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Considerations for extending benefits of energy retrofits at the building level to the building stock

Isaac Guedi Capeluto[1] and Carlos Ernesto Ochoa[2]

[1] Climate and Energy Laboratory in Architecture, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel.
Correspondence email: arrguedi@technion.ac.il;
[2] Climate and Energy Laboratory in Architecture, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel.

Abstract: Enhanced energy performance at the building level is mandated through regulations and certifications such as LEED, BREEAM, EPBD, Passivehaus, etc. Their impact is limited due to the large amount of existing buildings where they are not applied. Prefabricated building envelope energy retrofit systems offer viable alternatives for large-scale implementation, reducing costs and installation times while upgrading comfort levels. The number of buildings requiring refurbishment obliges using non-conventional methods responding to a variety of climates. This paper analyses, through computer modelling, two prefabricated retrofit systems placed on the external side of the existing building envelope. The first one includes mainly passive façade technologies with some user intervention, representing a conventional approach to renovation. The second system features mainly active technologies for application on roof and façades. It represents a more ambitious method to upgrade buildings with the latest technologies, where higher energy savings are the main objective. Both systems feature options for use in different climates. Results show the passive system accounted for 50% of energy savings, but the mainly active system reached 65% using finer control responses and a variety of combinations. Choosing adequate design directions from early design stages will affect effectiveness of retrofit policies.

Keywords: Energy Retrofit, Prefabricated Systems, Design Decisions, Facade, Urban Climate

Introduction

Design consciousness towards enhanced energy performance at the building level has been expressed in different regulations and certifications such as LEED, BREEAM, EPBD, Passivehaus, Minergie, etc (Chandratilake et al, 2013). However, **the global impact of new guidelines on national energy savings is limited due to the large amount of existing buildings constructed before their implementation**. In the United States, around 72% of built space is over 25 years old, previous to the introduction of energy certifications (EIA, 2006); while in the European Union over 50% of residential buildings were made prior to the introduction of the first energy regulations (EBSO, 2017). This makes energy retrofit of buildings a suitable option to minimize energy consumption of the entire building stock in a country and reduce emissions. Additionally, energy retrofit can be a cost-effective solution that also upgrades aesthetics and enhances comfort levels for occupants of structures that do not comply with current standards and expectations.

Nevertheless, as seen from the brief statistics that have been mentioned, the sheer amount of buildings requiring intervention obliges to think of non-conventional methods to implement energy retrofits while producing the least disruption to occupants. Prefabricated façade and roof systems become a suitable option in order to reduce costs and installation times. The idea has even been considered as an energy policy by international bodies (Atanasiu et al, 2011).

Diverse options for integrated prefabricated façade and roof energy retrofit systems have been proposed as research outputs, while others are available on the market as separate components. Although it is out of the scope of this paper to provide a review of each retrofit system, they can be divided into passive and active ones, which satisfy building energy demand or supply (Ma et al, 2012). Combined systems can also be found (Passer et al, 2016).

Each building retrofit system has different characteristics that make them suitable for a variety of cases. Nevertheless, it is usual that early during the retrofit process a decision will be made on applying a particular one. Such decision will affect final retrofit performance. Although ideally the "best" system should be chosen, different criteria and constraints unrelated to energy performance affect selecting one system over the other. Examples include installation costs and local regulations. Choosing a given system option is a not trivial task in building retrofits, which require feasibility studies for different scenarios. To this end, computer simulation is a valuable tool that has helped take decisions in projects of different sizes, including large scale envelope retrofits in healthcare (Staljanssens et al, 2015) and residential buildings (Salvalai et al, 2017).

This paper analyses, through computer modelling, the performance of two prefabricated retrofit systems placed on the external side of the building envelope. It will also serve to explore how early stage retrofit design decisions affect final energy performance, by contrasting a conservative design approach with a performance-driven one. It will also indicate how energy retrofit policies can be affected from application of a given direction.

Description of the retrofit systems under study

Two modular building envelope energy retrofit systems still under development will be explored. The first system features mostly passive façade technologies, with some limited user intervention (Paiho et al, 2015). The second system features a higher degree of automation, using recent technologies that can be applied on the roof and façade (Bresaer, 2017). The former system represents a conventional approach to renovation, which can satisfy factors such as reduced cost and less maintenance. The latter system represents a more ambitious method to upgrade buildings with the latest technologies and where obtaining high energy savings is the main objective. Both systems are purposed for large-scale prefabrication. They are placed on the external side of the existing building envelope without need to demolish existing elements, accommodating a series of different technologies at once. The two systems allow flexible combinations according to each climate case. Their main characteristics are described as follows:

Mostly passive retrofit system

The main climatic strategies implemented by this system are well-known, requiring minimal or no mechanical parts, despite some user intervention needed such as opening and closing shades or regulating air intake. The system is modular, and each module in this system can offer one of the following façade strategies: improvement of insulation levels, improvement of outer surface reflectivity (albedo), glazing upgrading, a manual shading system applied according to season, and a module that regulates passive ventilation during summer. These modules can be used separately and in combination, with each alternative providing different levels of energy savings. Finding which arrangement is best for a given situation depends on studying weather characteristics in order to apply a set of pre-defined strategy choices (Capeluto et al, 2014).

Mostly active retrofit system

This system is characterized by the combination of passive and active strategies, and has more constructive flexibility in terms of modularity. It can be placed on both roof and façade. Passive strategies include improvement of insulation levels to minimum contemporary requirements, improvements in outer reflectivity, and infiltration reduction.

Options that can be chosen according to each particular case include: adding a lightweight super insulating panel, two types of solar collector cavities for air preheating, one with forced ventilation while the other with buoyant flow. There is also glazing improvement with automated solar-tracking external blinds that provide night insulation. Active ventilation is provided through an electric fan. These strategies are regulated by a building management system (BMS), which coordinates them to achieve comfort levels. Figure 1 gives a scheme that represents how the components are placed.

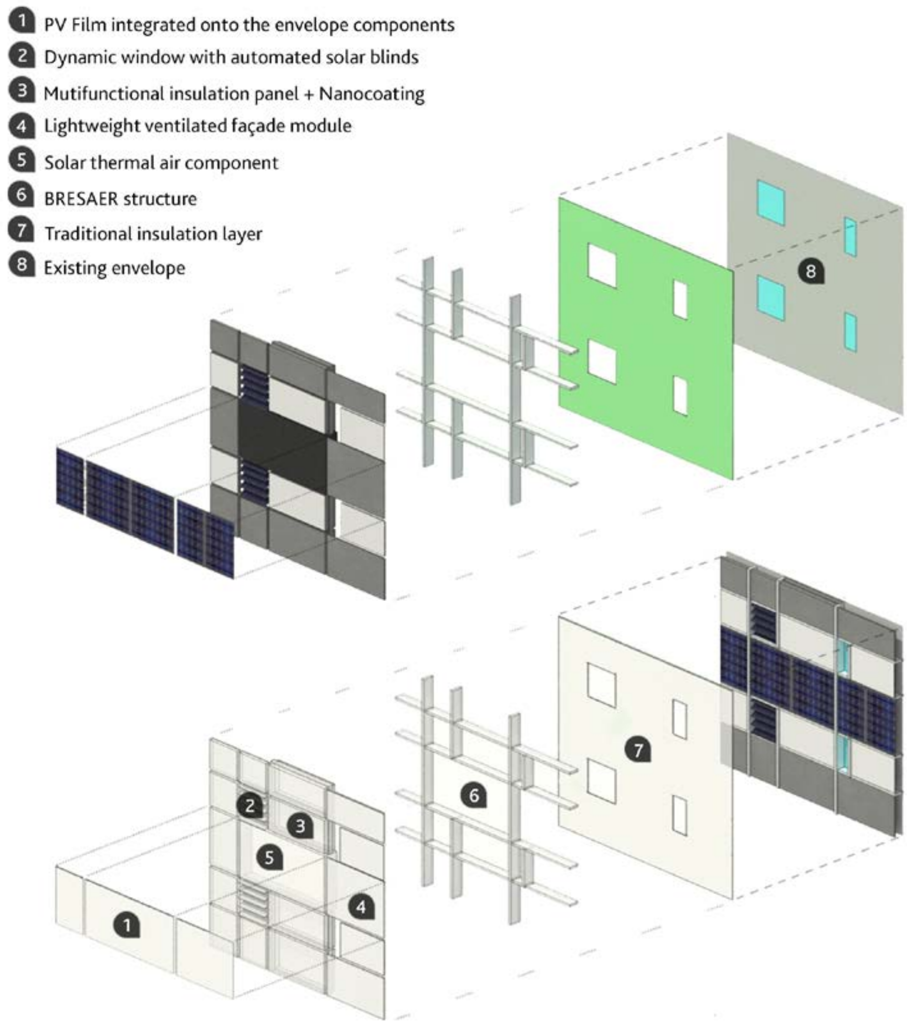

Figure 1. Schematic representation of the mostly active system. Image source: http://www.bresaer.eu

Passive strategies in this system (basic improvements in insulation, infiltration and reflectivity) must be applied together, being a pre-requisite for intervention in any retrofit project. Choices for active strategies are then applied separately or in conjunction, according to the requirements of each location under study. Optionally, a thin-layer photovoltaic panel can also be placed for energy self-generation, but it was not taken into account for this paper. Table 1 shows the strategies used by both systems.

Table 1. Climate strategies followed by each system. X* = applied as prerequisite to the system.

Strategy	Mostly passive system	Mostly active system
Insulation improvement	X	X*
Infiltration reduction	-	X*
Improvement outer reflectivity	X	X*
Glazing improvement only	X	-
Controlled summer time ventilation	X	-
Manual seasonal shading	X	-
Active cavity ventilation and air pre-heating	-	X
Insulating automated outer blinds and glazing improvement	-	X
Highly insulating panel	-	X

Conditions for comparison of the design approaches

A hypothetical case study was made to evaluate both systems focusing on their energy performance. They were modelled using the software EnergyPlus (USDOE, 2017) on a middle-floor apartment located in the urban area of Athens, Greece.

Some of the key parameters that were used for the study are based on examination of building stock databases for that area (Episcope, 2017). The example corresponds to a residential building made before the introduction of the first energy regulations, as a typical situation that would qualify for renovation. Improvement values are based on the Energy Performance for Buildings Directive (EPBD) 2010. The apartment has a floor area of 94.5 m2, with a 1:1 proportion. Window area is 25% of the total floor area, and it is assumed there are no restrictions for conservation or technology selection.

For simplicity, the apartment is assumed to have only one external wall, oriented to the South to represent a favourable location for management of solar radiation, and to test technologies designed to handle natural light penetration.

In the comparison, the external facade was retrofitted with either the active or passive system. Both systems allow a large number of combinations. All possible options were tested in the mostly passive system, but in the case of the mostly active system (which allows for many more options), verification was made on two technology combinations in the façade that could be compared with the passive system, and all strategies together. Yearly energy consumption was calculated for the two systems and detailed for heating, cooling, and where relevant, fan consumption. A summary of the main parameters used for modelling is shown in Table 2.

Table 2. Main characteristics for the residential building under study. Improvement values: EPBD 2010

Feature	Initial	Improvement
Location	Athens, Greece	-
Façade orientation	South	-
Typical apartment floor area (m2)	94.5	-
Typical apartment façade area (m2)	36.5	-
Window area as percentage floor area (%)	25.0	-
Typical existing total load consumption (W/m^2) max.	8.8	-
U-value external wall (W/m^2-K)	2.2	0.42
U-value window (W/m2-K)	6.0	2.0
Visible absorptance	0.7	0.94*
Ventilation, natural (air changes-hour)	4	4*
Recovery rate HVAC (%)	0	50%
Infiltration (air changes-hour)	1.0	0.15*
*not in EPBD		

Results

Energy consumption mostly passive system

Simulation results for this system are shown in Figure 2. Maximum energy savings of about 40-50% are achieved under the described conditions. A total of 11 combinations were checked. As anticipated in a cooling-dominated climate, strategies addressing direct solar penetration such as shading and glazing improvement helped achieve highest energy savings.

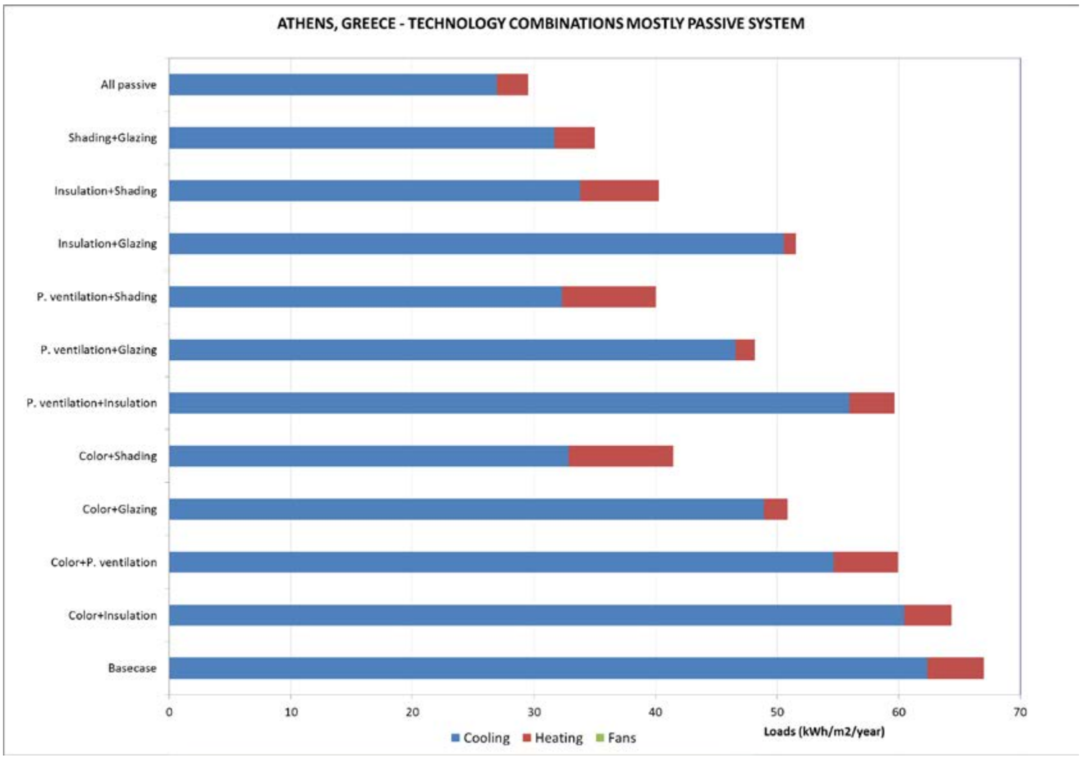

Figure 2. Energy consumption results for a mostly passive system on a residential building facade. Athens, Greece, South orientation

Energy consumption mostly active system

Cooling, heating and ventilation results for simulations using this system can be seen in Figure 3. In total, 6 combinations were studied as well as the influence of system pre-requisites (improvements in basic insulation infiltration and reflectivity). Due to mechanical requirements and resulting low infiltration, electric fan ventilation loads became more noticeable than in the passive system. Heating from external sources was practically not needed when using these active technologies and the pre-requisites.

As expected, active elements brought the highest total energy savings, around 65% when compared to the initial basecase. Heating needs were practically covered by the system. For cooling, which is important for this type of climate, using improved glazing and automated blinds helped reduce cooling consumption around 60% compared to the initial basecase. However, it was observed that despite the addition of all active elements, consumption could not be reduced further in the existing building.

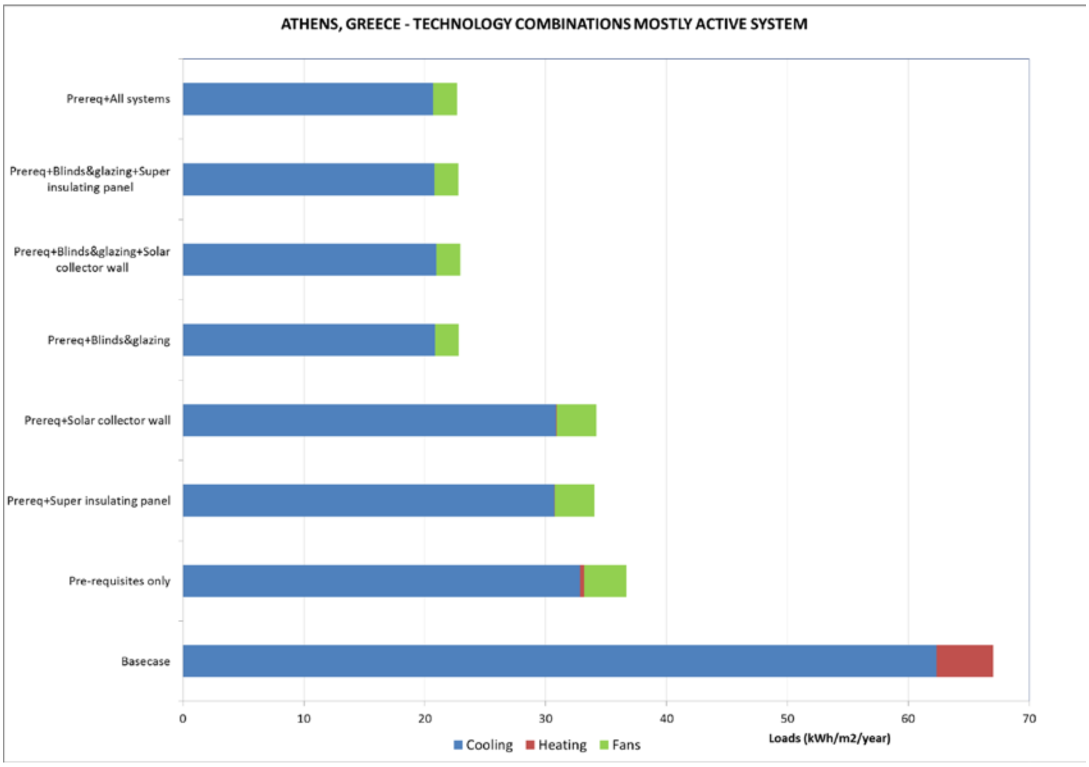

Figure 3. Energy consumption results for a mostly active system on a residential building facade. Athens, Greece, South orientation

Discussion

The mainly active system achieved the highest energy savings due to its adaptability and control systems, while these savings can be achieved using various combinations. This provides an advantage to planners and designers, who can choose a given combination according to the particular needs of their project. The active system, in order to work correctly, had as previous requirements a series of important intervention measures that help reduce energy losses. This enables the active systems to perform correctly and achieve high overall energy savings.

Energy savings achieved after adding the active systems were 40% compared to the basecase. Savings could not be reduced further despite adding all the available options. This suggests that the starting point before retrofit is important, where a "very bad" building in terms of energy consumption will benefit more from upgrading than a more recent, "better" energy-performing one using the same retrofit system.

When extended to the urban level, it can be said that energy saving estimates from renovation are not lineal or cumulative, due to dissimilar energy performances found in diverse sections of the building stock. Although it can be safely assumed that pursuing a high-performance retrofit policy path will bring the highest energy savings, not all buildings will benefit on the same percentage level, with the most recent ones not seeing significant improvements. Therefore, feasibility studies and retrofit regulations must consider differentiated time frames and specific actions for the main historic characteristics in the region's buildings and focus first on the worst performing buildings first for significant and worthwhile effects.

The two design paths also represent the materialization of different criteria influencing design decisions. Examples include preference of policy makers towards promoting local industry, funding tax incentives for building renovation, influence of payback periods, etc.

Considering the design paths in the retrofit process, planners are faced with deciding on the best elements for obtaining suitable results in the retrofit. Choosing on one path or the other (mostly active or mostly passive) is taken early during the design process and will influence the outcome. Flexibility in taking decisions is also a desirable factor for stakeholders, and the mostly active system presented here has that feature. Such characteristic is convenient when other considerations come into play such as ease of maintenance or initial installation cost. Having different options within the same system will also help adequate and methodological assessments on performance, which need to include relevant criteria that affects the decision outcome (Ochoa et al, 2015).

Conclusions

Energy retrofits are required in the existing building stock to extend the benefit of recent energy certifications and standards. Prefabrication is a suitable alternative for large-scale implementation, but deciding on the most suitable path is an early design stage decision, which will influence final performance, therefore needing careful consideration. Paths need to be chosen according to the starting condition of the building in order to obtain maximum performance, although other factors will influence the final choice, such as cost or local regulations.

The expected impact from energy retrofit interventions has to consider performance of existing buildings according to their main historic constructive characteristics. The mostly passive system provided up to 50% savings while the active system provided higher performance (65% energy savings when compared to the basecase). Additionally, the mostly active system provides high performance through a variety of options that adapt to different project conditions.

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