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GIS-based Decision Support System for Building Retrofit

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Abstract

In order to reduce the energy demand of the building sector the energy demand of existing buildings need to be reduced. However, the retrofit of buildings is a complex task. Many options, such as replacing windows, improving the building envelope or replacing the heating system are available to improve the energy efficiency of a building or lower carbon emissions. Most building owners are not energy experts and are thus overwhelmed by the available choices for retrofitting their buildings. Furthermore, they can have false beliefs about the payback of energetic refurbishment. We propose a web based decision support system (DSS) using a geographic information system (GIS) based building stock model to inform building owners in a fashion, which is as simple as possible. This is achieved by using an extensive GIS database of building data. This eliminates the need for users to know the dimension of their building envelope or local climate data. The system allows users to select and compare different retrofit scenarios in terms of carbon emissions and energy savings and thus to inform themselves about the potential of energetic retrofit of their building.

1. Introduction

The residential sector is estimated to be responsible for 24% (Lucon et al. [1]) to 30% (Saidur et al. [2]) of the world-wide final energy consumption. In 2015 households were responsible for 27.7% of the total final energy demand of Switzerland [3]. Energy used for heating, such as room heat or warm water, is responsible for 56% of residential building energy demand, respectively 45% for commercial buildings [4]. Space heat demand is especially important as the vast majority of residential buildings in Switzerland use fossil energy sources [5]. A recent study identified a 38% reduction potential of greenhouse gas (GHG) emissions for the Swiss building sector (Jakob et al. [6]). To reach

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this reduction potential, the contribution of new buildings is small compared to refurbished buildings (Siller et al. [7]). The Swiss government set as target to reduce the mean energy consumption per habitant by 43% until 2035 [8] compared to the year 2000. The retrofit of old buildings is crucial to reach this target. Meanwhile according to the Swiss Society of Engineers and Architects (SIA) the energetic retrofit rate is currently less than 1% [9]. It is thus important to find means to increase the retrofit rate.

A hindrance to increase retrofit rates is that due to low energy prices, efficient retrofits are currently not profitable (Amstalden et al. [10]). In Stiess et al. [11], an empirical survey of 1008 homeowners who retrofitted their homes was conducted. They found that in general the consultation of professional energy advisors resulted in more ambitious and qualitatively better energy efficiency measures. However, only homeowners that are already convinced of the benefits have a positive attitude towards professional consultation and advising. Furthermore, the group of homeowners unfavorable of energetic retrofit tends to overestimate the energy performance of their homes and therefore underrate the energy saving potential of their buildings.

We argue that homeowners are more in favor of energy consultations or energy retrofit in general if they are well informed about the energy potentials of their homes. Energetic retrofit is a very complex task. Many different options, such as replacing windows, improving the building envelope or replacing the heating system are available to improve the energy efficiency of a building or lower carbon emissions. Most building owners are not energy experts and are thus overwhelmed by the available choices for retrofitting their buildings. Furthermore, they can have false beliefs about the payback of energetic refurbishment. In Wohlgemuth et al. [12] optimal insulation thickness concerning economic and environmental impacts is investigated using a mathematical model for the life cycle impacts of different insulation scenarios of buildings. The authors show that no universal recommendation can be given and that the environmental and economic performance depends largely on climate, indoor temperature, building size, insulation material type, service life, and energy source for space heat.

Decision support systems (DSS) are tools to assist decision makers in complex decision-making processes. The focus of state-of-the art research for retrofit DSS is on finding the best retrofit scenario subject to social, environmental or economic sustainability. In Nielsen et al. [13] a review of 43 decision support tools for building retrofit is conducted. Out of the reviewed systems, 84% use energy simulations in order to estimate the performance of specific retrofit scenarios. This shows that energy simulations are an integral part in the decision-making process. The authors of such DSS studies either connect to external heat demand simulation programs, such as EnergyPlus [14] or TRNYS [15], or integrate their own heat demand simulation routines. While physical heat demand models are able to estimate heat demand for different retrofit scenarios with sufficient accuracy, they require a multitude of input parameters such as the geometric shape of a building, surface areas, building age or physical properties of the used materials (Magouls [16], Foucquier et al. [17]). This forms a significant barrier for non-expert users as the required input data are not effortlessly available. Furthermore, the data retrieval by non-experts may lead to additional uncertainty in the measurements.

We propose a web based DSS using our developed geographic information system (GIS) based building stock model to inform building owners in an as simple as possible fashion. This system allows users to evaluate different retrofit scenarios based on the characteristics of their own house. The system resorts on a recent and validated building stock heat model of Switzerland [18]. The model represents an extension of the models by Saner et a. [19] and Heeren et al. [20] enriched with a detailed GIS based building database. None of the in [13] reviewed DSS used GIS to reduce the data demand from its users. In contrast to previous work, the goal of the DSS is not to identify the optimal retrofit scenario, but to demonstrate to homeowners the potential of different energy refurbishment measures. It is thus not intended to replace a proper energetic analysis by experts, but lower the barrier for building owners to explore refurbishment solutions and provide a convenient initial overview of the saving potentials.

This paper is structured as follows: the next section describes the implementation of the decision support system including a brief description of the used building stock model. Then the paper concludes with a discussion of the obtained results.

2. Decision Support System

The first part of this section describes the architecture of the DSS, followed by a brief description of the user experience of the system and its capabilities. The last part of the section covers the building heat model.
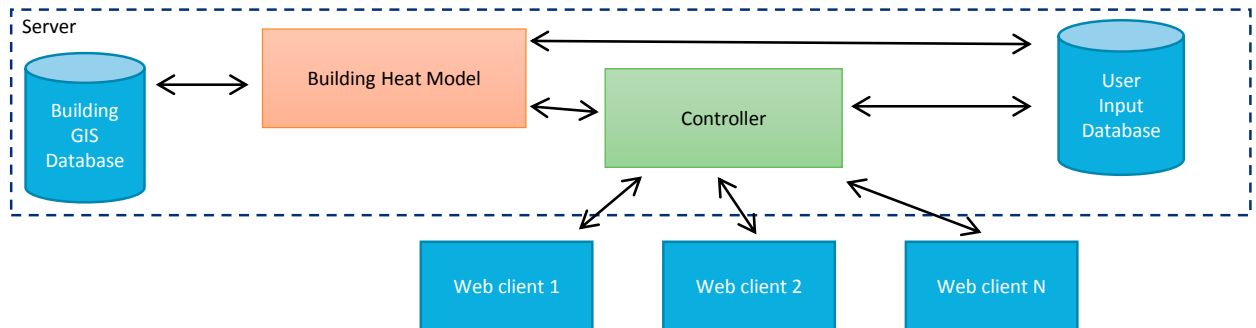
2.1. Architecture

Fig. 1: The server-side infrastructure of the DSS consists of a controller, two separate databases for buildings data and user input, and a heat model. Arrows indicate interfaces between the different components. Web clients communicate via the controller with the server-side infrastructure.

The design of the decision support system is shown in Fig. 1. It consists of a web client coupled with a server infrastructure. The server infrastructure consists of several components. A controller manages the requests from the web clients. The controller can update the user input database or send requests to the building heat simulation module. This module has access to both the user database as well as the spatial buildings database. We chose this design to ensure that only simulated heat demands and carbon emissions are sent to the client and never actual data from the building database used for the building heat simulation. This is necessary because used datasets, such as the registry of buildings and dwellings [21], cannot be transmitted externally for legal reasons and therefore must be protected.
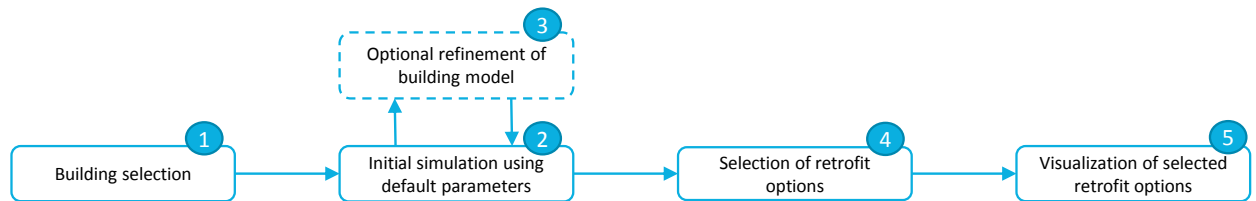
2.2. Workflow of the DSS

Fig. 2: The DSS consists of four mandatory (solid) and one optional (dashed) step.

Fig. 2 provides an overview of the five steps of the DSS. When users start the DSS they are presented with a map of Switzerland. This map, shown in Fig. 3a, can be zoomed or panned in order to find the building of the homeowner. Alternatively, the users can directly search for their address. By clicking on a building, the user can start the decision support process.
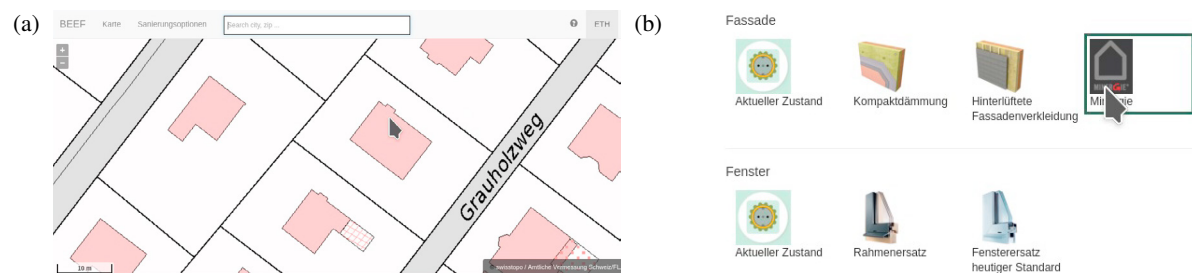

Fig. 3: (a) Users can select their building using a map of all buildings in Switzerland. (b) Different retrofit scenarios can be combined.

When a building is selected, the heat demand of this building is simulated using the default parameters of the building stock model for this building. The heat demand of the non-modified building is later used as a baseline scenario for the visualization process. There are two types of default parameters. The first category consists of parameters derived from spatial datasets, such as the building shape, volume or local climate data. These parameters are not likely to be changed by the user, as they are not easily available without detailed plans of a building or access to climatological data. The second category consists of parameters that cannot be derived from spatial datasets. These include parameters such as the heat transfer coefficients of building components (U-values), ventilation behavior or room temperature. These parameters are not available for each building and are derived from the building stock model using typical literature values depending on the building age and building type. More information about the used data and the building heat simulation can be found in Section 2.3.

The user then have two options: if they are satisfied with the default values they can go directly to the selection process of different retrofit scenarios shown in Fig. 3b. Otherwise, they have the option to calibrate the heat simulation model using several methods. The users can enter measured energy consumption data of the past years, such as consumed oil or gas (e.g., from the last oil or gas bills) or directly specify model parameters such as the category of the windows or type of the heating system. Advanced users can directly modify the simulation model by adjusting the physical parameters such as U-values or window area. Changed parameters override thereby the default parameters. The baseline heat demand is then replaced with the result of the simulation using the new set of parameters.

The selection process of retrofit scenarios is straightforward. A user can simply graphically select multiple retrofit scenario, such as improving windows, walls or replacing the heating system. For each retrofit scenario, the effect on the heat demand is immediately recalculated (see Section 2.3). For example, when windows are replaced to the best available technology appropriate U-values are used to simulate the retrofit scenario heat demand. All parameters not affected by the selected retrofit scenarios correspond to the values of the baseline scenario.

Fig. 4: After a selection of different retrofit scenarios, the impact of the selected choices compared to the status quo are visualized for monthly heat demand as well as carbon emissions.

The heat demand of the baseline and retrofit scenarios are instantaneously visualized as shown in Fig. 4. The visualization includes the annual energy demand and the monthly energy demands for both the status quo as well as the retrofit scenario. To give the user a comprehensible indication the equivalent yearly demand of oil and the relative change in carbon emissions are shown. We use percentages for carbon emission because we believe that the relative change to the baseline scenario is easier to grasp compared to an absolute change in tons of carbon emissions per year. It is important to note, that, for example, replacing a heating system with a pellet-fueled heating system does not necessarily decrease the heat demand but has an impact on the carbon emissions.

2.3. Building Heat Model

To simulate the heat demand of buildings the SIA 380/1 heat model is used [22]. This model is widely utilized in Switzerland to verify that new and renovated buildings satisfy heat insulation requirements. It is based on the EN ISO 13790 standard [23] and uses a monthly steady-state method with simplified physical equations to model the monthly heat balance [22]. This means the sum of the heat losses is subtracted from the heat gains. Heat losses include transmission losses of exterior walls, roof, floor and windows as well as ventilation losses. Heat gains consist of gains from windows, electric devices and inhabitants. Heat gains and losses are derived from physical properties of a building, such as the areas of exterior walls, roof or base floor in combination with physical properties of the buildings components in the form of heat transfer coefficients (U- and g-Values of the used materials).

Where possible the input parameters of the heat model are derived for each building from spatial datasets. For example, the volume and areas of wall, roof and floor are derived from a digital surface model of Switzerland with a resolution of 0.5 m [24] in combination with building footprints. Solar irradiation level for windows facing in different orientations are derived from the CM SAF Sahra [25] spatial solar irradiance dataset. Ambient temperatures are derived from a spatial dataset of MeteoSwiss [26]. The spatial resolution of the temperature dataset is roughly 2 km and of the solar irradiation dataset 5 km. Using spatial climate data is beneficial as especially in Switzerland with its complex, mountainous terrain temperature and solar irradiation can vary already at short distances of a few kilometers. The age of a building as well as the building types are important information to derive typical values from archetypes. These two parameters are derived from the registry of buildings and dwellings [21] from the Swiss Statistical Office. Using this data set, an extensive GIS database containing data of each building in Switzerland is compiled. Not all required input parameters of the model can be derived from spatial data. These parameters include, for example, the room temperature, ventilation habits or the presence time of inhabitants. Similar to [19] and [20] these parameters are derived from typical values based on building type and building age. If the user has specified parameters for the building heat model, such as the U-values of the windows, the user defined values are used instead of the default values. In Buffat et al. [18], the building stock model is validated against the measured heat consumption of 1845 buildings of the Swiss city of St. Gallen. For the validation, the yearly measured heat demand of all buildings is compared with the modelled heat demand. The validation shows a goodness of fit (R^2) of 0.63 over all buildings. The yearly carbon emissions are estimated based on the energy consumption and the source used to provide the energy.

3. Discussion

Research shows that homeowners not in favor of energetic refurbishments underrate the energy saving potential of their homes [11]. An information platform is lacking that allows homeowners to inform themselves about the potentials of their buildings with a minimal amount of time and money. We developed a decision support system to fill this gap that does not require any previous knowledge of the users. This is possible due to a novel approach to combine a DSS with a GIS based building stock model using spatial data. The system allows identifying carbon emissions and energy saving potential of different retrofit scenarios. Nevertheless, the tool is flexible. Advanced users are able to calibrate the model using either their historic consumption data or by specifying model parameters directly.

While the system currently focuses on single buildings, the spatial modelling would also allow the assessment of the potential to share heating systems between neighboring buildings or to create micro district heating systems. Furthermore, location dependent energy sources, such as the solar irradiation on rooftops for electricity or warm water production, locally available wood resources for pellet furnaces or the feasibility of heat pumps could be integrated.

The model currently lacks an economic component. Having such a component allows finding cost optimal retrofit scenarios.

Validation data for building stock modelling is only sparsely available. A secondary benefit of the DSS is that it can be used as crowdsourcing tool to gather validation data for building stock models. With the consent of the user, historic consumption data as well as building data are stored and can be used to improve and validate future building stock models.

4. Conclusion

We developed a web-based decision support system for building owners. The system allows users to explore energy savings and carbon emission reduction potentials of different retrofit scenarios. In contrast to existing platforms, our system does not require any knowledge of users about their building. This is achieved by using an extensive GIS database. This database contains required input parameters of the used heat model, such as building volume or envelope, for each building in Switzerland. Advanced users can calibrate the heat model by adjusting used default values, such as for room temperature, or enter historic energy consumption data. The aim of the platform is to offer building owners who are not willing to invest a lot of effort in time and money an easy-to-use tool to inform themselves about the potential of energy retrofits of their building. Home owners aware of the energy saving potentials are more likely to consider professional energetic consulting, thus such a system can contribute to increasing the energetic retrofit rate of buildings.

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