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Abstract. The concept of smartness in building dates to the 1970s, but, in face of the breakthrough technological developments, a new notion of smart building is currently recognized. We talk about ambient intelligence, referring to a building which is responsive to the needs of the occupants and of the energy system. An ambient-intelligent building is human-centric; new services and interfaces are provided to the buildings occupants to learn and set their preferences, with a positive impact on their comfort level and satisfaction with the indoor environmental quality. ICT and IoT are part of the enabling technologies to exploit the potentials of smart buildings, by unlocking the capability of buildings to interact with the system they belong to. To bolster the diffusion of new technologies, methodologies to get quantitative results proving their effectiveness should be provided. In this paper the application of a well-established economic evaluation tool, the so-called Cost-Benefit Analysis, to the case of the deployment of new ICT-tools for occupants' engagement is presented. The methodology is adopted within the H2020 Mobistyle project, where two level of the evaluation are identified: the whole project level and the single demo case one. The purpose of the methodology is to assess the effectiveness of the adoption of the ICT-tools in producing economic value in terms of benefit for the occupants and the society. Some preliminary results of its application to the Italian case study are also presented, showing a positive socio-economic balance since the beginning of the deployment.

Keywords: Indoor Environmental Quality, Cost-Benefit Analysis, occupant engagement.

1 Introduction

"In a low-carbon society we will live and work in low-energy, low-emission buildings with intelligent heating and cooling system. We will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" [1]. This statement resumes what the European Commission means by "Post-Carbon City" (PCC), stressing how all the urban sectors should contribute in paving the way towards a more sustainable future for our cities, reviewing the current carbon-dependent socio-economic model. To reach the objective of building inclusive and sustainable urban contexts, some cities are setting new strategic plans, taking advantage of the growing diffusion of Information and Communication Technologies (ICT) to face the issues related to different areas as economy, energy, environment, mobility, governance, life quality, people, security, etc., in accordance with the definition of "Smart city".

Among the urban infrastructures, the building stock is the biggest one. The important role of buildings in reaching the sustainable objectives is well recognized, especially when it comes to the energy and environmental goals. In this domain, buildings are described as part of a broader system, in which they are responsive to the occupants' and the grid needs and, thanks to their flexibility, storage and production capabilities, they are able to bolster the energy transition, with an impact also on other urban sectors. As part of a PCC or a Smart City, buildings should be low-carbon intense, connected and smart.

The concept of smartness in building dates to the 1970s, but, in face of the breakthrough technological developments of the last decades, a new notion of smart building is currently recognized. We talk about ambient intelligence, referring to the idea that the building is sensitive and responsive to the needs of occupants and of the energy system. "A smart building is highly energy efficient and covers its very low energy demand to a large extent by on-site or district system-driven renewable energy sources. A smart building (i) stabilises and drives a faster decarbonisation of the energy system through energy storage and demand-side flexibility; (ii) empowers its users and occupants with control over the energy flows; (iii) recognises and reacts to users' and occupants' needs in terms of comfort, health, indoor air quality, safety as well as operational requirements." [2]. To do it, buildings should be equipped with a set of technological devices. Indeed, the concept of technological readiness to smartness is very popular, enforced also by the new Energy Performance of Building Directive 2018/844/UE [3].

In this context, ICT and IoT (Internet of Things) are recognized as enabling technologies. Among the offered opportunities, ICT and IoT in buildings enable the interactions of the building with the rest of the system it belongs to.

Between these interactions, the one with the occupants is considered particularly relevant. Indeed, the main novelty of the newest concept of intelligence of buildings it is in the role of people. An ambient-intelligent building is also human-centric; the building is capable to recognize and automatically adapt its operation according to the occupants' behaviour and preferences, and thereby it optimizes comfort, security, energy use and well-being [2]. New services and interfaces are provided to the buildings occupants to enable them to learn and set their preferences, with a positive impact on their comfort level and satisfaction with the indoor environment. Indeed, since the path towards a more sustainable world involves every area of human life, people cannot be kept outside the process; they have to be active actors, changing their attitudes and increasing their energy literacy. Also in this sense, ICT services supported by live data coming from the indoor environment can have an interesting role as educative tools, by translating data into meaningful information to be displayed to the occupants. This would result in including people in the transition process, which should be also supported at socio-economic level. In this context, Mobistyle project is giving its contribution, by providing a set of tools for occupants' engagement.

Mobistyle is a Horizon2020 European project aiming to drive behavioural changes in buildings occupants, increasing people perception about how their habits can influence energy consumptions and indoor environmental quality (IEQ) in buildings, but also their health and well-being. To reach this goal standing monitoring systems were installed in different pilots, including both residential and non-residential (offices and hotel) buildings. A specifically developed ICT platform enables the collection of the monitored data and their translation into meaningful information for the occupants and personalized feedback about energy, IEQ and well-being. They are displayed to the occupants via new ICT-tools; while for the residential case studies (Danish demo case, DK; and Polish one, PL) a game was developed, occupants of the offices (Slovenian demo case, SL; and part of the Italian one, IT) and of the hotel (Italian demo case, IT) were provided with a mobile App and its web version, a Dashboard. Therefore, the pilots cover different target groups (households, employees, hotel staff and hotel guests) resulting in their engagement towards more energy-responsible habits, with positive impacts also on health and well-being.

1.1 Research aim

A "Smart buildings benefit the environment (through lower energy consumption and more renewables), the society (better health, comfort and well-being) and the economy (cost-effectiveness and optimised energy use)." [2]. In the introduction it was mentioned how ICT and IoT are part of the enabling technologies to exploit these potentials of smart buildings. Among the ICT-tools, App and Dashboard for occupants' engagement as the ones developed in Mobistyle project are included. To bolster their diffusion, increasing the buildings technological readiness to smartness, methodologies to get quantitative results proving the effectiveness of their adoption should be provided.

The aim of this paper is to present how a well-established economic evaluation tool, the Cost-Benefit Analysis (CBA), was adjusted to the case of deployment of new ICT-tools that were used for the engagement of building occupants towards more responsible use of energy and aware interaction with the indoor environment. The purpose of the CBA is to assess the effectiveness of the adoption of these ICT-tools in producing economic value, in terms of benefits for both building occupants and the society. Indeed, a particular attention is given to the identification, quantification and monetization of the multiple benefits generated not only in terms of reduction of energy consumptions, but also in terms of improved IEQ and human well-being.

2 Method

2.1 Cost-Benefit Analysis

The CBA is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits [4]. Both costs and benefits are monetized, distributed over time and discounted to compute aggregated economic indicators to assess whether the investment has a positive or negative economic balance.

The main steps composing the CBA are:

- Objectives and context definition.
- Time horizon setting.
- Impacts definition, quantification and monetization.
- Cashflow and discounting.
- Economic performance evaluation.
- Sensitivity analyses performed to check the robustness of results.

2.2 CBA developed specifically for Mobistyle

In the followings, the application of the CBA to the Mobistyle project is described. In particular, two levels of the application were identified: the whole project level and the single demo case one. The latter enables the evaluation of the socio-economic performance of the deployment of the ICT tools (i.e. the game, the Dashboard and the mobile App), while the former gives a figure about the profitability of the investment for the adoption of the solutions at the overall project level. In this paper the focus is on the single demo case level.

Objectives and context definition. The objective of the evaluation is to assess the effectiveness of the deployment of the Mobistyle ICT-tools at building level when multiple impacts are considered. The solutions themselves are offered to the building occupants as new services where data gathered through a monitoring system are translated for them into meaningful information about energy, IEQ and well-being with the aim to push a behavioural change.

The context of the analysis was defined keeping in mind that the CBA adopts an incremental approach. It means that the project is evaluated upon a counterfactual scenario, where no investments are foreseen. Two scenarios, the one with and the one without-the-project are compared by computing their performances in terms of relevant impacts. "Without-the-project scenario" is referred to the conditions before the ICT-tools deployment, but after the monitoring system installation (obliged action to have data to compute the scenarios performances), while "with-the-project scenario" is related to the situation after the solutions deployment. Given this incremental approach, the investments for the monitoring system is not considered between the costs items, since it is part of both scenarios. Consequently, the focus of the evaluation is on the deployment of the ICT-tools at the single demo case level.

Moreover, the beneficiaries were identified, clarifying the viewpoint of the assessment. In this application, two perspectives are suggested: the owner-occupant perspective (who would burden the investment costs for the solution deployment), and the society viewpoint, where, adopting a macro-economic approach, also impacts spilling over the initial boundaries of the project (i.e. externalities) and burdening on the whole society are included.

Time horizon setting. The timespan of the analysis, called "reference period" or "time horizon", was set proportionally to the project economically useful life and to the timing according to which the potential impacts are expected to be expressed. In this application, the time horizon was set in a way that it does not exceed the duration of the deployment of the ICT-tools. Indeed, being the evaluation procedure based on monitored data, it is preferable not to assume that the potential benefits measured during the monitoring period would persist after the duration of the deployment (unless the gathered data are such to enable the analyst to performance some forecasting evaluation). Finally, given the incremental approach of the CBA, it is important to make sure that the overall timespan can be compared with a period equally long and homogeneous in terms of boundary conditions, when ICT-tools were not deployed.

Impacts definition, quantification and monetization. By deploying ICT-tools aiming at pushing a behavioural change towards a more responsible use of energy and a responsible and aware interaction with the indoor environment, different impacts could occur. In accordance to the two possible viewpoints of the assessment (the owner-occupants' and the society's one), Table 1 reports the identified impacts of the deployment to be taken into account to measure the effectiveness of the use of the ICT-tools. Based on the building use where the solutions are deployed and on the available monitored data, the methodology was adjusted to the different Mobistyle demo cases by selecting the relevant impacts.

Table 1. Impacts of the deployment of ICT-tools for occupants' engagement.

Impact	Context	Aim	Beneficiaries		Evaluation		
	Mobistyle demo case		Owner-occupant	Society	Physical indicator	Quantification	Appraisal method
Energy cons.	DK, PL and IT	Min	x		Energy consumption	kWh	Energy price (with taxes)
Water cons.	DK	Min	x		Water consumption	m^3	Water price (with taxes)
Productivity	SL, IT	Max	x		Indoor air temperature	% according to Seppanen et al. model [5]	Labour cost per employee
N. of complaints	SL	Min	x		Indoor air temperature	N. according to Federspiel et al. model [6]	Labour cost per technician handling the complaints
Market value	DK, PL, IT	Max	x		Perceived IEQ	Qualitative (in field survey) [7]	Selling/rental price

GHG emis-sions	DK, PL and IT	Min	x	Energy consump-tion	kWh * emis-sion coeff.	GHG cost [8]
PM emis-sions	DK, PL and IT	Min	x	Energy consump-tion	kWh * emis-sion coeff.	PM cost [9]
Head-ache cases	SL, IT	Min	x	Indoor air tempera-ture	Degree hours over 23°C [10, 11]	Cost of illness (direct + indi-rect)

DK (Danish), PL (Polish): residential; SL (Slovenian): Office; IT (Italian): Hotel

Once the possible impacts were identified, specific appraisal methods were selected to monetize those impacts. Priorly to the monetization, impacts were quantified in physical units. In Table 1, per each impact the approach to quantification and to monetization is reported. In particular, in the IEQ field, the quantification typically involves models that define the correlation between an indoor parameter and its effect on, for example, comfort, health and well-being [12, 0].

Cashflow and discounting. After impacts quantification and monetization in the "with-the-project" scenario and "without-the-project" one, they were subtracted per each time step of the analysis to define, depending on the sign of their differences, if they are benefits or costs. A table was built by distributing monetary values of costs and benefits over the timespan of the analysis to compute the cashflow per each time step. The so computed cashflows must be discounted. An annual discount rate equal to 3 % was selected, in accordance with the benchmark value recommended by the European Commission [4].

Economic performance evaluation. Starting from the discounted cashflows, the Net Present Value (NPV) was finally calculated as:

$$\mathrm{NPV(C)} = \sum_{t=1}^{n} a_t S_t = \frac{S_1}{(1+i)^1} + \frac{S_2}{(1+i)^2} + \cdots + \frac{S_n}{(1+i)^n} \quad (1)$$

Where $a_t = \frac{1}{(1+i)^t}$ represents the discounting formula, S_t is the balance of cashflow at time t and *i* is the discount rate per each time step t. If NPV is major than zero, the benefits produced by the ICT-tools adoption overcome the relative costs.

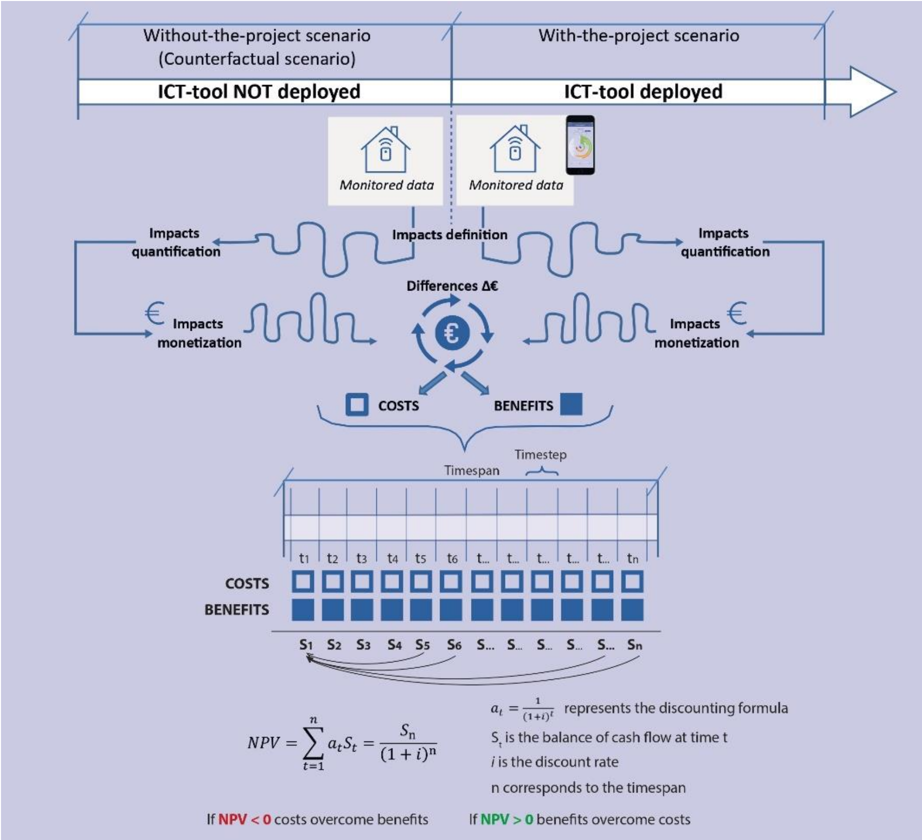

Fig. 1. Methodological schema of the CBA application in Mobistyle project.

Fig. 1 summarizes the whole evaluation framework. Starting from monitored data on two equally long and comparable periods (without and with the ICT-tool deployed), impacts were identified, quantified and monetized in order to compute their differences per each time step of the analysis. The cashflows per each time step (from S_1 to S_n) were computed. Cashflows were discounted and the Net Present Value was finally calculated to assess the economic performance of the project.

3 Results

In this section, some preliminary results of the application of the CBA on the office space (reception) of the hotel representing the Italian demo case are presented.

In this specific case study, the deployed ICT-tools are the Mobistyle App and its web version, a Dashboard. They were offered to two members of the staff. The tools, processing the monitored data, displayed to the employees some meaningful and easy-to-understand key performance indicators, with friendly icons (e.g. smiles coloured in different ways depending on the criticality of the consumptions and indoor conditions) and personalized feedback and tips. These last ones concern how to improve their habits in order to get better IEQ and to decrease their electricity consumptions, stressing on the positive impacts the new habits would have on their well-being. In particular, the monitoring system measured electricity consumptions (of the laptops and of the printer) and indoor parameters (temperature, relative humidity and CO_2 concentration).

The beneficiaries of the project are the owner of the hotel, having more satisfied employees and benefitting from their working performances and energy-responsible habits, and, on a second stage, the whole society, having advantage in terms of lower energy consumptions and environmental impacts.

To assess the socio-economic performance of the project at the demo side level, it was chosen to run the analysis on the first month of the deployment, during the winter-time. In order to have homogenous boundary conditions, the same month of the previous year was chosen as the counterfactual scenario.

Impacts accounted were:

- Electricity energy consumptions (owner viewpoint).
- Productivity (owner viewpoint).
- GHG emissions (society viewpoint).
- PM emissions (society viewpoint).
- Headache cases (society viewpoint).

Monitored electricity consumptions in kWh were monetized multiplying them for the electricity energy tariff expressed in €/kWh. Electricity consumptions were also multiplied for the emission factors expressed in $kgCO_{2eq}$/kWh and gPM/kWh, in order to quantify $CO_{2equivalent}$ and PM emissions. The quantities in terms of emissions were multiplied for parametric costs in €/$kgCO_{2eq}$ [8] and €/gPM [9] to estimate their costs for society. Monitored hourly indoor air temperature (during the occupied hours) were used to forecast the percentage productivity level of employees according to Seppanen at al. model [5]. The hourly percentage values were multiplied for the hourly labour cost per each employee (namely the cost the employer has to burden) per each working hour of the calculation period in order to assess the economic value of their performance. Finally, starting from monitored hourly indoor air temperature, degree hours were computed. Degree hours represent the number of degrees above a certain threshold multiplied by the number of hours they last. According to Mendell and Miere [11], per each 9 degree hours above 23°C there is an increase in headache cases, with an odd ratio of 1.19. Headache cases were forecasted according to Mendell and Miere model [11] and monetized by multiplying the number of cases for the unitary costs for their treatment, as was done by Fisk et al. [10].

The application of the CBA suggests that in the first three week from the deployment it was possible to measure a positive impact on productivity, which rose from 99.6% to 99.8%. In the same timespan, the electricity consumptions decreased of 2 kWh, with a subsequent decrease in GHG and PM emissions. In the same period, it is also possible to see a reduction of the degree hours from 43 to 3 with respect to the same period of the previous year, with a positive impact on healthcare costs.

Results of the economic evaluation suggest that in only one month at the beginning of the deployment, the initiative was able to produce a positive NPV of 4.77 € which rises to 4.86 € when the viewpoint is enlarged from the owner's one to the one of the whole society considering also impacts in terms of GHG emissions, PM emissions and Headache cases.

4 Conclusions

The paper presented the application of the CBA methodology to evaluate the effectiveness of the deployment of ICT-tools for occupants' engagement towards more energy-responsible habits, with positive impacts on IEQ, health and well-being.

Some preliminary results for the Italian case study of the Mobistyle project were provided. Because of the short timespan, the application field (namely the induction of new habits, which is a long-lasting process) and the choice of a period for the analysis close to the deployment, the results, in terms of absolute values, are small. However, it is important to keep in mind that only one office with two occupants is involved in the initiative; better results would be achievable enlarging the scope.

Therefore, it is important to mention that a big impact on results is given by the productivity level, which was quantified according to the model that Seppanen et al. [5] developed based on monitored data of different contexts. Indeed, even if it is possible to identify appraisal methods to monetize the impacts (some of them having already parametric monetary value, as the cost of GHG emissions), the quantification of the impacts, especially on health, is an open research field. Medical studies and infield experiments are required to cover this gap, but still the applicability of the defined models to different contexts then the one where they were developed is questionable. The goal of the application here proposed was to identify the impacts that influence the results the most and to explore the challenges in applying the CBA to this field.

The definition of the methodology and its adjustment to the different demo cases want to be the added value of this research, supporting the evaluation of the socio-economic performance of the deployment of ICT-tools for occupants' engagement when multiple impacts are considered, getting quantitative results to prove their effectiveness and to bolster their diffusion.

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References

1. European Commission: A Roadmap for moving to a competitive low carbon economy in 2050, COM (2011), 112. European Commission, Brussels (2012).
2. Building Performance Institute Europe: Smart Buildings decoded. The concept beyond the buzzword. Building Performance Institute Europe (BPIE), Brussels (2017).

3. European Parliament: Energy Performance of Building Directive ("New EPBD") 2018/844/EU. European Union, Brussel (2018).
4. European Commission: Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020. European Union, Brussels (2014).
5. Seppanen, O., Fisk, W., Lei, Q. H.: Effect of temperature on task performance in office environment. Ernest Orlando Lawrence Berkley National Laboratory, Berkley (2004).
6. Federspiel, C., Martin, R., Yan, H.: Thermal comfort models and complaint frequencies. Summary Report. Center for the Built Environment (CBE), Berkeley (2013).
7. Buso, T., Dell'Anna, F., Becchio, C., Bottero, M. C.: Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms. Energy Research & Social Science 32, 94-111 (2017).
8. European Commission: Commission delegated regulation (UE) n.244/2012. Brussels (2012).
9. Copenhagen Economics: Multiple benefits of investing in energy efficient renovation of buildings. Copenhagen (2012).
10. Fisk, W. J., Black, D., Brunner, G.: Benefits and costs of improved IEQ in U.S. offices. Indoor Air 21: 357-367 (2011).
11. Mendell, M. J., Miere, A. G.: Indoor thermal factors and symptoms in office workers: findings from the US EPA BASE study. Indoor Air 19: 291–302 (2009).
12. Seppanen, O., Fisk, W.: A model to estimate the cost effectiveness of indoor environment improvements in office work, Ernest Orlando Lawrence Berkley National Laboratory, Berkley (2004).

Fisk, W., Mirer, A. G., Mendell, M. J.: Quantitative relationship of sick building syndrome symptoms with ventilation rates, Ernest Orlando Lawrence Berkley National Laboratory. Berkley (2009).