Informing on Best Practices Using Design Builder and RET Screen to Calculate Energetic, Financial, and Environmental Impacts of Energy Systems for Buildings

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***Abstract*— Buildings represent 32% of total final energy consumption. In terms of primary energy consumption, buildings represent around 40% in most IEA countries (International Energy Agency). For such reason, strategies that lead to energy savings and greenhouse gases reduction are needed.**

This research aims to provide a methodology able to identify the best system configuration from a technical, economic and environmental point of view by using at the same time two energy software: Design builder, which is able to calculate buildings energy needs under dynamic conditions, and RETScreen, which allows feasibility analysis of clean energy projects.

In order to assess the effectiveness of this operating procedure, a historical building has been modelled and a Combined Cooling, Heat and Power system based on an internal combustion engine has been chosen to ensure environmentally sound way.

In this study it shows the application of the procedure to a case study as an historical building located in Orte City which is near Rome in Italy; the methodology could get a real preliminary analysis for choose the best active or passive system for improve the energy efficiency and environmental sustainability of existing buildings, also allowing a cost-benefit analysis useful for the concrete realization of the interventions studied.

***Index Terms*—Model, Buildings, Energy, Efficiency, Sustainability**

I. Introduction

Buildings energy consumption covers about the 40% of the total energy amount. Consequently, it is necessary to identify operating procedures that lead to energy savings and greenhouse gases reduction. These procedures need to be addressed to the whole building stock, considering envelopes [1,2] and plants [3]. Moreover, it is well known that a building-plant coupling is based on the buildings energy performance proper evaluation. In order to calculate the real buildings energy needs, the current simplified approach is not able to take into account walls heat storage and it is necessary to employ a dynamic calculation code [4,5,6,7,8,9,10]. Nowadays dynamic software are widely used in different fields [11,12,13,14,15,16,17,18,19,20] and they can be considered very effective tools.

III. On the other hand, air conditioning systems should be able to keep comfort [21] conditions with the lowest energy use. Nevertheless, in most cases, it does not occur because plants are inefficient or advanced technological solutions are not employed. Furthermore, another aspect which have to be taken into account is the environmental impact, characterized by high levels of pollutant emissions.

IV. To achieve an optimal solution for the current energy crisis, stakeholders need to focus on renewable sources of energy or look for recycling and utilization of wasted energy. For example, an alarming amount of heat is wasted from exhaust systems of thermal engines. Trigeneration systems use wasted heat from prime movers to generate heating and cooling [22]. In the last decades, several scientific contributions have investigated the potential benefits offered by the adoption of trigeneration systems in comparison with conventional. Goyal et al. work [22] describes the performance and emission characteristics of a micro trigeneration system based on a single cylinder diesel engine. This plant achieved a reduction of CO2 emission of about 54% in combined heating and power (CHP), 57% in combined cooling, heating and power (CCHP) and 8% in combined cooling and power (CCP) mode compared to that of a single generation (power generation only). Moreover the decrease in specific fuel consumption at full load was 53%, 51% and 7% in case of CHP, CCHP and CCP mode.

Moran et al. [23] highlighted the importance of using micro-CHP for decentralization of electricity generation coupled with thermally activated components for residential and small commercial applications. The authors used a case study to demonstrate differences in the system performances of micro-CHP systems driven by a natural gas internal combustion engine and a diesel engine. Some of the results show that system total efficiencies in cooler months of up to 80% could be obtained.

Buonomano et al. [24] presented the design, simulation and optimization of a small trigeneration plant supplied by geothermal and solar energies applied for developing a suitable

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case study referred to a hotel in Ischia reaching a Simple Pay Back period ranging between 2.5 and 7 years.

Fong and Lee [25] analyzed the dynamic performances of various types of internal combustion engines primed trigeneration (ICEPT) compared with conventional systems powered by electricity for a office building in Hong Kong. It was found that the employment of the ICEPT systems reduced the total energy demand from the building by at most 11% and the maximum saving in the carbon dioxide emission is 13% for a natural-gas-fueled ICEPT system.

Salata et al. [26] taken into account the reliability parameter with the aim to make the right choice between an energy system like CCHP and a traditional solutions. This work take an economic evaluation able to give some useful information about the feasibility of the technical choices previously made. As a matter of fact, a financial analysis has an important role in the feasibility of a complex system like CCHP. For this reason, it is useful to use RETScreen tool for energetic and economic purposes. In another study Salata et al. [27] determined the best systems able to satisfy the electric and thermal energy demand for a historical buildings complex in Rome. The economic convenience was achieved through the installation of trigeneration system finding a Simple Pay Back period ranging between 3.2 and 5.9 years.

The following study concerns the analysis of a historical building in order to obtain the best building-plant coupling. The aim of this work was achieved through a specific operating procedure consisting of a dynamic energy analysis followed by an environmental and financial study. This procedure allowed to estimate preliminary energy saving and greenhouse gases reduction by means of a numerical analysis carried out with RETScreen.

II. Methodology

The proposed operating procedure is based on two phases: In the first phase it is necessary to evaluate the thermophisical properties of the building envelope and considering the climatic phenomena evolution, the first step involves the building energy demands evaluation in a dynamic regime in order to simulate the actual energy performances. A building model was created considering the actual thermal performances and geometries and it was inputted into a hourly basis energetic analysis tool: DesignBuilder [28];

The second step consists on the comparison of different plants configurations from an energetic, environmental and financial point of view. This is possible by means of the calculation code RETScreen [29], which is available for feasibility analysis of clean energy projects, including energy-efficient technologies and renewable energy systems. The users input the initial costs and annual or periodic maintenance costs for the proposed case system. This tool can exploit as input the data obtained by a thermal analysis conducted under dynamic conditions.

RET Screen carries out a comparison between a so called "base case" (typically the existing plant type) and a proposed technology. Moreover, the software allows to perform a greenhouse gases emission analysis, showing the eventual reductions as a function of the chosen technology.

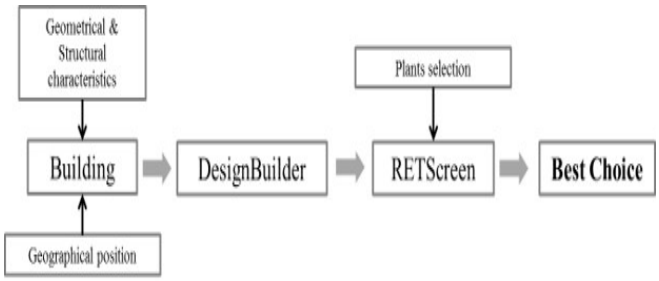


Fig. 1 Model Flowchart

III. Ease of Use

The aforementioned methodology has been applied to a historical building located in a central region of Italy. The building places over the ground and it consists of five floors. The structure is characterised by massive elements, made up of tuff blocks, plastered on both sides with thicknesses ranging from 10 to 170 cm. The building is represented in Figure 2.



Fig. 2 Building's structure



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Fig. 3 Photo of the building case studio and territorial framework

TABLE I. CLIMATIC DATA

Meteorological station elevation	51 m above sea level
Altitude zone	Internal hill
Latitude	42°27'37"08 N
Longitude	12°2'10"68 E
Degrees per day	1935
Climate zone	D
Coldest month/average monthly temperature	January/5.5 ◦C
Hottest month/average monthly temperature	August/24.4 ◦C

TABLE II. GEOMETRICAL CHARACTERISTICS OF THE BUILDING

Walkable inner surface (m^2)	1252
Gross volume (m^3)	2364
Total glazed area (m^2)	83
Surface area connected to the ground (m^2)	210

The buildings thermo-physical aspects were modelled through DesignBuilder. By means of this tool all opaque and transparent surfaces can be reproduced. Moreover, in order to simulate the building energy demands, an air conditioning system characterised by different set-point temperatures was implemented: the set-point temperature is 26 °C during summer and 20 °C during winter [21].

The heating, cooling and electrical peak loads were calculated. During winter, the required heating peak load is 92 kW. On the other hand, the cooling peak load needed during summer is approximately 30 kW. In order to evaluate the electrical power, the required lighting levels and other electrical loads have been considered. The calculated electrical peak load is up to 82 kW. The monthly average loads values for heating, cooling and electricity are shown in Figure 3.

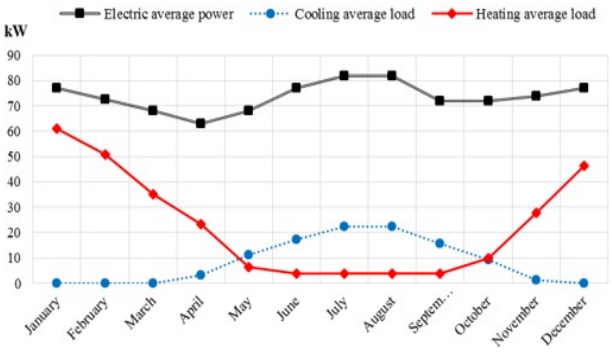


Fig. 4 Average power values for heating, cooling and electricity

The "base case" characteristics are listed in Table 3. Existing plants are different for winter and summer: during winter, the heating system is characterized by a water system with radiators. The heat generator is fueled by natural gas and the cooling system is characterized by split systems.

TABLE III. BASE CASE FOR HEATING AND COOLING SYSTEM

Base case characteristics	Value	Unit
Heated and cooled walkable area	1252	m^2
Fuel type for heating	Natural gas	/
Fuel type for cooling	Electricity	/
Heating load	73.5	W/m^2
Cooling load	24.0	W/m^2
Total heating energy demand	210	MWh
Total cooling energy demand	78	MWh

IV. RESULTS AND DISCUSSIONS

The data obtained by DesignBuilder were used as input in RETScreen where a Combined Cooling, Heat and Power (CCHP) - or trigeneration plant as it is also known - has been modelled. CCHP systems are the most economical and environmentally sound way to generate electricity, heat and cooling, in addition to energy production. CCHP energy schemes integrate Combined Heat and Power (CHP) systems with absorption chillers. Waste heat provides energy to produce chilled water used for cooling. The CCHP considered in this study is based on an internal combustion engine with a capacity of 81 kW at 2200 rpm, a heat rate of 12000 kJ/kWh and a heat recovery efficiency of 68%. A portion of the produced power is used for a heat pump with a capacity of 35.63 kW and with a cooling COP of 3.25.

CCHP model configuration has been compared with the base case and the obtained results are shown in Table 4.

TABLE IV. RESULTS COMPARISON BETWEEN THE PROPOSED CCHP SYSTEM AND THE BASE CASE

Parameters	Value
CCHP efficiency	77.6%
Total initial costs	€ 521488
Annual cost of fuel gas	€ 40233

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Annual cost saving	€ 136020
Project life	15 years
VAN	€ 1014877
Payback time	6.1 years
IRR	15.8 %
Annual greenhouse gases reduced	217.9 tCO2
Annual natural gas saving	20565 m3
Annual electricity saving	647 MWh

The proposed CCHP plant is setted with heating load following operation strategy. The thermal energy value of 210 MWh is achieved by the internal combustion engine. Furthermore an electric energy value of 132 MWh is available for the electric loads. The cooling delivered by the CCHP is 78 MWh in accordance with the building cooling demand (see Table 3). Nevertheless, the total building electricity demand is not satisfied. For this reason, it will be necessary to buy the remaining 513 MWh from the national electricity network. Despite that, the CCHP system allows to save the annual natural gas consumptions and it allows to reduce the annual greenhouse gases emissions. Finally, the results confirm the CCHP feasibility because the payback time is 6.1 years and the VAN is 1014877 €.

V. Conclusions

The study undertaken has the aim to individuate an integrated approach which can use for the individuation of the optimal building plant configuration. This methodology can be used to size and design thermo-mechanical systems evaluating the convenience in a technical, economical and environmental point of view. In fact, in this approach, after the defining of the input data relating to the user (calculation of surfaces and volumes, physical properties, stratigraphy and sun exposure), it was possible to obtain the required heat loads for the building (through the software DesignBuilder) and to get a comparison between a traditional model of subservience and a new concept one which leads to an analysis of technical, economic and environmental feasibility (through the program RETScreen).

The logic of the integrated approach allows the possibility to obtain a method to estimate the economic and environmental feasibility of a power plant, also for complex and newly developed plants. Furthermore, this methodology allows an evaluation of the economic and financial prevision with an immediate feedback in the numerical software, with different levels of accuracy depending on the number of input data (all types of costs or credits acquired, etc.).

References

[1] Battista G., Evangelisti L., Guattari C., Basilicata C., De Lieto Vollaro R. Buildings Energy Efficiency: Interventions Analysis under a Smart Cities Approach. Sustainability 2014; 6: 4694-4705.

[2] Salata, F., Golasi, I., Petitti, D., de Lieto Vollaro, E., Coppi, M., de Lieto Vollaro, A. Relating microclimate, humanthermal comfort and health during heat waves: an analysis of heat island mitigation strategies through a case study in an urban outdoor environment 2017 Sustainable Cities and Society, 30, pp. 79-96.

[3] De Lieto Vollaro R., Calvesi M., Battista G., Evangelisti L., Botta F. Calculation model for optimization design of low impact energy systems for buildings. Energy Procedia 2014; 48: 1459-1467.

[4] De Lieto Vollaro R., Guattari C., Evangelisti L., Battista G., Carnielo E., Gori P. Building energy performance analysis: A case study. Energy and Buildings 2015; 87: 87-94.

[5] Pagliaro, F., Cellucci, L., Burattini, C., Bisegna, F., Gugliermetti, F., de Lieto Vollaro, A., Salata, F., Golasi, I. A methodological comparison between energy and environmental performance evaluation 2015 Sustainability (Switzerland), 7 (8), pp. 10324-10342

[6] Evangelisti L., Battista G., Guattari C., Basilicata C., De Lieto Vollaro R. Influence of the Thermal Inertia in the European Simplified Procedures for the Assessment of Buildings' Energy Performance. Sustainability 2014; 6: 4514-4524.

[7] Evangelisti L., Battista G., Guattari C., Basilicata C., De Lieto Vollaro R. Analysis of Two Models for Evaluating Energy Performance of Different Buildings. Sustainability 2014; 6: 5311-5321.

[8] Evangelisti, L., Guattari, C., Gori, P., De Lieto Vollaro, R. In situ thermal transmittance measurements for investigating differences between wall models and actual building performance 2015 Sustainability 7 (8), pp. 10388-10398

[9] De Lieto Vollaro R., Evangelisti L., Carnielo E., Battista G., Gori P., Guattari C., Fanchiotti A. An integrated approach for an historical buildings energy analysis in a smart cities perspective. Energy Procedia 2014; 45: 372-378.

[10] Burattini, C., Nardecchia, F., Bisegna, F., Cellucci, L., Gugliermetti, F., de Lieto Vollaro, A., Salata, F., Golasi, I. Methodological approach to the energy analysis of unconstrained historical buildings (2015) Sustainability (Switzerland), 7 (8), pp. 10428-10444

[11] De Lieto Vollaro R., Evangelisti L., Battista G., Gori P., Guattari C., Fanchiotti A. Bus for Urban Public Transport: Energy Performance Optimization. Energy Procedia 2014; 45: 731-738.

[12] Zinzi M., Carnielo E., Federici A. Preliminary studies of a cool roofs' energy-rating system in Italy. Advances in Building Energy Research 2014; 8 (1): 84-96

[13] Zinzi M., Carnielo E., Agnoli S. Characterization and assessment of cool colored solar protection devices for Mediterranean residential buildings application. Energy and Buildings 2012; 50: 111-119

[14] Carnielo E., Zinzi M. Optical and thermal characterization of cool asphalts to mitigate urban temperatures and building cooling demand. Building and Environment 2013; 60: 56-65

[15] Battista, G., Carnielo, E., De Lieto Vollaro, R. Thermal impact of a redeveloped area on localized urban microclimate: A case study in Rome Energy and Buildings 2012 133, pp. 446-454

[16] de Lieto Vollaro, R., Vallati, A., Bottillo, S Differents methods to estimate the mean radiant temperature in an urban canyon Advanced Materials Research 2013 650, pp. 647-651

[17] Soares N., Costa J.J., Gaspar A.R., Santos P. Review of passive PCM latent heat thermal energy storage systems towards buildings' energy efficiency. Energy and Buildings 2013; 59: 82-103

[18] Dullinger C., Struckl W., Kozek M. A modular thermal simulation tool for computing energy consumption of HVAC

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units in rail vehicles. Applied Thermal Engineering 2015; 78: 616-629

[19] Stazi F., Vegliò A., Di Perna C., Munafò P. Retrofitting using a dynamic envelope to ensure thermal comfort, energy savings and low environmental impact in Mediterranean climates. Energy and Buildings 2012; 54: 350-362

[20] Golasi, I., Salata, F., de Lieto Vollaro, E., Coppi, M., de Lieto Vollaro, A. Thermal perception in the Mediterranean area: Comparing the Mediterranean Outdoor Comfort Index (MOCI) to other outdoor thermal comfort indices 2016 Energies, 9 (7), pp. 1-16

[21] Battista, G., Carnielo, E., Evangelisti, L., Frascarolo, M., Vollaro, R.L. Energy performance and thermal comfort of a high efficiency house: RhOME for denCity, winner of Solar Decathlon Europe 20142015 Sustainability 7 (7), pp. 9681-9695

[22] Goyal R., Sharma D., Soni S.L., Gupta P.K., Johar D., Sonar D. Performance and emission analysis of CI engine operated microtrigeneration system for power, heating and space cooling. Applied Thermal Engineering 2015; 75: 817-825

[23] Moran A, Magoy PJ, Chamra LM. Thermoeconomic modeling of micro-chp (micro-cooling, heating, and power) for small commercial applications. International Journal of Energy Research 2008; 32: 808-823

[24] Buonomano A., Calise F., Palombo A., Vicidomini M. Energy and economic analysis of geothermal–solar trigeneration systems: A case study for a hotel building in Ischia. Applied Energy 2015; 138: 224-241

[25] Fong K.F., Lee C.K. Performance analysis of internal-combustion-engine primed trigeneration systems for use in high-rise office buildings in Hong Kong. Energy Procedia 2014; 61: 2319-2322

[26] Salata F., De Lieto Vollaro A., De Lieto Vollaro R., Mancieri L. Method for energy optimization with reliability analysis of a trigeneration and teleheating system on urban scale: A case study. Energy and Buildings 2015; 86: 118-136

[27] Salata F., De Lieto Vollaro A., De Lieto Vollaro R. A case study of technical and economic comparison among energy production systems in a complex of historic buildings in Rome. Energy Procedia 2014; 45: 482-491

[28] http://www.designbuilder.co.uk/

[29] http://www.retscreen.net/it/home.php

[30] UNI TS 11300 - Determination of the buildings energy demand for the air-conditioning in summer and winter.

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