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Manuscript title: Low Energy Design Strategies for Retrofitting Existing Residential Buildings in Cyprus

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Abstract

Problems on mass housing estates are currently a topic for research on energy and policy interventions for in the Turkish Republic of Northern Cyprus (TRNC). Modernist urban detached/semi-detached and suburban row houses often have insufficient green areas and lack consideration of the climatic features of the building site where the neighbourhoods are designed without concern for urban planning laws and regulations. These purpose-built residential building stock models represent 30% of the existing building stock in the TRNC. This research primarily investigates the potential of particular design interventions, in detached 2-storey houses in a Mediterranean climate, to reduce the need for fossil fuel to heat and cool the house. The aim of this study is to develop and test feasible retrofit strategies aimed at optimising the energy performance of the existing residential buildings in the TRNC. To accomplish this, the study first examines the energy performance of a building before and after the retrofitting phases as base case scenario models. The Autodesk REVIT 2017 plug-in 'Green Building Studio' and 'Insight 360' energy performance analysis software were used for simulation of the adapted energy-efficient retrofit measures. This study also outlines the results from the prototype analysis to demonstrate that the difference between a retrofitted building and the existing state of a building in their respective energy use impacts are correlated with the degree of energy management via implementing cost-effective energy efficiency systems.

1. Introduction

The high density of residential development and soaring land values in the Mediterranean city of Famagusta have prompted residents to maximise their liveable spaces by modifying their properties (Ozarisoy & Altan, 2016). Therefore, understanding the problems caused by the high land value and the increase in energy consumption, as a result of the rapid increase in population growth and unplanned urbanisation, has led to research on the adaptability of local construction practices into energy-efficient retrofits (Ozarisoy & Altan, 2017a). In this research context, the construction industry lacks strong drivers to implement energy efficiency regulations and technologies through building construction and retrofitting (Ozarisoy & Altan, 2017b). Given this challenging context, reducing energy consumption of buildings (heating, cooling and lighting) is crucial. At the same time, there is developing interest in improving the thermal performance of buildings in response to occupants' thermal comfort, particularly in the residential sector, where possible energy savings may be offset by retrofit strategies (Ozarisoy & Elsharkawy, 2017). This work combines research on materials and material applications, interactive software systems and systemic retrofit design—all the intersection of energy efficiency and retrofitting.

The study aims to investigate and consolidate the current energy consumption patterns (heating and cooling demand) of a sample of existing detached houses and the tangible outcomes of implementing energy-efficient technologies in testing different retrofit strategies. The study also intends to propose cost-effective retrofit strategies which would result in significant energy savings and carbon reductions in the residential sector. The main question is:

What are feasible retrofit approaches for upgrading energy performance of the sample prototype of a detached house? A sub-question is: How can cost-effective retrofit strategies contribute to the retrofitting of existing residential buildings? These questions would achieve the research objectives as follows: by developing an understanding of the determinants of existing energy use consumption characteristics for similar detached houses; by measuring the effect of retrofitting strategies on energy use; by comparing current energy-efficient construction materials; by putting in place cost-effective retrofitting strategies; and by increasing the emphasis on energy consumption reduction during the design stage of detached houses.

This study focuses on the energy performance of a prototype detached house and seeks to develop an understanding of the energy demand related to occupants' thermal comfort in order to implement viable cost-effective retrofit scenarios accordingly. A representative prototype retrofit model was also developed to aid households, privately-owned construction company owners and designers by understanding existing buildings' dynamic thermal performance and demonstrating both the energy consumption patterns and the occupants' thermal comfort in retrofitting scenarios. This would be pursued through energy use, which varies significantly according to occupants' energy use patterns and their thermal comfort levels in different seasons. However, detached houses risk overheating, particularly in the summer. Thus, correlations between energy use and occupants' thermal comfort and context will be explored to help establish guidelines for the next stage of developing retrofit scenarios. Furthermore, the impact of these devised approaches on the sustainability of the 'systematic retrofit' applications are for the benefit of the entire society and also include impacts for Mediterranean countries with similar climates.

2. Background

2.1 Location and climate

Cyprus is the third largest island in the Mediterranean after Sicily and Sardinia. It is located in the eastern part of the Mediterranean area and sits at latitude 35° North and longitude 33°East as shown in Figure 1. According to the Köppen Geiger climate classification, Cyprus has climate characteristics that are typically Mediterranean. The Köppen Geiger climate data shows that the overall climate of Cyprus is a subtropical (Csa) type climate and a partly semi-arid (Bsh) type climate in the northeastern part of the island (Kottek, 2006). That is to say, the climate characteristics of Cyprus are hot and humid during summertime. Table 1 illustrates the average minimum and maximum outdoor temperatures in summer and winter, as well as the humidity levels in summer. The 2013 Cyprus Meteorological Service statistics show that significant differences exist between mid-summer and mid-winter temperatures. Winter temperatures vary from 18°C inland to about 14 °C on the coast. There are also wide differences between day and night-time temperatures, especially inland in the summer (Cyprus Meteorological Service, 2013). The coastal city of Famagusta has a mild Mediterranean climate with an average annual temperature of 16.7 °C. The 2015 Annual Report of the Ministry of the Environmental and Natural Resources Department of Meteorology (Cevre ve Dogal Kaynaklar Bakanligi in Turkish) demonstrates that the winter is not so severe, with an average of 21 days with temperatures below 0 °C. January is the coldest month, with an average temperature of 12.3 °C. The hottest month, August, has an average temperature of 34.7 °C (Ministry of Environmental and Natural Resources, 2015).

2.2 Urban sprawl and its impact on society

Famagusta is confused with an eponymous, immaterial city. The functioning city is a heterogeneous and continuous agglomeration spreading through 'Down-town Varosha', 'Mid-town Varosha' and 'Upper-town Varosha' and beyond its neighbourhood districts. The vast expanse of low-density residential clusters are scattered through the Varosha territory's pre-1974's residential building stock, which extends all the way to the Engomi territory's post-2000's property boom period residential building stock. More recently, attention has focused on the debates about mass housing estates in the city of Famagusta, as in many other European countries, about housing stock built in the 1970's, 1990's and early 2010's as shown in Figure 2.

During this period, the housing and construction industries were characterised by social, economic and political changes, and political priority was given to uncontrolled housing production. The Economic and Social Indicators Statistics of the State Planning Organisation (Devlet Planlama Orgutu–Turkish Republic of Northern Cyprus (TRNC)) indicate that about 40% of the total residential building stock in Famagusta was built from the 1930's to the 1970's. Peak production was achieved in 1972 and 1973, with the construction of over 1,500 houses each year. These figures show that the number of purpose-built houses was twice the volume of housing production than that during the pre-1974 period (State Planning Organisation, 2017). Most of the urban and suburban housing was constructed in these estates as large-scale, uniform, mono-functional housing buildings at the urban agglomerations of the city. This large-scale unregulated growth expanded the ‘mass housing’ sector of property market and aimed to generate a rapid profit for the privately-owned construction companies selling these properties to international buyers (Arabia, 2013). The outcomes of these property boom years are evident. Housing production reached a peak in the mid-2000’s and early 2010’s, not coincidentally the same years that detached and semi-detached construction peaked. Today, housing estates are built as high-rise residential tower blocks in large quantities at high speeds. Many mass housing estate developments are built in convenient but inappropriate locations, such as near river deltas or in marshlands. The location depends on the initiative of the privately-owned construction companies rather than government control, and some estates are far away from the city centre, while others are swallowed up by further urban agglomeration expansions. In many regions of Northern Cyprus, particularly urban agglomerations, the ignorance of environmental protection, energy reduction and individual thermal comfort resulted in the disproportionate growth of the city’s peripheries and the social segregation of the population. While the new suburbs were populated primarily by the upper-middle class and higher earners, the older inner city, such as the Old Walled City of Famagusta’s residential areas, saw an increased concentration of poor and migrant group settlements. In addition to the above-stated problems, experts currently see suburbanisation as a twentieth-century lapse in urban design, as its heavy demand for space, materials and energy is difficult to reconcile with the sustainability goals of the twenty-first century.

3. Current retrofitting and sustainability practices in European member states

Many European post-war residential buildings were designed and built in accordance with criteria which usually did not take into account reducing energy requirements (Corrado, Balarini, Cognati & Tala, 2011). Most of these residential buildings have not yet undergone 'deep retrofit' interventions and constitute a residential building stock characterised by poor energy performance and thermal comfort issues. As per the European Council conclusions in the 2011 Energy Efficiency Plan, the residential sector is estimated to be responsible for 41% of the total energy consumption in the European Union (EU) (EPISCOPE, 2016). Many studies have been carried out (Gillot, Rodrigues & Spataru et al., 2010; Rodrigues & Gillot, 2010; Lupíšek, Nehasilová, March, Železná, Růzčka, Fiala, Tywoniak & Hájek, 2016) with the aim to optimize building design strategies for reducing embodied energy and embodied carbon dioxide emissions. These studies highlight the major unresolved issues regarding the insufficient building envelope and building systems (e.g. windows, thermal mass). Although, little research has been conducted concerning technical solutions and technologies for ensuring occupant comfort and preventing summer overheating in multi-family dwellings, and they are likely to become increasingly important as temperatures rise because of man-made climate change.

Additionally, two studies were published by Serghides (2007, 2010) where the first study investigated the energy performance of a detached post-war contemporary residential building in Cyprus. The study concluded that the owners of typical multi-family dwelling would have spent from 29% to 51% of their income for cooling and heating of their indoor environment.

The study also argued that insulating the building envelope led to a significant decrease in energy consumption simultaneously. In the second study, the author embedded a dynamic thermal simulation method to evaluate the thermal behaviour of a base case representative multi-family row house unit in Cyprus. From the findings, the study concluded that, in concrete walls without insulation, the building material had larger rates of heat loss when compared with the 30 cm thickness and U-value of 3.5 W/ m^2K local brick wall material, a commonly used construction material throughout the island. As previously stated, in most cases in the situation currently in operation and with particular regard to inefficiencies in the building construction, the indoor comfort standards are considered primary. However, these needs still do not meet basic energy efficiency standards, and the expectations of occupants still focus on improving indoor living conditions. Therefore, this study offers significant added value to internal effort towards achieving energy savings within the poorly-built post-war residential stock in Famagusta, Northern Cyprus.

3.1 Cost-effective retrofit strategies

A feasible solution for achieving energy savings in existing residential buildings through adapting the buildings' construction is by upgrading the interior and exterior wall systems. In order to reduce building energy consumption, incorporating energy-efficient insulation materials is a practical and cost-effective solution for the retrofitting (Papadopoulos et al., 2013). Various strategies have been considered, both active and passive design strategies, focusing on the cost-effective energy retrofit of building design and components, such as the envelope and roof systems (Pisello & Asdrubali, 2014). Similarly, numerous studies have highlighted how a cost-effective energy retrofit contribution to reducing building energy consumption is important. More recently, attention has focused on upgrading the external envelope of the buildings. The energy saving potential of retrofitting residential buildings via embedding the Energieeinsparverordnung (German thermal energy efficiency for buildings' envelope) (EnEV) standard is 33%, and the economically viable potential of thermal retrofits in Germany is around 25% (Galvin & Sunikka-Blank, 2013). Furthermore, various studies need to be conducted to investigate cost-effective measures for analysing the energy performance of existing buildings (Poel, Cruchten & Balars, 2007). Taking into account the effective energy retrofit solutions during the design process for housing assessment and optimization of pay-back period levels of buildings has been proposed by Juan et al. (2009).

The life cycle energy use of retrofitting with improved thermal, ventilation, heat recovery and efficient hot water tap models has been developed to upgrade the existing energy performance of a building (Dodoo, Gustavsson & Sathre, 2010). A recently published supplementary document by The European Parliament and the Council of the European Union in 2010 mentions that the cost-effective methodology for calculating energy performance should not only be based on the peak seasons' energy demand and running costs in which heating and cooling are required, but should also consider the annual energy performance of a building, in particular for energy-efficient systems (European Union, 2010). Thus, a thorough evaluation of an economically viable energy retrofit is challenging due to complex systems regarding the technical, technological, social, aesthetic, ecological, comfort and other factors which affect the final outcomes of a residential retrofit (Asadi et al., Silva, Antunes, Dias &

Glicksman, 2014). However, the main retrofit approaches adopted in this study are based on understanding the energy consumption patterns of the occupants both in the summer and winter seasons to measure and test the existing energy performance of a building, including its physical parameters and conditions of the built environment such as climate.

3.2 Life cycle energy use

The current relevance of considering energy consumption reduction could be established by the fact that a comprehensive range of literature has been published on life cycle energy use in the residential sector. However, in many cases, such investigations and studies relate to large-scale mass housing estate developments, with the focus on densely built environment areas with different energy standards, such as low and very low energy buildings (Kniefel et al., 2010; Marszal, 2011; Sesana, 2013). The assumptions via embedding energy saving measures for space heating and cooling have been compared for long-term cost benefits, in addition to the challenges of using solar boilers and photovoltaic (PV) panels, which have been utilised for net zero-energy building design (Hens, 2010). The hierarchical pathway for achieving the design standards of zero-carbon building energy retrofitting is to minimise energy demand and match it with the local renewable energy supply. It is worthy of note that cost-optimal energy performance and thermal comfort have also been tackled using cost-effective optimisation measures (Ascione, 2015).

3.3 Renewable energy potential

Existing studies on the investigation of the implementation of renewable energy systems also include different strategies, such as PV modules, or the entire systems is composed of modules and a dedicated mounting system to fulfil a list of requirements related to their functions in the building envelope system (Weller, Hemmerle & Jakubetz, 2010). For this reason and considering the requirements of cost-effective energy retrofitting, it is crucial to identify economically feasible methods and strategies to choose renewable energy systems, such as solar collectors of PV (Eicker, Demir & Gurlich, 2015). From a practical point of view, the study discusses the feasibility of implementing the EN 50583-1:2016 regulation code (prepared by CLC/TC 82 solar photovoltaic energy systems) (Ceron, 2013). The installation of PV panels can generate electrical energy from the direct conversion of solar radiation (Sognamiglio, Bosisio & Di Dio, 2009). At the same time, such an installation can power any kind of energy requirement of the building, both thermally and electrically. It has long been known that, theoretically, a building could be entirely powered by PV panels. Furthermore, they can be used where the energy is consumed (on-site generation). Based on this information, they can be easily integrated anywhere into the building envelope. This technical feature allows the design of different optimisation strategies: on/in rooftops, opaque and semi-transparent envelope surfaces having a structural function, such as sun-shading and cladding functions, thus enabling a construction cost reduction (ibid.). It is also interesting to note that the implementation of the PV-associated heat pumps is the most often used solutions set; in cooling-dominated climates, PV shading systems are a common solution for using the renewable energy potentialities (Scognamiglio & Garde, 2016).

4. Approach and methodology

4.1 A case study model: Famagusta, Northern Cyprus

The prototype design research is employed with the general aim of providing a series of guides, tools and findings which may inform the energy consumption reduction and retrofitting processes of both existing and recently built housing stock, as well as neighbourhood urban blocks in Famagusta, Cyprus. The researcher identified the sample city, Famagusta, and its urban agglomeration of the 'Engomi' territory, located on the eastern periphery of Cyprus, as a model and proxy for other coastal cities in Cyprus, as shown in Figure 3.

Its role as a secondary city to the capital of Nicosia provided an appropriate model for second and third-tier cities, as well as towns, which are projected to be the areas of more significant future growth and transformation, by offering alternatives for how these fragmented environment areas may urbanise under threat of the rapid construction process. The objective of this study is to offer guidance on the future urbanisation and re-urbanisation of the island to provide optimal thermal comfort conditions to occupants and reduce energy consumption.

4.2 Prototype house as a base case scenario

The prototype building is a two-storey detached house located in the Engomi area of the urban agglomeration of Famagusta, which is surrounded by several large-scale mass housing estate developments. The prototype building is located on the river delta, around 5 km from the

Famagusta Bay coastline of the Mediterranean Sea. The estate was built in 2010's, and there are 32 detached houses with similar floor plan layouts and construction characteristics. Since 2013, some of the houses have been internally and externally retrofitted, but without any homogenous criteria. The conditioned gross floor area of the case study building is 185 m^2 (pre-retrofitting) and 235 m^2 (post-retrofitting). The original U-values were 0.35 W/ m^2K for external walls, 1.23 W/m^2K for the internal walls, 0. $/m^2K$ for the roof and 2.10 W/m^2K for the windows and doors.The prototype retrofit work presented in this study was designed in 2015, and the construction work was started in 2016, as shown in Figure 4(a) and (b). A monitoring study was carried out before these works, in order to make a diagnosis of the building and, taking into account these data, to define optimal retrofitting strategies. Table 2 illustrates the occupancy schedules and internal gains for both the monitoring and simulation periods of the base case prototype house. Even with its specificities, the building can be considered as representative of other buildings on the estate. Thus, it will allow replication of the retrofitting strategies by quasi-direct extrapolation to other similar residential buildings.

4.3 Research design

The primary underlying basis of the research is to investigate the potentiality of the impact of several 'systemic retrofit' scenarios in energy use and measures to improve the energy efficiency of residential buildings in the TRNC. To ensure systematic analysis of the key aims and objectives, this research adopts a 'quantitative research design'. The study focuses on a 'case study approach' in order to carry out analysis of the most common multi-family detached house prototype in Famagusta. This research was used for monitoring, modelling and energy performance simulations. To capture the existing energy use consumption characteristics for incorporation into the modelling and energy simulation processes, a monitoring programme was carried out for the representative sample of prototype houses. Monitoring of indoor and outdoor temperature and humidity were carried out over two distinct periods during the summer and winter by using Tiny-Tag and i-button data loggers. The periods were spread throughout the year with the aim to capture the heating and cooling demand of the living units. The monitoring study was begun before the start of retrofitting work, and the measured data was assessed taking into account two different periods: one, before retrofitting work; the other one, once the work had concluded.

Obtained data were used to compare two situations (before and after retrofitting work) and then to evaluate the real effects of the action, and the data obtained from the first period were used to feed and validate the simulation model used to try to foresee the expected effects and modify some project decisions to optimise the works and obtain better results. The input parameters required for the modelling include building geometry and properties of the construction materials, energy characteristics of the building components and the required outdoor air temperature. The periods of construction are determined by the building techniques influenced by the building regulation code valid for the particular year of construction which, in turn, influenced the choice of materials for windows, roofs and other building features for the existing state of a building. Energy simulations of the thermal behaviour of the prototype house were conducted for conditions of the typical meteorological year of Famagusta. The framework for the methodology includes the following:

1. Architectural and other technical data from the privately-owned construction companies' archives for case study building were collected and analysed.
2. The building geometry was created for its initial existing state and every floor with correspondent thermal zones and subdivisions, indicating clearly which zones and spaces are not heated, such as balconies and storages, are shown in Figure 5 (a), (b) and (c).
3. Evaluation of the possible installation of solar panels and architectural measures in the scope of local construction practices. Analysis and energy-related optimisation of building components' physics of all created models.
4. Definition of scenarios: Models of energy use intensity, in order to identify the cost-optimal solution. The scenarios were created by adding annual energy use and cost measures consecutively, where the last scenarios have all the possible actions taken into consideration.
5. Building performance simulation: The monitoring of a prototype detached house using data loggers to measure temperature and humidity of the indoor environment was performed to calibrate the initial results from the modelling. Simulations were conducted by 'Green Building Studio' and 'Insight 360' software engines incorporated into the Autodesk 'REVIT 2017'. Simulation was only performed on the same facing (south-east) detached housing unit, output intervals were recorded daily, and the simulation period was for the whole year.

6. Determination of the best scenario/model based on the analysis of results obtained in previous step (Step 5) and evaluation of indoor comfort parameters: air temperature and relative humidity; heat losses and heat gains of the building's' components; and annual final energy demand for heating, cooling and electricity.
7. Financial feasibility of the payback period for improvement of the prototype model.

5. Analysis, results and discussion

5.1 Energy performance of a prototype house

The building energy performance during summer and winter was analysed as a first approach. With the aim of presenting some analysis examples from this study, data sets collected from August 2015 and from September to February 2017 (for summer and winter analyses, respectively) are here displayed. The graphs presented in this section correspond to measurements taken on the ground floor of the prototype house. The first graph depicted in Figure 6 (a) shows that the indoor temperature follows a similar evaluation during the four weeks of August. However, important differences in absolute values due to outdoor conditions can be observed in Figure 6 (b). The data demonstrate that the warmest and coldest weeks of September are the 3rd and 4th weeks, respectively. This explains the differences found when temperature profiles are compared. Moreover, it must be highlighted that indoor temperature is, in the majority of cases, higher than 25°C, reaching, at times, maximum temperatures close to 30°C. In order to calibrate the monitoring results, the detached house was modelled according to building geometry, floor plan layout and sun-path orientation.

The economically viable retrofit strategies have been chosen in line with the theoretical review to achieve and demonstrate the research objectives stated above. By the energy performance simulations/investigation and optimisation of different building components' structures, it has been demonstrated that there are significant differences between heating and cooling loads in the case study building. The simulation results of the existing performance for the detached house indicated that the biggest share of the heat losses comes from air infiltration, exterior walls without insulation and windows (provoking a high annual energy demand for cooling). The results of simulations were analysed for understanding the existing energy use conditions to calibrate the energy consumption patterns (heating and cooling demand) of both ground and first floor areas. Table 3 demonstrates that there is a good accordance of the results of energy demand determined by the energy simulations with the measured consumption of building performance factors.

In order to take into account the contextual features and simulation benchmarks of the prototype house, the energy use defined by the occupants' energy consumption patterns was essentially calculated as an aggregate of the identified indoor thermal comfort temperatures of each zone. Tables 4 and 5 illustrate the actual indoor temperature, which people in the region accept as being comfortable in summer, and the operative temperature levels and fluctuations of both ground and first floor areas. It seems that a more robust generalised method might be provided by defining parameters of openings during the simulation process. It is important to highlight that the obtained results are based on simulations only. This will form the basis for the subsequent phase of the research which will investigate actual retrofit measures in the future.

In terms of examining energy consumption in respect to specific heat losses, the prototype house consumed 81% of its energy during the pre-retrofitting phase and 68% during the post-retrofitting phase through its HVAC system, as shown in Figure 7 (a) and (b) and Figure 8 (a) and (b), respectively. The approach taken during the case study analysis was to assign activities to each zone of the occupied spaces and assess the energy use on these terms. It was found that the material use characteristics of the building's components for each zone of these activities were, in most cases, quite similar between the living and dining room areas, particularly in southeast facing living room areas. An enhanced approach would be to develop zone-specific, rather than building-aggregated benchmarks, to assist with analysing thermal comfort level conditions. According to the simulation results, it was found that the sun-path orientation and monthly wind speed rates were found to be strong determinants of electrical energy use. The results show how, in the prototype house, electrical energy use dropped when the air-conditioning system of the building was converted from mechanically ventilated to naturally ventilated; moreover, the results also show that, for a selection of activities, the naturally ventilated master bedroom area in the first floor was significantly lower in electricity use than non-naturally ventilated areas.

Additionally, starting from these base case studies, when the adaptive set-point is used, the decrease in the cooling demand due to the additional ventilation is required, in particular for the heavier construction materials and the systems. This is due to the strong effect of heat loss from the heavy weight structures caused by the additional discharge rate during the night-time. This is because the adaptive indices have been developed according to the occupants' thermal sensations and preferences (Ferrari & Zanatto, 2009; Nicol, Humphreys & Roaf, 2012; Nicol, 2017). In this study, the adaptive comfort temperature represents the climatization system set-point as autonomously managed by the occupants, according to the external climatic conditions. This is due to having to take into account a cooling need assessment by the traditional chimney area in the base case prototype house. It is remarkable to note that the height of a chimney influences the air infiltration rates of occupied indoor spaces, particularly in the summer. A base case prototype house is subjected to the effects from 'buoyancy-driven air movement' by the traditional chimney area. This natural ventilation system allows hot air from lower levels to rise up through the building and, with no chance of escaping the occupied ground floor areas, it accumulates fresh-air on the top levels of building envelope surfaces.

It can be seen that, during the peak cooling season in the summer, the occupied spaces reveal significant differences based on the adaptive temperature set-point of the heavy weight construction materials, in particular for this base case model, which was not provided with any insulation on the building envelope before retrofitting was undertaken. Apart from that, this can also be clearly seen in the retrofitted case, where only a night ventilation strategy, allowing the loss of the stored heat, significantly reduces the calculated need of the heavy weight conventional building with a traditional chimney. Furthermore, it is important to highlight the fact that, comparing the base case and the retrofitted case, the reduction in the cooling need for heavy weight construction tends to decrease with changes in the height of the floor level and orientation of occupied spaces, while this is not the case with the implementation of low-energy building systems used to reduce energy consumption of households both in the summer and winter. This is due to the fact that, in the first floor occupied spaces, there is larger gap between the conventional set-point temperature and the occupants' expected one.

Tables 6 and 7 illustrate the energy use intensity of prototype building, both before and after retrofitting. It would seem that the difference may be largely attributed to the electricity use avoided in mechanical ventilation and cooling where natural ventilation measures are employed. However, whilst calibrating the prototype model, it was observed that the system energy difference was not always sufficient to account for the overall difference in electricity use between the mechanical and natural ventilation systems. This suggests that some correlation also exists between the sun-path orientation strategy and other electrical loads, such as those for equipment and lighting.

5.2 Applicability of energy conscious retrofitting scenarios

The aim of analysing both existing and retrofitted energy performance of the prototype house presented in this study is to identify available building variants concerning applicability of retrofit strategies and the building envelope, which is an important component in the building structure as the interface between the interior of the building and the outdoor environment. By testing the current condition of thermal barriers, it was determined that the building envelope plays an important role in regulating interior temperatures and optimises the thermal comfort levels of the occupants. It helps to determine the amount of energy required for heating and cooling. Besides modelling and energy simulations, cost-effective energy retrofit scenarios have considered the architectural measures, such as the building geometry, occupied floor areas, orientation and type of construction material, which affect overall improvement of the household's social standard. The proposed solution for cost-effective energy retrofitting of the building envelope was the instalment of a thick thermal insulation composite system, replacement of window and door glazing (from single to double or even triple low-e glazing) and using timber-framed shading elements which led to a considerable reduction in the heat loss through the building envelope. The presented scenarios were reviewed and studied globally, including the use of renewable energy systems (RESs) measures and local construction codes, and have yielded models of improvement particularly suitable for this region. Building energy retrofitting within existing envelopes provides substantial prospects for reducing energy consumption (Giannakopoulos, 2010). The retrofitting measures of the design alternative solution are the following: exterior walls—existing outer layer removed, new insulation of 245 mm fixed on an inner layer and new outer concrete layer with terracotta ceramic tile installed (new U-value of 0.14 W/m^{2}K); roof—old roof mastics and insulation removal and new insulation of 340 mm and new asphalt mastic cover installed (new U-value of 0.10/m^{2}K); base floor—additional external insulation (new U-value of 0.15 W/m^{2}K); and renewal of windows, balcony doors, and front doors—changing the existing double pane windows to triple pane windows (new U-value of 0.7 W/ m^{2}K) (Figure 9).

It is important to emphasise that insulating the exterior of the external walls showed the highest energy consumption reduction. Depending on the location of a room and the ratio of the window area to the façade area, the insulation of the external wall reduces heating energy use by 20–30% in the winter. The strategy of increasing the insulation layer thickness over 200–300 mm on the reduction of cooling energy use was small. In addition, the strategy of insulating the roof and floors depends strongly on the location of a room. It can be seen that the replacement of roof material reduces heating energy use by 14% and cooling energy use by 6–7%, respectively. At the same time, replacement of windows reduced all occupied spaces' energy consumption by 6% because of the high thermal transmittance of U-value 1.1 W/m^{2}K (double glazing with a low-emissivity coating). Additionally, 150 of mm additional insulation of ground floor surfaces was installed to improve the thermal comfort of the occupants. The weighted annual average use of energy consumption in the current state was 241 kWh/m^2. However, after implementation of the above-mentioned retrofit scenarios, the economical optimum of annual energy consumption reduction measures for a base case prototype detached house is around of 120 kWh/m^2, which corresponds to the requirements for low-energy residential buildings. Therefore, it is possible to reduce overall energy consumption by 50% without increasing the current level of investment costs. For this purpose, an economically optimal annual range of the payback is 150 kWh/m^2 over a period of 19–21 years.

In this study, the retrofitting strategies were chosen from measures that are used in upgrading existing buildings' energy performance and, therefore, could be considered as suitable measures. However, the empirical selection of energy efficiency measures cannot guarantee the same accuracy and feasibility of the life cycle cost analysis because all the possible solutions are not examined (Ascione, 2015). For this reason, in this study, the intention was not to explore all possible solutions, but to use retrofitting measures for which accurate cost data were available. Tables 8 and 9 illustrate the life cycle analysis of the prototype house, including the before and after retrofitting phases.

The new appearance of the building envelope, with its adaptable openings and shading devices, was created to provide a controlled buffer zone for the winter and summer. For this purpose, the insulated wall enclosure of balconies was proposed, and it is evident that the greater effect on reducing the need for cooling was achieved. Retrofit technologies are specifically tested, verified and certified by the administrators for effective energy savings and offering comfortable environmental conditions (Santamouris, 2014). In this study, one essential element in the actions proposed was the covering of balconies within the insulated walls and providing adaptable double-glazed openings to optimise sunlight and ventilate natural air. A ventilated facade was proposed, which can reduce the amount of heat which a building absorbs due to the partial reflection of solar radiation by the existing large surface of window openings. The building component of the walls for the whole building consists of a ventilated facade with 3 cm of VP panels, which leads to a U-value of 0.246 W/ m^{2}K. An outcome of these analyses is that the most applicable and feasible retrofitting scenarios are thick thermal insulation, implementation of a ventilated facade and installation of renewable energy systems. As previously discussed, these three retrofitting strategies have huge potentialities for being used in developing a prototype detached house, and, in particular, when designing nearly (or net) zero energy buildings, these are three state-of-the-art technologies, as shown in Figure 10. In order to measure the efficiency of renewable energy systems, the building-integrated PV modules were proposed for use in the prototype house directly, or within other building subsystems, such as mounting systems. According to the International Energy Agency (IEA) data in 2014, the mounting structures which have been developed especially for building-integrated photovoltaic (BIPV) systems, include PV facades and sloped and flat roof mountings (IEA, 2014). In this study, particularly in the case of warm facades, insulated glazing can be replaced with PV modules in the transparent or semi-transparent areas of the façade, and, since these building components were not ventilated, the PV modules yielded slightly less energy due to heat-up.

Tables 10 and 11 illustrate the implementation of renewable energy use potentialities of the prototype house. In the case of cold facades, PV glazing constituted the outer skin of the envelope-closing system. Since it was ventilated, possible heat-up of PV modules was prevented.

6. Conclusions and recommendations

6.1 Conclusions

The findings of these measurements and optimisation results help us calibrate the extent to which data on detached house design has a bearing on energy performance when analysed in terms of implementing cost-efficient retrofit strategies and energy demand reduction. This will allow the diagnosis of the worst-case scenario of residential building typology's built-form, floor plan layout, orientation and existing energy use before undergoing deep retrofitting. Life cycle cost assessment methods can provide a valid support for the retrofitting design solutions (Todorovic et al. 2012; Ascione, Bianco, De Stasio, Mauro & Vanoli, 2016). For this reason, a demonstration visualisation tool can be developed to establish a background for further energy simulations. In such a case, the aim is for the tool to be effective and feasible for taking into account cost-cycle analysis of residential buildings before and after retrofitting phases, including optimisation of energy retrofitting strategies. This research provides a novel way with specific tools and the adoption of retrofit strategies to utilise a real market data set for sustainable design optimisation, which will allow designers, contractors, suppliers, property owners and researchers to identify both effective and feasible retrofitting options for upgrading the existing residential building stocks to help improve building efficiency. Furthermore, future work will be conducted for different climatic conditions and building types.

6.2 Recommendations

The construction sector is aware of the problems with energy efficiency implementations. It is also aware that there are regulations and their implementation for the residential building sector, in general, in the EU lack systemic retrofitting rules; thus, the practice of building these mass housing units in the TRNC continues without any control mechanism. The application of these retrofitting strategies from a single prototype unit to the regional scale retrofitting of housing units will result in immeasurable sustainability benefits for the occupants and the surrounding environment. In addition to that, the present study attempts to identify key features from policy instruments and retrofitting initiatives among the EU member states which currently implement similar policies, most specifically the other southern EU member states which have similar building regulations. The impact of implementing these retrofitting strategies will be beneficial for the society, as they will result in the development of sensitive and engaging constructed habitats which sustainably evolve the social, economic and natural ecologies of their contextual sites. The consideration of offering energy-efficient solutions is important because it enables households to focus on all of the benefits of fulfilling the single objective of environmental integration. The study may provide both theoretical and practical answers to the systematic retrofitting impact on sustainability and society. Also, the study could be used as a base case for the formation of policies and their implementation for the purpose of changing building designs and construction systems for the island in general. Furthermore, the climatic condition of Cyprus is similar to numerous Mediterranean countries outside of Europe, which are currently in the process of implementing energy performance directives in order to upgrade the existing residential building stock and to reduce energy consumption within energy efficiency building systems.

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Table 1. Geographical data and boundary conditions assumed in this research context

Geographical Data			
Place	Altitude	Latitude	Longitude
Cyprus	1,1952m	35° North	33° East
Thermal Data			
Degree day: 2259		Climatic area:	
Average cooling period temperature: 21°C		Average solar radiation on a horizontal plane during the cooling period: 21.92 MJ/m^2	
Data			
Month of max solar radiation: July Summer max temperature: 45°C Relative Humidity max: 90% - min: 46%		Average monthly summer min temperature: 28°C Difference in temperature during the hottest day:9 -12°C	
Month of min solar radiation: December Winter max temperature: 18°C Relative Humidity max: 88% - min: 60%		Average monthly winter min temperature: 7°C Difference in temperature during the coldest day: 8-10°C	

Table 2. Occupancy schedules of the monitored prototype house

WEEKDAY SCHEDULE																								
Room type																								
Living room															▨	▨	▨	▨	▨	▨				
Kitchen						▨	▨																	
Bedroom 1	▨	▨	▨	▨	▨																		▨	▨
Bedroom 2	▨	▨	▨	▨	▨															▨	▨	▨	▨	▨
Bedroom 3	▨	▨	▨	▨	▨															▨	▨	▨	▨	▨
WEEKEND SCHEDULE																								
Room type																								
Living room									▨	▨	▨	▨	▨	▨				▨	▨	▨	▨	▨	▨	
Kitchen								▨	▨	▨			▨	▨						▨	▨			
Bedroom 1	▨	▨	▨	▨	▨	▨	▨	▨																▨
Bedroom 2	▨	▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	▨					▨	▨	▨
Bedroom 3	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				▨	▨	▨					▨	▨	▨	▨

Table 3. The contextual features and simulation benchmarks of the prototype house

Energy Use Intensity	
Electricity EUI:	216kWh/sm/yr.
Fuel EUI:	187MJ/sm/yr.
Total EUI:	964MJ/sm/yr.
Building Performance Factors	
Location	35°.166015625,33.8896446228027
Weather Station	1253311
Outdoor Temperature	Max: 40 °C /Min:1 °C
Floor Area	185m^2
Exterior Wall Area	267m^2
Average Lighting Power	6.46W/m^2
Exterior Window Ratio	0.21
Electrical Cost	$0.14/kWh
Fuel Cost	$0.78/Therm
Number of the subjects involved	1 male/1 female (parents), 1 boy and 1 girl
Age of the subjects	Between 2 and 40
Internal heat gains in the simulation	
Occupants: 3W/m^2	Usage rate: 0.6 (15.8 kWh/m^2-year)
Appliances equipment: 3W/m^2	Usage rate: 0.6 (15.8 kWh/m^2-year)
Lighting: 8W/m^2	Usage rate: 0.1 (7.0 kWh/m^2-year)

Table 4. Accepted comfort level parameters and operative temperature (°C) levels of the ground floor

Parameter	**REF**	**KITCHEN**	**LIVING ROOM**	**BEDROOM1**	**BEDROOM2**	**BEDROOM3**	**Accepted comfort level**
Mean T(max)	29.2	29.1	29.2	28.6	28.9	28.4	31.4
Mean T(min)	27.3	27.1	27.3	26.2	26.3	25.8	22.8
Mean Daily Fluctuation	1.9	2.0	1.9	2.4	2.6	2.6	8.7
Mean T(max)	29.6	29.5	29.6	29.1	29.3	28.9	32.0
Mean T(min)	27.9	27.7	27.8	26.8	26.9	26.4	23.3
Mean Daily Fluctuation	1.7	1.8	1.7	2.2	2.4	2.4	8.7
Percentage of time within the comfort zone for 80% acceptability	96.8	97.6	96.8	99.1	97.6	99.9	

Table 5. Accepted comfort level parameters and operative temperature (°C) levels of the first floor

Parameter	REF	KITCHEN	LIVING ROOM	BEDROOM1	BEDROOM2	BEDROOM3	Accepted comfort level
Mean T(max)	30.8	30.7	30.8	30.2	30.4	30.0	31.4
Mean T(min)	28.8	28.5	28.7	27.9	28.0	27.5	22.8
Mean Daily Fluctuation	2.1	2.2	2.1	2.3	2.4	2.5	8.7
Mean T(max)	31.4	31.3	31.4	30.8	31.0	30.6	32.0
Mean T(min)	29.4	29.2	29.4	28.6	28.7	28.3	23.3
Mean Daily Fluctuation	1.9	2.1	2.0	2.2	2.2	2.4	8.7
Percentage of time within the comfort zone for 80% acceptability	38.8	46.2	40.2	64.0	59.3	71.6	

Table 6. The energy use intensity of the prototype house pre-retrofitting

Energy Use Intensity	
Electricity EUI:	216kWh/sm/yr.
Fuel EUI:	187MJ/sm/yr.
Total EUI:	964MJ/sm/yr.

Table 7. The energy use intensity of the prototype house post-retrofitting

Life Cycle Energy Use	
Life Cycle Electricity Use:	994.164 kWh
Life Cycle Fuel Use:	862.909MJ
Life Cycle Energy Cost:	$68.356

Table 8. The life cycle energy use and cost analysis of the prototype house pre-retrofitting

Life Cycle Energy Use	
Life Cycle Electricity Use:	994.164 kWh
Life Cycle Fuel Use:	862.909MJ
Life Cycle Energy Cost:	$68.356

Table 9. The life cycle energy use and cost analysis of the prototype house post-retrofitting

Life Cycle Energy Use	
Life Cycle Electricity Use:	515.087kWh
Life Cycle Fuel Use:	621.232MJ
Life Cycle Energy Cost:	$36.069

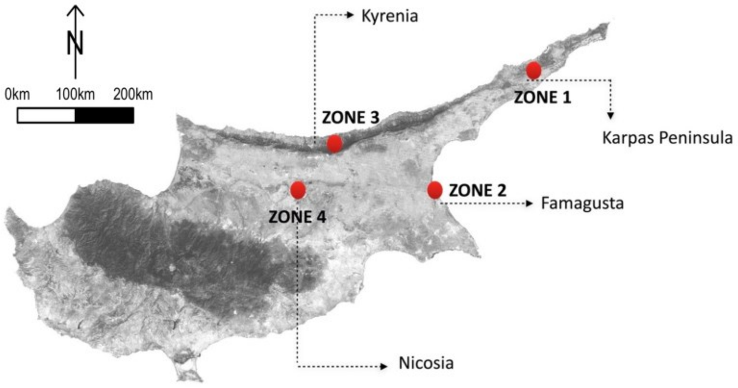
Table 10. The renewable energy use potentialities of the prototype house pre-retrofitting

Life Cycle Energy Use	
Roof Mounted PV System (Low efficiency):	3.317 kWh/yr.
Roof Mounted PV System (Medium efficiency):	6.635 kWh/yr.
Roof Mounted PV System (High efficiency):	9.952 kWh/yr.

Table 11. The renewable energy use potentialities of the prototype house post-retrofitting

Life Cycle Energy Use	
Roof Mounted PV System (Low efficiency):	4.156 kWh/yr.
Roof Mounted PV System (Medium efficiency):	8.313 kWh/yr.
Roof Mounted PV System (High efficiency):	12.469 kWh/yr.

Figure 1. Map of four different climatic regions in Cyprus



ZONE 1 Semi-mountainous climatic zone

ZONE 2 Coastal climatic zone

ZONE 3 Mountainous climatic zone

ZONE 4 Inland climatic zone

Figure 2. Mapping of densely built detached/semi-detached and row houses and the location of the case study area

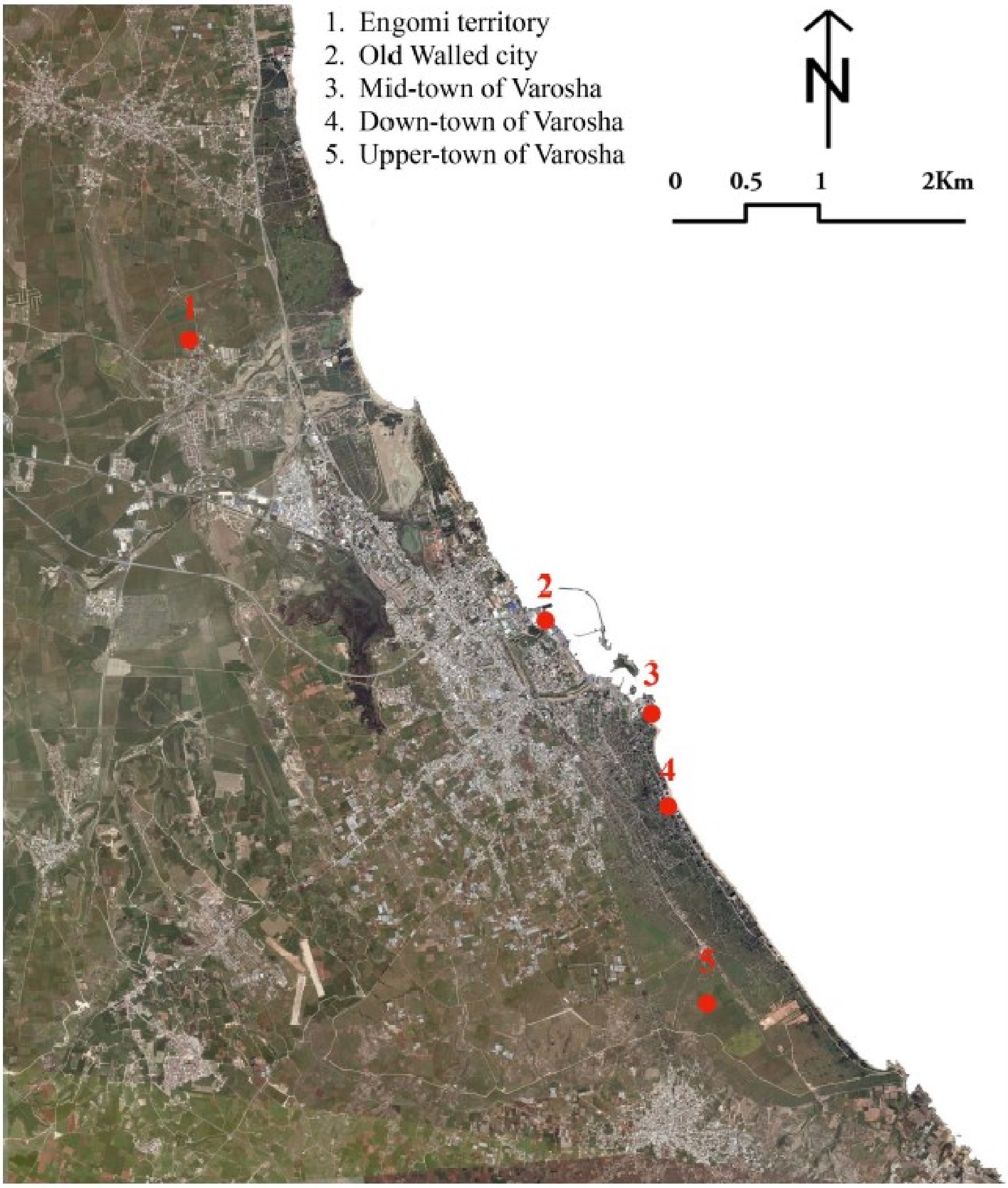


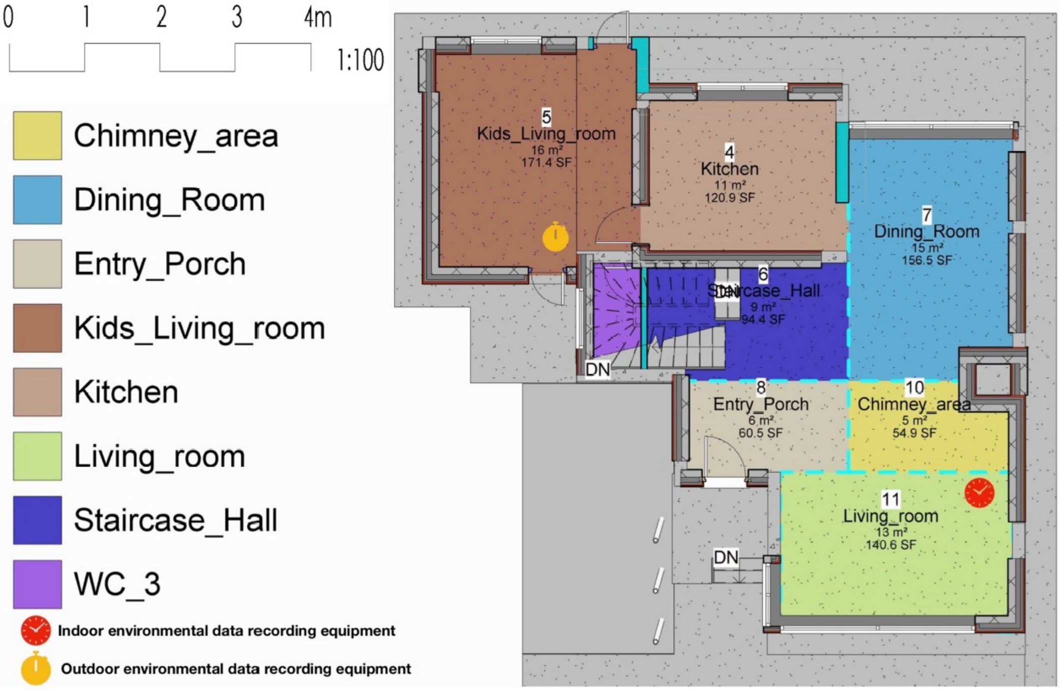
Figure 3. The tested prototype house model in a large-scale mass housing estate development in Famagusta

Figure 4. (a) The monitored and simulated southwest facing two storey detached housing unit pre-retrofitting. (b) The monitored and simulated northeast facing two storey detached housing unit post-retrofitting

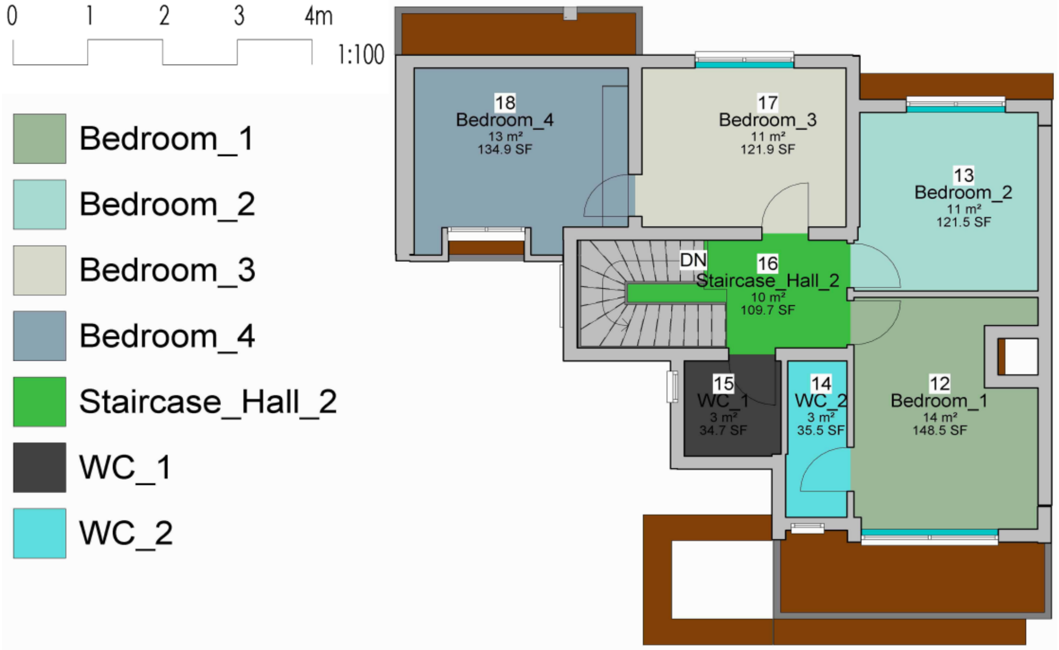
(a)

(b)

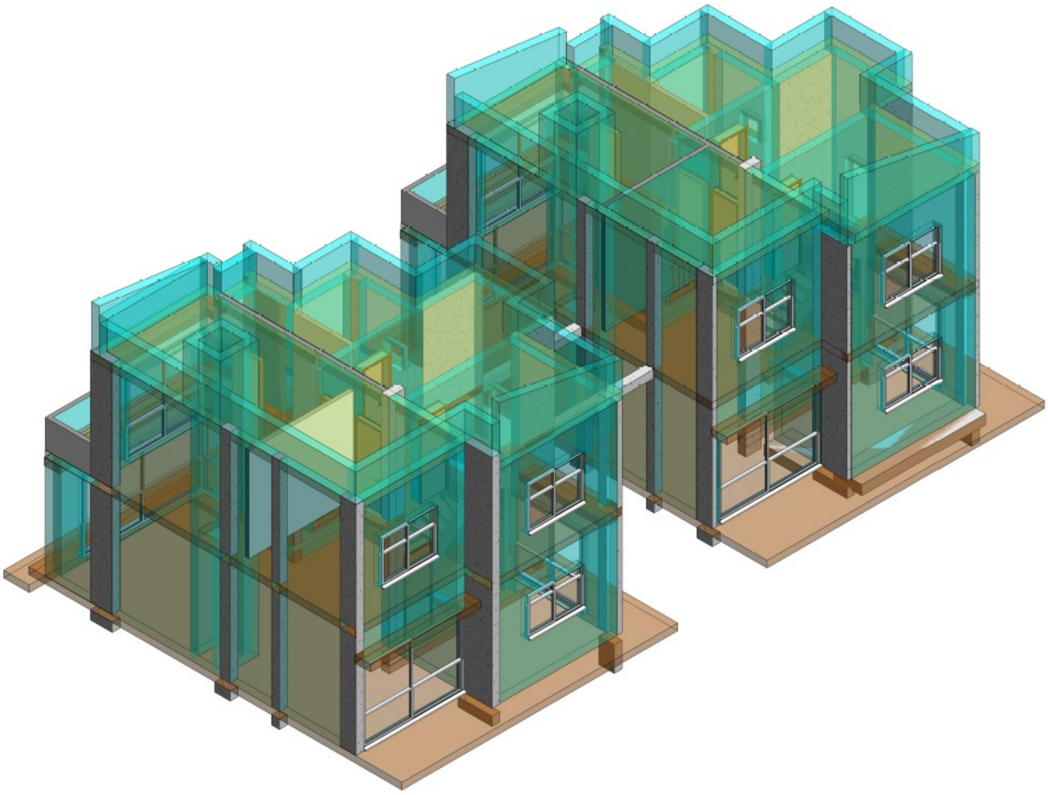
Figure 5. (a) The tested and simulated ground floor areas and the locations of the installed recording equipment for indoor and outdoor environmental conditions are indicated. (b) The tested and simulated first floor areas. (c) The analytical energy model of the tested and simulated prototype house model



(a)



(b)



(c)

Figure 6. (a) The monitoring results in August 2015 pre-retrofitting. (b) The monitoring results from September 2015 to February 2016 post-retrofitting

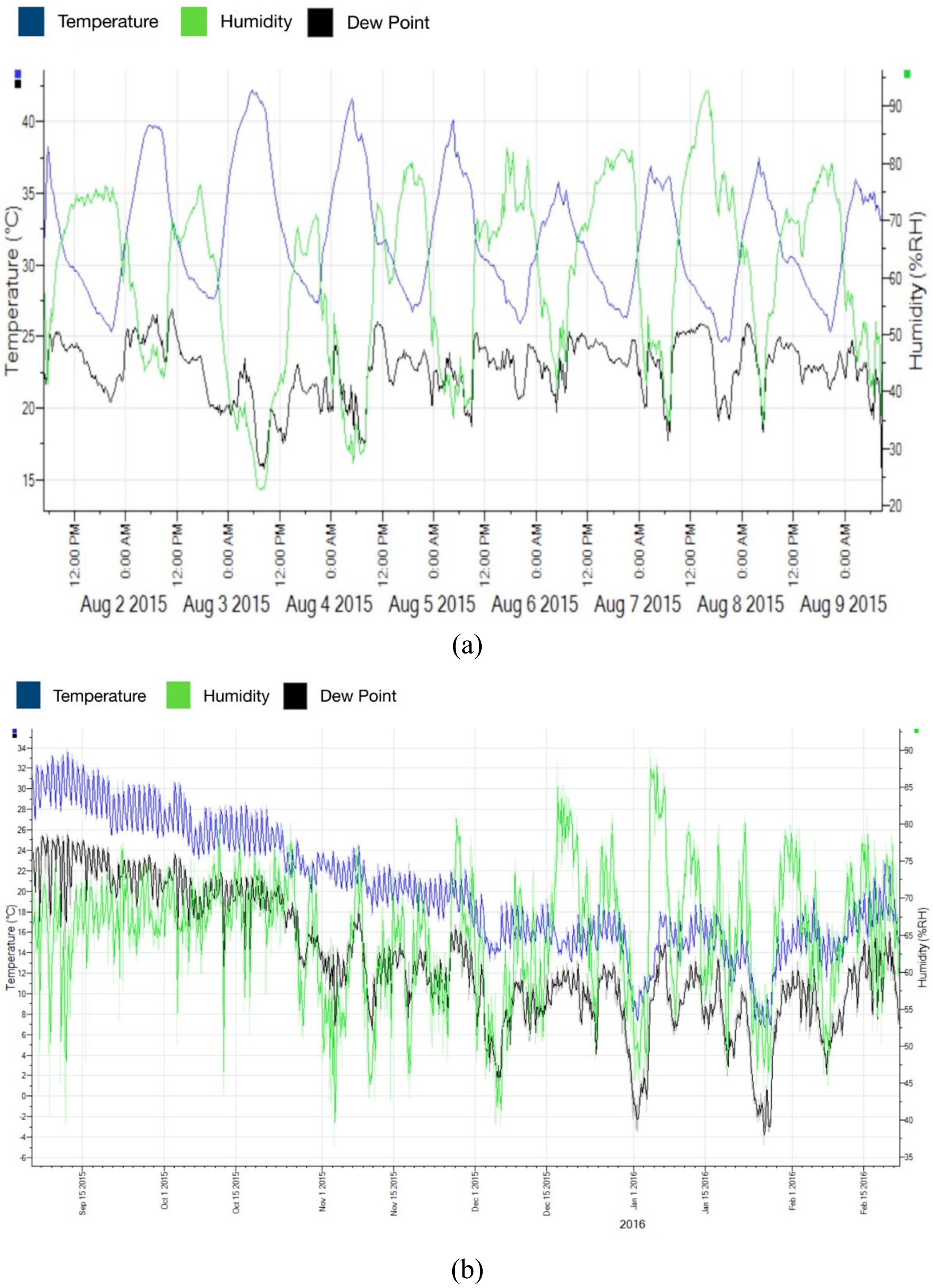
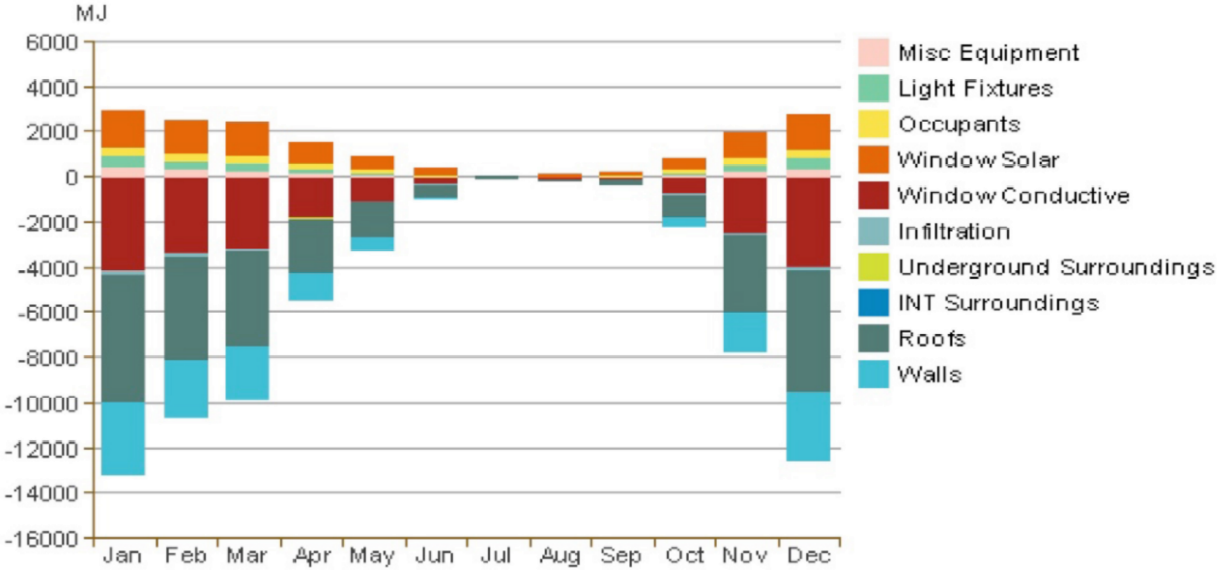
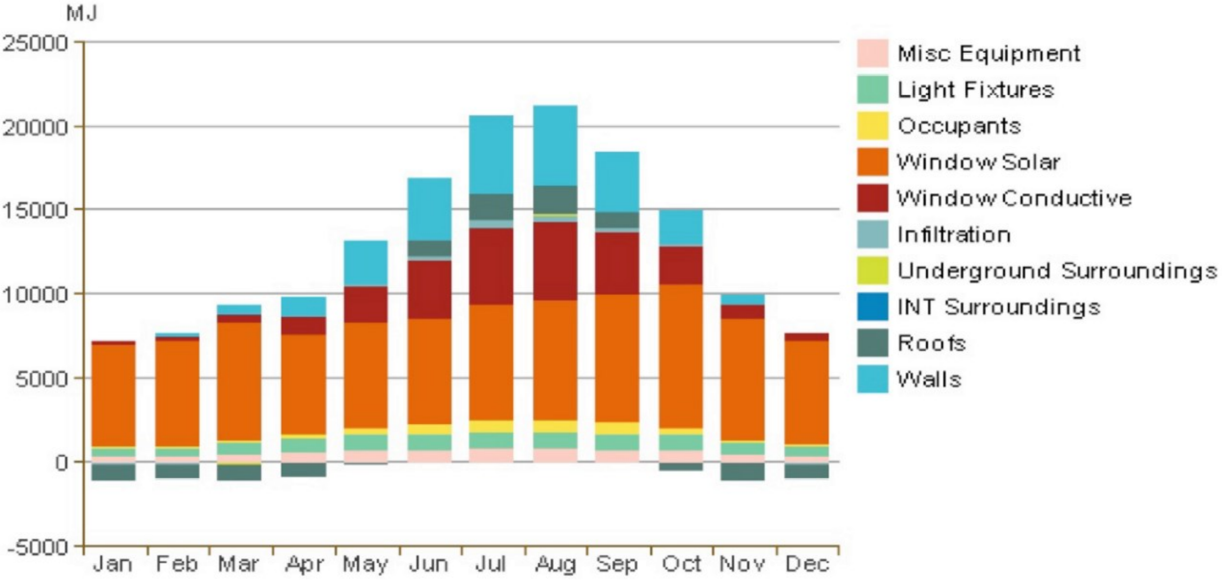


Figure 7. (a) The monthly heating load of the prototype house pre-retrofitting. (b) The monthly cooling load of the prototype house pre-retrofitting. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com).

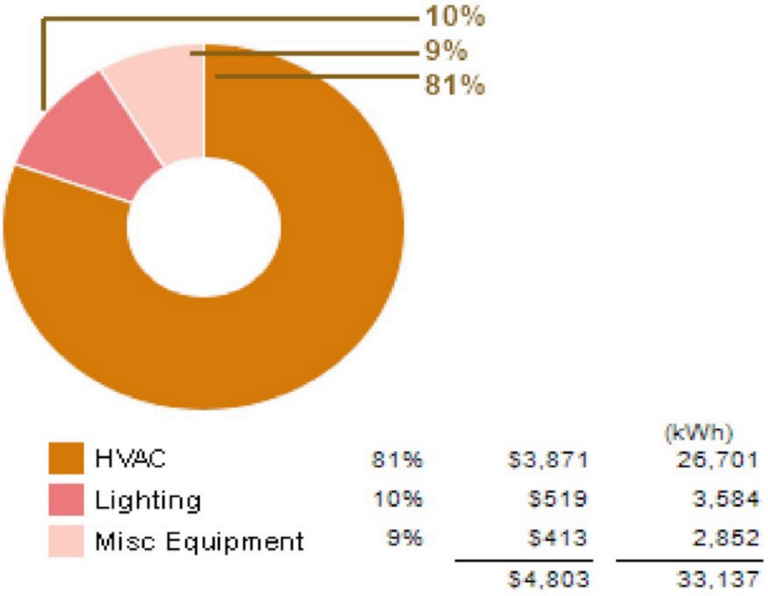


(a)

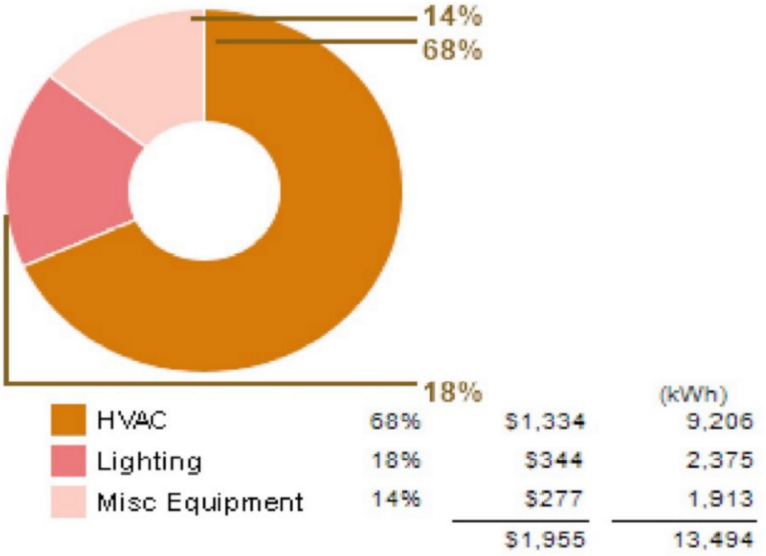


(b)

Figure 8. (a) The energy usage of the prototype house pre-retrofitting. (b) The energy usage of the prototype house post-retrofitting



(a)



(b)

Figure 9. The exploded axonometric of the prototype house construction system post retrofitting

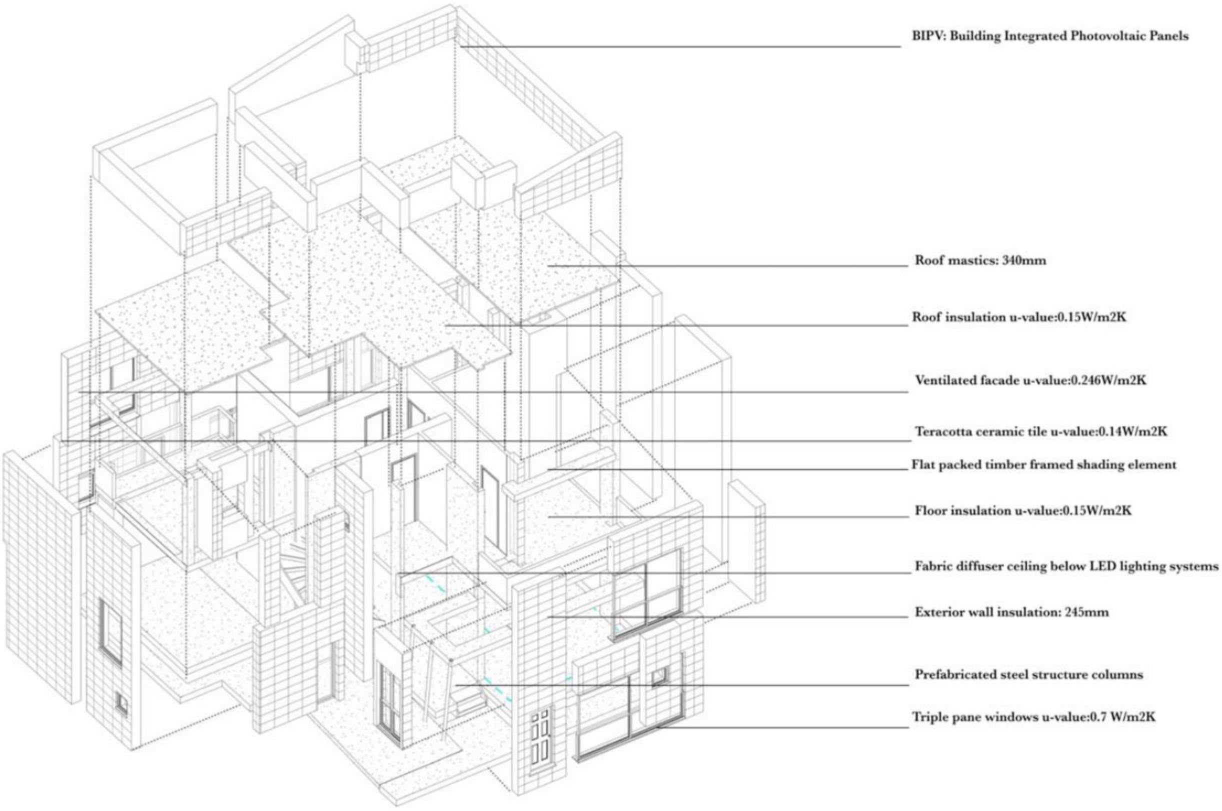


Figure 10. The annual carbon emissions of the prototype house post retrofitting. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com).