DanBERA: A tool for Danish buildings energy renovation design and assessment

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Abstract. The paper presents the development and implementation of DanBERA tool for Danish buildings energy renovation design and assessment. Unlike the static tools used in the current building renovation market, DanBERA is based on dynamic energy performance simulations of case study buildings considering various building characteristics and specifications and taking into account the dynamic impact of occupancy and weather conditions. The tool uses a systematic and comprehensive renovation assessment methodology considering technical, economic and environmental impacts. A list of standard energy renovation measures is considered, targeting the building physical envelope upgrade in addition to energy systems performance improvement and installation of renewable energy systems. In addition, DanBERA provides a comprehensive assessment of various renovation measures and packages, yet using limited number of inputs including building type, indoor floor area, construction or last renovated year and location. The possibility of having a building ventilation system is also available. Four major building categories are included in the current version, single-story and two-story residential houses, residential apartments and office buildings. The tool implementation is demonstrated in the paper by considering 3 Danish case studies and reporting the renovation design and assessment results regarding energy consumption and indoor air quality.

1. Introduction

Denmark has an ambitious goal to attain a fossil fuel-free energy sector by 2050, along with 7.6% reduction in gross energy consumption and 34% reduction on greenhouse gas emission compared to 2010 numbers [1]. To realize this holistic goal, the country has taken serious steps towards upgrading and re-shaping the overall energy generation, distribution and supply scheme. This has been accompanied by the implementation of strict energy-efficient and cost-effective measures along with the dramatic expansion in the country’s renewable energy profile, in particular wind energy. Being a key component in the overall energy scheme, the buildings sector consumes 35-40% of the overall Danish energy consumption profile [2], with equivalent contribution to greenhouse gas emissions. In its 2050 holistic energy plan, Denmark has prioritized the buildings sector [3], highlighting that improving the energy performance of both newly built buildings and existing buildings is a key milestone in attaining the country’s energy and environmental goals. Therefore, building regulations and standards have been continuously tightened aiming for a better design and efficient operation of newly built buildings and calling for cost-effective existing buildings renovation projects. In this context, the Danish government has developed in 2014 a comprehensive Danish buildings renovation strategy, “Strategy for the energy renovation of the existing building stock” [4], with 21 initiatives to enhance energy efficient and cost-effective buildings retrofit projects in Denmark. By implementing the strategy, the aim is to achieve 35% reduction on the overall heating consumption demand in buildings by 2050 compared to 2010 numbers. Considering that around 80% of the country buildings were built before 1979, the strategy has accelerated building energy retrofit projects, implementing cost-effective and energy efficient improvement measures targeting energy systems and buildings physical envelope.
However, the majority of the renovation projects implemented in Denmark in the last two decades were driven by the need to upgrade or modify old buildings with the absence of a systematic methodology to assess the future impacts of such projects [5]. In addition, tools with simplified and static energy modelling and simulation approaches are extensively used to aid the decision making of Danish renovation projects. This has resulted into a large performance gap between the expected and the actual building performance after renovation. This is majorly due to the fact that various energy improvement measures are dynamically inter-related to a large extent. For example, if windows are to be changed, walls and roof insulation to be implemented and ventilation system to be upgraded, evaluating the impact of each measure alone without considering the other implemented measures would lead to either over- or under-estimating the impact of the renovation process. In this paper, the development and implementation of DanBERA tool for Danish buildings energy renovation design and assessment is presented. The tool uses a systematic and comprehensive renovation assessment methodology considering technical, economic and environmental impacts. The tool allows the selection between four building categories, single-story and two-story residential houses, residential apartments and office buildings. With basic information about the building to be renovated, the tool provides a preliminary assessment on the technical, economic and environmental impact of various energy improvement measures and packages, and thus aiding the building renovation decision-making.

2. Approach
A holistic dynamic energy modelling and simulation methodology is employed in this work. A detailed description of the used modelling and simulation framework is presented by Jradi et al. [6]. A package of three tools was used, Sketchup Pro, OpenStudio and EnergyPlus. Sketchup Pro is used to develop the 3D architectural models of the various case study buildings considered. The 3D models were then introduced to OpenStudio, where the major parts of the energy model is developed, defining information on the building physical envelope, materials and constructions, energy systems, loads and equipment, occupancy, schedules and weather conditions. Finally, the well-established and validated simulation engine of EnergyPlus was used to simulate the overall energy performance of the different case studies baseline scenario, as well as simulating the impact of various energy improvement and upgrade measures and packages. Figure 1 provides an overview of the methodology implemented in this work starting from energy models development and all the way leading to the DanBERA tool development.

3. Case study buildings
Four case study building types were chosen in this study, representing the majority of the Danish buildings stock. The four types are as follows: One-story house; Two-story house; Residential apartments building; and Office building. For each case, a 3D architectural model was developed in Sketchup Pro with detailed building geometry and orientation specifications. For the one-story house and the two-story house, a 3D generic architectural model with an indoor area of 150 m² is considered. For the apartments building and the office building, an indoor area of 1200 m² was considered, with five floors and a basement. The 3D models developed in Sketchup Pro for the four case study buildings are shown in figure 2. The same 3D architectural model was used for both the apartments and the office building, but the developed energy model in OpenStudio differentiates between an apartment building and an office building, considering specific definition of occupancy, loads, equipment and systems.
Figure 2. 3D model of (a) 1-story house, (b) 2-story house and (c) the apartment and office building.

The four architectural models in Sketchup Pro were introduced to OpenStudio where all the buildings specifications and characteristics are defined, including the physical envelope properties and the energy systems layout. In developing the energy models, six different scenarios were considered for each case study, resulting into 24 developed scenarios of building energy models. For example, six one-story houses were modelled, and their respective specifications and characteristics were defined leading to six different energy models as follows:

- one-story house built before 1961
- one-story house built between 1961 and 1985
- one-story house built between 1985 and 1998
- one-story house built between 1998 and 2008
- one-story house built between 2008 and 2015
- one-story house built after 2015

The same approach was followed for each of the three other cases. In terms of the building constructions and materials, standard Danish building constructions were assumed and modelled for each case. In defining the building envelope thermal properties for each scenario, thermal transmittance coefficient U-value requirements of various constructions were used as set by different building energy codes from 1961 until 2015 [7]. The recommended U-value for external walls, roof, ceilings, exterior windows and doors for each building regulation are presented in table 1. Moreover, each energy model of the 24 cases considered was calibrated based on the overall building maximum allowable energy consumption, considering the year of construction and the corresponding building regulation governing the case.

| Table 1. Set U-values, in W/m².K, of different constructions in each building regulation [7]. |
|------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                              | BR<1961 | BR1961 | BR1985 | BR1998 | BR2008 | BR2015 |
| External walls                | 1.39    | 0.93   | 0.35   | 0.30   | 0.30   | 0.18   |
| Roof                          | 0.64    | 0.43   | 0.20   | 0.15   | 0.15   | 0.12   |
| Floor                         | 0.64    | 0.43   | 0.30   | 0.20   | 0.15   | 0.10   |
| Horizontal division           | 0.83    | 0.55   |        |        |        | 0.50   |
| Windows                       | 5.03    | 3.35   | 2.90   | 1.80   | 1.50   | 1.50   |
| Doors                         | 5.03    | 3.35   | 2.00   | 1.80   | 1.50   | 1.50   |

The first two cases, one- and two-story buildings, were assumed to have a single family with four people, being an average number of members in a Danish standard family. Therefore, loads, equipment and schedules were defined for each specific case to characterise a generic Danish family life pattern and behaviours. For the residential apartments building, it was assumed that the residential complex has 10 apartments, 2 per floor, and each with a 100 m² indoor area and 2 persons in each apartment. This is in addition to having a basement, being a common component of standard Danish residential buildings. On the other hand, the office building is divided into multiple offices per floor, in addition to a basement, with an occupancy pattern of a person in each 20 m² office space. Along with the office rooms, the building has meeting rooms, conference rooms, kitchen and common spaces.
4. Base case energy simulation results

For each of the 24 building scenarios presented in the previous section, an overall building energy simulation was carried out to predict the energy consumption for heating and electricity. Table 2 shows the annual energy consumption for each of the 4 building types, considering the 6 scenarios highlighted above. It shall be mentioned that each of the 24 models was calibrated in order to meet the heating and electricity demands set by each building regulation throughout the years for different building types.

| Table 2. Annual energy consumption of the base case scenarios |
|---------------------------------------------------------------|
| Consumption (kWh/m²) | One Story House | Two Story House | Apartment Building | Office Building |
|----------------------|-----------------|-----------------|--------------------|-----------------|
| BR2015               |                 |                 |                    |                 |
| Electricity          | 32,6            | 32,6            | 21,5               | 21,1            |
| Heating              | 37,8            | 39,9            | 27,4               | 29,0            |
| BR2008               |                 |                 |                    |                 |
| Electricity          | 33,4            | 33,5            | 22,2               | 21,8            |
| Heating              | 68,6            | 75,0            | 50,3               | 52,0            |
| BR1998               |                 |                 |                    |                 |
| Electricity          | 33,8            | 33,9            | 22,5               | 22,1            |
| Heating              | 82,3            | 89,1            | 59,7               | 61,8            |
| BR1985               |                 |                 |                    |                 |
| Electricity          | 35,0            | 35,2            | 23,5               | 23,1            |
| Heating              | 130,2           | 140,3           | 96,1               | 97,9            |
| BR1961               |                 |                 |                    |                 |
| Electricity          | 37,0            | 37,4            | 25,0               | 24,6            |
| Heating              | 216,0           | 232,6           | 158,6              | 160,8           |
| BR<1961              |                 |                 |                    |                 |
| Electricity          | 39,5            | 40,0            | 27,1               | 26,8            |
| Heating              | 331,9           | 345,4           | 253,3              | 255,5           |

After model development, performance simulation and calibration, a list of energy renovation measures was developed to be implemented and simulated in each of the 24 scenarios considered. The energy renovation measures were selected and designed based on the recommendations of the latest building regulation in Denmark BR15 [8]. The first part of the renovation measures targets the physical envelope, including walls, roof and floor insulation, as well as upgrading exterior windows. In addition, measures targeting the heating system include heating setpoint temperature management and hot water circulation pump upgrade. Additional measures were simulated including lights upgrade, installing daylight sensors, installing motion sensors, electrical equipment upgrade in addition to installing a PV system covering 10-20% of the roof area. In addition to the renovation measures, four retrofit packages were considered and simulated for each case as follows:

- Package 1: Walls and roof insulation
- Package 2: Walls, roof and floor insulation
- Package 3: Circulation pump upgrade, lights upgrade, lighting control and equipment upgrade
- Package 4: Walls, roof and floor insulation and hot water circulation pump upgrade

The four retrofit packages were chosen for the tool demonstration and thus more packages can be added. Finally, implementing a ventilation system, with and without a heat exchanger, was also investigated and simulated for buildings built after 2008 to improve indoor air quality and thermal comfort.

5. DanBERA tool development and demonstration

Considering the energy simulation results for the 24 base case scenarios, along with the results of the simulations of the different energy renovation measures and retrofit packages defined earlier, a tool for Danish buildings energy renovation and assessment (DanBERA) was developed. The tool, developed in MATLAB, uses a systematic and comprehensive renovation assessment methodology considering technical, economic and environmental impacts. The tool has four main inputs, building type from the 4 types considered in the study, year of building construction or last renovation, building indoor area and the region in Denmark where the building is situated. Based on those four inputs, the tool will provide an overview of the technical, economic and CO₂ emissions savings due to implementing each of the considered renovation measures and retrofit packages. Additional part of the tool deals mainly
with installing a ventilation system, with and without an integrated heat exchanger in the buildings built after 2008. The DanBERA tool developed is demonstrated by considering three building cases to assess the technical, economic and environmental impacts of the different energy measures and packages.

5.1 One-story house case

Figure 3 shows a screenshot of the overall tool assessment results for energy renovation of a one-story single-family house of 150 m$^2$ indoor area, built in 1970 in Funen.

![Figure 3. DanBERA results for a 150 m$^2$ one-story house from 1970.](image)

5.2 Office building case

Figure 4 shows a screenshot of the overall tool assessment results for energy renovation of an office building of 500 m$^2$ indoor area, built in 1985 in Funen.

![Figure 4. DanBERA results for a 500 m$^2$ office building from 1985.](image)

5.3 Ventilation system with heat exchanger implemented in one-story house

To improve the indoor thermal comfort, a ventilation system is implemented in a one-story single-family residential building of 150 m$^2$ built between 2008 and 2015. Figure 5 shows an assessment of the impact of adding a ventilation system with and without an integrated heat exchanger. It is shown that adding a ventilation system will increase the overall energy consumption for both electricity and heating. However, it was noted that a ventilation system would allow reducing the average temperature in the summer months by around 2 to 4 °C, and thus enhancing the thermal comfort.

![Figure 5. DanBERA results for implementing a ventilation system in a 2015 one-story house.](image)
6. Discussion and Conclusions

Denmark is exhibiting a large evolution in terms of the renovation projects and activities. However, there is an absence of a holistic energy renovation design and assessment tool which could aid a systematic and energy-efficient building renovation process. The trend in most of these processes is that renovation is driven by the need to modify or change on different levels of the building. So, the process is reactive, and generally miss on valuable energy and operational savings. In addition, static tools are very popular in the market, allowing investigating the impact of renovation measures but based on simple calculations with large assumptions and without considering the integration and trade-off between various upgrades. This static and simple approach has led to major gaps between what customers are promised in terms of performance after renovation, and what the actual performance turns out to be. To reduce this gap, and to aid a more systematic decision making for renovation projects, this study presents the DanBERA tool for Danish buildings energy renovation design and assessment. The tool uses, as a database, a set of dynamic energy performance simulations of energy renovation measures, taking into account the building type, size, age and location. Being simple, yet comprehensive, the tool requires minimal inputs from the user and could be used as a design tool for preliminary calculations of the impact of various energy upgrades to be implemented. It shall be mentioned that the tool has certain assumptions, where it restricts the building age to only six building regulations in Denmark. This means that the tool will provide the same assessment results for two different buildings from 1972 and 1979, of the same nature and of the same interior area. In addition, the tool is generic in terms of building occupancy, loads and schedules. This includes the assumption of a single family with four people in a house. However, those assumptions are meant to keep the tool simple and easy to use, while still preserves its accuracy considering Danish building regulations and dynamic energy model simulations as a database. The first version of the tool is demonstrated in this study, and currently the tool is being upgraded with additional building intelligence and systems control and management measures to be added and assessed as part of the overall design tool. This includes implementing adaptive heating control, CO2-driven ventilation, ventilation air preheating, along with multiple combined packages. Moreover, additional building types could be included, as hotels, schools and hospitals. In addition, the results of the tool could be combined with a more detailed analysis on the level of each specific building, based on a holistic methodology presented earlier by the Jradi et al. [6]. The methodology allows extending the preliminary analysis performed in DanBERA with a a whole building dynamic energy modelling and simulation process using EnergyPlus, which considers detailed and specific building characteristics in terms of the physical envelope, energy systems, occupancy profiles and specific weather conditions.

References

[1] Lund H and Mathiesen BV 2009, Energy system analysis of 100% renewable energy systems- The case of Denmark in years 2030 and 2050, Energy 34 524-31.
[2] Jradi M, Veje C and Jørgensen BN 2017, Deep energy renovation of the Mærsk office building in Denmark using a holistic design approach, Energy Build 151 306-19.
[3] Nielsen AN, Jensen RL, Larsen TS and Nissen SB 2016, Early stage decision support for sustainable building renovation – A review, Build Environ 103 165-81.
[4] Strategy for energy renovation of Buildings: The route to energy-efficient buildings in tomorrow’s Denmark, The Ministry of Climate, Energy and Building in Denmark. https://ec.europa.eu/energy/sites/ener/files/documents/2014_article4_en_denmark.pdf, May 2014 (accessed on 22.2.2019)
[5] Rose J and Thomsen KE 2015, Energy saving potential in retrofitting of non-residential buildings in Denmark, Energy Procedia 78 1009-14.
[6] Jradi M, Veje C and Jørgensen BN 2018, A dynamic energy performance-driven approach for assessment of buildings energy renovation – Danish case studies, Energy Build 158 62-76.
[7] Kjaerbye VH, Larsen A and Togeby M 2010, The effect of building regulations on energy consumption in single-family houses in Denmark. Copenhagen: Energi Analysers, April 29.
[8] Executive Order on the Publication of the Danish Building Regulations 2015 (BR15). https://historisk.bygningsreglementet.dk/file/591081/br15_english.pdf, (accessed on 28.2.2019)