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A top-down approach based on simulations and optimisations to evaluate renovation of public buildings

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Abstract:

The renovation of buildings in urban areas has become an urgent need for public authorities to reduce energy consumption and comply with the Paris Agreement's objectives. The potential for energy consumption reduction through renovation is especially high in old European cities considering that in average 70% of the buildings were built before 1981. This paper presents the work realised within the Charl-e-district project, which addresses the renovation of public buildings through a new approach combining numerical simulations and optimisations. The objective is to develop a tool to help public authorities in decision-making regarding refurbishment of public buildings (measure, intensity, building selection, expected benefits). Firstly, a numerical building model is constructed using OpenStudio/EnergyPlus and calibrated using monitored data. Secondly, renovation scenarios are defined depending on the complexity and costs of implementation. A set of optimizations is then run to determine the values of parameters that will allow the maximum reduction in energy consumption. The novelty of this methodology is the top-down approach, indeed the sets of renovation measures to be investigated are known, the values of the parameters of interest are to be determined. The results are visualised in the METRON platform, with comprehensive modules and user-friendly dashboards that allow dynamic comparisons with monitored data and KPIs for renovation scenarios.

Keywords:

Building Energy Model; Optimisation; Renovation scenarios, Energy monitoring platform.

1. Introduction

The importance of the building stock in the global energy consumption is well-known internationally and the urge to reduce the energy consumption of buildings is commonly shared. To do so, several ways are available: build energy performant buildings, ensure an appropriate maintenance of buildings energy production and distribution systems and renovate existing buildings [1]. On the one hand considering that most of the buildings that will be in use by 2050 are already built and on the other hand considering that in old European cities in average 70% of the buildings were built before 1981 [2], the renovation of existing non-performant building is capital to reach the objectives of energy consumption reduction and CO2 emissions reductions in the building sector [3-5]. The Charl-e-district project consists in evaluating various renovation strategies of public buildings of the city of Charleroi, Belgium, to raise awareness of public authorities regarding their building assets and help in the decision-making process by providing insights regarding the potential and the impact of renovation measures (to improve their energy performance and indoor comfort, to reduce their carbon footprint and operation costs). This paper presents the work carried out within the framework of the Charl-e-district project for the evaluation of renovation scenarios of one public building.

As thermal renovation of buildings is not a new area of research, several methodologies and tools are available to evaluate the renovation potential of buildings. These tools are usually made for a quick estimation of renovation possibilities based on a few characteristics of the energy demand [6-8]. In such tools, the lack of details in the demand evaluation and building thermal characteristics lead to generic solutions. In [9] the authors developed a methodology based on Life Cycle Analysis to find optimal retrofitting solutions to introduce sustainability criteria in the evaluation and provide more insights. Several literature reviews on methodologies for building refurbishment have been carried out, considering different approaches

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of classification. Today the common statement highlighted in all the literature reviews is the lack of a common evaluation framework, leading to the assessment of common renovation packages, but various results, interpretation, and considerations. In [10] the authors present a literature review of methodologies to evaluate renovation measures, categorized by building type and renovation packages, showing the difficulties in the decision-making process to pick the appropriate tool or evaluation method. In [11] the authors make a scientific and ‘grey’ literature review of challenges of the built environment and building renovations and conclude on the wide variety of tools, approaches and methodologies, but underline that there is no holistic or systematic approach to evaluate renovation potentials. Additionally, methodologies for assessment of building renovation measures are usually applied to residential buildings, and by consequence are not directly transferable to tertiary public buildings, because of their different energy behaviours (in terms of energy demand, building usage and potential for energy production). Based on these considerations, a new methodology using a detailed building numerical model and advanced optimisation methods, is developed for public buildings, providing very specific results to help the public authorities in developing their renovation plan at building scale. This methodology using a top-down approach, is developed and applied to a detailed multi-zone numerical building model after it is calibrated with real measured data. Packages of renovation measures are defined in 3 scenarios and the building model parameters related to the renovation measures are optimised with the objective to minimize the gas consumption. The results of the optimisations give the values of parameters of interest that will allow to reach the lowest gas consumption taking into account electricity consumption and thermal comfort constraints, to ensure the satisfaction of occupants needs. Through this top-down methodology, the renovation measures are sized to the studied building in terms of type and intensity of renovation.

2. Building case description

The building studied in this paper is a public school located in Charleroi, Belgium which host 1200 students. This building of 3 130m2 has 3 floors above ground and 2 underground floors. A gas boiler of 240kW supplies heat to the building, which has an annual consumption of approximately 560 633.76kWh of gas and 41 414.99kWh of electricity. As it is a public school and no domestic hot water (DHW) measured data are available, the DHW is not included in the study. The building was built in 1963 and no data were available regarding possible renovations.

3. Methodology for development and calibration of building model

The building iss modelled in two steps, first the 3D geometry along with the neighbouring shading surfaces are created from scratch in SketchUp, as illustrated in Figure 1, based on 2D architect plans and visual checks on the building. Then the building energy model is developed with 31 thermal zones, using the OpenStudio software, and thermal characteristics are added based on technical data, typical values, etc. The EnergyPlus calculation engine is used through the OpenStudio interface to simulate the energy behaviour of the building.

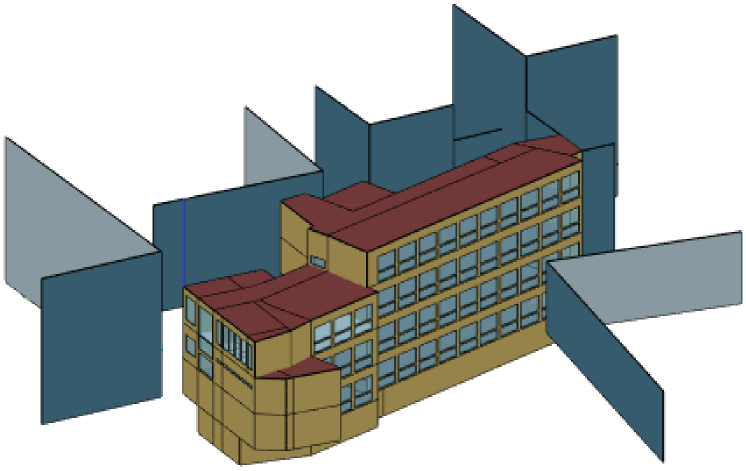

Figure. 1. 3D sketch of the studied building.

In this paper the objective of the study at building scale is to evaluate different renovation scenarios using dynamic Building Energy Simulation (BES). Therefore, the building model must be calibrated to provide relevant results. The building model is manually calibrated based on monitoring data, typically the gas

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consumption measured by the gas meter and available through the METRON energy monitoring platform used by the city of Charleroi [12]. Based on previous experience [13] and literature review [14-16], key parameters are chosen, see Table 1, to be adjusted until the model is able to reproduce well enough the energy behaviour of the real building.

Table 1. Building's parameters to be adjusted to calibrate the model.

Type of parameter	Parameters
Building use	Building equipment schedule Building occupancy schedule Electrical loads
Heat production/distribution	Boiler capacity Boiler efficiency Heating setpoint temperature Pump motor efficiency Rated pump head Operating temperatures

The quality of the calibrated model is then evaluated by two statistical indices, often used as a pair to analyse the goodness-to-fit of Building Energy Model (BEM) i.e., NMBE (Normalized Mean Bias Error) and Cv(RMSE) (Coefficient of variation of the Root Mean Square Error). The definition of these statistical indices is given by the equations Eq. (1), Eq. (2) and Eq. (3). The NMBE measures the distance between simulated and monitored data, the closer it is to zero, the better the model represents the behaviour of the real building. For a monthly calibration of BEMs, the ASHRAE Guidelines 14-2002 [17] recommend: NMBE < 5% and Cv(RMSE) < 15%.

$$\mathrm{NMBE} = \frac{\frac{1}{N}\sum_{i}^{N}(S_i - M_i)}{\bar{M}} \tag{1}$$

$$\bar{M} = \frac{\sum_{i=1}^{N} M_i}{N} \tag{2}$$

Where:

- M_i is the measured value of i^{th} point
- S_i is simulated value corresponding to the ith point.
- N is the number of measured points

$$\mathrm{Cv}(RMSE) = \frac{1}{\bar{M}}\sqrt{\frac{\sum_{i}^{N}(S_i - M_i)^2}{\mathrm{N}}} \tag{3}$$

The results of the calibration evaluations are shown in Table 2, and the model results are illustrated in Figure 2 for the gas consumption and Figure 3 for the electricity consumption. Considering that the energy consumption presents both missing data and important variations from one year to the next one, especially during the covid years, several years of monthly gas and electricity consumption data are used to adjust the model parameters values and evaluate the precision of the model's responses (gas and electricity consumption). The so-called Reference year ("Ref" in this paper) is a virtual monthly profile generated based on the average monthly data available. Both indicators are calculated for 3 years and a reference year. Considering the values of NMBE and Cv(RMSE) correspond to the Guidelines criteria, (values highlighted in Table 2), the model is considered as calibrated.

Table 2. Values of NMBE et Cv(RMSE) indices after calibration using several years of monthly gas and electricity consumption data.

		2019	2020	2021	Ref
Elec	NMBE (%)	**6.77**	23.35	**-16.49**	**-2.41**
	RMSE	569.78	1062.40	810.32	334.40
	CV(RMSE)	16.51	30.78	23.48	**9.69**
Gas	NMBE (%)	**-0.56**	**11.10**	**-10.83**	**-3.71**
	RMSE	5822.09	12056.96	8164.90	3587.85
	CV(RMSE)	**12.46**	25.81	17.48	**7.68**

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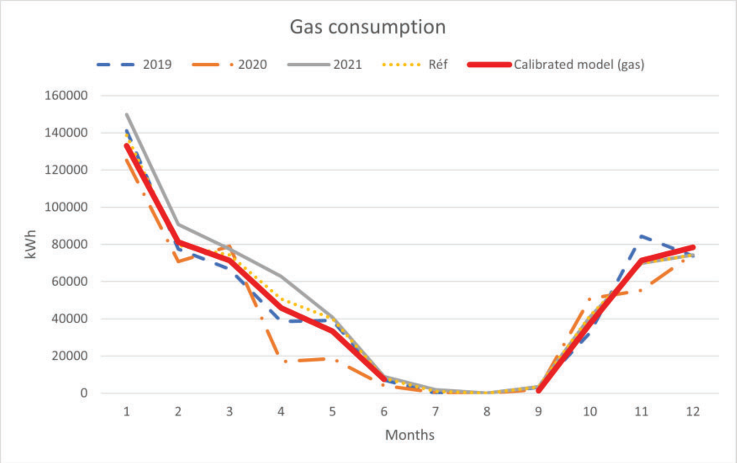

Figure. 2. Comparison between measured data and model results for gas consumption after calibration.

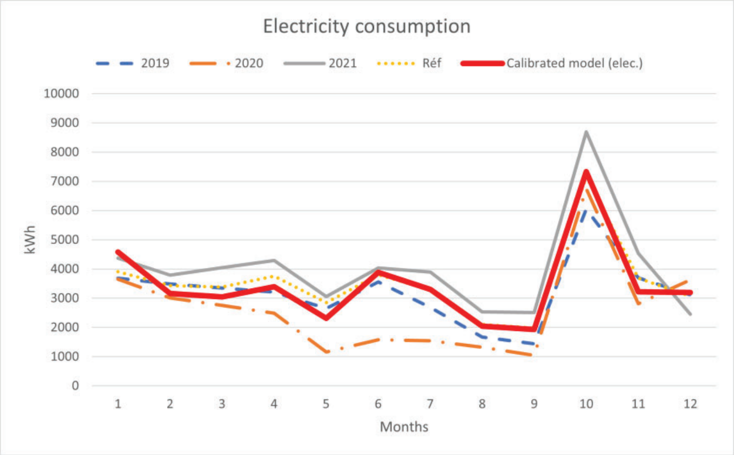

Figure. 3. Comparison between measured data and model results for electricity consumption after calibration.

3. Methodology for renovation scenarios study

The objective of the model calibration is to have a model detailed and reliable to perform renovation scenarios and evaluate the impact of the proposed renovation measures on the model responses (gas and electricity consumption). Different renovation measures are proposed within 3 scenarios, as presented in Table 3, depending on the complexity and costs of implementation. Indeed Scenario 1 (SC1) does not require any renovation works, only an improvement in the regulation of systems, while Scenario 2 (SC2) implies an adjustment of the regulation and deep renovation works, such as adding new material as insulation into walls, roofs and floors of the building. Scenario 3 (SC3) proposes to add the replacement of the gas boiler and pumps to all the previous measures. The model parameters corresponding to the renovation measures are identified with their variation ranges and a set of optimizations is run to optimise the values of these parameters and by doing so, allow the maximum reduction in energy consumption. In SC3, the measures of SC1 are applied except the "Improved boiler regulation measures", because these regulations are linearly linked to the "Replacement of boiler" measures. To avoid losing in thermal comfort, the ranges of variation of the relative humidity and the temperature in the constraints used in the optimizations are the same as the initial ranges calculated as simulation results in the Base Scenario (Base SC).

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Table 3. Description of renovations scenarios.

	Measures	Building parameters in EnergyPlus	Min value	Max value	ref value (Base SC)	Unit
SC1	Setpoint temperatures reduction	Setpoint temperatures	20	24	24	°C
	Improved boiler regulation	Boiler operating temperatures	85	120	110	°C
		Distribution system temperatures (at heat exchangers and radiants)	85	115	110	°C
SC2	SC1 Measures					
	Renovation of insulation	Wall Insulation : Thickness	0.0566	0.25	0.0566	m
		Wall Insulation : Conductivity	0.035	0.05	0.0432	W/(m.K)
		Roof Insulation : Thickness	0.05	0.3	0.05	m
		Roof Insulation : Conductivity	0.035	0.05	0.049	W/(m.K)
		Floor Insulation : Thickness	0.00001	0.3	0.00001	m
		Floor Insulation : Conductivity	0.022	0.04	0.035	W/(m.K)
	Replacement of windows	Thickness	0.003	0.24	0.003	m
		Conductivity	0.0195	0.672	0.0195	W/(m.K)
SC3	SC1 Measures SC2 Measures					
	Replacement of boiler	Nominal Thermal Efficiency	0.55	1	0.55	-
		Water Outlet Upper Temperature Limit	55	120	120	°C
	Replacement of pumps	Rated pump head	7000	17000	7000	Pa

The objective function for all the sets of optimisations is as in Eq. (4)

$$f = \sum_{i=1}^{N} C_i^{gas} \tag{4}$$

Where C_i^{gas} is the gas consumption of ith day over a total number of N days. The constraints considered in all Scenarios are described in equations Eq. (5), Eq. (6) and Eq. (7). These constraints are related to electricity consumption (to avoid that the model compensates the reduction of heat gains by extra electricity consumption of appliances) and to thermal comfort of occupants (in terms of humidity and temperature).

$$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times a \tag{5}$$

$$15\% < RH < 85\% \tag{6}$$

$$24 < T < 31 \tag{7}$$

Where $C_{Base\ SC}^{Elec}$ and C_{SC}^{Elec} are respectively the annual electricity consumption of the Base Scenario and the current Scenario, a is a coefficient equal to 1.015 (to simulate a slight increase of 1.5%) for Opti and 0.845 for Opti_2 et Opti_3 (to simulate a decrease of 15.5%). RH and T are the relative humidity and the temperature in each thermal zone at each time step. The different sets of optimisations and their related constraints are summarized in Table 4.

To optimise the parameters values in Scenario 3, only one set of optimisations that consider all constraints, is run. Indeed, Scenario 3 considers the same parameters as Scenario 2 plus extra parameters to be optimised. As the optimisation results of Scenario 2 show the importance of all the constraints (including the thermal comfort constraints) to optimise the parameters, it was chosen to run the optimisation for Scenario 3, using only one set of optimisations that consider all constraints.

The optimisations are performed using Cenaero's in-house multi-disciplinary optimization tool, Minamo, which uses a Surrogate Based Optimization (SBO) approach and relies on a genetic algorithm. A brief explanation is given in the following, but for further details about the Minamo tool and the use of SBO optimisation see [18]. The surrogate model used by Minamo for this study is the Tuned RBF model (Tuned Radial Basis Function), for more details about Minamo's surrogate models, see [19-20].

For each scenario, the first step while using the Minamo tool is to generate and evaluate a Design of Experiments (DoE). The DoE is a randomly generating set of points (each point (or individual) represents a set of optimization parameters or variables) sufficiently well distributed in the design space, illustrated by the blue circles on the Figure 4, Figure 5 and Figure7. Based on the evaluation of output results of the DoE, a surrogate model is built, it will allow to evaluate the objective function and constraints at low computational cost. Then the optimisations are run using the surrogate model to determine the optimum values of parameters that minimize the gas consumption (objective function).

Table 4. Constraints for the sets of optimisations of all Scenarios.

	Optimisation set 1		Optimisation set 2		Optimisation set 3	
	ID	Constraints	ID	Constraints	ID	Constraints
SC 1	Opti	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 1.015$	Opti_2	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 0.845$	Opti_cont.	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 0.845$ $15\% < RH < 85\%$ $24 < T < 31$
SC 2	Opti	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 1.015$	Opti_2	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 0.845$	Opti_3	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 0.845$ $15\% < RH < 85\%$ $24 < T < 31$
SC 3	-		-		Opti	$C_{SC}^{Elec} \leq C_{Base\ SC}^{Elec} \times 0.845$ $15\% < RH < 85\%$ $24 < T < 31$

3. Results analysis

Figure 4, Figure 5 and Figure 7 illustrate the set of values for the annual gas consumption after the DoE and different optimisations. Each dot of the graphs represents an experiment, in other words a set of parameters values from which the model responses are calculated. For each set of optimisations, various graphs are generated to interpretate the results, typically the responses and parameters vs the experiments. In the following, only the most relevant graphs are shown.

For Scenario 1, the first set of optimisations (Opti) gives better results than the later ones, in terms of annual gas consumption and at the same time these first optimisations respect the thermal comfort conditions (without imposing them as constraints). When the electricity constraint become stricter (Opti_2) and when comfort constraints are added (Opti_cont.), the gas consumption results from Opti to Opti_cont. increase of around 72% (from 325MWh to 560MWh). That is why the optimum parameters values belong to the first set of optimisations (Opti, orange dots on Figure 4). For Scenario 2, the first and second sets of optimisations give a lower gas consumption than the third set of optimisations, as illustrated by Figure 5, but for these two first sets the maximum comfort temperature constraint is not respected (between 40°C and 47°C) as illustrated by Figure 6, while for the third set of optimisations, the maximum temperature is between 30°C and 32.5°C, which is an acceptable range. For this scenario, the optimum parameters values belong to the Opti_3 set of optimisations. The DoE and optimisation results of Scenario 3 are illustrated by Figure 7. For this scenario, the results from the different runs of experiments converge rapidly to the optimum parameters values (the orange dots reach a value close to 100 000kWh from the 5th experiment).

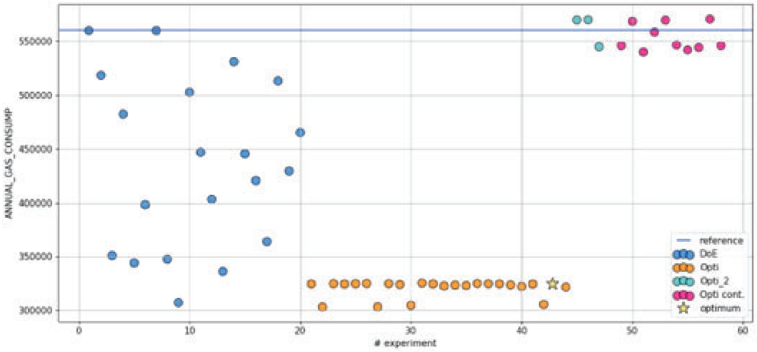

Figure. 4. DoE and optimisations results for Scenario 1.

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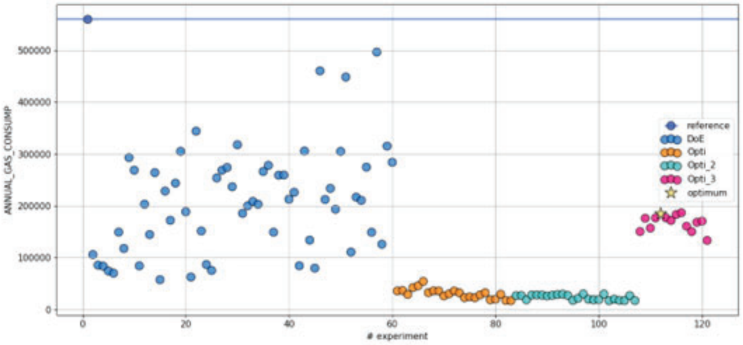

Figure. 5. DoE and optimisations results for Scenario 2.

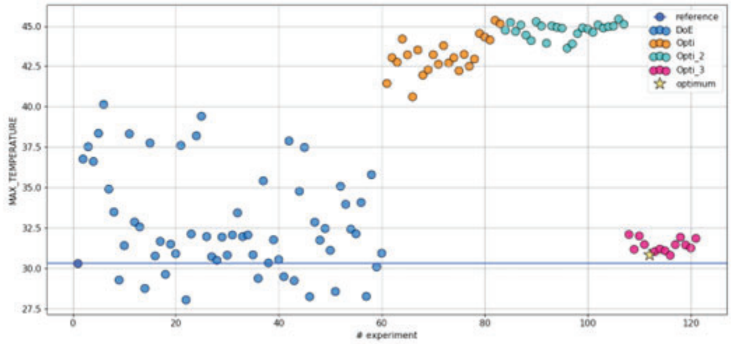

Figure. 6. Evolution of maximum temperature in the building for the DoE and different sets of optimisations for Scenario 2.

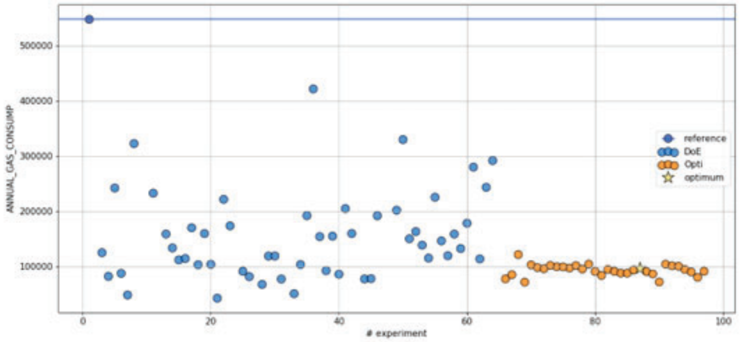

Figure. 7. DoE and optimisations results for Scenario 3.

The optimum values of the evaluated building parameters and the model responses are presented in Table 5 and illustrated by Figure 8. The optimum parameters values for SC1 indicate a reduction of all temperatures except the radiant temperature, while in the other scenarios all temperatures are reduced. For all scenarios, the optimum value of heating setpoint temperature is (or is close to) the lower boundary of the variation range of that parameter (20°C). A variance analysis (ANOVA), based on the decomposition of the variance of a function, [21-22], is carried out after the optimisations and shows that the setpoint temperature is by far (more than 50%) the most influencing parameter for the gas consumption. The results of this ANOVA are not shown in this paper because of the limited number of pages. The optimum values of thickness parameters for SC2 and SC3 are close to the upper boundaries of the variation ranges while the conductivity parameters are chosen by the optimizer around the mid-value of their variation ranges.

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Table 5. Optimum values of parameters and model responses for all scenarios.

Parameters	Base SC	SC1	SC2	SC3
SETPOINT_REDUCTION	24	20	20.3	20
SETPOINT_SUPPLY_BOILER	110	104.2	102.7	-
SETPOINT_HX_RADIANTS	110	98.7	107.5	-
RADIANT_TEMPERATURE	110	115	107.5	-
WALL_INSULATION_THICKNESS (m)	0.0566	-	0.24	0.242
WALL_INSULATION_CONDUCTIVITY (W/mK)	0.0432	-	0.04	0.036
FLOOR_INSULATION_THICKNESS (m)	0.00001	-	0.217	0.3
FLOOR_INSULATION_CONDUCTIVITY (W/mK)	0.035	-	0.03	0.037
ROOF_INSULATION_THICKNESS (m)	0.05	-	0.216	0.197
ROOF_INSULATION_CONDUCTIVITY (W/mK)	0.049	-	0.043	0.037
DVITRAGE_INSULATION_THICKNESS (m)	0.003	-	0.1	0.089
DVITRAGE_INSULATION_CONDUCTIVITY (W/mK)	0.0195	-	0.497	0.437
BOILER_ETA	0.55	-		1
OUTLET_TEMP_LIMIT (°C)	120	-		90.7
SERVICE_PUMP_HEAD (Pa)	7000	-		7842.9
PLANT_PUMP_HEAD (Pa)	7000	-		7000
Responses				
ANNUAL_GAS_CONSUMP (kWh)	560.633	324.727	185.532	96.503
ANNUAL_ELEC_CONSUMP (kWh)	41.415	33.972	33.511	34.346
MINIMUM_HUMIDITY (%)	15.00	19.31	19.19	19.33
MAXIMUM_HUMIDITY (%)	85.00	84.40	79.62	79.62
MINIMUM_TEMPERATURE (°C)	24.00	20.00	20.26	20.00
MAXIMUM_TEMPERATURE (°C)	31.00	29.65	30.87	30.91

SC3 which proposes a replacement of the boiler, gives an optimum efficiency value of 1, which is relevant for the installation of a condensing boiler (this type of boilers generally presents efficiencies around 110%). The optimum values for rated pumps heads are surprisingly low considering the initial variation range, which would basically mean that there is no need to replace the pumps because the other measures are sufficient to decrease the total heat demand and the operating boiler temperatures, and consequently the gas consumption (objective function).

When analysing the simulation results for the optimum parameter values, one can clearly notice the decrease in gas consumption from one scenario to another. Indeed, in SC1 the annual gas consumption decreases of 42% compared to the Base SC, while this decrease is steeper in SC2 (-67%) and SC3 (-83%). As the electricity consumption is not part of the objective function for the optimisation, but part of a constraint, the reduction of electricity consumption is noticeable but not very different between the scenarios, it ranges between -17% for SC3 to -19% for SC2 compared to the Base SC. From SC1 to SC3, the maximum and minimum relative humidities are closer to the constraints limits, but tend to get respectively lower and higher than their maximum and minimum limits. The maximum and minimum temperatures are respectively around 4°C lower and 0.5°C lower than Base SC. The results from the simulations of the building model with the optimum values give maximum and minimum temperatures very close between all the scenarios (around 30°C and 20°C).

The results from the simulation runs with the optimum parameters values are pushed into the METRON energy platform database and visible through various comprehensive modules, named widgets, and user-friendly dashboards developed in the platform itself. The objective is to allow users, here public authorities, to visualize quickly the indicators calculated for each scenario and compare the KPIs of the different scenarios with monitored data, in order to understand better the current situation and the renovation potential and possibilities. The simplicity of the visualisation that allows dynamic comparisons together with the corresponding database if further analyses are required, give to this approach a powerful weight in decision-making processes. Examples of widgets are given by Figure 9 and Figure 10 to compare the scenarios in terms of monthly gas consumption, CO2 emission reductions and evolution of temperature throughout the year in one typical thermal zone (classroom) of the building. Other widgets are available on the platform, to visualise KPIs such as savings in gas consumption (economic indicator) or humidity heatmaps (thermal comfort indicator).

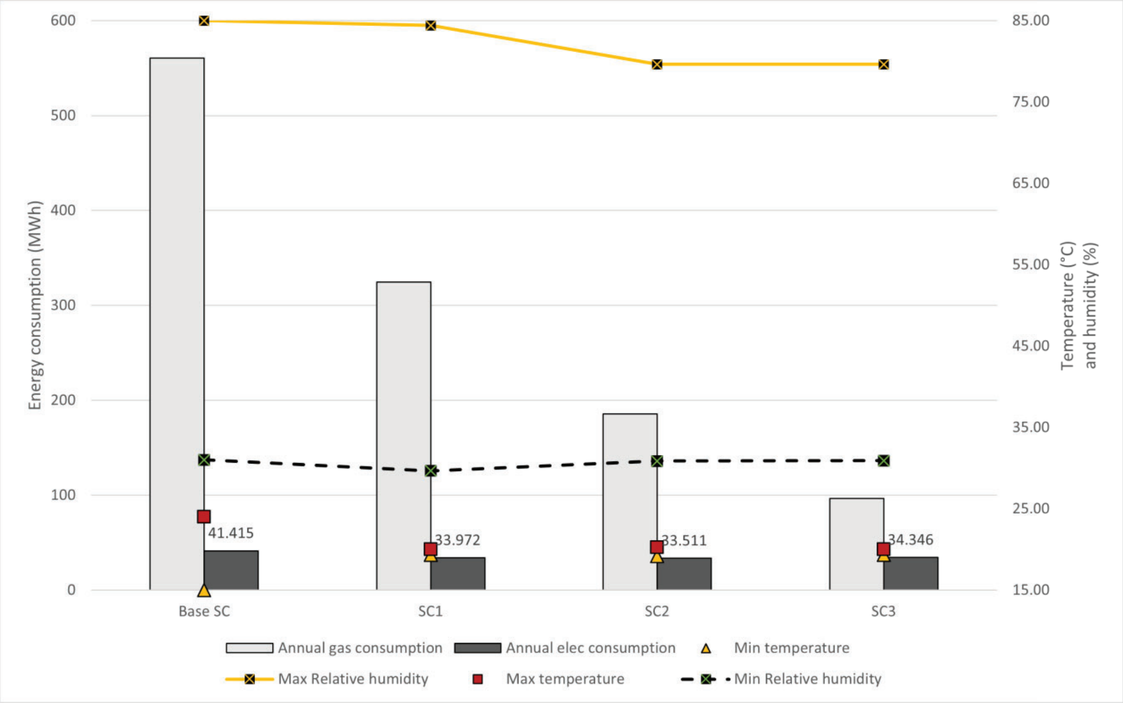
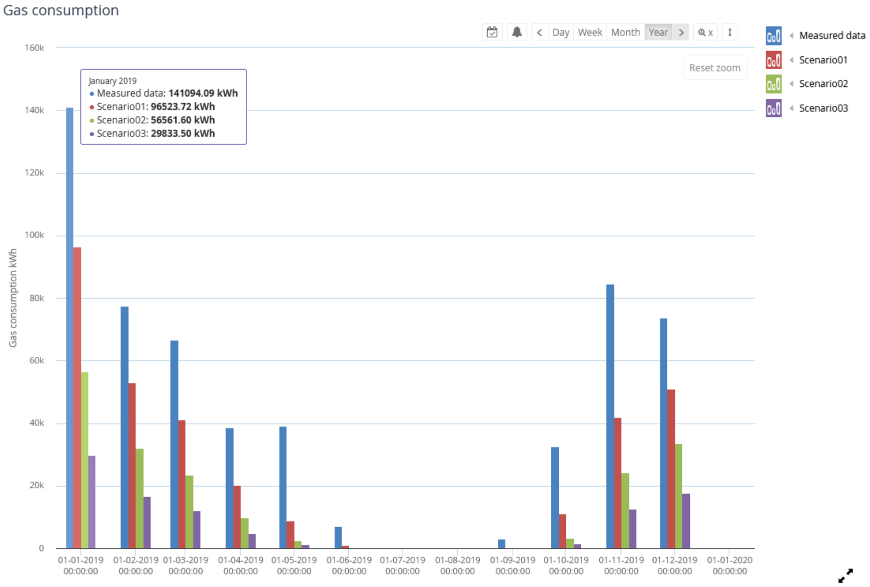


Figure. 8. Simulation results from optimum values of parameters for all Scenarios.



January 2019
- Measured data: **141094.09 kWh**
- Scenario01: **96523.72 kWh**
- Scenario02: **56561.60 kWh**
- Scenario03: **29833.50 kWh**

Figure. 9. Histogram widget in the METRON energy platform. Comparison of gas consumption between the measured data and the different results from optimum scenarios.

Figure. 10. Gauges widgets in the METRON energy platform. Comparison of CO2 emission reductions and temperature heatmaps in one typical thermal zone (classroom) between the different results from optimum scenarios.

3. Discussions and perspectives

To be useful and relevant, the results of the optimisations must be taken with hindsight. The optimum parameters are identified through advanced calculations and correspond to perfectly optimised systems. SC1 proposes the easiest measures to implement, because they do not require any work, only a new setup of the building setpoint temperature and a new setup of the regulation. Considering the uncertainties due to the assumptions made in the modelling (geometrical and technical assumptions) and the calibration steps (interpolation of measurements), one should expect some differences between the model results and the real gas consumption if the new setups are tested, however this scenario is in any case recommended for implementation insofar as it results in more than one third of gas consumption reduction compared to the Base SC. It is important to note that the renovation measures resulting from SC2 and SC3, correspond to deep renovation in real-life implementation (improvement of insulation, replacement of windows, boiler and pumps, etc.) and are implemented at building scale (all the walls are renovated, all the windows are replaced, etc.), which explains why the reduction of gas consumption decreases drastically for each scenario, to reach -83% with SC3 compared to the Base SC. In real-life implementation, such deep renovation is extremely costly and it is most probable that the renovation measures regarding the improvement of insulation would not be made for all building's walls, but only on the less exposed façades and the walls that present the most heat losses. For a more complete renovation study, it would be interesting to precise the renovation scenarios with measures that would consider partial building envelop renovation and evaluate the potential and interest of implementation of greener solutions, such as air-sourced heat pumps or the connection to the local district heating network. Further exploitation of results through economic analyses would also be an added value to help public authorities in the decision-making process.

4. Conclusions

This paper presents a new top-down approach to evaluate various renovation strategy, in terms of type and intensity of renovation measures, for a public building of the city of Charleroi, Belgium. In a first step, a numerical building model is developed and calibrated based on real gas consumption measurements, before being studied through 3 renovation scenarios for which the main parameters related to the renovation measures are optimised using a Surrogate Based Optimisation approach. The optimisations are carried out using Minamo, the Cenaero's in-house multi-disciplinary optimisation tool. The results of different optimisations of the parameters within the studied scenarios give combinations of values that ensure in general the same quality of thermal comfort (indoor temperature and humidity) and lead to similar results in terms of electricity consumption. The main difference in the scenarios results lies in the gas consumption reduction, which varies greatly from one scenario to another. Considering the investment costs and the complexity of implementation of the measures proposed in the scenarios (increasing from SC1 to SC3), the public authorities would have to consider other indicators such as investment costs, payback time, energy savings over time, urgency to reach objectives of CO2 emission reductions, etc. to choose a renovation strategy and how deep they want to implement the different measures.

A follow-up study is being carried out at district level, to evaluate the benefits of the connection of public buildings to the district heating network, with scenarios varying in terms of buildings number and renovation levels of connected buildings. The work detailed in this paper will serve as input to the district approach to facilitate the definition of building typologies and calibrate a district model using an Urban Building Energy Modelling (UBEM) tool. The objective is again to help the public authorities in decision-making regarding the

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interests of renovation of public buildings together with / or the extension of the existing district heating network.

4. Acknowledgement

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