Application of MyBEM, a BIM to BEM platform, to a building renovation concept with solar harvesting technologies

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Abstract

This paper describes how MyBEM, a building energy modeling and simulation platform based on a modular architecture, has been adapted for a renovation concept that integrates solar technologies on opaque and glazed parts of the façade, and then applied to a three-story social housing residential building located in the Netherlands. The energy balance and dynamic behavior of the whole energy system are reported. They show how low temperature solar collectors on façades can provide most of the thermal energy demand.

Key Innovations

- Automated BIM (Building Information Modeling) to BEM (Building energy Modeling) process
- Energy retrofit concept that integrates solar harvesting technology on the whole building envelope
- Energy system concept able to fulfill most of the heat demand from low temperature solar collectors

Practical implications

An energy system based on low temperature solar collectors can provide a major part of the energy needs for a high energy performance residential building, even in a Northern Europe climate. This system can produce excess energy and inject it on a district heating network.

Introduction

Improving the thermal insulation of the whole European building stock is mandatory to make it energy-neutral, but it will not be sufficient (IEA, 2019). Harvested solar energy from all surfaces of buildings should be maximized in order to provide the remaining energy needs. Installation of photovoltaic panels and thermal collectors has increased considerably in recent years, but mainly on roofs due to aesthetics, practical reasons and cost. However, still billions of square meters are available on the vertical façades. Solar technologies adapted to vertical façades would help a lot for meeting the remaining energy needs with solar energy.

Within the H2020 Envision project, a consortium of European partners is developing a concept of residential buildings renovation that integrates both the reduction of energy demand – through a standard improvement of the thermal insulation – and the integration of solar energy harvesting technologies on the whole building envelope, including opaque façades and windows. The following technologies are developed within the project:

- Two versions of solar collectors for opaque walls – a covered version (with glass span) and an uncovered version (without glass span) – that are colored but capable of harvesting most of the solar irradiance in the near infrared (NIR). The performance can thus approach that of black panels, which absorb most of the solar spectrum but have a low social acceptability for integration in facades due to aesthetic concerns.
- Photovoltaic (PV) windows, which integrate PV strips to produce electricity from the solar flux.
- Ventilated windows, meant to warm up the indoor air in winter and pre-heat domestic hot water in summer.

The main goal for H2020 project is to develop a building energy system based on these solar technologies and able to collect and exploit – locally or remotely, thanks to an energy network – the maximum of the solar irradiation that reaches a building envelope. The evaluation of this target in an integrated approach is not simple, due to the complexity of the solar harvesting technologies and energy system coupled to the high variability of the solar resource and energy demand of a building during a year (Behzadi and Arabkoohsar, 2020; Rosato et al., 2019). This is why a detailed dynamic modeling tool is required to understand and optimize the system operation. Thanks to its versatility, Modelica has been applied successfully to building energy modeling by several research institutes in the last decade (Wetter and van Treek, 2017). Among all Modelica libraries dedicated to building energy modeling, we have chosen BuildSysPro (Plessis et al., 2014), so that we can benefit from recent improvements regarding heat pump modeling by Deutz et al. (2018).

From the last decades, the development of the BIM (Sacks et al. 2018) – Building Information Modelling – is a major transformation of the building sector. It can be defined as a structured numerical description of all the components of a building – including 3D geometry and any technical or physical property – and also as an approach for an interdisciplinary and collaborative work during the whole lifetime of a building. When open standards are used, interoperability and modularity work are strongly facilitated. In particular, the compatibility of tools dedicated Building Energy Modeling (BEM) with open standards of BIM appears as a key feature for these tools (Reeves et al., 2015), though the BIM to BEM process is still not straightforward (Kamel and Memari, 2019; Van Dessel et al., 2019).

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A BIM to BEM workflow, using MyBEM platform – a toolchain developed by EDF R&D and notably resulting from the ANR MERUBBI project (Schumann et al., 2017; Bouquerel et al., 2019) – has been applied in the project. This toolchain is able to produce a Modelica building energy model from a BIM file. Thermal exchange through the building envelope and also between internal zones are taken into account in the generated model. MyBEM uses the gbXML (Green Building XML, 2017) as a BIM standard for data exchange, whereas the IFC (ISO, 2005) is used in similar works conducted by Andriamamonjy et al. (2018) or Nytsch-Geusen et al. (2019). MyBEM is also able to take into account accurately solar shading due to surrounding buildings thanks to ray tracing calculation.

This paper presents in a first section the architecture and workflow of MyBEM, and in a second section its adaptation to the Envision project. After that comes a description of the case study (a residential building in the Netherlands), the simulation results and discussion, and finally a brief conclusion.

Modeling and simulation tools

MyBEM platform

MyBEM is a modular platform developed by EDF R&D for building energy modeling and simulation. It allows to take into account the impact of its location and surrounding urban context on the solar irradiation reaching the building. A specific BIM-based automatic model generation process is also implemented in MyBEM. A detailed description of the platform is available in Bouquerel et al. (2019). A shorter description is made hereafter.

The following functionalities are implemented in MyBEM:

- Import of the geometric description of the studied building(s) and the surrounding district
- Assignment of thermal and radiative properties of the building envelope
- Implementation of building usage scenarios
- Calculation of local boundary conditions taking into account the impact of the surrounding district
- Generation of the building energy model
- Simulation of the building energy model and assessment of energy performances

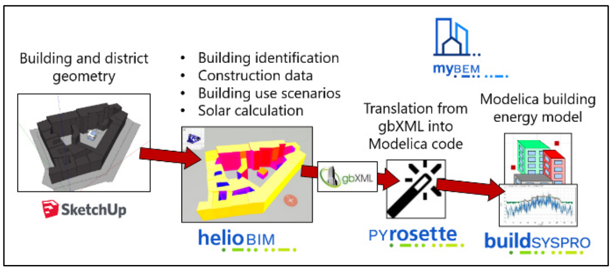

Figure 1: Workflow in MyBEM for the case study

MyBEM is based on a modular architecture. It is a toolchain consisting of several independent modules, which are run successively and communicate by file exchange. For interoperability purpose, open standards are used to the maximum. The tools and workflow of the process used for the case study of this paper are reported in Figure 1. Each module of this platform is detailed hereafter.

HelioBIM

HelioBIM is the pre-processing tool of MyBEM, available as desktop or web application. It is dedicated to the generation of a comprehensive building energy oriented BIM file, a so-called *thermal mockup*. The gbXML – green building XML, an open source standard for interoperability in building energy engineering (Green Building XML, 2017) – is used as standard for this thermal mockup.

HelioBIM provides a geometrical and analytical tool that can convert a simple SketchUp™ file into a thermal mockup by identifying the thermal zones and building construction parts (walls, floors, roofs, windows…). It is also able to directly import a thermal mockup, from gbXML files, or from EnergyPlus™ (US Department of Energy, 2018). A first module prototype for importing IFC (ISO, 2005) is also available.

Once the thermal mockup is imported, HelioBIM provides a set of functionalities for editing the components of the building(s). They are used to set all the data needed for solar and thermal calculation:

- Hierarchy of **District / Buildings / Zones / Spaces** (rooms considered as air nodes);
- **Boundary conditions**: possibility to set a specific boundary condition (soil, crawlspace, adiabatic, heated or non-heated room) for each surface;
- **Usage scenarios**: possibility to set the heating / cooling / lighting / ventilation / internal gains scenarios;
- **Construction systems**: possibility to set the materials and opaque wall compositions and apply them to indoor / outdoor walls, floors and roofs. Possibility to set thermal characteristics of openings;
- **Thermal bridges**: possibility to set thermal bridge coefficients individually or by type;

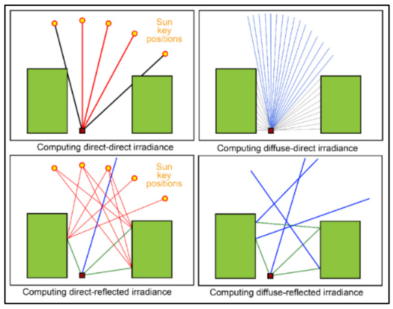

Figure 2: The four components of solar irradiance calculated by HelioBIM

HelioBIM is able to carry out solar calculation on the building envelope as a pre-process to building energy simulation. The location is extracted from a weather data file (TMY2 or EnergyPlus™ EPW), and then HelioBIM runs a backward Monte-Carlo ray tracing algorithm, able to take into account the impact of solar shading and solar reflections due to the district morphology on the solar irradiance from the weather data file. Four components of

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the irradiance are calculated: direct-direct, direct-reflected, diffuse-direct, and diffuse-reflected (see Figure 2). The solar irradiance is calculated for each envelope surface (opaque walls, roofs, openings…) and each hour of the annual weather data file. HelioBIM can export the thermal mockup as a gbXML file, and the results of the solar calculation as CSV files.

PyRosette

PyRosette is an EDF python package dedicated to the generation of a Building Energy Model (BEM) from a gbXML file. It contains a translation function able to convert the building thermal mockup stored in the gbXML file into a building energy model in Modelica. This model is based on BuildSysPro, the Modelica library developed by EDF R&D (see next paragraph for more details) which contains elementary models for building energy modeling (Plessis et al., 2014).

The gbXML schema and the Modelica library BuildSysPro are both relying on an object-oriented description of buildings. They use similar segmentation patterns and properties, so the translation from gbXML to Modelica is fairly natural. The BIM to BEM process run by PyRosette contains the following actions:

1. to parse the gbXML in order to get the list of building components to be integrated in the BEM
2. to instantiate in a Modelica template each building component as a BuildSysPro model instance
3. to set the parameters of each instance according to the attributes of the corresponding gbXML tag
4. to connect all instances according to their relations stated in the gbXML through the ID system.

BuildSysPro

The Modelica library BuildSysPro is a free open-source Modelica library for building and energy system modeling, developed by EDF R&D (Plessis et al., 2014). It provides a set of elementary 0D/1D components to describe envelope components, energy systems and devices, and control systems. It is mainly based on two branches of physics: pure thermal and airflow dynamics modeling. These classes are compliant with the packages Modelica.Thermal.HeatTransfer and Modelica.Media of the Modelica standard library to ensure a good level of interoperability with other Modelica libraries. These models are designed for static and dynamic modeling.

The way of modeling building energy systems with BuildSysPro is similar to the approach commonly used by the building science community. An energy simulation is performed by assembling a building envelope, with energy systems and devices, their controls, and boundary conditions for external and internal conditions. The meteorological conditions are part of the external conditions and occupancy or heating patterns are considered through the internal conditions.

Figure 3 gives an example of a single building energy model built with BuildSysPro. This model contains the building envelope (façade walls, roof, floor, and windows), the internal air volume (blue disk), a ventilation model, and a weather simulator (left part).

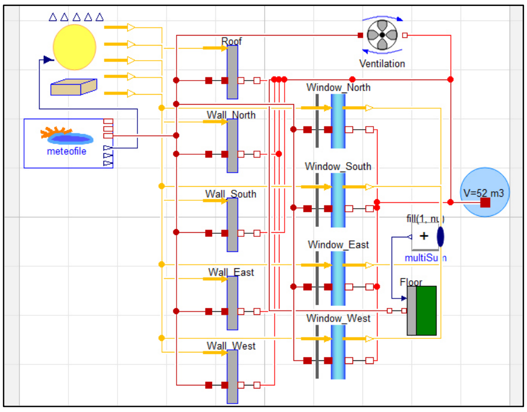

Figure 3: Example of a single building energy model based on BuildSysPro

Due to the size of the models generated by PyRosette which can contain several tens of thermal zones or more, and several tens or thousands of envelope parts, the exported models do not contain a detailed graphical view of all sub-parts of the model, as in Figure 3, only the Modelica code is exported.

Once the Modelica model has been generated by PyRosette, it can be simulated. The simulation is done preferably thanks to the commercial software Dymola. OpenModelica can be used also but there is not a full compatibility with it. The model is run over one full year, and the simulation results exported with an hourly time step resolution.

Integration of Envision technologies in MyBEM

Among the four solar technologies considered in the project, the case study integrates two of them: uncovered solar collectors and PV windows. A description of the technologies, corresponding models and integration into MyBEM is given below.

Uncovered solar collectors

Standard uncovered solar collectors are based on the following principles:

- A metal panel is exposed to solar irradiation and used as a flat solar energy collector
- The collected heat is transferred to a fluid.
- The fluid carries heat to the building's energy system through a piping system

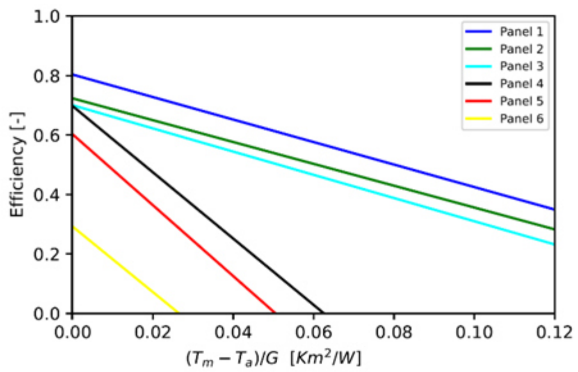

Figure 4: Efficiency curve for covered (panels 1 to 3) and uncovered collectors (panels 4 to 6) (Bulut, 2018)

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This uncovered design is also called low temperature collectors, because the efficiency is good only if the temperature is around the outdoor air temperature. In contrast, the covered version is called high temperature collectors: they have a glass pane and an air layer in front of the metal plate – in order to reduce the heat loss from the collector to the ambient through reduced conducto-convection and thermal radiation – so that the efficiency is good even for a fluid temperature significantly higher than the air temperature. The difference is clear in Figure 4 which shows the efficiency as a function of the reduced temperature (difference between ambient air and mean water temperature divided by the solar irradiance): the efficiency drop due to the increase of the reduced temperature is much faster for uncovered collectors than for covered collectors.

The major difference in comparison to standard uncovered collectors is that in the project, they are painted with a NIR absorbing colored coating: specific additives in the coating make it able to absorb the major part of the NIR from the Sun without disturbing the visible color (Erich, 2019). Figure 5 shows uncovered collectors tested for the project at the Solar Energy Application Centre (SEAC) of TNO, NL.

Figure 5: Uncovered solar collectors tested during the project at SEAC, NL (Erich, 2019)

The Modelica model developed for these solar collectors is based on the quasi-dynamic equation from ISO 9806:2013 (ISO, 2013), an international standard which gives the output power of a solar collector as a function of the weather conditions and a set of coefficients that are dependent on the collector reference.

Model inputs are:

- Incident solar irradiance
- Outdoor air temperature
- Wind speed
- Long wave irradiance or sky temperature
- Temperature and mass flow rate of incoming water

Model outputs are:

- Output thermal power
- Output energy (time integration of power)
- Temperature and mass flow rate of outcoming water

For the case study of this paper, only uncovered collectors have been used, but the work could be applied also to covered collectors just by setting the right parameters since ISO 9806:2013 equation can be used for both uncovered and covered collectors.

PV window concept

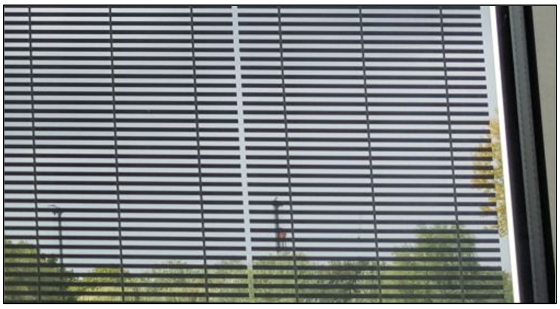

Figure 6: prototype of PV window

The PV window concept developed for the project integrates PV strips into double glazing windows (Valckenborg, 2019). PV strips are positioned on the back of the outer glazing. The coverage rate is about 50%, so transmission of sunlight is roughly half that of a standard double glazing window. PV windows can be used for traffic areas (corridors, stairs…) or façades with a high glazing ratio. See Figure 6 for an example of a PV window prototype.

In BuildSysPro, models are already available for double glazing windows and for PV panels. A model for PV windows has been developed by combining both models. As the properties for the PV window given by the manufacturer are the same as for standard double glazing (U-value U_g, light transmittance LT and solar heat gain coefficient g), the double glazing part of the model is directly parameterized from these values. For the PV strips, the standard PV panel model is used, with an area corresponding to the total area of the strips, and the temperature of the PV layer is set equal to the outer glazing.

Integration in the platform

There is no specific tag in the gbXML schema for stating which walls or windows are equipped with a solar harvesting technology, and what are their performances. To overcome this lack, the insertion of a specific keyword in the gbXML name field has been used to specify if a façade element is a solar collector, and if a window is a PV window. These keywords are detected by PyRosette, and the instantiation in the Modelica model is adapted.

The same principle is used to specify the piping pattern of solar collectors, which can be installed in several parallel loops where collectors are in series. So keywords are used to match collectors with their corresponding loop, and position in the loop. Then PyRosette can connect the water outlets and inlets of all collectors with the right pattern.

Description of the case study

Building envelope renovation

The case study is a typical social housing residential building in the Netherlands. It has 24 apartments of around 80 m² living area each, on 3 floors, distributed on 4 staircases. The total heated area is 1980 m². 3D drawings of the building in the actual configuration and after renovation are plotted in Figure 7. The main façade (front side) is oriented South-East (140°).

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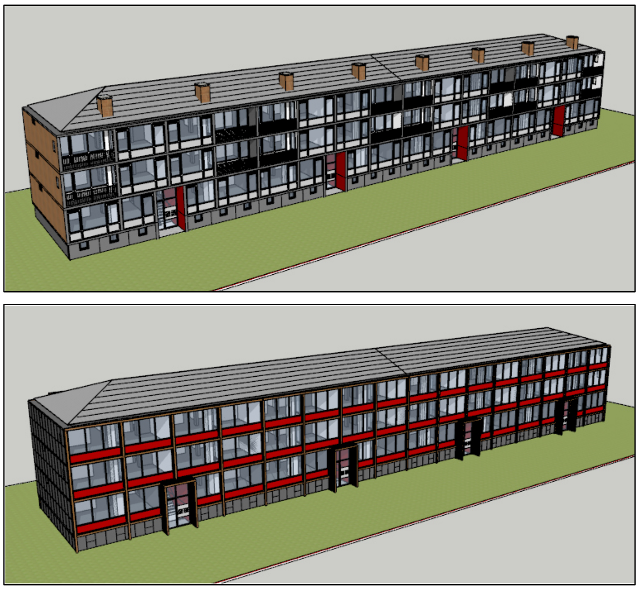

Figure 7: Case study building in the actual configuration (top) and after renovation (bottom)

The design of the renovation to be implemented is based on the following assumptions:

- All balconies of the front side façade are closed
- All balconies of the rear side façade are removed
- Both main façades have the same pattern, with a glazing ratio of 73%
- Both edge façades are fully opaque walls
- Thermal resistance of opaque parts are between 4 and 6 m².K/W
- U_w of windows are between 1.1 and 1.3 W/(m².K)
- Uncovered solar collectors are installed on three façades (total area 305.3 m² for 81 collectors):
    - Font side façade: 48 collectors for a total area of 133.7 m² (2.05 m² for 8, 2.93 m² for 40)
    - Each edge side façade: 33 collectors of 2.60 m², for a total of 85.8 m²
- Water is flowing from the bottom to the top in the simulation (for simplification purpose).
- Collectors efficiency (according to ISO 9806:2013):

η_0	c_1 Heat loss coefficient	c_3 Wind on c_1	c_4 Longwave radiation	c_5 Heat capacity	c_6 Wind on η_0
0.62	8	3.5	0.45	1.9e4	0.08

- 12 PV windows are installed on the staircase windows of the rear façade for a a total area of 69 m (5.55 m² for 4 windows, 5.85 m² for 8 windows)
- Nominal electrical efficiency of PV windows: 7.15% (PV coverage ratio = 50%)

Energy system description

The Envision energy system is presented in Figure 8. The main originality of this system is that it takes its energy from multiple sources to cover multiple needs. The sources are the solar irradiation and the ambient air energy – harvested through the façade collectors – and the geothermal energy - harvested through a ground loop used as a backup. The needs are space heating and domestic hot water pre-heating. A connection with a District Heating Network (DHN) has been added to allow energy exchange with it, in case of excess or lack of energy. Note that there is no DHN connected to the real building, but in order to assess how such building could interact with a DHN, a virtual DHN has been considered in the model.

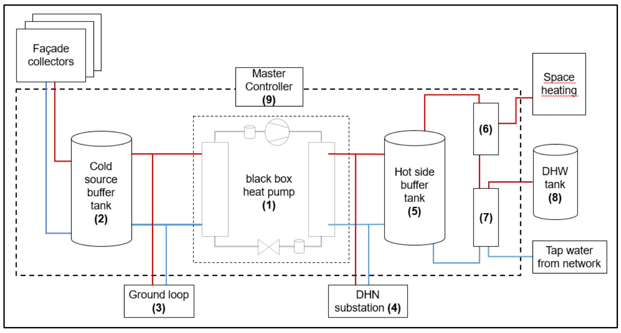

Figure 8: Energy system for three dwellings

To interface the low temperature sources and the high temperature needs, the idea is to use water-to-water heat pumps. In terms of implementation, the system concept is split in 8 individual systems, in order to lower the nominal power of the heat pumps. Each system covers the demand for a block of three dwellings (one dwelling per floor).

Each heat pump **(1 – Fig. 8)** is coupled to a primary water loop (left part of Figure 8) harvesting all the energy sources on the cold side (the water flowing from all solar collectors are merged on this primary water loop). A secondary water loop (right part of Figure 8) distributes the harvested energy at a higher temperature for the needs of three dwellings. On the primary side, it was decided to have for each heat pump:

- A cold source buffer tank **(2 – Fig. 8)** connected to the façade collectors that stores the solar and aerothermal energy
- A valve that switches to the ground loop **(3 – Fig. 8)** when the buffer tank is at a temperature too low for the heat pump.

On the secondary side, it was decide to have:

- A bivalent DHN substation **(4 – Fig. 8)**
- A hot side buffer tank **(5 – Fig. 8)** allowing to shave peak thermal demands. This buffer tanks connects a secondary distribution loop that delivers heat via a heat exchanger **(6 – Fig. 8)** for space heating and provides tap water preheating through another heat exchanger **(7 – Fig. 8)** for an electric hot water tanks **(8 – Fig. 8)** that covers the DHW demand.

In order to study the performances of the system, a model of each of the above elements was build using the BuildSysPro library (Plessis et al., 2014) under Dymola. It successfully allowed modeling all the hydraulic components dynamically using a flow and temperature approach rather than only energy or power levels. This is of crucial importance when assessing the performance of such a multisource system with different temperature levels and different time patterns. In order to get the best compromise between precision and speed of the model, the following modeling assumptions are taken:

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- Black box steady state heat pump fitted with reference manufacturer data (Deutz, 2018) such as presented in NIBE (2017) for thermal capacity and electric power.
- Bi-zonal tank discretization with a cold and hot zone separated by a thermocline that varies according to the enthalpy flows of the inputs and outputs
- No pressure drop in the distribution loops – constant auxiliary pump consumption
- Constant heat exchanger efficiencies set to 70 % for Domestic Hot Water (DHW) pre-heating
- One zone electric water tanks and fixed daily tapping profiles taken from EN 16147 (CEN, 2017)

Energy system sizing and control

Each heat pump is sized according to maximum annual heat demand predicted by the building energy model. To manage the system, a master controller **(9 – Fig. 8)** is used to:

- Switch between solar collectors or ground loop. Two modes are available:
  - Mode 1 – Optimized between solar and ground. This mode uses the ground loop when the temperature provided by the façade collectors is inferior to the ground loop temperature.
  - Mode 2 – Full solar mode. This mode uses the back up ground loop only when the temperature of the cold source is below the minimum operating temperature of the heat pump.
- Turn off the solar loop pump if the solar loop temperature is inferior to the average tank temperature
- Set the demand temperature for the intermediary loop through a preset heat curve controlling the intermediary set point temperature according to the external air temperature. The demand temperature is send to the water to water heat pump that regulates the compressor
- Force the heat pump to be on when the Envision building has no heat demand and that solar energy is available.

Simulation hypotheses

Results reported hereafter were obtained by a simulation with the following hypotheses:

- Connection of the building with an ideal DHN able to inject heat when requested, and extract unused heat when available, with no constraint on the water temperature. Since this simulation is focused on the energy system at building scale, the interaction with the DHN has been simplified on purpose
- Switch between solar collectors and ground loop when temperature of water coming from the solar collectors is below the lowest temperature that can be handled by the heat pumps (Mode 2, see Energy system sizing and control section)
- Heat pumps have a maximal heat power of 6 kW
- Constant flow rate in each solar collector loop
- Constant electricity demand due to 46 auxiliary pumps: 50 W / pump (no pressure drop modeling)
- Constant electricity demand due to the ventilation system: 100 kWh/y per dwelling (no detailed airflow modeling)
- Constant electricity demand due to electric appliances in dwellings: 3W/m²
- Constant internal gains: 5 W/m² (3 W/m² for electric appliances and 2 W/m² for people)
- Constant ventilation rate: ACH = 0.3 h-1 in the dwellings, ACH = 1 h-1 in the staircases, ACH = 5 h-1 in the basement and attic
- Constant temperature set point for heating: 20°C
- No cooling system

Results and Discussion

Building energy balance

The annual energy demand at the building scale, and the mean value per dwelling, are reported in Table 1.

Table 1: Annual building energy demand

Annual energy demand	Total building demand [MWh]	Mean demand per dwelling [kWh]
Space heating (heat)	61.8	2 573
Domestic Hot Water (heat)	38.7	1 612
Ventilation and domestic appliances (electricity)	54.4	2 168
Total	**154.9**	**6 453**

In Figure 9, one can see the energy balance of the whole building energy system, in particular the annual thermal energy transfers related to the heat pump and buffer tanks (in red), the energy exchanges with the DHN (in orange), and the electricity demands (in blue). Heat pumps are covering more than 95% of the space heating demand, and more than 55% of the heat demand for domestic hot water.

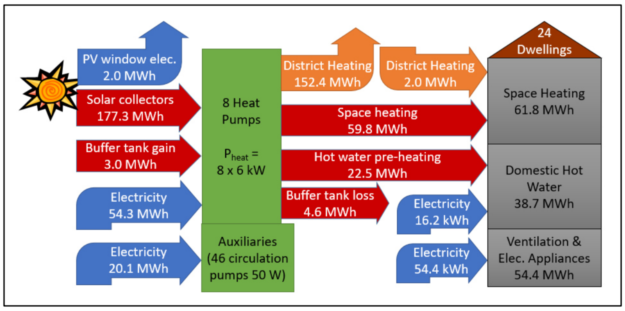

Figure 9: Annual energy balance at building scale

The annual thermal energy delivered by the heat pumps is 239.2 MWh for an electricity consumption of 54.3 MWh. The mean annual COP of the heat pump only is 4.4 for a system performance of 3.15, which is a good performance. The dynamic evolution for the heat fluxes listed below is reported in Figure 10:

- Thermal power from solar collectors (red)
- Electricity used by the heat pump (blue)
- Heat exchange with the DHN (orange)
- Thermal power from the heat pump (green)
- Space heating power (black)

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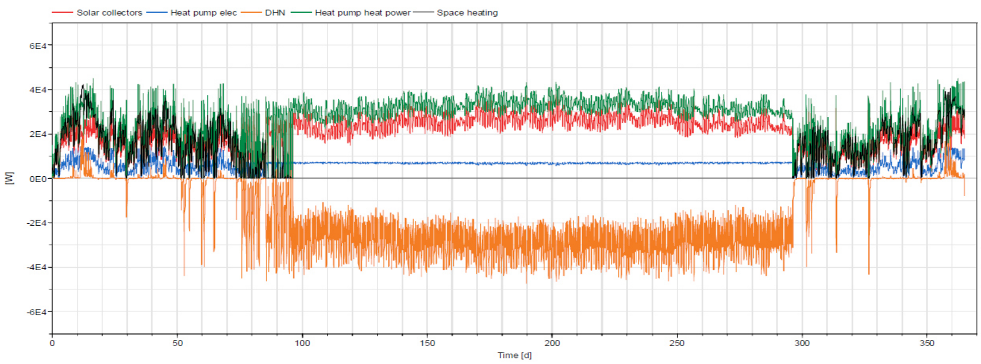

Figure 10: Thermal power at building scale as a function of time for a one year simulation

Solar collectors

The distribution of the annual solar irradiation on the South-West, South-East, and North-East façades can be seen in Figure 11. It is clear on this figure that the surrounding buildings (in grey) are responsible for solar shading, so that the solar potential is lower for the lower floors and for the surfaces located near the edges and at the edges of this façade. Indeed these parts of the façades are closer to surrounding buildings, so more subjected to the influence of their shading.

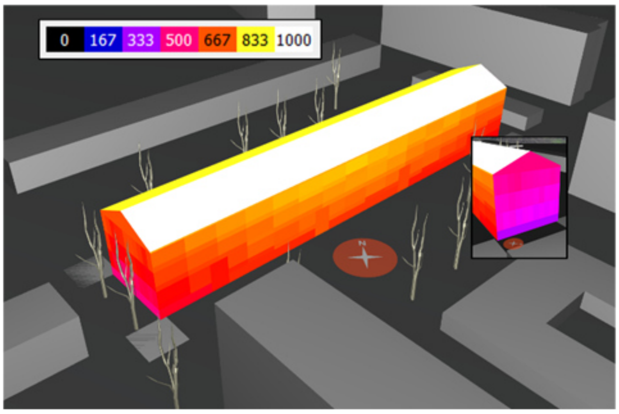

Figure 11: Annual solar irradiation on the front side and edge façades [kWh/(m².y)]

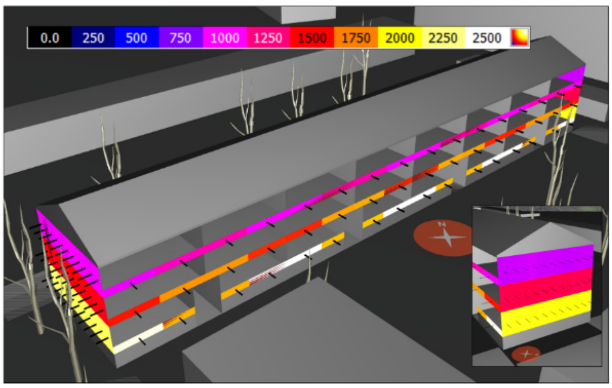

Figure 12: Thermal energy harvested by each solar collector [kWh/y]

The annual thermal energy harvested by each solar collector can be seen in Figure 12. For simplification purpose in this model, the water is chosen to flow from the bottom to the top of the façade. So the higher the collector, the warmer the water: water at the inlet of the upper floor has been warmed up by collectors of the lower floors. Thus, regarding the typical shape of the efficiency curve (see Figure 4) one can expect a lower efficiency for collectors of upper floors, which is clearly what the figure shows.

One can see also that collectors adjacent to the four main entrances have a lower energy outcome, but it is only due to the fact that they have a lower area (around 2 m² compared to 3 m² for all other collectors).

The annual solar irradiation on the solar collectors and harvested energy per orientation are reported on Table 2. The annual harvested energy is close to the annual irradiation, or even higher for the North-East façade. This is due to the fact that opaque collectors behave not only as solar collectors, but also as heat exchangers with the ambient air when the solar irradiation is not sufficient to cover the energy needs. This is achieved by lowering the temperature of the fluid in collectors below the ambient air temperature. So the total energy potential is the sum of two contributions: the solar irradiation, and the potential of ambient air, the latter depending on the temperature of the fluid in the collectors.

Table 2: Annual solar irradiation on solar collectors and harvested energy per orientation

Orientation	**Solar collectors area [m²]**	**Annual solar irradiation [MWh]**	**Annual harvested energy [MWh]**
South-East (front side)	133.7	90.3	79.1
South-West	85.8	51.2	50.9
North-East	85.8	37.2	47.2
Total	**305.3**	**178.7**	**177.2**

The mean water temperature flowing into and from collectors for July are reported in Figure 13 together with the outdoor air temperature, in order to illustrate that behavior. During this period, the water coming from the collectors is at a higher temperature than the outdoor air during the day, indicating that the collectors are harvesting the solar radiation. However, during the night, the temperature of the water coming from collectors is lower than the outdoor air temperature, but they still have a positive energy output due to the difference between the water temperature at the inlet and outlet of collectors. This shows that during the night, collectors are harvesting energy from the ambient air through heat exchange.

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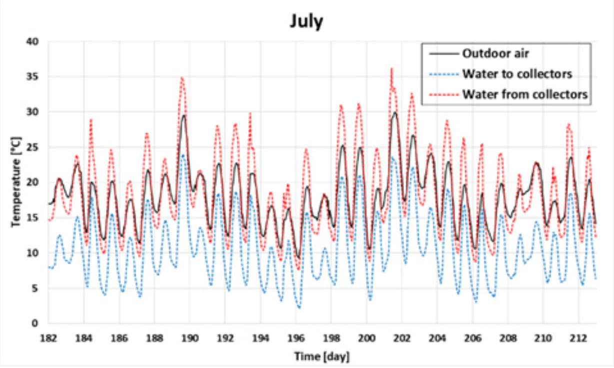

Figure 13: Outdoor air and water temperature in solar collectors during January (top) and July (bottom)

PV windows

The annual electricity production is 2.00 MWh/y, which corresponds to a mean value of 29.0 kWh/(m².y) for the 69 m² of PV window. The peak production is 3.05 kW (44 W/m²). Frame shading is not taken into account in this simulation, it may decrease significantly the energy performance of the PV windows especially with the orientation of these PV windows (North-West) which implies a grazing angle of incidence of direct solar irradiance at the end of the day.

Conclusion

The high versatility of MyBEM platform and the flexibility of BuildSysPro library allowed to easily model and integrate the different technologies of Envision renovation concept into the building energy simulation process. A case study that consists in a three-story residential building located in the Netherlands is used to assess the efficiency of the energy system concept. Dynamic simulation is of great interest for this case study, in particular the simulation of coupled solar collectors and heat pumps both with their dependency to source and sink temperature levels. Indeed, water temperature in such a system varies a lot, according to the simulation results, since it has to be adjusted with the ambient air temperature to ensure a good efficiency.

For the case study reported in this paper, solar collectors provide more than 95% of the energy required for space heating, and more than 55% for domestic hot water. 152 MWh can also be produced an injected in a District Heating System, mostly during summer time.

Still some physical phenomena are not perfectly taken into account, in particular the electricity demand due to the auxiliaries and the impact of condensation & frost on the solar collectors. Therefore experiments are still needed to measure how the simplifications can affect the accuracy of the simulation results.

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References

Andriamamonjy, A., Saelens, D., Klein, R. (2018). An automated IFC-based workflow for building energy performance simulation with Modelica. *Automation in Construction 91*, 166-181.

Behzadi, A., Arabkoohsar, A. (2020). Comparative performance assessment of a novel cogeneration solar-driven building energy system integrating with various district heating designs. *Energy Conversion and Management 220*.

Bouquerel, M., Bermes, S., Brun, A., Bouia, H., & Lecussan, R. (2019). Building Energy Modeling at District Scale through BIM Based Automatic Model Generation – Towards Building Envelope Optimization. *Proceedings of Building Simulation 2019 Conference*. Rome (Italy), 2-4 September 2019.

Bulut, Y. (2018). *Performance Assessment of Colored Façade Integrated Solar Collectors and Numerical Analysis of Solar Collector-Heat Pump System with TRNSYS*. Master of Science Thesis. Eindhoven (Netherlands)

CEN – European Committee for Standardization (2017). *Heat pumps with electrically driven compressors — Testing, performance rating and requirements for marking of domestic hot water units (EN 16147:2017)*.

Deutz, K., Cauret, O., Rullière, R., Haberschill, P. (2018). Multi-criteria Air Source Heat Pump Water Heater optimization combining optimized thermodynamic performance and control. *Proceedings of the 10th International Conference on System Simulation in Buildings*. Liège (Belgium), 10-12 December 2018.

Erich, B. et al. (2019). Energy harvesting by invisible solar façade collector. *Proceedings of 14th Conference on Advanced Building Skins*. Bern (Switzeland), 28-29 October 2019.

Green Building XML (2017). *gbXML Schema 6.01*.

Kamel, E., Memari, A. (2019). Review of BIM's application in energy simulation: Tools, issues, and solutions. *Automation in Construction 97*, 164-180.IEA – International Energy Agency (2019). *Perspectives for the Clean Energy Transitio – The Critical Role of Buildings*.

ISO – International Organisation for Standardization (2005). *Industry Foundation Classes, Release 2x, Platform Specification (IFC2x Platform) (ISO/PAS 16739:2005)*.

ISO – International Organisation for Standardization (2013). *Solar energy — Solar thermal collectors — Test methods (ISO 9806:2013)*.

NIBE (2017). *F1255 Installation guide*.

Nytsch-Geusen, C., Rädler, J., Thorade, M., Tugores, C. (2019). BIM2Modelica - An open source toolchain for generating and simulating thermal multi-zone building models by using structured data from BIM

https://doi.org/10.26868/25222708.2021.30153

models. *Proceedings of the 13th International Modelica Conference*. Regensburg (Germany) 4-6 March 2019.

Plessis, G., Kaemmerlan, A., Lindsay, A. (2014). BuildSysPro: a Modelica library for modelling buildings and energy systems. *Proceedings of the 10th International Modelica Conference*. Lund (Sweden), 10-12 March 2014.

Rosato, A., Ciervo, A., Ciampi, G., Scorpio, M., Sibilio, S. (2019). Impact of seasonal thermal energy storage design on the dynamic performance of a solar heating system serving a small-scale Italian district composed of residential and school buildings, *Journal of Energy Storage 25*.

Reeves, T., Olbina, S., Issa, R. (2015). Guidelines for Using Building Information Modeling for Energy Analysis of Buildings. *Buildings 5*, 1361-1388.

Sacks, R., Eastman, C., Lee, G., Teicholz, P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*. John Wiley & Sons, Inc.

Schumman, M. et al. (2017) Interdisciplinarity around design tools for new buildings and districts: the ANR MERUBBI project. *Proceedings of 33rd PLEA International Conference*. Edinburgh (UK), 3-5 July 2017.

US Department of Energy (2018). *EnergyPlus™ Version 9.0.1 Documentation*.

Valckenborg, R. (2019) Performance of semi-transparent PV windows. *Proceedings of 14th Conference on Advanced Building Skins*. Bern (Switzeland), 28-29 October 2019.

Van Dessel, M., Maile, T., O'Donnell, J. (2019). BIM to Building Energy Performance Simulation: An Evaluation of Current Industry Transfer Processes. *Proceedings of Building Simulation 2019 Conference*. Rome (Italy), 2-4 September 2019.

Wetter, M., van Treeck, C. (2017). *IEA EBC Annex 60: New Generation Computing Tools for Building and Community Energy Systems*.

https://doi.org/10.26868/25222708.2021.30153