REMOURBAN: Evaluation Results After the Implementation of Actions for Improving the Energy Efficiency in a District in Valladolid (Spain)

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Abstract. REMOURBAN is a large-scale demonstration project whose main objective is to accelerate the urban transformation towards the smart city concept considering all aspects of sustainability. For this purpose, an Urban Regeneration Model has been developed and validated in the three lighthouse cities of the project (Valladolid-Spain, Nottingham-United Kingdom and Tepebaşı-Turkey). REMOURBAN has carried out different interventions in the city of Valladolid with the aim of transforming it in a more sustainable and smarter city. These actions have been evaluated using the evaluation framework developed within the project, to know the real impact of these interventions in the project area and to transfer the knowledge to other cities that want replicate these solutions for improving their sustainability and smartness. This paper is focused on showing the evaluation results after the application of the evaluation framework to the energy actions in a district in the city of Valladolid (Spain).

Keywords: Smart city · Near zero energy district · District heating · Biomass · Evaluation · Sustainability · Photovoltaic

1 Introduction

The sustainable development of urban areas is a key challenge for Europe where the retrofitting of its buildings and, more specifically, its thermal retrofitting takes on special importance. In Spain, more than half of the buildings are built without adequate

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thermal insulation, which means very high energy consumption and mostly from fossil fuels which exacerbates the problem of external energy dependence. In order to deal with this situation, projects such as REMOURBAN are demonstrating innovative, efficient and accessible technologies and processes in districts whose energy problems are evident in order to achieve Near Zero Energy Districts that serve as a reference and allow the replicability of this type of actions in other similar neighborhoods, improving the environment and the quality of life of citizens.

In order to help other cities to identify their needs and to establish the most suitable interventions for covering that demand and replicate the success of the project, REMOURBAN has designed a methodology, the Urban Regeneration Model, which covers all the phases of the transformation process. Within this model, the evaluation is sought as the main supporting mechanism throughout the deployment of this process. REMOURBAN evaluation framework considers two levels of evaluation: city level, to assess both sustainability and smartness of the city as a whole, from a comprehensive and integrated perspective, and project level, to provide a clear identification of the impact of implementation of technologies and solutions on the three key priority areas (sustainable districts and built environment, sustainable urban mobility and integrated infrastructures and processes) aimed at achieving the city high-level goals.

The objective of this paper is to present the evaluation framework at project level developed in REMOURBAN and to show the results of the final evaluation of the energy interventions implemented in the FASA district in Valladolid.

2 Description of the Interventions Implemented

In Valladolid, one of the lighthouse cities of the project, the FASA neighbourhood was selected for the implementation of a set of interventions designed in order to become a Near Zero Energy District and contribute to the city transformation to a more sustainable environment. This neighborhood was built during the 60 s for the workers of the Renault factory in Valladolid, and it is composed by 19 blocks, a tower and a building that contains the thermal power station that supplies heating to the 398 homes that make up the neighborhood. These buildings presented severe deficiencies in their thermal insulation that resulted in lack of habitability and comfort, as well as low energy efficiency.

The heating system consisted of a district network supplied by two fossil fuel boilers (natural gas and gasoil) and it was divided into three different circuits that provided the 398 dwellings with space heating, whereas the domestic hot water (DHW) was individually produced in each dwelling with different technologies depending of the energy source in each particular case: natural gas, butane and electricity.

In REMOURBAN, with the aim of turning the neighbourhood into a Near Zero Energy District, a set of actions have been designed and those are described in following sub-sections:

2.1 Passive Measures: Façade and Roof Insulation

One of the main objectives considered for the design of the interventions, was the reduction of the energy demand. For achieving the aim of decreasing it, it was needed to improvement the thermal isolation of the building envelope, including roof and façade.

For the thermal insulation of the façades, it was taken into account the least intrusive solution that could solve the thermal bridges completely. The external insulation was the final solution chosen, which consists of fixing an insulation board to the external side of the façade and later applying a finish over the board.

In FASA district, the installed insulation consisted of a four-layer scheme, based on a 60 mm expanded polystyrene (EPS) board fixed on the brick wall, a first layer of mortar, followed by a glass fiber mesh and a second layer of mortar. Finally, a surface finish was applied for aesthetical reasons.

Regarding the insulation of the blocks roofs, among the available options for their insulation, an intermediate insulation was chosen for the blocks and external insulation for the tower. The intermediate insulation offers a combination of best performance, easy installation and no disturbance on the tenants. 60 mm of sprayed foam (SPF) insulation were laid under the roof and over the last slab of the block.

The tower roof insulation was improved by adding an external insulation over the existing asphaltic layer. The scheme was an inverted roof system consisting of 60 mm of extruded polystyrene (XPS) insulation, a geotextile layer and gravel.

2.2 Active Measures

Once the energy demand was reduced thanks to the passive measures implemented, the next step was to retrofit the thermal facilities in order to improve their energy efficiency and integrate renewable sources to the system.

The existing district heating system was renovated, on one hand the fossil fuel boilers were replace by biomass ones with occasional support from natural gas and on the other hand the 20 substations of the district were renovated together with the distribution network which was updated with pre-insulated pipes to minimize heat losses.

With this new system, the dependence of the system on fossil fuels has decreased given that now the system depends fundamentally on a renewable energy source. Other relevant advantage is the decrease in the CO_2 emissions from the district heating to the environment because the CO_2 emissions factor for biomass is significantly lower than that for fossil fuels.

In addition to the new biomass boilers, with the aim of increasing the energy supply through renewable sources, a photovoltaic installation has been carried out. This new PV system was built on the south façade of the tower, which has a deviation of 12º and no shading obstacles, and the ventilation effect reduces overheating during summer improving the efficiency of the modules. The PV modules selected have a nominal power of 77.5 Wp. They were installed in two rows in the flat area of the façade avoiding interferences with the existing windows, finally adding up to a total aggregated capacity of 27.435 kWp.

The PV energy is fed into a circuit with 8 electrical resistors that heat up the water tank, which acts as a buffer. Then the hot water harnessed is used to preheat the DHW, and therefore reduce the biomass consumption.

Other intervention aiming to improve the energy efficiency of the district was the substitution of the incandescent lamps by LED in common areas of all buildings.

Last but not least, an Energy Management System (EMS) structured in three different levels has been implemented in the district. There are a District EMS that is responsible for managing the district heating as a whole, a Building EMS in charge of monitoring and controlling both the heating and DHW facilities in each of the 20 buildings and a Home EMS that has been installed in all 398 dwellings of the district. At this level there are two different kinds of devices: heat cost allocators installed in each radiator to measure the individual consumption of the dwellings and thermostatic valves to allow the tenants to adjust the temperature inside each room.

3 REMOURBAN Evaluation Framework

REMOURBAN Evaluation Framework establishes the basis of the evaluation mechanisms for the REMOURBAN Project. The framework defines two levels of evaluation: Project Level, to provide a clear identification of the project impact regarding interventions, and City Level, to assess both sustainability and smartness of participating cities and the impact of the Sustainable Urban Regeneration Model developed in the project on the sustainability and smartness goals.

This paper is focused on the evaluation at project level and more specifically in the evaluation of energy actions in Valladolid. For the evaluation at project level, a specific index was defined; the Demo Site Index (Ds) that is used to evaluate the actions described in the previous section and others interventions related to urban mobility, ICT and non-technical actions.

Although the Ds index is used for the evaluation at project level, the specific actions in each city can be evaluated through one or various measurable objectives or sub-indexes to assist the evaluation of the project impacts and assess the progress of the lighthouse cities interventions.

The basis for the evaluation process are the KPIs (Key Performance Indicators) which are normalized, weighted and aggregated to calculate the Ds global index. Project level indicators (showed in Table 1) are weighted to estimate partial indexes defined for each of the areas of intervention (Buildings and District, Urban Mobility, integrated infrastructures through ICTs and Non-Technical actions). This framework of indicators, sub-indexes and project evaluation index constitute a valuable supporting tool for the evaluation of the impact and expected result of the REMOURBAN project.

Table 1. Project level indicators

Measurable objective	Indicators	
Buildings and Districts	Energy demand	CO_2 emissions
	Energy consumption	Thermal comfort
	Primary energy consumption	Indoor air quality comfort
	Useful energy	Energy bill
	Renewable energy production	Investment
Urban mobility	Energy consumption (buses)	PM emissions (buses)
	Energy consumption (cars)	PM emissions (cars)
	CO2 emissions (buses)	EV penetration rate
	CO2 emissions (cars)	EV charging points
	NOx emissions (buses)	Total KWh recharged
	NOx emissions (cars)	Energy bill (buses)
	HC emissions (buses)	Energy bill (cars)
	HC emissions (cars)	Investment
ICT	Smart electricity meters	Indoor sensors
	Visualising real-time information	Web applications and services
	Modes of transport integrated on smart cards	Visits/Access to webs/Services
	Rate of trips using smart cards	Registered users
	Location tracker sensors	App downloads
	Meteorological sensors	Investment
	Air quality sensors	
Non-technical	Initiatives of public incentives	Initiatives of public incentives
	Awareness raising campaigns	Marketable products
	Learned solutions for non-technical barriers	Innovative/Green public procurement
	Channels used for citizen engagement	Papers for innovative actions
	Visits to project information	Cities interested to be followers
	Social media accounts	Investment

4 Methodology for the Evaluation at Project Level

This section presents the methodology of the project level assessment through the calculation of the Demo Site Index after the demonstration phase of the REMOURBAN project. This methodology requires of the following steps.

– Scope definition: It is each of the three demo-sites (Valladolid, Nottingham and Tepebaşi) including the four areas of intervention (energy, mobility, ICT and Non-technical).

- Baseline period definition: it is the timeframe chosen to represent the initial status of the project level indicators that is used as reference for comparison in order to measure the impact due to the implementation of the project interventions.
- Reporting period definition: it should encompass at least one complete normal operating cycle, in order to fully characterize the effectiveness of the actions. Depending on the specific implementation timings for each of the actions in each demo-site a specific reporting period has been defined for each one. In REMOURBAN, the reporting periods of the energy and mobility actions implemented cover at least the last year of the project, but in most cases this period is longer, exceeding 24 months.
- Data collection and analysis: the collection of data is one of the most challenging tasks of the process and at the same time the quality and amount of data used for calculating the indicators is one of the most critical issues to obtain a reliable index. Most of the data required for the calculation of the indicators at project level is gathered directly from direct measurement, statistical information and in some cases also from simulations. Data is collected and processed in each of the three Local ICT platforms deployed in each of the three lighthouse cities; and sent to the REMOURBAN Global ICT platform.
- Calculation of the index: the computer-based Evaluation Tool STILE has been defined and developed in the REMOURBAN framework to be used for the calculation of the established indices. STILE tool calculate and normalize the indicators, weights and aggregate them in order to calculate the Ds index in an automatic way based on the methodology and calculations implemented within the tool.
- Evaluation of the results. At this point it is possible to perform the comparison and detailed analysis of the reporting period index results and the baseline period index results.

5 Evaluation Supporting Tool: STILE

A valuable computer-based tool, named SmarTness and SustaInabiLity Evaluation Tool (STILE) has been developed as one of the core services that form part of the REMOURBAN ICT solutions. STILE was conceived as the service to support, automate and help to achieve the objectives set out in the Evaluation Framework. Therefore, in line with the Evaluation Framework, this tool allows for a quantified measurement of the cities' progress on the way to sustainability and smartness on one hand, and the performance of REMOURBAN project in terms of efficiency and effectiveness of its interventions on the other hand. This way, STILE arises as the cornerstone to reinforce the communication between stakeholders and decision-makers in the cities.

STILE enables to run evaluations for any of the REMOURBAN lighthouse cities at any moment. When an evaluation is launched, STILE takes the set of monitored variables stored in the Global ICT Platform for that city and the corresponding period of time.

The tool, at a first step, calculates a set of indicators taking those variables as inputs, by applying the formulas defined in the Evaluation Framework. Then, the set of formulas and calculations designed in the Evaluation Framework to obtain the Measurable Objectives from the indicators, were programmed as part of the tool and, finally, by implementing the corresponding formulas from the Measurable Objectives, the indices are obtained.

The key benefit of using STILE is not only the quantification of the indices, but a powerful presentation of the whole data set behind the final value of the index, that goes from the set of variables to an index value, with several intermediate calculation levels in between, all depicted in a graphical way, making it easier for the user to have full information at a glance.

The picture below let us find the direct relation of the general schema proposed by the Evaluation Framework for the Demo Site Index and its computer-based implementation (Fig. 1):

STILE Evaluation Framework

Fig. 1. Direct relation of the evaluation framework and the computer based implementation

STILE visualization solution to represent the whole data set from variables to the final index makes it easier information understanding, having all figures in just one screen, quantified and depicted in a hierarchical way for a deeper insight into grouping levels and dependencies (Fig. 2).

Besides, the user can dig into any level or branch to get more information, just by clicking on each of the elements in a fully interactive way, which helps to better understand the final value of the indexes, based on its indicators and measurable objectives.

This way, the main objective of STILE tool implementing the Ds index is to help in the assessment of the effectiveness of the demo site interventions in cities, supporting decision-making when some new interventions or improvement of the existing ones is being under discussion or evaluation in the city.

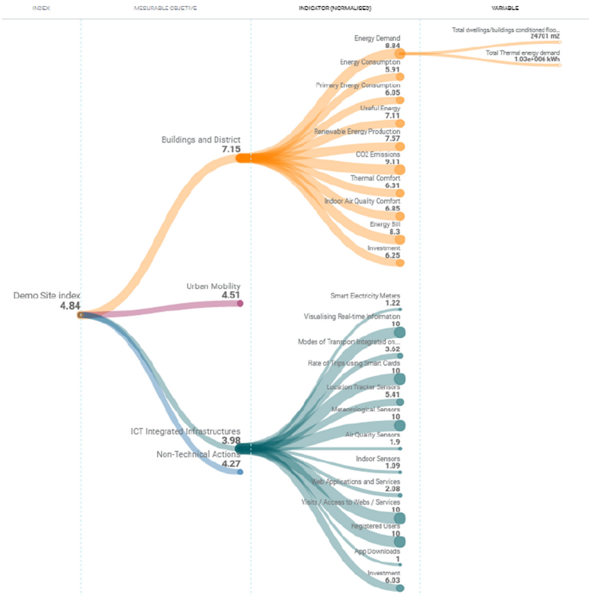

Fig. 2. Example of calculation and representation of Ds

6 Evaluation of Valladolid Demo Site

The Ds index is defined to assist on the assessment of the impacts of the overall project in each of the demo cities. This section presents the results of the calculation of the Demo Site Index (Ds) of the interventions in Valladolid.

The demo site index of Valladolid has increased from 1.89 to 4.84 showing the great impact of REMOURBAN interventions in the different areas of the city (Fig. 3).

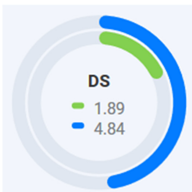

Fig. 3. Valladolid Ds Index (Baseline (Green) vs. Reporting 2019 (Blue)) (Color figure online)

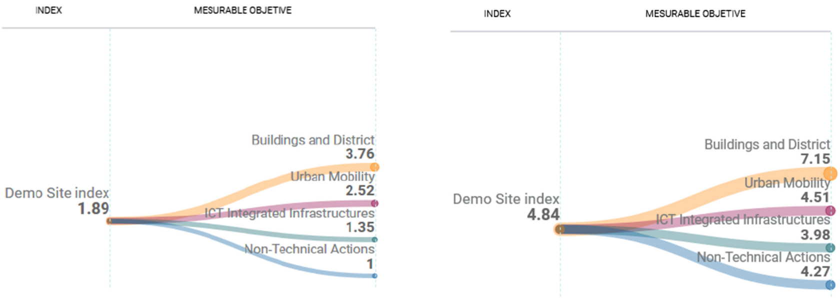

Fig. 4. Valladolid Ds Index. Baseline tree diagram (Left) vs. Reporting tree diagram (Right)

In Fig. 4 can be appreciated as all the interventions areas (Buildings and District, Urban Mobility, ICT and non-technical) have increased their values. Since this paper is focused on Energy Interventions, looking at the Buildings and District sub-index it possible to conclude that both active (such as the new district heating system and PV panels) and passive (façade and roof insulation) interventions in the Valladolid district have had a positive impact, it is possible to see how these actions have allowed Buildings and District measureable objective to move from a baseline of 3.76 to 7.15 in the after retrofitting situation doubling practically the value.

6.1 Evaluation of Buildings and District Indicators for Valladolid Demo Site

The main aim of the REMOURBAN project within the scope of Buildings and District is to improve the efficiency in the use of energy and to change the current energy sources by decarbonising the energy supplies and increasing the share of renewable at the same time that improving the users comfort and reducing energy bill.

The Buildings and District Sub-Index it is composed by a group of indicators which allow to assess the impact of the specific actions and interventions of the project i.e., Energy demand, Energy consumption, Renewable energy production, Thermal comfort, etc., comparing the situation before and after the interventions.

Calculation algorithms have been implemented in STILE tool to calculate the buildings and district indicators according to their definition. These indicators are weighted to estimate the “Buildings and district sub-index” and to evaluate the impact of the area of the project related to buildings and district.

Fig. 5 shows the comparison of the Valladolid demonstrator indicators’ results in the baseline and the reporting periods of Buildings and District. It shows an overall improvement in the district.

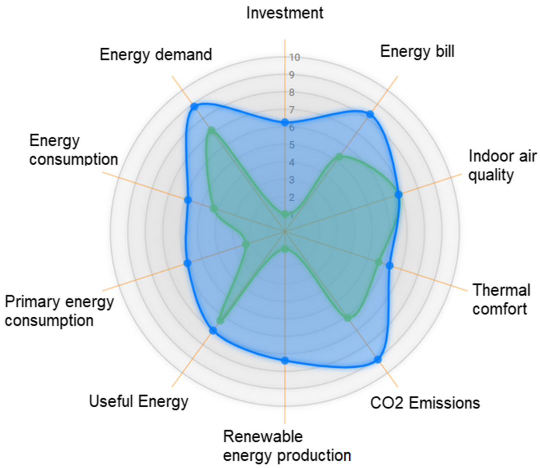

Fig. 5. Valladolid Ds Evaluation. Indicators related to the measurable objective "Building and Districts" Baseline (Green) vs Reporting 2019 (Blue) (Color figure online)

The most affected indicator is the renewable energy production. In the baseline period, the energy produced for the heating and the domestic hot water came from non-renewable sources. The heating was produced with natural gas and diesel sources and the DHW with individual heaters fed with natural gas, butane and electricity. The intervention meant the replacement of one of the existing natural gas/diesel boilers with two new biomass boilers (renewable) and the centralization of the DHW in 46% of the dwellings. Furthermore, a new PV system was installed as support for the thermal plant. These measures implied that the renewable energy production was over 70% during the reporting period, making the value of the indicator increase up to 7.57.

Both energy demand and energy consumption improved almost in parallel. The energy demand was reduced due to the improvement in the insulation of the buildings carried out during the retrofitting. It was reported a reduction of 30% in "Thermal Energy Demand" (mainly due to the façade insulation carried out), and a 28% reduction in "Energy Consumption" (mainly also as improved efficiency in DH system). As buildings now have lower energy losses, the energy demand was reduced and the indicator improved. Together with this indicator goes the energy consumption. A reduction in the energy demand means also a reduction in the consumption, which considering also the higher increase of the systems efficiency implies the improvement on this parameter.

Furthermore, as buildings now have better thermal response to thermal fluctuations, the parameter "Thermal Comfort" increased a 12% showing a better thermal behaviour of insulated dwellings.

The primary energy consumption is also related to the energy consumption. However, it involves the typology of fuel too. The use of biomass boilers and PV system implied a variation on the fuel share and, thus, a variation on the primary energy factors, as the primary energy factor for biomass and PV are lower than the one for natural gas/diesel and electricity from grid respectively. The combination of a lower (better) primary energy factor together with lower energy consumption implied an important improvement in the primary energy consumption indicator.

A parameter that improved too is the useful energy. As the energy demand was reduced during the intervention, the useful energy necessary to heat the dwellings was also reduced, meaning that this indicator improved.

The energy bill for the tenants has also been reduced due to several factors. On one hand, the energy demand is lower, which means a lower consumption. On the other hand, the fuel changed from natural gas/diesel to biomass/natural gas. The cost of biomass is lower compared with the other two and the biomass share is close to 80%. Also the PV contribution to cover part of the heating needs of the district should be considered as it is reducing the use of biomass/natural gas and therefore reducing the operational costs. These two factors of energy consumption reduction and RES contribution justify the improvement on this indicator.

Important to highlight also the great reduction in CO_2 emissions, where a reduction of 70% was achieved, mainly due to high increase in renewable energy use, and efficiency achieved with dwellings insulation.

7 Conclusions

Evaluation is one of the key frameworks of the Urban Regeneration Model defined and developed in the REMOURBAN project. This evaluation framework defines metrics and standards for implementing the evaluation mechanisms in the project.

The evaluation of the results is key to assess the achievement of the expected impacts but also it brings an essential mechanism to foster replication of the solutions developed which, indeed, is one of the strategic elements of the project. To ensure the replicability of the actions it is needed to create a consolidated and consistent reference of impacts.

For the evaluation of the actions, two levels have been considered within REMOURBAN evaluation framework: the Project Level, to provide a clear identification of the project impact regarding actions on the three key priority areas and the City Level, to assess both sustainability and smartness of participating cities.

The work presented in this paper is focused on the project level showing the Demo Site Index (Ds) which has been designed for this aim and more specifically the results achieved thanks to the actions implemented to reach a Near Zero Energy District in Valladolid.

The interventions carried out in the buildings (both passive and active) have reduced all forms of energy (demand, consumption, primary and useful). The increase of the use of renewable sources has considerable contributed to achieving a very low dependence on fossil fuels through the implementation of solutions such as biomass boilers and PV system. Interventions in buildings have not only reduced CO_2 emissions, but they have also improved indoor air quality and thermal comfort for people living in these buildings. From an economic perspective, the energy bill per household has been reduced considerably thanks to the combination of all the energy measures.

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