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Evaluating the Interaction of Occupant Behavior and BACS (Building Automation and Control System) on Energy Consumptions: A Feasibility Analysis

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ABSTRACT

As highlighted by the European Union legislation, the building sector is considered crucial in order to achieve the expected objectives in terms of reduction in greenhouse gases emissions to net zero and below. Furthermore, the impact that user's behavior has on the energy consumption of residential buildings and consequently on well-being and comfort is well documented. In these regards, the application of Building Automation and Control System (BACS) aims at achieving an improvement in the user's indoor comfort conditions, as well as a significant reduction in energy consumption due to an optimization of its delivery. This study verifies the potentialities of BACS installation to two case studies; a nearly Zero Energy single-family house and an energy retrofitted apartment located in the Northern Italy. In detail, different scenarios were designed, combining different energy consumers' profiles, and building automation systems configurations. In order to measure the feasibility of the projects, Cost-Benefit Analyses (CBA) were performed, comparing investment cost with energy savings and extra economic benefits. The latter were estimated through a survey in terms of consumers' willingness to pay for the installation of smart devices in their homes through a contingent valuation in the iterative bidding format.

Keywords: Cost-Benefit Analysis (CBA), Nearly-Zero Energy Building (nZEB), Willingness To Pay (WTP), economic convenience, smart building, consumer behavior.

NONMENCLATURE

Abbreviations	
BACS	Building Automation and Control Systems
LC	Low Consumer
AC	Average Consumer
HC	High Consumer
CBA	Cost Benefit Analysis
WTP	Willingness To Pay

1. INTRODUCTION

The building sector is recognized as one of the main contributor to greenhouse gas (GHG) emissions [4]. In addition to the intrinsic characteristics of buildings, a major role is played by the occupants' behave [5]. In particular, six factors affect energy consumption in buildings: (1) climate, (2) envelope characteristics, (3) building management services and energy systems characteristics, (4) building operation and maintenance, (5) occupant activities and behave, (6) indoor quality services.

When focusing on the expected results of the design phase in the actual operational phase of buildings, a large discrepancy in results has been noted by numerous scholars [1, 5, 6, 7] recording an increase in energy consumption up to 300% due to occupants' behave [8]. This led to the introduction of the Robustness

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concept as the sensitivity of a determined performance indicator to errors in the design assumptions in terms of difference between predictions and actual performance [9].

To guarantee an energy consumption reduction, as well as high level of comfort for the occupants, the introduction of Building Automation and Controlling Systems (BACS) has been seen capable of achieving good results without making the two instances compete [10, 11].

BACS are network of devices that are interconnected with the aim of controlling three different layers of energy consumption: (1) the external climate, (2) the intrinsic building characteristics and (3) operational energy with high possibility of control over energy losses [12] and optimization [13].

2. METHODOLOGY

In order to evaluate the impacts of the implementation of BACS project in existing buildings, the energy consumption of two case studies was calculated with different users' profile assumed with reference to previous studies.

Then the simplified energy assessment model provided by EN15232 [2] was applied to evaluate energy savings, finally a Cost-Benefit Analysis (CBA) was performed. Among the benefits, the estimation of the Willingness to Pay (WTP) [17] for smart energy efficient systems was considered.

2.1 Occupants' behave characteristics

According to previous studies, three consumers' profile has been considered [1]: Low Consumer (LC), Average Consumer (AC) and High Consumer (HC); these profiles are shown in Table 1. These three profiles differ from each other in the assumptions made to evaluate the energy consumption of the buildings under investigation: in terms of heating/cooling set points and ventilation rates they refer to the comfort categories as defined in the EN15251 [18]: I category, II category and III category for the HC, AC and LC respectively. The LC and AC present a setback temperature during evening and night while the HC has a constant heating/cooling set point. Regarding the electric consumption for lighting and equipment, the AC schedules have been modelled based on reference residential buildings occupancy as from the dataset of the Department of Energy (DOE), with an increase/decrease of 10% of these operational levels in order to define the HC and LC respectively [1]. Additionally, the LC presents an optimization of lighting related consumption through daylight control. Considering the opening/closing schedule of the blinds, they have been assumed always open for the HC, while the LC and AC occupants are assumed to close them after certain thresholds: a solar radiation over 300W/m2 for the AC and glare index major of 22 for the LC. Finally, the Domestic Hot Water (DHW) consumption is defined based on previous literature [1].

2.2 EN15232

In order to calculate the impact of implementing a BACS in existing buildings, the simplified method provided by the EN15232 [2] "Energy performance of buildings - Impact of Building Automation. Controls and Building Management" has been applied. This method allows to estimate different percentages of energy reduction in relation to four classes of automation systems: class D considering a building with no

Table 1. Low Consumer (LC, Average Consumer (AV) and High Consumer (HC)

	LC	AC	HC
Heating operation and set point	5 am-11 pm 18°C 11 pm-5 am 16°C	7 am-8 pm 20°C 8 pm-7 am 18°C	0 am-12 pm 21°C
Cooling operation and set point	5 am-11 pm 27°C 11 pm-5 am 28°C	7 am-8 pm 26°C 8 pm-7 am 27°C	0 am-12 pm 25.5°C
Ventilation Rate (AHC)	0.5	0.6	0.7
Equipment	-10% compared to AC	Average operational levels	+10% compared to AC
Lighting Schedule	-10% compared to AC +optimized control (continuous/off dimm.)	Average operational level for lighting	+10% compared to AC
Blinds	Optimized through daylight control (if glare index>22)	Only if solar radiation>300W/m2 on glazed surface in summer	Always open
Domestic Hot Water (DHW)	40 [l/pers*day]	60 [l/pers*day]	80 [l/pers*day]

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automation systems related to energy savings, class C is the reference one considering a minimal degree of automation and standard BACS, class B with an advanced degree of automation and some degree of centralized control, and class A that comprise high levels of accuracy and completeness ensuring high energy performances.

The percentages given for each service and energy vector by the Standard, in combination with the different user's profiles, was used to calculate potential energy savings.

2.3 Iterative Bidding Game (IBG)

In order to estimate the WTP for energy efficient intelligent systems, it was necessary to define a proxy which was identified in three different intelligent appliances. For each of them, prices for their installation were identified. These prices were used to build an Iterative Bidding Game (IBG) in the framework of the Contingent Valuation Methods (CVM). The Iterative Bidding Game asked the interviewed to state if he/she would purchase a good for a specific price and, in case of a positive answer, reiterated the proposal with a higher price; in case of deny, the interviewer asked for a purchase at a lower price until a positive answer was reached. The experiment was conducted hand in hand with a questionnaire that collected other socio-economic as well as preference data stated by the respondent allowing for different econometrics studies by means of statistical regressions.

The data collected were analyzed using IBM SSPS software.

To check for the influence of the starting price on the outcome of the Bidding Game, three experiments has been developed using a different price to start with.

In Fig1 an example of one Bidding Game experiment scheme is provided.

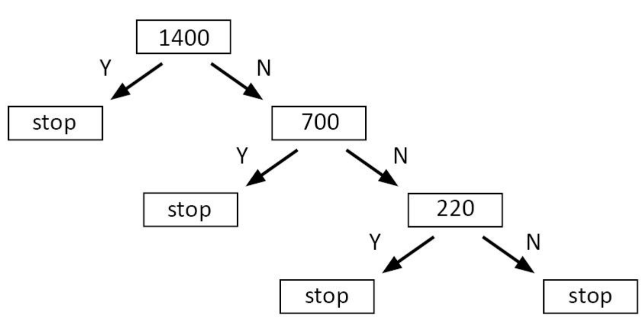

Fig. 1. Example of one Bidding Game scheme.

3. CASE STUDY

3.1 The two buildings

The above mentioned methodology was applied to two case studies from previous publications: CorTau house, a 147m2 retrofitted traditional rural single-story house for one family located in Piedmont region (Italy) [1], and a 78.5m2 retroffited apartment in a six-story apartment block dated between 1991 and 2005 located in Turin (Piedmont, Italy) [14]. In particular, the CorTau house is an nZEB building, characterized by high performance solutions for energy reduction; while the second case study presents measures in accordance with the national Standard (see provided references for more details).

For both case studies, the saving potentials of the application of class B and class A percentages according to EN15232 were calculated taking into consideration different services of the two houses: heating and cooling system, lighting (including presence/absence sensors, dimming and LED technologies), controlled mechanical ventilation, visualization of the energy loads, energy data logger to control production and consumption. Both class A and class B were applied to the LC and HC profile while the Average Consumer was considered with a BACS class C system already in place. The prices for the installation of the two classes were calculated referring to a well-known automation systems provider's price list [15].

The BAC efficiency factors provided by the Standard are reported in Table 2.

Table 2. BACS efficiency factors (EN15232).

	BAC efficiency factors			
Class	D	C	B	A
Electricity	1.08	1.00	0.93	0.92
Thermal	1.10	1.00	0.88	0.81

3.2 Iterative Bidding Game

The Iterative Bidding Game methodology was used to evaluate the attitude of respondents towards energy saving smart devices. In doing so, three different high performances appliances were considered as proxies to calculate the WTP: (1) a washing machine, (2) a dishwasher, (3) smart sockets able to program the energy uses. The prices of the three appliances were calculated through a mean of the selling prices found by a market survey and are reported in Table 3 along with the energy savings calculated according to the National

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Energy Regulation Authority [16] using an electricity price of 0.195891 €/kWh (price referred to the last four months of 2017).

Table 3. Average cost and Energy Consumption of the three appliances

	Averaged Price	Energy consumption	Savings *
Washing Machine	720.68 €	152 kWh	33%
Dishwasher	690.71 €	255 kWh	16.3%
Smart Socket	42.73 €	-	-

*compared to class A

The IBG was performed by means of a questionnaire distributed both online (using Google Form) and via face to face interviews using the three mean costs calculated as previously described as starting points: (1) 1400 € as the combined cost of both a high performance dishwasher and an energy efficient washing machine, (2) 700 € as the cost of one appliance, and (3) 220 € is the purchase of 5 smart sockets (due to the low price of only one socket, a multiple purchase has been proposed to make the question consistent).

Table 4. CorTau house savings potential in different scenarios

	AC	LC	LC+B	LC+A	HC	HC+B	HC+A
Heating (€/m2y)	3.97	3.35	2.97	2.73	4.65	4.11	3.78
Cooling (€/m2y)	2.25	1.33	1.41	1.30	3.12	2.99	2.75
Ventilation (€/m2y)	1.09	0.91	0.85	0.84	1.23	1.14	1.13
Lighting (€/m2y)	2.19	1.16	1.08	1.07	2.80	2.61	2.58
Equipment (€/m2y)	6.25	5.33	4.79	4.74	7.07	6.36	6.29
Difference (%)		-23.3	-29.5	-32.2	+19.8	+9.3	+5.0

Table 5. Apartment savings potential in different scenarios

	AC	LC	LC+B	LC+A	HC	HC+B	HC+A
Heating (€/m2y)	9.72	8.00	7.61	7.00	10.58	10.10	9.31
Cooling (€/m2y)	2.51	2.91	2.67	2.46	2.34	2.17	1.99
Ventilation (€/m2y)	-	0.66	0.61	0.60	-	-	-
Lighting (€/m2y)	2.47	2.47	2.29	2.27	2.47	2.29	2.27
Equipment (€/m2y)	4.08	4.08	3.67	3.63	4.08	3.67	3.63
Difference (%)		-3.5	-10.3	-13.9	3.7	-2.9	-8.4

4. RESULTS & DISCUSSION

4.1 BACS applied to the consumers' profile

The energy savings related to the implementation of BACS systems in the two case studies are shown in Table 4 and Table 5.

As highlighted in the first table, the impact of advanced BACS systems is not enough to compensate the increasing in energy consumption due to a HC's profile either applying a B class (+9.3%) and an A class (+5.0), while the further reductions in case of a LC's profile increase the savings from 23.3% to 29.5% and 32.2% applying a class B and class A respectively.

Regarding the second case study, the application of BACS results in a reduction of energy consumptions in each scenario. In particular, the LC's profile coupled with class B and A resulted in slightly less than three times the savings (from 3.5% to 10.3%) with class B and almost four times (13,9%) with class A. Regarding the HC's profile, the scenario without the implementation of any automation system results in an increase of energy consumption (+3.7%) counterbalanced by the two automation scenarios resulting in a decrease of energy consumption of 2.9% and 8.4% in case of the application of BACS class B and A respectively.

4.2 Questionnaires

A total of 153 questionnaires has been answered with an even ratio (51 for each typology), showing an average WTP of 807,06 €. In particular, the percentages of positive answers for the two questionnaires with a starting point of 1400 € and 700 € are more or less aligned (68,6% and 78,4% respectively) while the rate for the 220 € starting point is slightly lower (52.9%, resulting in a specific WTP of 520.78 €); this could be explained by the difficulty of stating an unambiguous saving potential for the smart sockets.

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4.3 Cost Benefit Analysis (CBA)

Finally, a cost-benefit analysis was carried out to establish the feasibility of the project to implement the two BACS systems (class B and class A).

A calculation period of 25 years was considered taking into account the investment cost, installation costs, maintenance costs, 20% investment cost as residual value and a discount rate of 2% for the calculation of Discounted Cash Flow (DCF). A sensitivity analysis was considered with regard to WTP, including it as a one-off benefit and accounting for it every five years as a recurring benefit.

The investment cost for the class A and B in the CorTau House are 22,006.23 € and 19,991.37 € respectively, while for the apartment they amount to 11,363 € and 10,150 € for class A and B respectively. The installation cost has been estimated in 3,134 € and the maintenance cost in 100 €/year for both case studies and both scenarios.

The calculation resulted in a not competitive solution due to an excessive initial investment cost compared to the benefits during the life span, as well as a too high value for maintenance costs.

5. CONCLUSIONS

The paper has analyzed the possible energy savings that could arise by the implementation of Building Automation and Control Systems in two case studies. The results have shown that in case of an already very high performing dwelling, the impact of the occupant behave is higher than the savings that a class A and class B of BACS could guarantee. In particular, both the High Consumer profile alone and the implementation of class B and class A BACS result in higher consumptions (19.8%, 9.3% and 5.0% compared to the Average Consumption profile), while the major savings are already achieved by the Low Consumer profile alone (-23.3%) further icreased by the implementation of BACS (-29.5% and -32.2% for class B and class A). On the other hand, in case of an apartment with characteristics in accordance to the national Standards, the implementation of BASC systems results in a counterbalance of the increased consumption due to a less energy conscious behave of the occupant (+3.7% for HC alone and -2.9% and -8.4% for HC coupled with class B and class A respectively).

The CBA performed to evaluate the feasibility of the project that took into account the WTP calculated with a Bidding Game methodology assessing the attitude of respondents towards energy efficient investments has highlighted the difficulties to undergo such projects caused by still too high investment costs as well as maintenance costs and resulted in a not economically desirability of the BACS implementation projects.

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