Advances in Modelling and Analysis A
Vol. 55, No. 3, September, 2018, pp. 136-143
Journal homepage: http://iieta.org/Journals/AMA/AMA_A

Study of an integrated retrofit system for energy positive buildings in urban areas

Francesco Ruggiero[1], Silvia Di Turi[2*], Angelina Mastrorilli[1]

[1] DICAR, Department of Civil Engineering and Architecture, Polytechnic University of Bari, via Orabona 4, Bari 70125, Italy
[2] ITC-CNR, Construction Technologies Institute, Italian National Research Council, Bari Branch, via Paolo Lembo 38/B, Bari 70126, Italy

Corresponding Author Email: silvia.dituri@itc.cnr.it

https://doi.org/10.18280/ama_a.550306

Received: 11 March 2018
Accepted: 6 May 2018

Keywords:
energy efficiency, energy refurbishment, integrated building envelope, retrofitting system, residential buildings

ABSTRACT

The paper describes a research carried out in collaboration with the Regional Agency for home and living of Apulia (Arca Puglia Centrale) that aims to implement systems and building technologies for the refurbishment of public housing, according to the European Directive 27/2012. It proposes an innovative retrofitting system, which integrates traditional thermal plant with renewable energies (solar and photovoltaic) and passive modules (vegetation shelters, buffer space, water collectors). It consists in a kit of replicable assembled elements, installed externally as a "second skin" on the building. The kit is flexible and it can be fitted to different orientations of existing buildings, area morphology and climatic conditions. An abacus of the performance of each module is created in order to provide a tool for a quick dimensioning of its energy benefits. Subsequently, the system is applied to an existing multi-storey building and it is studied in different configurations of building renovation through dynamic simulations. Therefore, it is possible to quantify both the achieved energy savings and the energy production from renewable sources for a common building typology in Mediterranean area. The system allows existing building to achieve the targets of positive energy building and it is adaptable to any type of building.

1. INTRODUCTION

The energy efficiency of building heritage has been one of the most important challenges in recent years. At present, building sector is responsible for about 40% of the total primary energy consumed by the European Union, with two-thirds of this demand being due to heating, ventilation and air conditioning (HVAC) systems. Generally, the energy efficiency of existing buildings is poor compared to the current standards and the users' expectations [1].

Energy savings in the buildings sector cannot be delayed: for this reason, the Directive 2012/27/EU [2] establishes a set of binding measures for further energy efficiency in buildings and to reduce their environmental impact in the coming years.

In this regard, a focus on the building stock of social housing is interesting: it was realized in all Europe during the second half of the Twentieth century. More than 50% of social houses consumes up to 150 kWh m-2 year-1 [3], so that the energy improvement of such buildings becomes crucial in order to satisfy energy standards and indoor comforts.

In particular, this trend is confirmed in Southern Italy. The buildings suffer overheating, caused also by the lack of shutters, poor ventilation, moisture problems, high transmittance of envelope components and condensation on the walls. Moreover, there are obsolete heating systems with low efficiency [4].

The demolition with the following rebuilt of existing buildings is not the solution: it would be very expensive and inhabitants would have to move out of the houses, abandoning them temporarily [5].

Consequently, the most used actions for their refurbishment would involve external insulation of the walls and replacement of obsolete plant systems, in order to achieve the high energy performances required by standards.

Many studies have analyzed this kind of strategies [6-11], in order to evaluate the reduction of consumptions and greenhouse gas emissions, focusing also on the cost-benefit analysis [12-13].

However, it is fundamental to provide a new kind of intervention that could ensure not only an improvement regarding the energy performance of the buildings, but also the respect for the residents' needs and the reduction of costs as well as electrical consumptions [14], in a sustainable way.

In this regard, many researchers oriented their study toward the use of new systems of building envelope and materials [15-20].

In particular, many studies are related to the use of new façade technologies for better thermal insulation, shading of solar radiation, improved thermal comfort and visual quality, especially focusing on advanced double-skin façades that are considered an efficient solution to control the interactions of indoor and outdoor environments [21-24].

However, there is still a lack of optimized technologies that allow the integration of multiple passive and active systems and that are conceived specifically for the existing buildings. That is due to the complexity and high number of architectural building typologies, urban context and climate.

For this reason, the work deepens the analysis of an original retrofitting system, inspired by the concept of "arbour", a characteristic element of the Mediterranean architecture: the

aim of this system is to achieve a high level of sustainability, aesthetic and architectural quality, adding on the improvement of building energy performance.

2. THE SOLAR TREE KIT: ANALYSIS OF AN INNOVATIVE SYSTEM

The proposed solution is a construction system that, applied externally to the building, improves its energetic performances and its structural safety.

The building envelope is often the object of a serious campaign of retrofitting actions, from the solution to operate directly to the façade, e.g. adding shading systems, to the total substitution of walls and roof systems. This can determine an increase in building external volume, creating a new envelope that defines a new architecture. Moreover, it is important to integrate active and passive strategies of refurbishment, in a complementary use that allows achieving an energy self-sufficiency of the building.

One of the main purposes of the proposed system (Figure 1) is to increase the surface area available for solar panels because, in the existing buildings, the suitable areas of solar collectors are limited to the roof.

Figure 1. An example of retrofit using the "solar tree kit"[25]

Thus, facades give the opportunity to install collectors and to provide a further potential envelope surface for solar thermal integration to supply hot water for domestic use, space heating and cooling [26].

The proposed system consists in a kit of replicable elements with simple assembly mode where the active and passive modules are mounted (Figure 2), such as PV, solar thermal, buffer spaces, green (deciduous plant), collecting rainwater modules, shading systems etc.

The kit envelops the building, like a “second skin”, that allows the creation of solar greenhouses, liveable buffer spaces, green shading, solar and rainwater collectors.

Each element mitigates high summer temperatures and improves living comfort during the year.

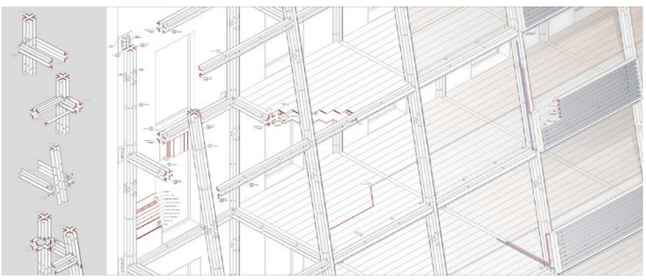

Figure 2. Kit overlaid to the existing building, with focus on the connections of the assembled profiles [25]

The kit has been thought to be flexible and it can be fitted to the different orientations of the existing buildings, to the morphology of the area and to the climatic conditions (Figure 3).

Moreover, it does not interfere with the indoor environments, which continue to be occupied by the residents. Many other invasive works require that users move out of their houses.

Figure 4 shows a prototype under construction for an on-site experimentation.

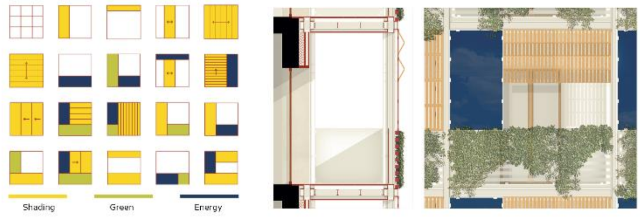

Figure 3. Possible combinations of different modules and example of a kit configuration [24]

Figure 4. The construction of the prototype [25]

3. METHOD

The study of the interaction between the proposed system and the building is carried out through two different steps, by the use of a dynamic simulation software DesignBuilder [27].

The first step is the construction of an abacus that summarizes the energy performance of the active and passive systems employed in order to have a first immediate dimensioning of the benefits represented by the kit. This was done through the simulation of a generic reference multi-storey building that is the most common social housing typology in the city of Bari, in order to evaluate the performances of each kind of module.

The building was characterized with an insufficient constructive quality as facing brick walls with air cavity and inadequate insulation that is the typical construction technique of Italian social housing. One kit with only one kind of module per simulation was studied, varying different parameters like the location (walls, horizontal roof or roof with inclination of 34°C) or the orientation of the modules. Instead, they are independent from construction materials and from the kind of plant systems.

In the second phase, these results were used for the simulation of a kit applied to an existing building with the proposal of different retrofitting methods in order to evaluate the best energy benefits. The energy performances of the kit were evaluated on a case study owned by Arca Puglia, consisting of poor-quality social housing, located at the periphery of Bari, in the South of Italy.

Bari is located in a Mediterranean area and its climate is characterized by hot summers and mild winters, with moderate temperatures. According to the Typical Meteorological Year (TMY) generated by Meteotest [28], the maximum Dry Bulb temperature is 36.6 °C on 21st July and the minimum is 0.7 °C on 12th January.

3.1 The abacus of the energy performances

The abacus represents a quick dimensioning of energy benefits that it is possible to achieve from renewable sources and from the reduction of external loads depending on the areas used for each passive and active system. This is possible for different kinds of buildings with different orientations.

This demonstrates the extreme flexibility and replicability of this system with the same modular kits for multi-storey buildings and tower buildings of social housing.

3.1.1 List of active and passive modules

The photovoltaic module consists of two polycrystalline panels of 1.640 x 0.992 x 0.050 m, with a nominal power of 250 W and an efficiency of 15%. Overall, also considering the dimensions of the supporting elements, the module assumes the dimensions of 2.240 x 1.984 x 0.300 m with a capturing area of 2.92 m^2.

The photovoltaic system was studied providing the efficiency and the electrical power rating from two photovoltaic panels (which make up the module), the direct current inverter, and one electrical switchboard.

The simulation results, derived from the application of this single module to the reference buildings, are summarized in Table 1.

Table 1. Energy production of PV module [kWh m^{-2} $year^{-1}$]

Installation		Orientation							
		N	NE	E	SE	S	SW	W	NW
Wall		50	65	95	119	125	118	95	65
Roof	Tilt 34°	117	130	160	188	199	188	160	130
Roof	Tilt 0°	178	178	178	178	178	178	178	178

The most efficient solution is obtained from the location of the module on the roof, with an angle of 34° and Southern exposure. In these conditions, it produces 199 kWh m^{-2} $year^{-1}$. The worst result is obtained from modules located on the wall, exposed to North. In these conditions, they produce 50 kWh m-2 year-1.

The solar module consists of a single solar collector of 1.221 x 2.046 x 0.090 m. Overall, the module assumes the dimensions of 1.281 x 2.046 x 0.300 mm with an effective absorber area of 4.3 m^2 (Table 2).

In order to evaluate the performance of the solar module, it was necessary to model the solar plant system in Design Builder (detailed HVAC mode). It is a forced circulation system with auxiliary heating, with two circuits: heating and domestic hot water production. The design temperature of the fluid is equal to 80° C (heating system) and to 56 °C (hot water supply).

Table 2. Solar module features

Size	12.210 x 20.468 x 0.090 m
Effective absorber area	2.15 m^2
Efficiency (η)	0.783
Linear loss Coefficient (a_1)	3.88 W/(m^2K)
Quadratic loss Coefficient (a_2)	0.0180 W/(m^2K^2)

Table 3. Energy production of solar module [kWh m^{-2} $year^{-1}$]

Installation		Orientation							
		N	NE	E	SE	S	SW	W	NW
Wall		55	77	133	175	168	177	132	77
Roof	Tilt 34°	144	189	289	383	439	389	292	195
Roof	Tilt 0°	319	319	319	319	319	319	319	319

The performance of the modules was simulated depending on the installation on wall or roof (horizontal or inclined), and on the orientation. The simulation results are summarized in Table 3.

The best solution is obtained in the case of the solar module installed on the roof with a tilt of 34° and South orientation with a production of 439 kWh m^{-2} $year^{-1}$.

The presence of vegetation, integrated with the building envelope, acts as a solar shield, increases the thermal resistance and the inertial mass, normalizes surface temperatures and allows a reduction of the radiant temperatures [29]. Furthermore, these properties increase energy efficiency and indoor thermal comfort.

The study analyzes the benefits in terms of shading, with a type of deciduous vegetation that provides shade in the summer and sunshine in the winter.

The module has dimensions of 2.240 x 1.984 x 0.300 m.

The software does not require the definition of plant species. The degree of transparency of the green wall varies during the year from 0 (covered vegetation) to 1 (leafless vegetation).

Table 4 presents the simulated results of the incident radiation (covered/leafless vegetation) referred to a period of six months, from October to March (winter) and from April to September (summer).

Table 4. Incident radiation transmitted by green module to the walls of the buildings [kWh m^{-2} $year^{-1}$]

Period		Orientation							
		N	NE	E	SE	S	SW	W	NW
Winter	without vegetation	158	172	272	434	528	434	272	172
Winter	with vegetation	142	154	240	380	459	381	241	154
Summer	without vegetation	345	489	689	764	734	764	689	489
Summer	with vegetation	256	355	461	589	625	588	462	356

During winter, the module without vegetation is preferable: it allows the penetration of radiation in the houses, increases solar gains and reduces the heating that energy needs.

In summer the situation reverses. Green modules, assembled together, create a green wall that allows a reduction of the cooling that energy needs.

Buffer spaces connect the indoor with the outdoor. These greenhouses exploit direct solar gain during winter, increasing the indoor temperature and reducing heating energy needs; in summer they overheat and have to be properly shielded and ventilated.

So the benefits were calculated in winter (Table 5), evaluating solar gains that result from a buffer space module of 2.24 x 2.70 x 2.10 m.

Table 5. Solar gains [kWh m^{-3} $year^{-1}$] thanks to the buffer space module in winter (from October to March)

Period	Orientation							
	N	NE	E	SE	S	SW	W	NW
Winter	26	3	46	64	73	65	47	31

Finally, the design of the rainwater collectors was done using rainfall data [30]. The rainwater collector is 2.240 x 1.984 x 0.300 m with a collection area of 3.85 m^2, and it was installed on the roof. Each module allows collecting 0.05 $dm^3s^{-1}y^{-1}m^{-2}$.

4. CASE STUDY

In order to apply the study of the kit on an existing case, a multi-storey building was chosen and its energy performance was analyzed through dynamic simulations.

The considered block was built during the second half of the 70s in Bari and it has six staircases and different heights, but the study is focused on one of the staircase units with eight floors above ground (Figure 5).

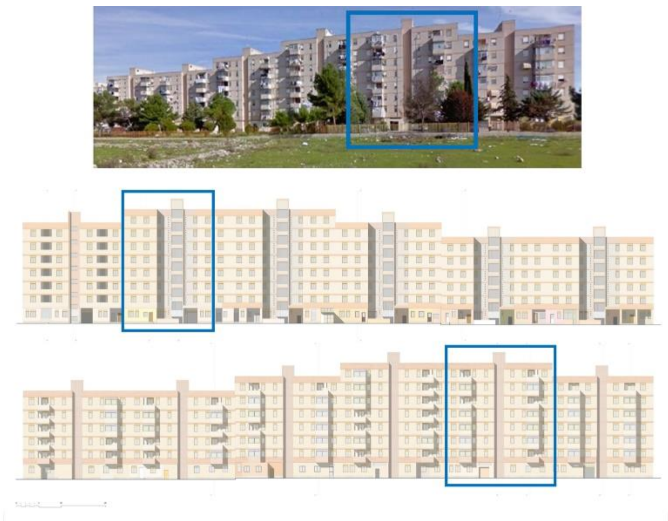

Figure 5. The case study: a multi-storey building in the periphery of Bari [25]

Table 6 reports the thermal properties of the existing building envelope used in the simulation.

It has a reinforced concrete framed structure, with facing brick walls with air cavity. The floors are a mixed structure of reinforced concrete or pre-stressed concrete and bricks, while the roof is a reinforced concrete hollow-tile floor with low thermal insulation. The single-glazed windows have galvanized steel frame.

The heating system is autonomous, with radiators and an obsolete gas boiler for each apartment.

The energy consumption was simulated for present configuration of the building without insulation and with obsolete boilers (Figure 6) and for three different hypothesis of refurbishment:

(1) external insulation (0.09 m of polystyrene);

(2) external insulation and replacement of the obsolete gas boilers (η100% = 88.2%) with high efficient gas boilers (η100% = 98%);

(3) external insulation, a geothermal heat pump and electrical boilers for hot water production.

Table 6. Features of the studied building and thermal transmittance (U)

Building Feature	Description	U (W/m²K)
Roof	Reinforced concrete hollow-tile floor, low insulation	0.45
Intermediate floor	Reinforced concrete hollow-tile floor	1.75
Opaque external wall	Cavity wall, without insulation (30 cm)	1.32
Window	Single-glazed window, galvanized steel frame	$U_W = 5.10$ $U_g = 4.64$

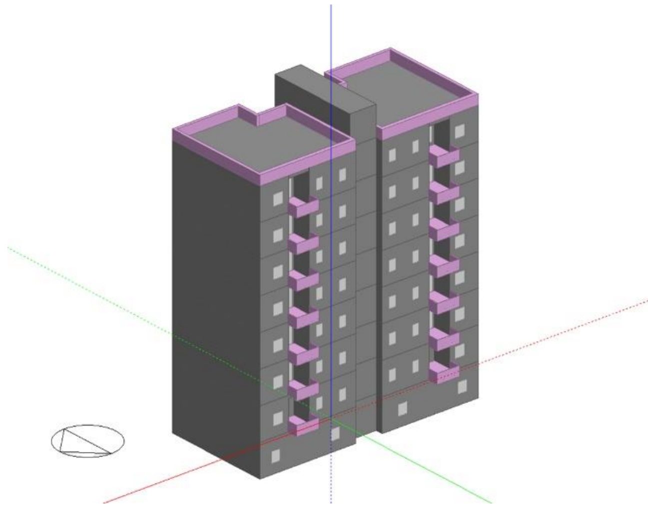

Figure 6. DesignBuilder 3D model of the case of study

Table 7 shows the results of the simulations in terms of energy need and consumption for cooling and heating [31].

The results of the simulations demonstrate that the refurbishment, obviously, improves the energy performance of the building, with a reduction of the energy needs compared to the present state. Hypothesis I causes an annual reduction of heating requirement of 24% (from 61,863 kWh to 46,517 kWh).

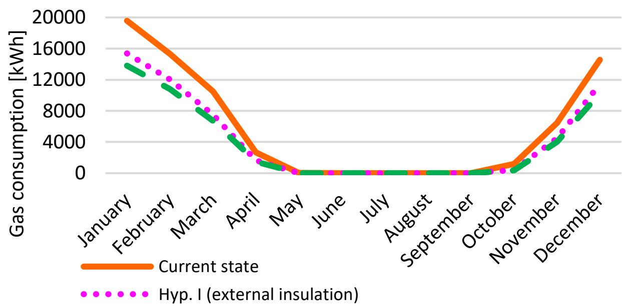

Figure 7. Gas consumption in current state, hyp. I and II

Table 7. Energy need for heating (E_H) and cooling (E_C) and consumption (gas G; electricity El) for Heating and Domestic Hot Water (DHW) in all the configurations

Config.	E_H		G_H		G_{DHW}
Current	61,839 kWh (58.89 kWh m^{-2} year^{-1})		70,727 kWh (67.36 kWh m^{-2} year^{-1})		107,371 kWh (102.26 kWh m^{-2} year^{-1})
Hyp. I	46,517 kWh (44.30 kWh m^{-2} year^{-1})		52,860 kWh (50.34 kWh m^{-2} year^{-1})		107,371 kWh (102.26 kWh m^{-2} year^{-1})
Hyp. II	46,491 kWh (44.28 kWh m^{-2} year^{-1})		47,440 kWh (45.18 kWh m^{-2} year^{-1})		96,415 kWh (91.82 kWh m^{-2} year^{-1})
	E_H	E_C	El_H	El_C	El_{DHW}
Hyp. III	44,244 kWh (42.14 kWh m^{-2} year^{-1})	27,556 kWh (26.24 kWh m^{-2} year^{-1})	11,432 kWh (10.89 kWh m^{-2} year^{-1})	9,906 kWh (9.43 kWh m^{-2} year^{-1})	86,483 kWh (82.36 kWh m^{-2} year^{-1})

In the colder months, January, February and December, 21% of reduction was reached, while more savings were calculated during fall and spring (from 30% in March up to 66% in October).

The Figure 7 shows the energy needs related to the gas consumption during the year for the present configuration compared to hypothesis I and II.

The external insulation decreases the energy needs, especially in the first months of the year by changing the obsolete boiler, energy savings get even higher: 32% less than the present configuration. Furthermore, the more efficient boilers reduce the consumption of gas for hot water production by 10%.

In the third case, the electricity consumption is not comparable directly with the gas consumption.

In all the cases, the annual electricity consumption for lighting is equal to 16,281 kWh/year (9.55 kWh m^{-2}year^{-1}).

5. RESULTS AND DISCUSSION

Table 8. Kits' properties and performances resulting from the abacus

	KIT n. 1 - KIT n. 5		
Modules Types	PV		
Placement	West Wall	East Wall	Flat Roof
Number of modules	7	12	6
Electric energy produced kWh/year	1,946	3,336	3,132
	KIT n. 2 - KIT n. 4		
Modules Types	SOLAR		
Placement	West Wall	East Wall	Flat Roof
Number of modules	12	7	5
Thermal energy produced kWh /year	6,768	3,941	6,800
	KIT n. 3		
Modules Types	SOLAR		
Placement	West Wall	East Wall	Flat Roof
Number of modules	12	12	5
Thermal energy produced kWh/year	6,768	6,756	6,800

The simulations provide data on the energy needs of the existing building so that it is possible to define the type and the quantity of the kit modules. The data contained in the abacus, obtained previously, allow pre-sizing the potential of the system. In this way, it is possible to estimate the performance of the kit in the three situations. The system allows the reduction of thermal and electrical consumption.

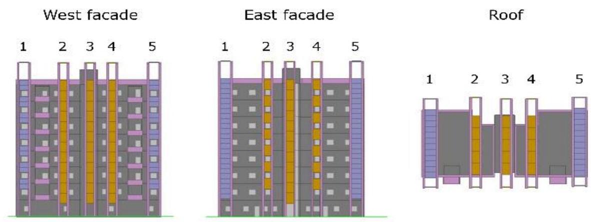

Figure 8. Arrangement of the five kits (PV modules in blue, thermal solar modules in orange)

Five kits, three with solar thermal modules and two with PV modules (Table 8 and Figure 8), were installed on the buildings.

This configuration produces 16,966 kWh electrical per year and 55,309 kWh thermal per year.

At this point, by means of the dynamic simulation the energy performance of the building has been calculated with the new applied system (Figure 9).

Outputs show that the kit causes shading in all the considered cases and that it leads to an increase of the heating requirements and a consequent increase in the consumption of gas in winter.

In all the cases, the consumption of gas for heating increases by 6 %. On the contrary, the shadowing effect is positive in the Hypothesis III (exterior insulation and geothermal heat pump) where the electricity consumes for cooling are reduced by 37 %.

There is a considerable reduction of energy consumption, by analysing the annual results of the simulations.

The solar modules allow covering half of the annual consumption for the production of hot water: about 51 % in the case of the simple application of the system without any redevelopment, and up to 57 % in the case of the external insulation and the replacement of the low efficiency boilers.

Moreover, in three out of the four considered scenarios (present configuration, hypothesis I and II), the energy produced by the PV modules is sufficient to cover all consumption arising from lighting.

In the last case (with heat pump), the solar system covers up to 64 % of the annual consumption for hot water produced for example by electric water boilers, while the PV meets 100 % of the energy consumption of the heat pump for heating and cooling.

The dynamic simulations allow to compare and analyse the results and to confirm the improvement of energy efficiency of the building when the refurbishment is more efficient.

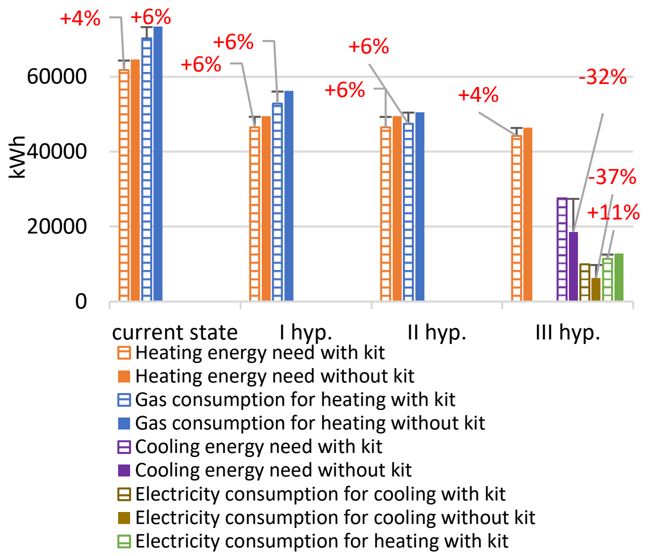

Figure 9. Energy need and consumption, with and without the kit [kWh]

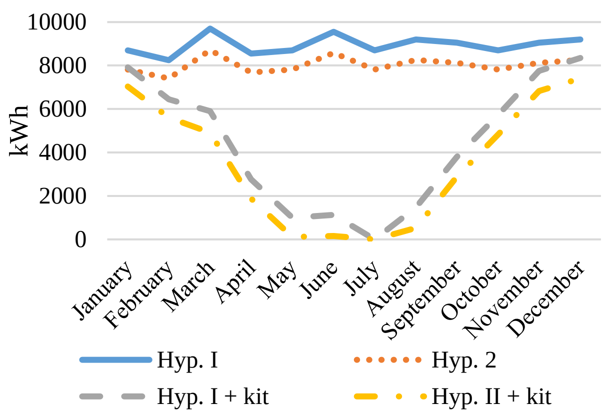

Figure 10. Lighting consumption

With the proposed retrofit system, in the current state and in the first two cases of redevelopment, simulations reveal a considerable reduction of the consumption for lighting and gas. The solar energy output from the PV modules meets most of energy consumption for lighting. In particular, from April to September the PV plant produces an excess of energy (Figure 10). The maximum value is reached in July (+ 44 %).

The comparison between the first (current boilers) and the second (efficient boilers) refurbishment hypothesis shows that the yearly trends are almost the same (10 % less in the second hypothesis). Introducing the kit, consumption trends for the production of hot water varies: the lower values occur in summer. From May to July, there is no gas consumption in the second case, whereas only in July there is no gas consumption in the first case (Figure 11).

The outputs of the third hypothesis show significant reductions of the consumptions.

In particular, the PV modules allow a reduction of power consumption for heating and cooling, while the thermal solar modules reduce the consumptions of the electric boiler for hot water production.

The PV modules meet the electricity consumptions for heating only in April and October, generating a surplus of energy (83 % and 97 % respectively). The consumptions for cooling are zero in every month with the exception of July when the solar panels cover maximum 84% of consumptions (Figure 12).

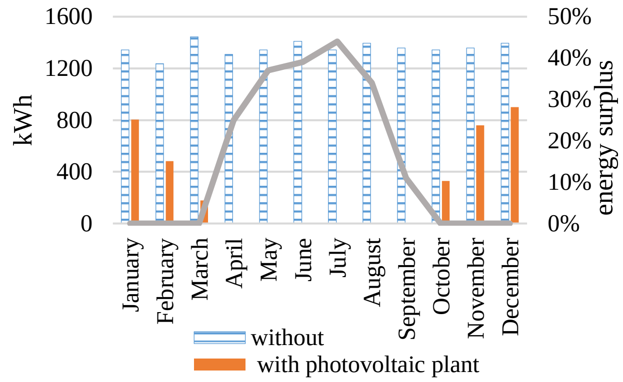

Figure 11. Trends of gas consumption during the year

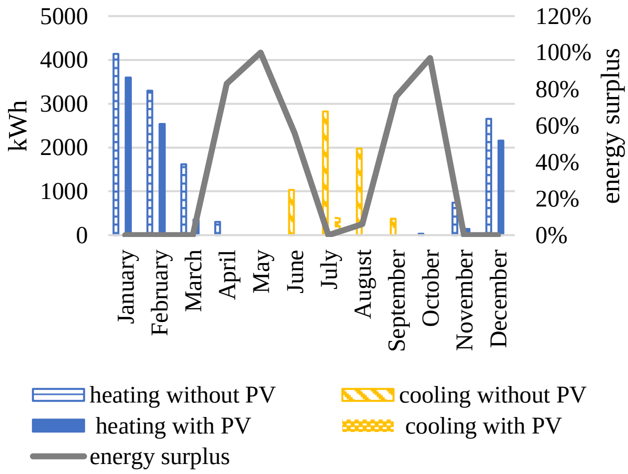

Figure 12. Third refurbishment hypothesis: electricity consumption for heating and cooling with and without PV modules

Energy consumptions for the production of hot water are completely covered from May to August. In the rest of the year, the maximum coverage is 80 % (in September) and the minimum up to 10 % (in January and in December).

6. CONCLUSIONS

This paper has presented a research in collaboration with ARCA Puglia, relating to the study of an innovative retrofitting system, conceived for the social housing in Southern Italy, but replicable on any type of building.

All the results confirm the validity of the proposed system, applied to the buildings, showing improvement in energy efficiency and the reduction of consumption in all the cases. Even if it provides an increase in shading that seems not to be convenient in winter, there is a compensation during the summer, when the energy need for cooling decreases. This is a significant result in the case of the Mediterranean and hot climates.

Obviously, the best results are obtained with the insulation of the building and the installation of a heat pump.

The benefits of the proposed system, made up of active and passive solar systems, ventilation and shading strategies, were proven by carrying out dynamic simulations of a building, with different levels of building renovation.

The results are very encouraging, because the proposed system, along with a few other interventions, considerably reduces energy requirements and it allows existing buildings to achieve the targets of positive energy buildings.

In addition, the proposed retrofitting system offers the opportunity to improve the economic conditions of the inhabitants, because it reduces the cost of energy bills and increases the value of real estate, considering that the starting investment has to be supported by the public administration.

Finally, the attention to the aesthetic quality of the system makes it suitable to achieve a refurbishment not only at architectural level, but also at urban level, in the degraded and highly marginalized suburbs.

The research is going on with the construction of the prototype for a further on-site experimentation in order to test the actual performance and to validate the simulation results. Moreover, the potential of this system in the structural upgrading of the building was investigated [32], studying the possibility of achieving the improvement to the new anti-seismic regulations in order to provide a multifunctional and prefabricated kit to the market for a modern retrofit of the existing buildings.

ACKNOWLEDGMENT

The authors would like to acknowledge Prof. Nicola Parisi of the Department of Civil Engineering and Architecture, Polytechnic University of Bari, the architects Cristina Bernasconi, Gaetano Vito Lerario, Addolorata Maranci, Cecilia Moramarco, Nicoletta Rotolo, Pierpaolo Treglia for the illustrations (Figures 1,2,3,4,5).

REFERENCES

[1] Hall MR. (2010). Materials for Energy Efficiency and Thermal Comfort in Buildings, Crc Press.

[2] European Parliament and Council of the European Union. (2012). Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

[3] Corsetti M. (2011). Innovative and effective trials for upgrading efficiency in social housing in Italy, aimed at sustainability and the reduction of energy poverty. Presented at World Sustainable Building Conference, Association of Civil Engineers RIL and VTT Technical Research Centre of Finland Helsinki, Finland 18-21.

[4] Di Turi S, Stefanizzi P. (2015). Energy analysis and refurbishment proposals for public housing in the city of Bari. Italy. Energy Policy 79: 58-71. https://doi.org/10.1016/j.enpol.2015.01.016

[5] Crawford K, Johnson C, Davies F, Joo S, Bell S. (2014). Demolition or Refurbishment of Social Housing. A review of the evidence. Technical Report. UCL Urban Lab and Engineering Exchange for Just Space and the London Tenants Federation, London, UK.

[6] Ma Z, Cooper P, Daly D, Ledo L. (2012). Existing building retrofits: Methodology and state-of-the-art. Energy and Buildings 55: 889–902. https://doi.org/10.1016/j.enbuild.2012.08.018

[7] Pombo O, Allacker K, Rivela B, Neila J. (2016). Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting - A case study of the Spanish housing stock. Energy and Buildings 116: 384-394. https://doi.org/10.1016/j.enbuild.2016.01.019

[8] Rhodes JD, Bouhou NI, Upshaw CR, Blackhurst MF, Webber ME. (2016). Residential energy retrofits in a cooling climate. Journal of Building Engineering 6: 112-118. https://doi.org/10.1016/j.jobe.2016.03.001

[9] Collins M, Curtis J. (2016). An examination of energy efficiency retrofit depth in Ireland. Energy and Buildings 127: 170-182. https://doi.org/10.1016/j.enbuild.2016.06.012

[10] Schuetze T, Lee JW, Lee TG. (2013). Sustainable urban (re-) development with building integrated energy, water and waste systems. Sustainability 5(3): 1114–1127. https://doi.org/10.3390/su5031114

[11] Aprea C, Greco A, Maiorino A, Masselli C. (2017). A comparison between electrocaloric and magnetocaloric materials for solid-state refrigeration. International Journal of Heat and Technology 35(1): 225-234. https://doi.org/10.18280/ijht.350130

[12] Ballarini I, Corrado V, Madonna F, Paduos S, Ravasio F. (2017). Energy refurbishment of the Italian residential building stock: Energy and cost analysis through the application of the building typology. Energy Policy 105: 148-160. https://doi.org/10.1016/j.enpol.2017.02.026

[13] Magrini A, Lazzari S, Marenco L, Guazzi G. (2018). Cost optimal analysis of energy refurbishment actions depending on the local climate and its variations. Mathematical Modelling of Engineering Problems 5(3): 268-274. https://doi.org/10.18280/mmep.050321

[14] Caldera M, Ungaro P, Cammarata G, Puglisi G. (2018). Survey-based analysis of the electrical energy demand in Italian households. Mathematical Modelling of Engineering Problems 5(3): 217-224. https://doi.org/10.18280/mmep.050313

[15] Saadon S, Gaillard L, Giroux S, Ménézo C. (2015). Simulation study of a naturally ventilated building integrated photovoltaic (BIPV) envelope. Energy Procedia 78: 2004-2009. https://doi.org/10.1016/j.egypro.2015.11.394

[16] Imbabi MSE. (2012). A passive–active dynamic insulation system for all climates. International Journal of Sustainable Built Environment 1: 247-258. https://doi.org/10.1016/j.ijsbe.2013.03.002

[17] Iwaro J, Mwasha A. (2013). The impact of sustainable building envelope design on building sustainability using Integrated Performance Model. International Journal of Sustainable Built Environment 2(2): 153-171. https://doi.org/10.1016/j.ijsbe.2014.03.002

[18] Galliano R, Ghazi Wakili K, Binder B, Daniotti B. (2016). Performance evaluation of aerogel-based and perlite-based prototyped insulations for internal thermal retrofitting: HMT model validation by monitoring at demo scale. Energy and Buildings 126: 275-286. https://doi.org/10.1016/j.enbuild.2016.05.021

[19] Di Turi S, Ruggiero F. (2017). Re-interpretation of an ancient passive cooling strategy: A new system of wooden lattice openings. Energy Procedia 126: 289-296. https://doi.org/10.1016/j.egypro.2017.08.159

[20] Lassandro P, Di Turi S. (2017). Façade retrofitting: From energy efficiency to climate change mitigation. Energy Procedia 140: 182-193. https://doi.org/10.1016/j.egypro.2017.11.134

[21] Ghaffarianhoseini A, Ghaffarianhoseini A, Berardi U, Tookey J, Li DHW, Kariminia S. (2016). Exploring the advantages and challenges of double-skin façades (DSFs). Renewable and Sustainable Energy Reviews 60: 1052–1065. https://doi.org/10.1016/j.rser.2016.01.130

[22] Pomponi F, Piroozfar PAE, Southall R, Ashton P, Farr ERP. (2016). Energy performance of Double-Skin Façades in temperate climates: A systematic review and meta-analysis. Renewable and Sustainable Energy Reviews 54: 1525–1536. https://doi.org/10.1016/j.rser.2015.10.075

[23] Lassandro P, Di Turi S. (2017). Energy efficiency and resilience against increasing temperatures in summer: the use of PCM and cool materials in buildings. International Journal of Heat and Technology 35(Sp.1): S307-S315. https://doi.org/10.18280/ijht.35Sp0142

[24] Shameri MA, Alghoul MA, Sopian K, Zain MFM, Elayeb O. (2011). Perspectives of double skin facade systems in buildings and energy saving. Renewable and Sustainable Energy Reviews 15: 1468–1475. https://doi.org/10.1016/j.rser.2010.10.016

[25] Parisi N, Ruggiero F, Bernasconi C, Lerario GV, Maranci A, Moramarco C, Rotolo N, Treglia P. (2015). Renew urban. Arti Grafiche Favia s.r.l., Modugno, Bari.

[26] Giovanardi A, Passera A, Zottele F, Lollini R. (2015). Integrated solar thermal facade system for building retrofit. Solar Energy 122: 1100–1116. https://doi.org/10.1016/j.solener.2015.10.034

[27] Design Builder Software, v4.2.0.054. https://www.designbuilder.co.uk/ accessed on April 16, 2018.

[28] Meteotest (2008) Meteonorm version 7.1. www.meteonorm.com, accessed on May 15, 2018.

[29] Papadakis G, Tzamis P, Kyritzis S. (2001). An experimental investigation of the effect of shading with plants for solar control of buildings. Energy and buildings 33: 831-836. https://doi.org/10.1016/S0378-7788(01)00066-4

[30] European Committee for Standardization (CEN) EN 12056-3/2000. Gravity drainage systems inside buildings. Part 3: Roof drainage, layout and calculation.

[31] Energy performance of buildings -- Indicators for partial EPB requirements related to thermal energy balance and fabric features. ISO 52018:2017.

[32] Foti D, Ruggiero F. (2017). External steel frames retrofitting for earthquake resistant and eco-efficient buildings. Presented at XXVI Congress of Steel technicians, Venice.