Optimizing energy performance of a neighborhood via IMM® methodology: Case Study of Barcelona

A. Behfar, M. M. Riyahi Alam, R. Shahmoradi, M. Tadi, S. Vahabzadeh

Abstract— Current policies to mitigate the climate change caused by human activities are oriented toward sustainable urban transformations to reduce the emission of greenhouse gases. The reason is that cities are energy-using systems in their own right, and they can use energy in dramatically more or less efficient ways. The urban settlement forms could have a disproportionately large effect over the Energy consumption and consequently on any effective long-term strategy for reducing $C0_2$ emission in atmosphere. Hence, this paper demonstrates how to transform an existing neighbourhood region (1) into a lower energy consumption system, using the IMM® (Integrated Modification Methodology). In this approach, the city is considered as a Complex Adaptive System; the research discusses how the urban system performance could be optimized via IMM®, expanding the energy efficiency goals from buildings to the urban scale, (2) including a possible mitigating solution for the Urban Heat Island phenomenon. Actually, the replacement of the existing traditional energy consuming buildings by new energy efficient or net-zero energy buildings could be a very slow process due to the economic reasons and the fact that these existing buildings are part of cultural heritage of the cities. As an energy retrofit method, a cluster of buildings in the neighborhood area was grouped together to be the subject of potential solar power installations. City of Barcelona, as the case study, with available an average solar radiation of about 1500 kWh/m^2/year has a potential to produce a significant amount of energy. Secondly, IMM® methodology has been associated together with the UHI (Urban Heat Island) mitigation method; city quarter was transformed with a symbiotic integration, of built-up mass layer; open spaces, streets, etc. layer; land use layer; Transportation and Mobility Layer, in order to improve the sustainability as well the living conditions, comfort and health for inhabitants in the urban and building environment.

***Keywords*—**Renewable energy, Solar power systems, Sustainable urban design, IMM® (Integrated Modification Methodology)

I. INTRODUCTION

Currently there is a very high confidence that the global average net effect of human activities since 1750 has been the main cause for global warming [1]. According to climate scenarios, the global mean temperature will increase continuously.

Since the first satellite recordings in 1979, satellite images show a steady decrease in the area of perennial ice at a rate of about 10% per decade.

Year 2005 had the warmest September in the last 4000 years (UNESCO). From a historical perspective, it is clear that fossil fuels will be exhausted in a very short time, after having been used by a small percentage of the world's population [2], [3].

Organization for Economic Co-operation and Development (OECD) indicates that the energy and environmental problems have an international scale. This is why the European Union has a strong role in defining sector strategies. The main issues are: environmental (pollution and Kyoto protocol compliance), economic and political (safety of energy supply).

European Union members make up for approximately 5% of the world's population, and they create about 15% of GHG globally. The energy production from renewable sources has a sustainable growth in the last decades due to the global policies adopted in that area. Therefore, the EU goal is to fight the spoliation of the natural environment due to the use of fossil fuels. EU committed itself to reduce GHG emissions by 8% when Kyoto protocol requires at least 5%. This requires great efforts (and money) for research to a sustainable development [4] which means the ability to satisfy the needs of the present without compromising the possibility of doing the same for the next generations (Brundtland report, over common future, 1987).

The 20/20/20 goal of EU members in 2020 is 20% increase in energy efficiency, 20% reduction of CO_2 emissions and 20% of energy produced from renewable energy resources (RES). In this term, a realistic strategy cannot ignore three main points:

1) Dependence on oil cannot be solved in short time; Resources are destined to exhaustion.
2) Our ability to use (RES) is quite limited at the moment.
3) No realistic forms of alternative energy for industrial, large-scale uses can be predicted in a short time.

All energy systems emit greenhouse gases (GHGs) and contribute to anthropogenic climate change. It is now widely recognized that GHG emissions resulting from the use of a particular energy technology need to be quantified over all stages of the technology and its fuel life cycle. Coal and natural gas have the largest share of utility power generation in the UE, which account for approximately 55 % of all utility-produced electricity [5].

Home to 80% of EU citizens and 70% of greenhouse gas emissions, urban areas play a key role in fighting climate change as well as energy consumption; but, cities' access to funding for green policies is proving a major stumbling

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block. “Although cities embody environmental damage, namely, increasing emissions due to transportation, energy consumption and other factors, policymakers and experts increasingly recognize the potential value of cities for long-term sustainability, after all, the majority of energy is consumed in cities. Therefore, it is an urban issue.” [6]

In consideration that the building sector represents 40% of the total primary energy demand in European Union countries and it is responsible for one third of the GHG emissions [7], while this amount would be approximately 23% in Spain which consists of two sectors: residential and commercial by 15% and 8% respectively [8], urban design principle can address the challenges in a comprehensive way, facilitating the conciliation between development and sustainability.

In 2008, Barcelona energy consumption represents 1.38% of all the energy consumption of Spain and is distributed as follows: tertiary sector 29.9%, residential 27.9%, transports 24.1%, industry 17.2% and in other sectors such as primary sector, energy, building and public works 0.8%. Electricity is the primary energy consumption source and represents 44.3% of total; natural gas represents 31.8% and the remainder diesel 15.4%, petrol 7% and liquefied petroleum gases (LPG) 1.4%. The consumption ratio per inhabitant was 10.52 MWh/inhabit with an average annual growth rate of 0.91% from 1999 to 2008, less than half the energy consumption by inhabitant of Spain (25.47 MWh/inhabit).

According to Energy, Climate Change and Air Quality Plan of Barcelona (PECQ), the analysis of the energy consumption evolution between 1999 and 2008 shows a rise of intensity in electricity consumption in the domestic sector as well as in the tertiary sector, which seems to go along with the evolution and rise of the ICT (Information and Communication Technology) in houses and offices, as well as a larger number and diversity of household appliances and electronic devices found in the market. This increase of electric consumption is frustrated with a high decrease, after 2005, in intensity in natural gas consumption within different sectors, which may be initially due to climate effects, and, later on, it may be due to the effect of the economic crisis. In 2008, the energy consumption of the secondary sector reached approximately the same level as the previous one in 1999, even though during this period it has not been a constant value, because the consumption increased until 2001; it showed a constant consumption until 2005, and finally it showed a fall of consumption down to the levels of the 90’s. Energy consumption in the transportation sector, whose figures in 2008 was above those in 1999, shows a light but sustained decrease since 2001. This performance derives most probably from the Public Administration policy in making public transportation more competitive than private transportation, and new efficient vehicles.

However, the GHG emissions in the city of Barcelona were decreased from 3.15 t GHG per inhabitant per year to of 2.51 t GHG per inhabitant per year, from 1999 to 2008, it does not necessarily mean energy efficiency improvement. An important part of this decrease in emissions is due to changes produced in this period for a better treatment of urban solid waste, while another part is due to methodological upgrades of emission factors.

The energy consumption of a specific building depends mainly on the building type, climatological conditions, building construction, annual hours of use, installations for heating, cooling, production of domestic hot water and lighting. Moreover, the policy making process in the urban scale, always deals with a variety of parameters in different urban fabrics and it is not reliable to make a decision based on a specific case study. In 2008, the residential sector in Barcelona consumed 4,794 GWh, 28% of final energy, which distributed equally between electricity and natural gas (approximately 48% each) while the remaining consumption was of LPG that progressively is declining year after year [9].

The limited availability of fossil energy resources at affordable prices and the related problems in terms of climate change necessitate the use of regenerative energies such as solar energy [10]. The real issue is how to integrate our well-being whilst safeguarding the environment.

Energy efficiency and sustainable development are definitely one of the urban issues. Therefore, for achieving any energy-saving policy, urban efficiency, quality of life, and generally, for any sustainable urban environments, it is necessary to work with an holistic and multi-scale approach involving simultaneously all the areas of energy, as well as water, waste, urban green spaces, mobility, and participation with social cohesion. Hence, a multi-disciplinary approach is needed to tackle the environmental issues. This research is devoted mostly to how to maximize the energy efficiency of the neighborhood area through the usage of renewable energy and better environmental conditions in the local region due to the UHI mitigation solution.

Since the end of 2004 to the end of 2008, solar photovoltaic (PV) capacity increased six fold to more than 16GW, wind power capacity increased 250% to 121GW and world’s total power capacity from new renewables increased 75% to 250GW[11]. Solar energy has been advocated for building applications for many years. The solar intensity on surfaces varies with geographical and environmental conditions. The availability is limited to the daytime, and may not be in line with the energy demands in buildings, such as for water heating or space heating [12]. Solar radiation resource availability in Barcelona is one of the highest in the EU region, ranging from 3.2 to 5.2 kWh/m^2/day [13]. In this regards, renewable energy production in Barcelona significantly increased up to 96.53 GWh in 2008. The energy sources used for this production were photovoltaic energy, solar thermal, small-scale hydraulics and biogas.

II. RESEARCH FOCUS

This research is solely a piece of multi-disciplinary transformation plan of a neighborhood, located in the city of Barcelona. This research is devoted to the optimization of solar energy usage and to improve the environmental conditions in the neighborhood; however, there are other aspects of IMM®, such as the Transportation, Functional and the Green layer, which are not discussed in this paper. A brief review of IMM® is presented before solar energy and UHI mitigation study as the main goals of the paper.

The economics, technical performance and optimization [14]-[19], as well as the modeling and sizing [20]-[31] of a number of different solar water heating technologies deployed in different climates, has been extensively investigated and reported in the literature. In this work, as part of the proposed sustainable recovery approach, we have looked into the efficiency of methodologies for evaluating the potential of solar energy utilization in the neighborhood scale of sustainable urban environment. Regarding the energy consumption in this region, Urban Heat Island phenomenon should be mitigated. It describes the phenomenon of higher temperature of an urban region in comparison to the rural surrounding. UHI, especially if intensified, could affect the cooling demands negatively [32]. There are currently several mitigation methods under study from which, planting of vegetation, as an effective climate regulator, has proved effective in Mediterranean climate [33].

III. METHODOLOGY

This paper demonstrates how an innovative methodology, called IMM® (Integrated Modification Methodology) [34] applied on a specific case study works to transform an existing urban context into a more efficient and sustainable urban assessment (Complex System), improving its energy and performance as well as the performance of every single component. In this approach, the city has been considered as a single entity, composed by heterogeneous constituents, which are connected together, either directly and indirectly [35].

In this type of holistic method, the final system performance results from the whole elements; moreover, the city reshapes itself through a dynamic and on-going adaptation process of its constituents. Hence, the IMM® (Integrated Modification Methodology) acted to transform locally the existing four Eixample courtyards in order to start a reaction involving the entire Barcelona urban context and changing the CAS structurally. As a consequence of the whole transformation's process a new morphology of the System has emerged as well as better performances results, that will lead the Barcelona urban system into a more sustainable one.

IV. THE INTERMEDIATE SCALE.

The initial request of the presented project was directed to individual transformation of four Barcelona urban block courtyards, toward sustainable public spaces, which could serve the surrounding area. Redesigning these four courtyards is part of a greater Barcelona urban strategy, called ProEixample [34], which aims to recover an identified number of courtyards. "The proposed approach is based on consideration of those blocks as a part of whole Barcelona urban system. In the other words, in chasing after sustainable urban blocks, not only sustainable building technology is considered, but also their effect on urban assessment as a member of whole system has to be taken into account. According to this holistic and multi-scale approach, the implemented intervention focuses on Global scale (city scale) as well as local scale (block scale) [35].

The neighbourhood scale (Fig. 1) as the scale of intervention (intermediate scale) has been defined including 41 blocks of the Eixample. Thanks to integration with the green corridor project and the modification of the Transportation Layer, the number of private cars is reduced, while public transportation is promoted increasing the Accessibility of the area.

Accordingly, and in order to increase the Accessibility, different functions such as administrations and services are proposed along the public transportation corridors

The intermediate scale also could be defined as the area that gets directly influenced by the local interventions, having a role of global transformation.

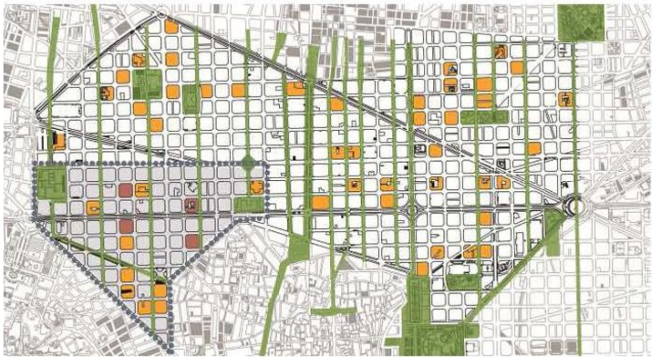


Fig.1. ProEixample courtyards regenerating project is indicated by orange; while, the location of the four design blocks under consideration of regeneration are indicated in dark red. Green lines show the green corridor, proposed by M.Gausa. The area bordered by blue dotted line is the intermediate scale project area.

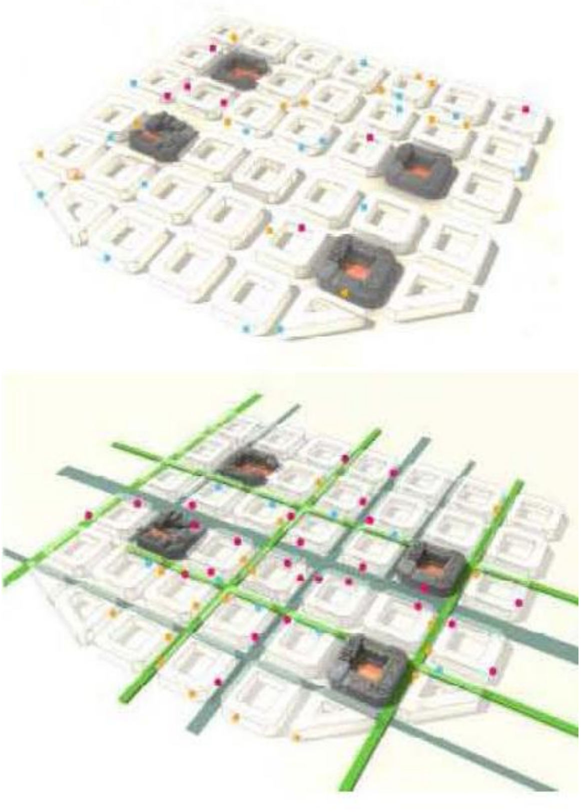


Fig.2. The location of four courtyards in the neighbourhood, administrations and services are indicated by red, when cultural and entertainment is shown with yellow and educational spaces with light blue. Above: Actual neighbourhood diversity situation is illustrated by coloured rectangles; Below M.Gausa green corridors are shown by green lines when new proposed transportation lines are illustrated by dark blue lines. Our proposal play with Diversity; Accessibility of the neighbourhood transforming its energy performance. [36]

The proposal improves the Diversity by increasing the number of key facilities. The modification of Diversity and Interface (Function layer, Void and Transportation layer) brings more Complexity to the neighborhood.

Simuntaneusly, in order to improve the Accessibility, new functions are proposed with consideration of symbiotic relationship with transportation and green layers, as well as the administrative and services are mostly located along to the public transportation lines and entertainment spaces are along green corridors.

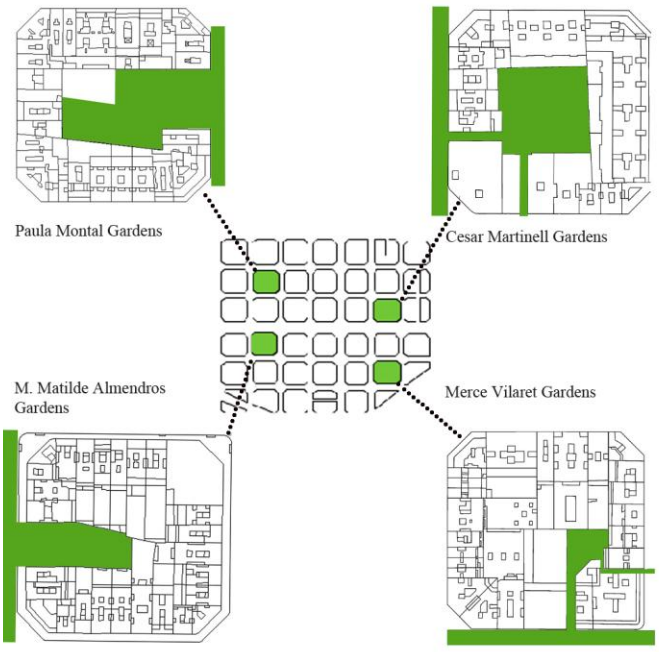


Fig.3. Eixample district and selected blocks as case studies

A. *Energy retrofit*

In accordance with the IMM® methodology every single element works as a multiplier of the performance of every other single component. In this proposal, renewable energy production consists of PV panels and solar collectors.

Despite the fact that residential blocks (6 floors, 113×113 m^2 and courtyard in the center) were chosen randomly among the potentially recoverable blocks in the area of the Eixample, the output design mean values will be reliable data in urban policy making processes. Details are presented in Table 1 and 2 and Fig. 3 and Fig. 4.

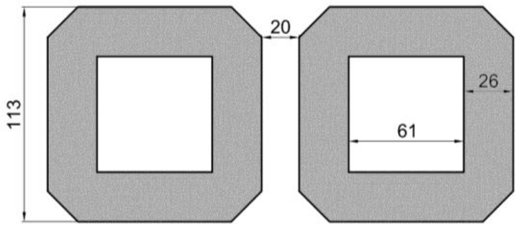
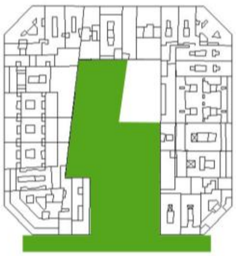
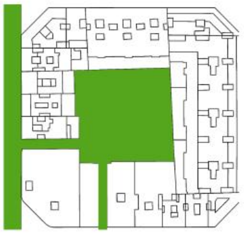
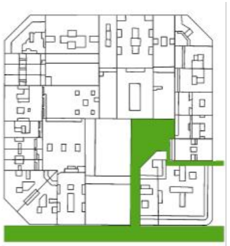


Fig.4. Dimensions of the identical blocks in meter shown in schematic view

In these case studies, the possible installation location of solar collectors and PV panels are: on the rooftop, facades and courtyard. The scale of the solar power systems' installations depend on:

1) Energy production capacity of the PV panels and solar collectors.
2) The desired efficiency: Pre-defined goals for the amount of electricity and hot water production in comparison to total consumption.
3) Spatial and installation parameters.
4) Solar access.

Table 1. Randomly selected blocks: plans and features.

Plan view of Blocks		Features
1		**Paula Montal** Courtyard is almost free which provides good opportunity for solar trees' installations. But less rooftop spaces are available.
2		**Cesar Martinel** This courtyard is suitable for both solar trees and occupation of rooftops
3		**Maria Matilde Almendros** The existing buildings occupy the courtyard but more free spaces are available for rooftops installations.
4		**Merce Vilaret** Small portion of the courtyard has been left. But more space in rooftops is available.

By obtaining the number of inhabitants in each block, an estimation of the total energy consumption was gained. Total energy consumption per each person is 2.96 MWh/year in residential sector, while the portion of the electricity is 1.43 MWh/year. This means that every year almost 50% of total energy consumption is spent on electricity for each individual. Therefore, installations of PVs are well advised and also contain a financial justification.

Table 2. Breakdown of residential population

	Eixample District	Stochastic Community	Single Block
Number of Blocks	415	4	1
Number of Inhabitants	266,874	2570	640

1) Energy Production Capacity

The energy production of blocks consists of two parts of PV panels and solar collectors. Depending on the apparatus type, the energy production would be different however; it would not affect our purpose. In equation (1) total produced energy of an installed solar power system (MWh/year) is defined:

$$EP_{sps} = E_{ADSR\ per\ square\ meter} * A_{sps} * n * \eta_{sps} \qquad (1)$$

In this equation, $E_{ADSR\ per\ square\ meter}$ is average daily solar radiation in MWh per square meter of the solar power system. A_{sps} defines the area of the surfaces which is obtained as a percentage of the roof or facade, and n is the solar power system working days in a year. Finally, η_{sps} accounts for the solar power system efficiency, which is discussed more in the following section.

2) Desired Efficiency

In this energy retrofit method, buildings with similar potentials of renewable energy production would be grouped together and are referred to as Clustered Neighborhood Buildings (CNB). The purpose is to move our attention from energy efficiency in building level to urban scale. Considerations of creating the CNBs, could be grouped as following:

1) Energy consumption per unit of apartments: Since the cluster of the buildings is to share some common power generating systems, therefore it is important that they have close energy consumption patterns.
2) Functions in the urban scale such as residential and commercial: Buildings with the same function are more likely to have the similar energy consumption patterns than buildings with different functions.
3) Inhabitants' attitude toward the usage of renewable sources of energy.

Total energy consumption reduction in existing urban patterns due to installations of solar power systems could be explained in two following energy efficiency terms: firstly, measuring of PV panels or solar collector efficiency, and secondly, expected energy efficiency of the Clustered Neighborhood Buildings.

Let us first start with the photovoltaic solar panels and solar collectors' efficiency, which is important to choose a correct product for installation system. For example, smaller roofs and surfaces with lower incident radiation flux require more efficient products. The area of the solar power system, which is necessary to produce the maximum power output, determines the efficiency of the solar power system. Therefore solar power system efficiency (η) is defined as:

$$\eta_{solar\ power\ system\ efficiency} = \frac{P_{max}}{E_{IRF}*A_{sps}} \qquad (2)$$

Where, P_{max} is the maximum power of the designed system, A_{sps} is the area needed to produce such power which represents solar power surface area, and E_{IRF} is the amount of the incident radiation flux on the earth surface in W/m^2.

After determining the efficiency for solar power systems to achieve the desired power output over a limited area, now the urban area efficiency subjected to the installation could be defined as:

$$\eta_{CNB} = \frac{EP_{CNB}}{EC_{CNB}} \qquad (3)$$

η_{CNB} accounts for the energy efficiency of the Clustered Neighborhood Buildings. EP_{CNB} defines the solar power systems energy production in CNB, and is the total energy consumption of the CNB.

The overall energy consumption of a block (EC_{CNB}) was calculated by multiplying the energy consumption of a person in the region per year to the number of inhabitants living in a block. Therefore, for the selected case studies, the annual value of 1900 MWh for each block was obtained; 50% is related to the electricity and the rest is necessary heating energy.

In Eixample district, it is worthwhile to mention that more than half of the cities electricity supply is provided by the nuclear plants. In addition, in the last decade about 50% of the residential energy consumption was due to water heating process for domestic purposes. This leads to the fact that the solar collector systems are more beneficial than PV panels in term of using solar renewable energy. This consideration along with other factors affected the proposals in this work.

3) Spatial and Installation Parameters

Solar collectors are equipped with a storage tank for water to use the hot water for periods in which the solar radiation is off or not sufficient. Application of the solar collectors in a huge scale means that the load of the water tanks and the necessary equipment should be considered, especially, when the subjected buildings are not newly built or there are some doubts about their stability under extra loading. Another important factor would be the consideration of the area occupied by the installations; For example, the PV panels are required to be installed in a large scale to produce a considerable amount of energy. This consideration is especially important for buildings, which already have some equipment, installed on rooftop. Therefore, the amount of installations would be limited to the available area.

4) Solar Access Analysis

Most preferably, the ideal space for installations would be an open space in which there is no surrounding shading effect to prevent energy production. In cities with high-density, it is not always possible to install the facilities in sufficient open areas. It means some projected shadow should be considered from the early stages of the design. The profitability and usefulness of the proposed installations are directly dependent on the amount of receiving solar radiation for the correct functioning of the PV panels and solar collectors that are suggested for available surfaces. Even without analysis, it is obvious that the surrounding buildings in the blocks would create shadows in some hours of the day in the central courtyard and on the adjacent or opposite buildings' façades. For the central courtyards, the projected shadow is closer to the buildings than in the central part. Similarly, for the facades, the highest level is preferred for installations. To obtain accurate quantitative data, the neighborhood area is modeled in the Ecotect software for solar access analysis in order to control and compare the minimum required values for installations. Ecotect was chosen as simulation tool, because it enables the designer to import 3D models of the site, and it is widely used by architects in the process of design.

In Ecotect, a solar access analysis with 'medium' settings was performed to obtain accurate incident solar radiation over the whole cluster of buildings in Paula Montal block. (Lat: 41.3 and Lng: 2.1).

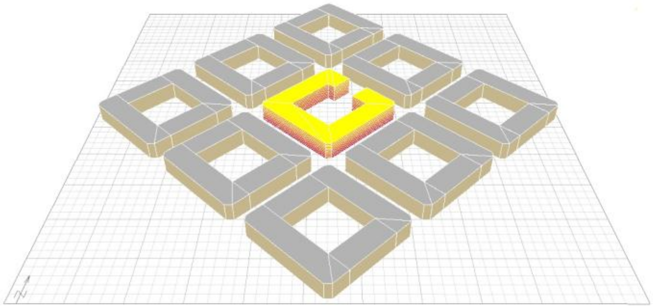


Fig.5. Clustered Neighborhood Buildings of Paula Montal in city quarter

Fig.6. Building sidewall in the Paula Montal block

Since blocks have the same dimensions and orientation, and also, the neighborhood is favoring a regular grid pattern all around it, therefore, a comprehensive solar access analysis on one of the blocks could be a reliable representation for the others. The purpose of this analysis was to identify suitable location for solar power installations, and to justify their applications. Therefore, within Ecotect, surfaces with an average daily solar radiation above 2000 Wh/m^2 were identified. This value creates 730 KWh/m^2/year, which with a 15% efficient PV cell, it produces about 110 KWh/m^2/year.

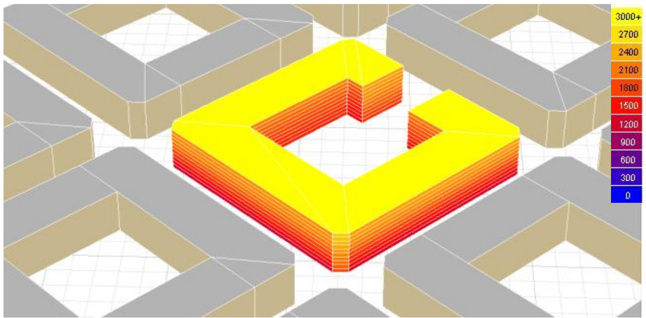


Fig.7. Solar average daily radiation in Wh/m^2 of roof top and envelopes in the Paula Montal (south façades)

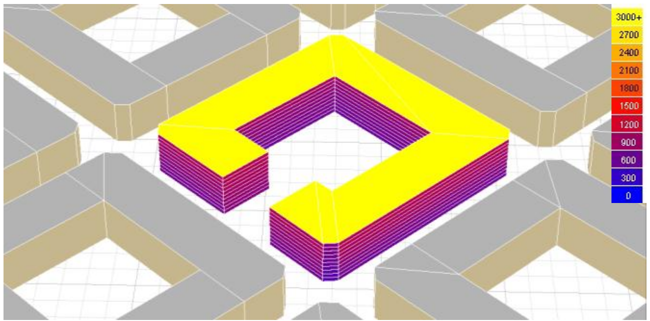


Fig.8. Solar average daily radiation in Wh/m^2 of roof top and envelopes in the Paula Montal (north façades)

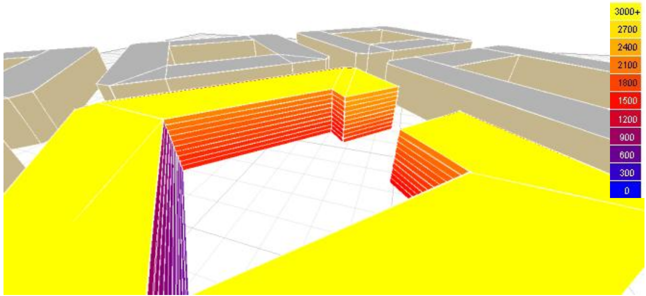


Fig.9. Solar average daily radiation in Wh/m^2 on facades of the Paula Montal interior courtyard

Analysis of incident radiation flux by Ecotect software in the city quarter is shown in Fig. 7 to 9. Fig. 5 contains CNB of Paula Montal in the city quarter. Incident radiation flux on the building envelope and roof top are shown in Fig. 7, 8 and 9 in more details. It is obvious that roof top and upper levels of envelope receive more solar radiation than the lower levels. This amount varies between 1500 Wh/m^2/day and 2400 Wh/m^2/day on south facing envelopes and between 150 Wh/m^2/day and 900 Wh/m^2/day on north facing facades. Roof top shows the maximum solar radiation of more than 3500 Wh/m^2/day and could be identified as the best surface for solar power installations.

It is true that roof top has the maximum incident radiation flux, but some potential areas on façade could also be identified which have high solar radiation. As an example of such surfaces is shown in fig. 6 and its solar access analysis is shown in Fig. 9. This portion of envelope with 200 m^2 has high solar irradiance of about 2000 Wh/m^2/day as an average value. Depending on the desired efficiency for the whole block, this location proves suitable for electricity production of 22 MWh per year (110 KWh/m^2/year * 200m^2). Fig. 10 shows a potential place for solar PV panels' installation. This detailed solar access analysis affected our decisions to arrive to the finale proposals of selected four CNBs energy retrofit.

Fig.10. Potential usage of the PV panels in Paula Montal block

B. *Urban Heat Island effect mitigation*

Most of the world's cities experience higher temperatures in the urban core which affects the thermal environment, health and energy consumption of the building. Typically, vegetation covers only a small fraction of the surface in cities, consequently, evapotranspiration is significantly reduced and radiant energy partition into sensible heat rather than latent heat. Vegetation is a mitigating solution since it reduces air temperature through direct shading or by moderating solar irradiance and converting them to latent heat [32], [33], [37], [38]. Among available UHI mitigation methods the conversion of artificial surfaces to natural surfaces is most suitable match with our sustainable recovery approach.

In this high dense city quarter, the division of the occupied surfaces is as follow: 48% roof top, 34% streets, 18% courtyards. In the under context under consideration in this work, greeneries exist mainly in the courtyards, however, there are some vegetation in the street sidewalks. The existing ration of green to built area was calculated as 9.94 percent for this region.

Solar access analysis on the city ground level demonstrates the high level of incident radiation flux of about 3500 Wh/m^2/day for the central part of the courtyards and about 2500 Wh/m^2/day for the street surfaces. The reason of such high amount of solar radiation on ground surface is that buildings have relatively low height and there is no high-rise building in the city quarter to create shadings on the region (fig. 11). Under such high solar radiation, dark and artificially covered surfaces help to increase the temperature of the surrounding by storing higher amount of heat. Therefore, as an attempt to mitigate UHI effect, it is tried to convert artificial covered surfaces to grass-covered areas.

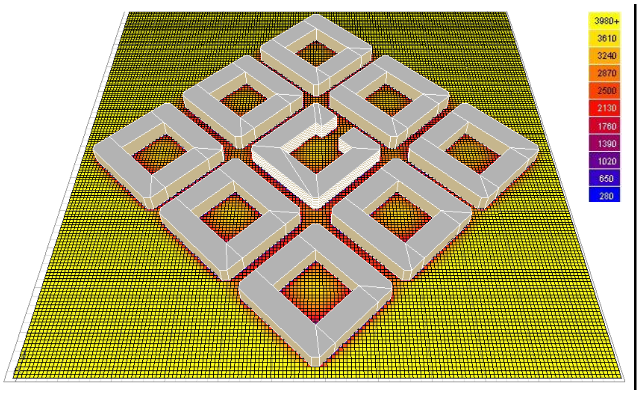


Fig.11. Solar access for grid line on the ground level showing intensity of the incident solar radiation (average daily values in Wh

Roof tops with 48% of the total area in the city quarter appear to be suitable area for this conversion, however due to the following reasons they were not considered in our approach:

1) Roof tops are considered mainly for solar power installations relating to the energy retrofit.
2) Technical difficulties in the implementation of vegetation on roof tops.
3) Cost of the implementation green roof, especially on the existing buildings.

However, as another solution for this problem, roof tops can be painted with white color to reduce the absorbed heat.

Interior courtyards already have good level of vegetation due to the recent recoveries from the municipality. Therefore, to further increase the ration of green to built area, in this work, by analyzing the street axes and traffic plan, it is tried to identify the suitable axes to convert them from vehicular use to pedestrian walk in order to increase grass-covered area in the region. In the city quarter, typical streets are 20 meters wide and with a relatively low aspect ratio of 1 (H/W=20/20) and are planted with trees with distance of each 5-10 meters in both sides.

C. *Transportation*

The transportation layer main approach is based on super imposition of two different existing strategies: superblock strategy proposed by Agència d'Ecologia Urbana de Barcelona [39] and the green corridor plan proposed by M. Gausa. This Superblock strategy is based on of a grid of basic roads forming a polygon, some 400 by 400 meters, with both interior and exterior components. The car free interior streets are covered by green and used solely by the superblock's residence cars, service cars and emergency vehicles. On the other hand, Superblocks' peripheral axes are devoted to motorized traffic circulates, and makes up the basic roads.

The Superblock plan significantly improves the urban quality while reduces the environmental impacts of vehicles. It also plays an important role for increasing the environmental quality as well as the urban energy performances while it improves the life of residents without major changes in urban planning, or without heavy restructuring project of the city. Indeed, this plan just changes the uses and hierarchy of the existing city grid.

Fig.12. A superblock is comprised of 9 blocks, confined by vehicular streets; the internal connections are pedestrianized and covered by green layer. Source: Agencia de Ecología Urbana de Bar Barcelona.

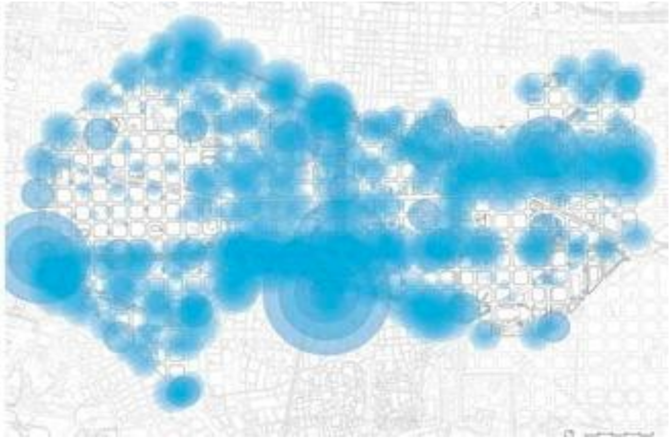


Fig.13. Bus intensity map. Circle dimension is related with bus number passing through certain points. Source: Municipality of Barcelona.

Hence, an important role has been played by the relationship between the new car free zone and Accessibility by public transportation (bus, metro lines) in order to achieve a relevant improvement of city performances. Accordingly, the main concern at this stage has devoted to the secondary axes to increase their environmental role. Due to the improvement of their vegetation level, creating an equally distributed vegetation area in the city quarter, the environmental performance of the neighborhood has been improved.

The inner axes in the fig. 14 devoted to the pedestrian uses are partially converted in public spaces with pedestrian and bicycle paths as well with new green areas.

In accordance with the Superblock plan, vehicular access in these streets has been partially removed and their asphalt surfaces have been converted to a green vegetation surface. In this inner axes also electrical vehicular are accepted. Fig. 15 shows the combined plan of the final street networks and the land conversions, which intends to attract pedestrians.

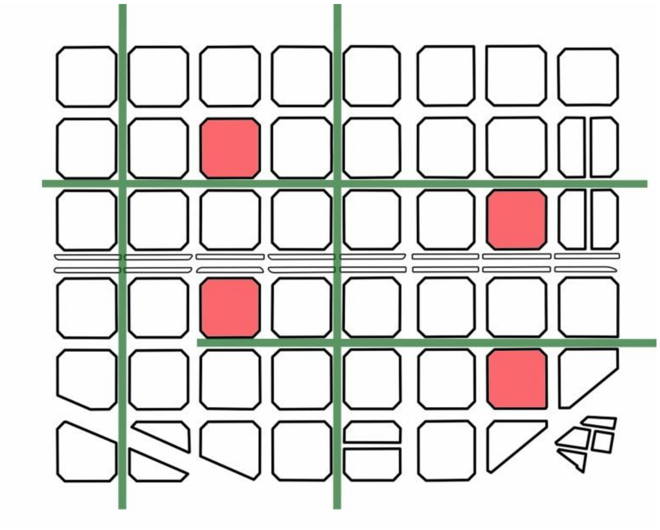


Fig.14. Proposed axes for partially conversion to grass-covered pedestrian walk, public spaces and pedestrian and bicycle paths

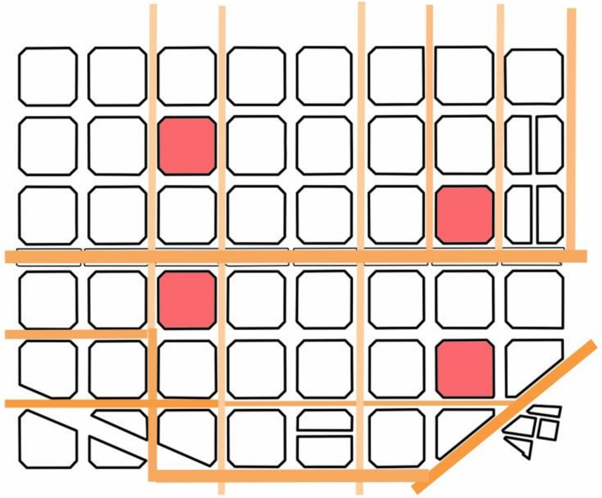


Fig.15. Existing road networks and the associated traffic load shown by the intensity of the color

In consideration that the actual energy consumption per capita in transportation sector in Barcelona has been estimated in 2.54 MWh, the implementation of a new mobility strategy for promoting public transportation as well as the bicycle and pedestrian connection are expected to reduce tremendously this demand.

In order to increase the feasibility of the transportation system and city configuration proposal, these interventions and modifications have been implemented through different phases [40]. At the end of the intervention process the saved energy in the transportation sector reached a considerable level. This reduction in private vehicular demands is emerged through following facts:

1) Removing the cars in the neighborhood; instead providing a public transportation substitution. It signifies the improvement of two Key Categories of the IMM®, which are Accessibility and Efficiency [41]. In this case, the willingness of public transport usage increases.
2) Increasing Proximity and Diversity, two other Key Categories of the IMM®, by providing diverse functions in vicinity of the neighborhood dwellings.
3) Providing bike sharing as well as electrical car sharing system for the neighborhood as the integrated part of the entire city.

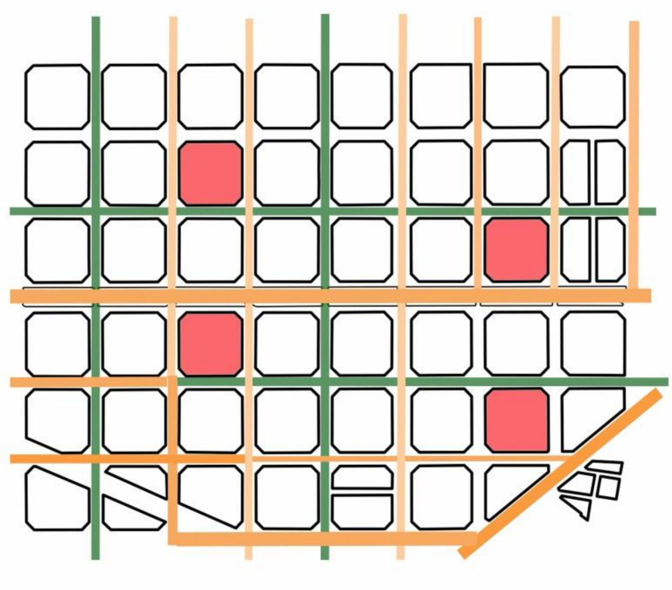


Fig.16. Proposal for the city quarter region

D. SCENARIOS OF land COVER CHANGE

In order to explore the effect of land cover change based on the proposed axes conversion in the neighborhood area from vehicular to pedestrian way, four scenarios were considered to have a better grasp of the effectiveness of this conversion, and to consider different conversion plans to increase the compatibility with the municipality policy. Here, four thresholds of the conversion level from asphalt-covered surfaces to grass-covered lands are considered: 25%, 50%, 75% and 100%; which are shown with their associated green area increase in table 3. In literature, there are some attempts to find the effect of vegetation increase on the local regions' air temperature. For the specific region under consideration in this paper, the accurate calculation and simulation of the effect of proposed green corridors on the temperature of its surrounding region remains as our future research and study. However, in order to show the potential benefit of our proposal, we make an analogy; we obtain a possible temperature reduction due to each scenario based on the findings of A. Dimoudi. et al. in [38]. They suggested that, as a good approximation, every 10 percent increase in the ration of green to built area in their specific region under consideration (not Barcelona), could cause the ambient air temperature to drop about 0.8 K.

Table 3. Total energy production and efficiency related to each selected block.

Scenarios				
	Land cover conversion	Total area of neighborhood in m^2	Threshold of conversion percentage	Associated green area increase in m^2
1	asphalt → grass	850000	25%	12968
2			50%	25935
3			75%	38903
4			100%	51870

V. RESULTS AND DISCUSSIONS

A. *Energy retrofit*

In this work, the total energy production due to installation area for all of the four blocks, namely Maria Matilde, Paula Montal, Cesar Martinell and Merce Vilaret, were obtained and shown in Table 4. On the other hand, Table 5 illustrates total energy generation and efficiency of the blocks in respect to their total consumption. Furthermore, while we wish to use courtyard as an installation base for PV panels in the shape of solar trees, absorbed solar energy should be considered. Simulation of the neighborhood area in Ecotect software revealed the following results:

1) Courtyards on ground level receive considerable amount of solar radiation and the shading effects of surrounding buildings in the center of the courtyard do not reduce the solar radiation flux considerably. This makes the application of solar trees possible and effective.
2) Roof tops, as it was expected, have a high level of solar irradiance. This fact is mainly because of the geographical location of the buildings and the fact that there is no high-rise building, which creates shading over the roofs.
3) Building envelopes in the interior courtyards have very different solar irradiation on their surfaces. This difference could reach up to 2000 Wh/m^2 between two opposite points in a courtyard. South facing envelops receive an average daily radiation of between 1500-2400 Wh/m^2, however, north facing facades solar radiation is poor and around 150-900 Wh/m^2. This huge difference emphasizes the necessity of performing solar simulations from the initial stages of any sustainable urban design or recovery.

Our results show that Maria Matilde and Merce Vilarte blocks with approximately same facade area for installation of PV panels, which is giving almost same total energy production and about 29 MWh/year that is the minimum amount among all four blocks. However, Cesar Martinell block by using both rooftop and solar trees in courtyard area reached to the maximum amount of 334.65 MWh/year energy productions compare to other blocks. In comparison to PV panels, solar collectors are used only on rooftops regarding to their installation problems for all of the cases. Due to wide area occupation for installation of solar collectors in Maria Matilde and Merce Vilaret (exactly twice of the area used in two other blocks), the total energy production in former blocks are twice the latters and equal to 843.15 MWh/year. It is clear that the main role of these differences played by area amount.

By summing up all total energy productions obtained from all four cases, we received to three different efficiency percentages of blocks, 30% and 40% for Paula Montal and Cesar Martinell respectively and 46% for both Maria Matilde and Merce Vilaret blocks. Eventually, it is apparent that solar power energy generation is more useful in case of Maria Matilde and Merce Vilaret blocks. These results are presented in table 5 and Fig. 17. In this bar chart, vertical axis shows energy consumption and energy production (MWh/year) while horizontal axis shows four different blocks situation. Actual energy consumption, solar collectors' energy production and PV panels' energy production are being represented by standing red, green and purple lines respectively. Our calculations demonstrate that the renewable energy generated by solar power, effectively reduce energy consumption of our stochastic community urban pattern in the range of 30% to 50% (table 5). This case study will be extensible as a suggesting pattern for other cities.

Table 4. area of PV panels and solar collectors and their associated energy production in four selected blocks

		Maria Matilde	Paula Montal	Cesar Martinel	Merce Vilaret
PV panel area(m^2) and energy production(MWh/year)					
Rooftops	m2	-	1100	2200	-
	MWh/year	-	140.52	281.51	-
façade	m2	222	-	-	230
	MWh/year	28.35	-	-	29.38
solar tree	m2	-	-	103.12	-
	MWh/year	-	-	26.57	-
energy production (MWh/year)		28.35	140.52	334.65	29.38
Solar collectors area(m^2) and energy production(MWh/year)					
Rooftops	m2	2200	1100	1100	2200
	MWh/year	843.15	421.57	421.57	843.15
façade	m2	-	-	-	-
	MWh/year	-	-	-	-
solar tree	m2	-	-	-	-
	MWh/year	-	-	-	-
energy production (MWh/year)		843.15	421.57	421.57	843.15

Table 5. Total energy production and efficiency

Case Study	Total Energy Production MWh/year	Efficiency of the block in respect to its total consumption
Maria Matilde	871.50	46%
Paula Montal	562.09	30%
Cesar Martinell	756.22	40%
Merce Vilaret	872.53	46%

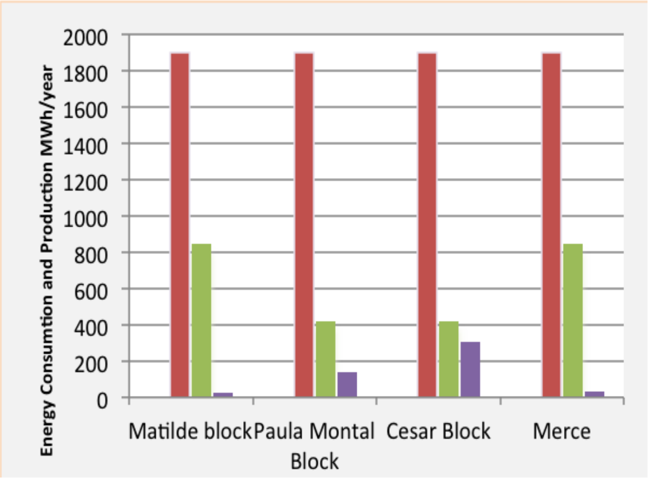


Fig.17. Actual energy consumption (left bar), solar collectors energy production (middle bar) and PV panels energy production (right bar) for each block

B. *UHI mitigation measure practicability and compatibility*

Beside this energy retrofit approach, the mitigation solution for UNI effect also could prove to be efficient for our purpose. The proposed grass-covered streets totally would add up to 3500 meters of length of greeneries. By considering maximum width of 15 meters of greeneries in the pedestrian walks of 20 meters, they add approximately 52000 m^2 of vegetation to this high-density urban environment. This mitigation method increased the ratio of green to built area in the studied region between 3% and 12%. By considering linear relationship between green to built ration and temperature variations, it is possible that these increases in the vegetation area could cause between 0.24-0.96 K decrease in the local urban temperature (table 6). As a limitation in this paper, it should be mentioned that this temperature reductions are only possible values associated with our green corridor proposal, and in reality, they could vary, because the climatic situation of Barceloan and the urban context under consideration in our paper are different from those in the work of A. Dimoudi. et al. in [38].

Table 6. Percentage increase in the G/B ratio and possible associated temperature reduction.

Scenarios					
	Land cover conversion	Existing Green to Built ratio %	New G/B ratio %	% increase in G/B ratio	Possible temperature reduction in degree Celsius
1	asphalt → grass	9.90	12.93	3	0.24
2			15.91	6	0.48
3			18.90	8.5	0.68
4			21.89	12	0.96

To put in summary, in this work, firstly, the neighborhood area was analyzed to identify possibility of increasing the vegetation area. Following that, suitable axes were realized and suggested for conversion from asphalt-covered to pedestrian grass-covered walk. Secondly, four scenarios were proposed to consider the level of conversion and increase in the vegetation level. Finally, an approximate and possible decrease in the local air temperature associated with each scenario revealed the effectiveness of the whole neighborhood recovery in terms of energy efficiency and UHI mitigation. Furthermore, the whole process considered the practicability of this mitigation measure of UHI problem. It is true that in literature, many alternative mitigating solutions with significant financial and environmental benefits were presented, but since they were solely the output of numerical simulations and were not applied on a realistic approach, currently, they are not considered by designers and architects in practice. A multifaceted consideration is needed especially when the goal is to improve not only the environmental conditions but the energy efficiency of the building sector. Therefore, in this work, especial care was paid on the practicability of this mitigation measure and its compatibility with other energy retrofit methods to improve the sustainability of the high-density urban environments. For instance, in this work, when roof tops and facades were identified as suitable positions for solar power installations, this was considered in selecting the measure of development of vegetation in suitable street axes for mitigating the UHI problem.

VI. CONCLUSION

Cities are playing a critical role in the reliability, affordability and environmental sustainability of their energy supply. Due to the fact that the city, is more than an aggregation of disconnected energy consumers and the total energy consumption of the city is different from the sum of the whole buildings' consumption. This considerable gap between the total energy consumption of the city and the sum of all consumers is concealed from the urban morphology and urban form of the city. According to this methodology, the energy efficiency of every element has to be optimised by its form; additionally, this element has to be designed in a way that improves the other elements of the energetic performance as well. The urban transformation emerges through the modification of its constituents and integration of its subsystems over time [35]. Therefore, potential areas include improving building energy efficiency in existing construction and promoting energy efficiency in new buildings. The first goal is the reduction of current energy consumption, which is very significant as remains the same for the whole life of the building. Buildings have a primary role in both consumption and potential savings in cities. The energy efficiency in this work was improved, firstly, by substituting part of the energy consumption of the buildings with renewable sources of energy, and secondly, by reducing UHI effect in the region.

In this study, various factors and their significance in an effective sustainable recovery work of high-density urban regions have been analyzed and discussed by considering both designing aspects and numerical facts. It was concluded that (1) energy efficiency of existing buildings could be improved by installation of solar power systems, despite the fact that these buildings have old energy consuming trend. (2) A UHI mitigation solution has to be developed as a supplement for other energy retrofit methods by considering their practicability and compatibility with the whole system.

This paper was developed as a pattern for cities with same situations. It gives an attitude of the challenges and approaches for implementing sustainable energy programs in urban fabric. In case of Eixample district, by randomly choosing 4 out of 415 blocks, energy production capacity, efficiency of devices, analyzing possible solutions to installing solar power devices were considered and a UHI mitigation solution in the form of street level vegetation was developed and studied.

Current studies indicate that the 30% up to 50% of energy consumption is covered by means of solar collectors and PV Panels and the local region temperature could be reduced by proposed vegetation which could further decrease buildings' cooling loads in summer and improve the thermal environment of the city at local scale.

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