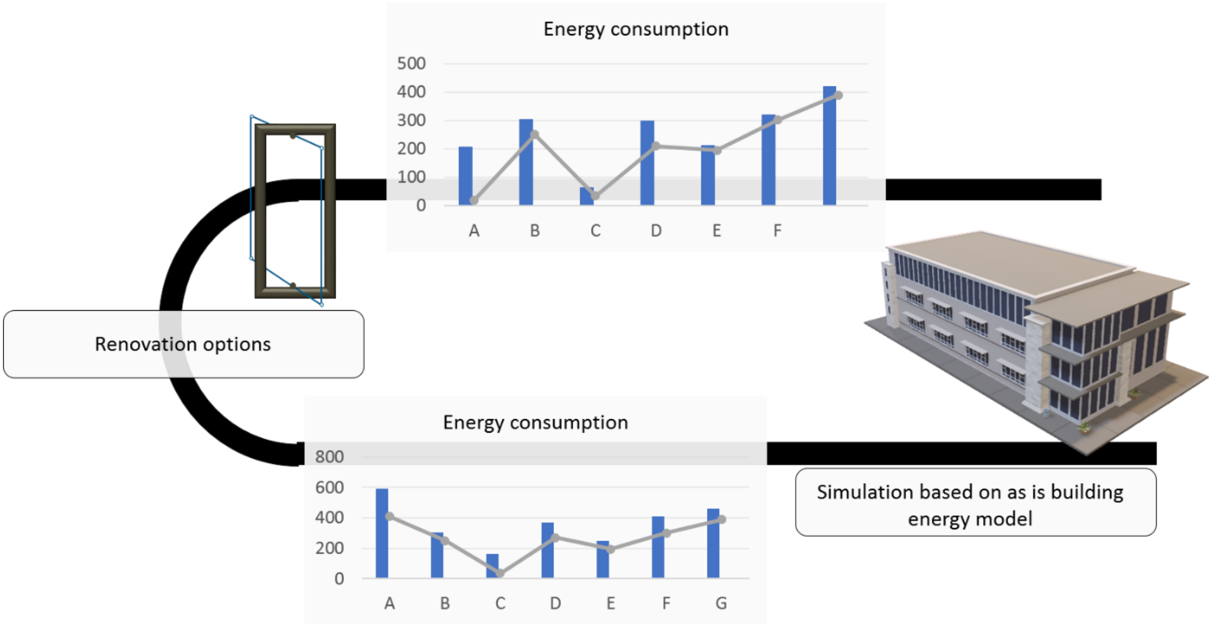


Figure 5: Preparing of energy consumption forecasts based on product centric data exchange within the building energy model

Figure 5 shows a possible operation process. We integrate our product centric data exchange approach into an application, which presents the outcome of the simulation results of the different renovation options. The potential user group can be reached from a homeowner with a single renovation project up to a municipality, who wants to renovate various buildings with nearly same construction features.

Based on the initial values, the software simulates and represents energetic values of the as-is building energy model. The user will get the initial energetic values of the building as the baseline for the further suggestions. As a second process step, building elements according to his renovation project can be add or replaced. Based on the design decision, the energy values are simulated and displayed again. Consider that, our approach can offer an energetic comparison and prediction of energetic values. The forecast of building energy consumptions regarding various renovation options can improve the outcome energy results and reduce unforeseen costs.

5. Conclusion

The paper presents a procedure to close the existing gap in the representation of building energy models in renovation projects. The procedure focuses on a product-centered approach. Renovation products can be exchanged within the existing energy model of the object to be renovated. Thus, various design options can be analyzed without having to create new energy models. Within the work we have demonstrated this approach by replacing window elements and adding new external facades. The intention of this work is to present a variant in order to make the optimal decision between building design and energy target values already during the planning of renovation projects. At the same time, this work would like to support future research efforts with a focus on product-centred assessment. On the other side, this paper wants to motivate for future research in the field of product centered assessment of the energy performance, especially in renovation projects. During the coming months we will continue to expand our process and be able to map more product types, such as HVAC systems, through our product-centered process.

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