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The Brescia Smart Campus demonstrator. Renovation toward a zero energy classroom building

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Abstract

The project is framed into the activities addressing the Smart Campus at University of Brescia. The classroom building is used as demonstrator of the energy strategies to improve the performance of existing buildings toward zero energy goals. Innovative systems to reduce energy consumption (i.e. heating, cooling and ventilation, lighting and electric equipment) and Smart Automation are crucial in the Smart Campus School Project of which this research is a preliminary step of development. The project is based on three main pillars: envelope refurbishment, improvement of building services efficiency, smart control of energy picking and placing peaks on the electrical net, also using energy uses other than building services (e.g. electrical vehicle charging station). The activities have been organized in phases, starting from the analysis of the possible interventions to improve the energy quality of the building and evaluating the efficiency of different measures. At the same time a plan for a preliminary operational conditions monitoring have been developed to increase the confidence and awareness on energy consumptions. The second phase is focused on consumption smart monitoring, users' behavior control and validation on technical and economic criteria. Moreover the demonstrator aims to define an interoperability practice, in order to enhance BIM to BEM procedures. In the paper, the preliminary phase of the research based the first pillar is described evaluating the energy reduction through envelope renovation and renewable energy production to pursue an energy balance between generation and consumption.
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Keywords: energy renovation, smart campus, zero energy building, BIM to BEM, laser scanner, solar systems

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1. Introduction

The Brescia Smart Campus project aims to demonstrate the feasibility of the improvement of energy efficiency (thermal and electric) of an education building through smart grid management, control systems and automation, user's consciousness, data collection and a continuous commissioning. The interest of the project is mainly related to the methodology adopted and the validation of the strategies based on the data analyses (i.e. BI business intelligence, Big Data Analysis) [1,2] that will be implemented in the following phases of the research. The paper deals with the first step of the analysis related to the energy retrofit of the envelope of a classroom building demonstrator. The second step of the research, in progress, is focused on the automation and control of the heating and cooling system and the generation of renewable energy through solar systems. In the present study, solar system size and production are estimated, however future detailed monitoring campaign data should be available. The third phase of the project will be the collection of data about energy consumption, also through the smart participation of the users [3]. Data will be analyzed by an observatory with the aim to use information to improve energy efficiency during the lifespan of the building by evolving strategies based on [4] (i.e. kaizen concept) [5]. Moreover, interaction with users and dissemination through the observatory is a key issue to promote energy consciousness in the stakeholder involved in the process of construction and operating of the built environment [6]. The methodology develops the three phases as three main pillars to implement an energy efficiency improvement, namely envelope refurbishment, improvement of heating and cooling services efficiency, smart monitoring and control of energy and users' behavior. The activities go in deep on the topics listed below:

- Energy retrofitting strategies;
- Energy consumption assessment;
- Preliminary operational monitoring;
- Innovative RES system installation (i.e. PV modules with super-capacitors, PVT system);
- Installation of an electrical vehicle charging station (i.e. EV);
- Smart control of energy picking and placing peaks on the electrical net;
- Strategies validation on technical and economic criteria.

The project is a collaboration between different partners i.e. construction, mechanical, electrical and IT experts. All the partners are working in team to develop the analyses needed in the Smart Campus demonstrator i.e. building information modeling, thermal analysis, electrical compatibility of the new systems and devices, monitoring of the users and indoor conditions, automation control to optimize the technical system, development of IT tools for data collection and users' interaction, security of information. The energy for the classroom building used as demonstrator of efficient measures and advanced technologies, e.g. system automation [7], lighting control [8], PV with supercapacitor and PVT, is provided by the local district heating system and the cooling is provided by an heat pump. A monitoring and control system [9,10], based on predictive models [11,12,13] has been designed and it is under verification with industrial partners; moreover, the monitoring system is suitable to improve the calibration of simulation model [14,15]. The goal is to modulate the setting of mechanical and electrical technical systems and concerns related to users' behavior. Furthermore, the project of the demonstrator has the target to state procedures to promote interoperability [16,17] working from advanced survey technology as 3D laser scanner to reproduce existing building into BIM and then to BEM [18,19] models used in a multi-criteria framework [20,21].

Nomenclature

BIM	Building Information Model
BEM	Building Energy Model
PV	Photovoltaic system
PVT	Photovoltaic thermal system
EV	Electrical vehicle

2. The Brescia Smart Campus demonstrator

The building used as demonstrator in the Brescia Smart Campus is a classroom building, located in the main campus of the University of Brescia, realized in the ‘90s and to which is attributed a specific architectural value. Thus, the possible interventions to enhance the energy quality of the building have been evaluated considering the national laws about energy saving [22] and build environment preservation [23].

The building is oriented at 18° to the west with the major axis going from southeast to northwest. In figure 1a a view of the rooftop where the renewable energy systems will be located is shown and the south-west and south-east façades denote the different relation with the environment of the functional parts of the building. The other buildings located in the campus do not constitute obstruction of solar radiation for the demonstrator building realized near the parking of the university. The experimental systems planned for the demonstrator are listed below:

- Installation on the rooftop of a photovoltaic system (PV) of 10-15 kW > 200 m^2;
- Installation on the rooftop of a photovoltaic thermal system (PVT) of 1-3 kW > 30 m^2;
- Installation on the north-east side, toward the parking lot, of a charging station for electric vehicles (EV).

The solar systems are innovative plants: the PV system will be realized with photovoltaic concentrator modules designed specifically for this project by the Dept. of Industrial Engineer of the University of Brescia and will be equipped with storage devices and control systems to interact with the electrical loads of the building. The electrical vehicle will be used inside the Smart campus and it is a further storage system for the electricity produced by the photovoltaic systems. The electricity that can be produced by the solar systems related to the energy consumption of the building has been estimated in this preliminary phase of development of the project, as described in section 5 toward a zero energy classroom building [24,25].

In any case, the core goal of the demonstrator is to enhance the synergy and thus the performance of the building through the application and the implementation of efficiency measures by different systems working in a network. The building is symmetrical and the north-east façade is equivalent to the south-west façade (figure 1b) while the north-west façade is equipped with glazed doors and a wide window at the first floor as described in the following. Actually, the building has mainly two different parts: the atrium and the classrooms.

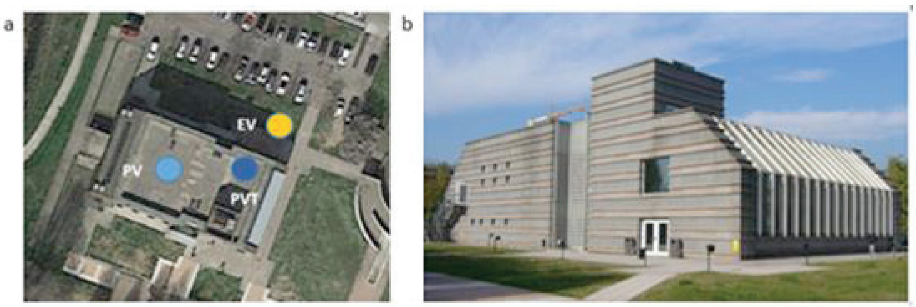

Fig. 1. (a) View of the demonstrator in the Smart Campus of the University of Brescia, Italy; (b) Facades of the demonstrator: south-east glazed façade and south-west façade.

The quite totally glazed south-east façade closes the atrium used to distribute the classrooms located in the two aboveground floors: the classrooms located at the ground floor and first floor are equipped with small windows (i.e. four windows at the ground floor and six windows at the first floor for each façade) in the south-west and north-east façades. A further floor with classrooms and technical rooms is located underground and equipped with four windows on the two major sides (i.e. south-west and north-east). The major quantity of daylight introduced into the classrooms aboveground is due to the glass bricks constituting the visual vertical subdivision between the atrium and the classrooms (figure 1b). A wide window is located in the sloped north-west façade and lights up a space used as thesis archive however in this moment is highly degraded and suffering of performance decay due to mold and rainfall infiltration (figure 2a). The atrium of the building is widely daylighted; the two floors are used by the students of the University of Brescia Campus as a free multifunctional space (figure 2b) between and during the lectures.

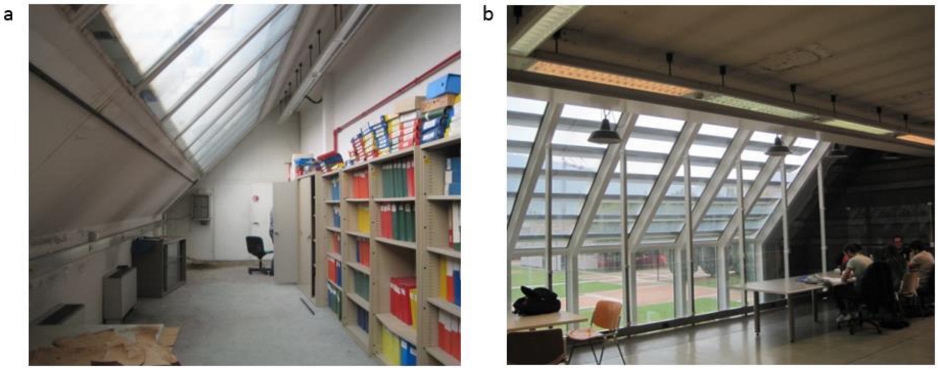

Fig. 2. (a) View of the north-west archive room with the wide window and (b) inside view of the atrium's glazed façade with a vertical portion and a sloped portion.

3. Issues and renovation strategies

The Smart Campus project aims to develop a pilot system in which to demonstrate the suitability and effectiveness of advanced technologies and improving strategies. In this moment, the classroom building used as demonstrator for the Brescia Smart Campus is not characterized by a high-energy efficiency due to the listed issues:

- The thermal properties of the envelope, realized before the national energy laws, are lower than the minimum required and unable in allowing energy saving reducing the energy needs;
- The openings of the classroom are not operable and it is not possible to properly ventilate the space (i.e. thermal conditions and indoor air quality are not complying the standard requirements to guarantee a convenient comfort level); in summer period, the users' open doors and windows (i.e. in the south-west and north-east façades) to promote a cross ventilation in the atrium;
- The shading systems (i.e. blades and coated glass to reduce solar gain) added as improvement to decrease the amount of solar radiation striking the glazed south-east façade are not so efficient in reducing the cooling loads during the summer period;
- The building is used for educational activities in the time schedule of the University of Brescia, moreover it is used by students for autonomous studying activities in the atrium which is not designed actually for this purpose; therefore the estimated internal gains are lower than in the real use of the building, the same occurs for electrical consumption (e.g. laptop, phone, tablet, electrical devices);
- The connection of the building to a local district heating is then combined at the different floors to outdated technical systems that do not allow modulating the operation referred to the real use and occupancy of the building.

The issues refer to transmission losses, ventilation, solar gains, internal loads (i.e. the whole framework of the energy balance calculation of the building) and mechanical systems. The technical systems used in the building are not updated and it is impossible to modulate and control the operation; furthermore, the efficiency of the energy production is not univocally defined, thus, this first step of analysis reported is focused on energy need due to the thermal quality of the envelope. The analysis of the classroom building has been realized considering some renovation strategies to evaluate the weight of these solutions on the annual energy need. The proposed strategies in the

Smart Campus Project, evaluated as reduction in energy need, are listed below and synthetically described in figure 3:

- addition of shading blades to the sloped portion of the glazed south-east façade (1)
- reduction of solar heat gain factor (i.e. SHGF from 0.75 to 0.5) in the vertical glazed façade (2)
- addition of internal insulation layers to the walls (i.e. polyurethane 3 cm) (3)
- addition of an external layer of insulation for the rooftop (i.e. polyurethane 7.5 cm) (4)
- windows change to enhance thermal transmittance (i.e. U value from 3.8 to 2.2 W/m^2K) and SHGF (5)
- north-east window change (i.e. U value from 3.8 to 2.2 W/m^2K) and resizing (i.e. reduction 57%) (6)
- installation of shading devices in summer to the glass bricks portions (i.e. shading 50%) (7)
- addition of shading blades for the vertical portion of the glazed façade (i.e. n.5 fixed blades) (8)
- installation of solar PV systems on the rooftop to produce energy and shade the flat roof (i.e. 18 kW) (9)
- realization of openings at the bottom and top of the atrium glazed façade (i.e. open 7 am/7 pm) (10)
- realization of openings at the bottom and top of the atrium glazed façade (i.e. always open) (11)
- ventilation of the atrium and classroom during all the day in summer period through operable windows (12)

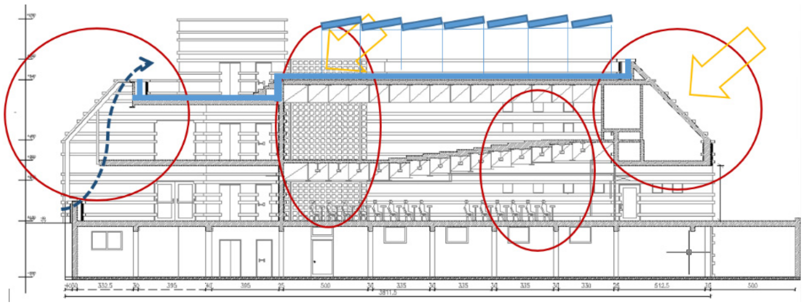

Fig. 3. Envelope renovation strategies proposed and analyzed to improve the energy performance of the classroom building.

The effects on energy need reduction with the above strategies are reported in table 1, section 5.

4. BIM to BEM

The analysis of the classroom building in the Brescia Smart Campus School Project has the additional value to introduce and test procedures to improve the interoperability of modeling processes, promoting a higher reliability of results and compatibility between skills, using advanced technologies. The project involves experts of different field of knowledge and the exchange of information is crucial for the success of such a project. The lack of information about the existing building is the first drug to promote energy efficiency. The existing building stock is often affected by an extended inaccuracy about information on as-built conditions and estimations and incongruences are commonplace. Thus, a first step has been the survey of the existing morphology of the building through the laser scanner technique and the transposition of the point cloud into an accurate parametric BIM model i.e. Autodesk Revit and then the model could be translated into a Sketch-up model (figure 4a) used for BEM.

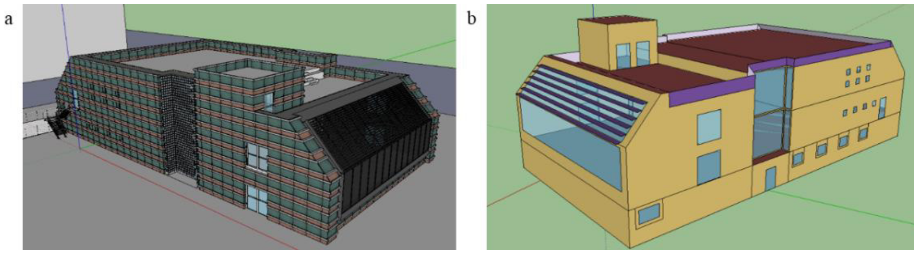

Fig. 4. (a) Exportation to Sketch-up of the Autodesk Revit BIM model and (b) simplified BEM model of the classroom building.

However, the 3D graphic information about morphology is higher that the needed input to the BEM model while information to perform energy simulation could not be imported, thus, a manually improved EnergyPlus geometry model in the OpenStudio/Sketchup interface was realized and energy simulation have been performed to evaluate the proposed energy saving strategies (figure 4b). Exportation through IFC converter to IDF process has been tested to translate information about thermal characteristics of materials. Figure 5 describes process and information.

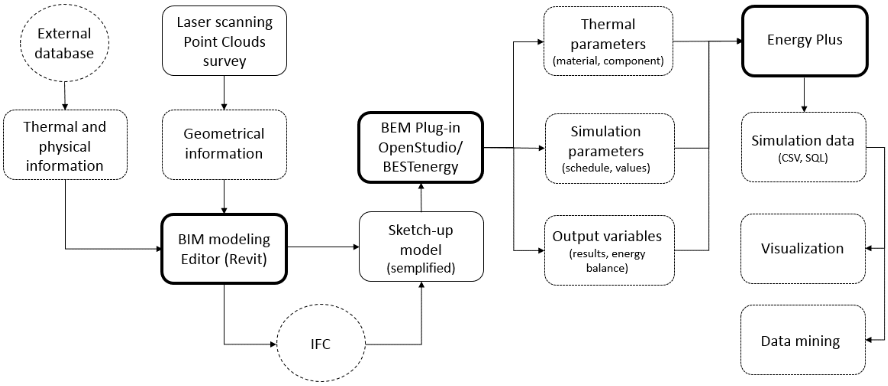

Fig. 5. Process to extract information from BIM model to create a BEM model to extract analysis data.

5. Results

The considered base case started from the original classroom building without shading devices on the glazed façade (i.e. blades and coated glass on the south-east façade). Than the strategies have been added checking the percentage of reduction in energy need. The strategies have been evaluated step-by-step to provide measurable insight on the effectiveness of each action and to give a comparable performance index for the following technical-economical analysis aiming the choice of the interventions associated to the Smart Campus School Project budget.

It has to be noted that the ventilation in the atrium is effective with the proposed openings located at different heights while the actually adopted cross ventilation (i.e. through the existing doors and windows) is not definitely capable to reduce cooling need. In table 1 the energy need and the percentage of reduction referred to the base case is reported on annual basis for each strategy.

Table 1. Annual Energy Need EN [kWh/m^2 year] and percentage of reduction PR [%] through the renovation strategies.

Strategy	Base case	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
EN [kWh/m^2 y]	104.7	97.3	96.5	94.3	93.9	92.6	93.1	90.8	86.2	85.3	86.0	83.9	65.6
PR [%]	-	6.1	7.9	9.9	10.2	11.5	11.1	13.2	14.8	18.4	17.8	19.8	37.3

As some strategies have a little influence on the performance enhancement, which can be read in table 1, a synthesis with monthly values to evaluate the variation in the different seasonal period is given. In the diagram (figure 6a) the main cases and the more effective strategies (i.e. shading and ventilation) are plotted. The contribution of the implementation progress of the whole strategies adopted can be read as a synergy in the results. The cases reported are: the base case, the existing situation (i.e. the base case with the basic shading devices actually installed), the proposed shading systems addition, the ventilation strategies for the atrium and the classrooms. The specific energy need in kWh/m^2 year is given for each floor of the classroom building for the base case and the design case (12) including all the proposed strategies (figure 6b). Considering a heat pump (coefficient of performance 5) as thermal system and the PV production on the roof (18 kW), the 75% of the energy consumption of the design case can be covered. The energy balance between consumption and production is compared to the solar fraction (figure 7a) and monthly cumulative energy values are plotted (figure 7b) to evaluate the load matching.

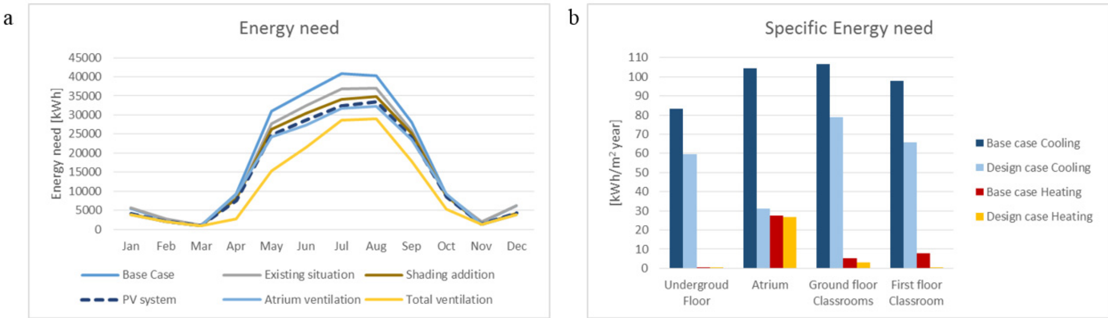

Fig. 6. (a) Energy need for the main cases (b) Specific energy need for the base case and the design case (12) for heating and for cooling.

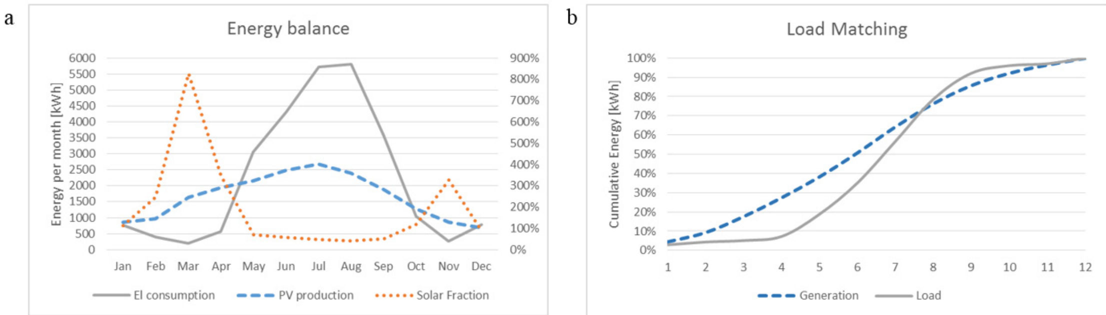

Fig. 7. (a) Energy consumption with a heat pump, PV production and solar fraction; (b) Generation and Load cumulative monthly energy values.

6. Conclusion

In the Brescia Smart Campus demonstrator the maximum energy reduction achieved is 37.3% enhancing the thermal properties of the envelope, protecting it from the solar gains (i.e. additional shading devices, reduction of solar heat gain factor of the windows) and using an effective ventilation. Indeed, the natural ventilation can be adopted during all the day including night ventilation to remove the heat stored in the thermal mass of the building. The ventilation assumed during the classroom time schedule (i.e. 7:00 a.m-7:00 p.m) is not enough effective in removing the cooling load, because during the day the inlet warm air can be a burden for the cooling system. Conversely, the night ventilation in the atrium allows a 20% of reduction in the energy need of the whole building although the continuous ventilation of all the spaces (i.e. atrium and classrooms) activates a crucial improvement (e.g.

from 20 to almost 40% of cooling reduction). The energy consumption obtained with an efficient system to provide heating and cooling can be covered for the 75% by the PV system designed, towards a zero energy goal for the existing building.

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