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Energy and Economic Evaluation of Thermal Comfort. The Case Study of the Hotel Residence L'Orologio

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Abstract

Nowadays, there is a need for reducing building's energy consumption while preserving a comfortable and healthy indoor environment. After a detailed analysis of the literature in the domain of indoor environmental quality, occupant well-being, health and productivity, the paper explores the relationships between energy retrofit, interventions, indoor comfort and economic benefits and it proposes a real application concerning the case study of a hotel in Turin (Italy). The simulation was carried out through a Cost-Benefit Analysis that allowed to monetize and optimize the economic benefits, in terms of clients' thermal comfort and employees' productivity, while preserving the heating energy costs.

Introduction

Nowadays, the awareness of the close relationship between the Indoor Environmental Quality (IEQ), the occupant's well-being, health and productivity, and the building energy efficiency is gradually growing. Indeed, the European Union Framework Programme for Research and Innovation, Horizon 2020, promoted the development of new funding opportunities on these focus areas in the future scientific researches. Furthermore, the recently approved revision of the European Parliament Building Directive (European Parliament, 2018) underlined the importance to build a comfortable indoor environment, introducing a new Smart Readiness Indicator (SRI) that could contribute to enhancing energy efficiency, comfort and well-being of the occupants. In the present-day, people spend about 80-90% of their life in enclosed spaces (ASHRAE, 2011) characterized by an indoor air from 2 to 5 times more polluted than outdoors (Wallace, 1987). To guarantee comfortable conditions and to ensure health and performance of building's occupants, it is necessary to monitor, verify and optimize the indoor environmental quality. For this reason, the paper critically shows the results of a literature review aimed at analyzing and evaluating how the IEQ influences health, comfort and productivity of the occupants. It is focused on collecting useful information for both energy-environmental and economic-financial assessments with regards to thermal comfort in the hospitality sector. The choice to investigate this sector is due to its multifunctionality, characterized by a variety of indoor environments, by different types of users and by high energy consumptions. Indeed, the hotel represents the most energy-intensive sector of the tourism industry, with approximately 50% of energy consumption due to space conditioning (heating, cooling and ventilation in order to maintain high standards of comfort) (Bohdanowicz and Martinec, 2002).

A field of studies demonstrated that a reduction in the temperature could positively contribute to reduce the energy costs; it has been shown that a 1°C decrease in indoor temperature accounts for a 10% reduction in heating costs (Bohdanowicz and Martinec, 2002). Focusing on thermal comfort, the dissatisfaction with the thermal conditions of the environment represents the most common problem among occupants. Furthermore, since the thermal preference is an extremely personal factor, studies on individual climate control systems were increased in order to maximize the indoor comfort (Arens et al., 1991; Melikov and Nielsen, 1989). Nowadays, the assessments are not only linked to building's energy efficiency but are based on the occupant; it is essential to consider the strong relationship occupant-building-system in order to ensure a better comfort inside building. Indeed, as active users, the occupants interact with the indoor environment in order to improve their comfort conditions. In detail, the paper shows the results of an energy efficiency action based on human interactions with the control of temperature inside the hotel. The simulation was carried out through a Cost-Benefit Analysis (CBA), method used to determine the best temperature setting scenario that allows obtaining benefits while preserving energy savings.

The study was developed using a range of literature review looking at papers, books and using the Standard concerning the IEQ. First, it is essential to identify the main keywords that can give information about the topic of the study. The paper is structured in the following way. Section "Methods" shows the methodology of data collection deriving from a literature review about the different methods of monetization of IEQ with regard to various uses in order to identify the optimal one for the hotel industry. Section "Application" concerns the application of the method, previously identified, to a real hotel building in Turin (Italy); in this section three indoor environments, guest rooms, service areas and common areas, are analysed in order to take into account the economic benefits of both the client and the employee. Finally, the last section describes the results of the economic evaluation on the different temperature setting

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scenarios in order to identify the optimal one, in economic and energy terms that guarantees the best economic benefit to the hotel owner.

Methods

The research starts from a state-of-the-art literature survey about the different methods of monetization of indoor environmental quality (thermal, visual, acoustic comfort and indoor air quality) for each building's categories (hotel, residence, school and office). Secondly, the case study of the hotel has been considered, estimating the economic benefits related to different energy requalification and interventions, and comparing alternative management scenarios by means of the Cost-Benefit Analysis (CBA). In particular, the results obtained in the CBA allowed to evaluate the optimal temperature setting scenario in the different hotel areas that both clients and employees should set up in order to maximize their benefits and to reduce the energy consumptions.

Literature Review

The purpose of this literature review was to identify an economic-financial method to evaluate the indoor comfort in a hotel building. Because of the lack of papers concerning the hospitality sector, the research widens the analysis to different typologies of buildings: hotel, residence, school and office. Table 1 shows the inspected papers divided according to the category previously mentioned. For each of them the authors, the year and the source are specified. Moreover, a review was conducted by Science Direct, Research Gate and Google Scholar as main research platforms.

From the literature analysis, different methods emerged for the various uses; in hotels, the Willingness To Pay (WTP) an extra cost for better comfort conditions in rooms was investigated (Buso et al., 2016; Buso et al., 2017); in residences, the method was based on future energy savings (Fang et al., 2012; Noris et al., 2013; Clinch and Healy, 2003); in schools, the quantification of indoor comfort in monetary terms was evaluated in relation to student's learning and performance (Clements-Croome et al., 2008; Wheeler, 2014); finally, in offices, the economic benefits of improving comfort were estimated quantitatively in relation to employee productivity, reduction from sickness absences, and reduction of Sick Building Syndrome (SBS) symptoms (Brager, 2013; Seppänen et al., 2004; Seppänen and Fisk, 2011). As a result of this review, some criticisms and limitations were made about the literature. All the analysed papers give a monetary quantification of Indoor Air Quality (IAQ) and thermal comfort effects, while the visual and acoustic comfort are evaluated only with a qualitative point of view. For this reason, the paper focuses on estimating the economic benefits in terms of thermal comfort. Lastly, concerning hotels, it was necessary not only to talk about monetization of comfort in relation to the WTP for better environmental conditions in the hotel rooms, but also to take into consideration the working comfort for employees. First because a wider view of the hotel spaces is needed (not focusing only on the rooms quality but also on common and service areas). and secondly because the workers give a 24h service to guarantee costumer's satisfaction. From these considerations, the research carries on finding three main areas in hotels:

- guest spaces, which are rooms made up of individual spaces with variable energy loads;
- common areas, consisting of reception, lobby, restaurant, bar, gym and conference room featuring both the clients and the staff;
- service areas, such as laundry, cooking and offices exclusively for employees.

In this context, it was essential to take into account the different requirements of occupants; on one hand, the employees prefer pleasant working conditions to achieve higher productivity and working performances; on the other hand, costumers or guests look for a comfortable indoor environment in hotel rooms and a safe stay.

Moreover, the influence of the thermo-hygrometric microclimate on the occupant's comfort, health and productivity, was amply demonstrated by the literature review. Thermal conditions can affect the performance of work in different ways (Wyon and Wargocki, 2006): (1) thermal discomfort generates complaints and increases maintenance costs; (2) warmth have a negative effect on SBS symptoms and on occupant's concentration (Willem, 2006); (3) cold conditions have a negative effect on manual tasks; (4) vertical thermal gradients lead to a reduction in room temperature.

In the present study, the economic benefits of improving thermal comfort in hotel work environments (service and common areas) were estimated quantitatively in relation to employees' productivity and salary. In order to quantify and monetize the economic benefit carried out from different indoor temperature setting, a field of studies about the effects of the temperature on worker's performance were investigated. Various papers discussed about the strong relationship between air temperature and employees' performance or absenteeism in workplaces. (Wyon, 1996) showed that thermal conditions within the thermal comfort zone can reduce performance by 5% to 15%. (Niemela et al., 2002) carried out a study in an office building discovering that the average talk-time was 5-7% lower when temperatures remained below 25°C. Moreover, in a call-centre the average talk-time of an operator improved by 4.9% when the air temperature was decreased by 2°C from 24.5°C (Tham et al., 2003). Another experiment conducted in the laboratory by Witterseh (2004) on 30 subjects engaged in activities that simulated normal office work demonstrated that at temperatures of 22°C, 26°C and 30°C, the percentage of dissatisfied due to perceived air quality was respectively 5%, 34% and 88%. Finally, the studies of Preller (1990) and Raw (1990) in an office building were demonstrated that self-estimated performance was higher when occupants can control their own thermal climate.

Table 1: Literature review of papers concerning economic and financial valuation of indoor comfort.

	Title	Author	Year	Source
HOTEL	Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms	Buso, et al.	2017	Energy Res. Soc. Sci., vol. 32
HOTEL	Thermal comfort and energy savings in the hotel industry	Bohdanowicz and Martinec	2002	16th International Society Conference on Biometeorology
HOTEL	Evaluation of perceived indoor environmental quality of five-star hotels in China: an application of online review analysis	Qi, et al.	2017	Build. Environment, vol. 111
HOTEL	Consumers' willingness to pay premium for green hotels: Fact or Fad?	Dimara, et al.	2015	14th International Marketing Trends Conference
HOTEL	Energy efficiency and financial performance of a reference hotel - proposing a global Cost-Benefit Analysis	Buso, et al.	2016	12th REHVA World Congress
HOTEL	Energy savings and guaranteed thermal comfort in hotel rooms through nonlinear model predictive controllers	Acosta, et al.	2016	Energy Build., vol. 129
RESIDENCE	Monetization of thermal comfort in residential buildings comfort model description	Fang, et al.	2012	17th ACEE Conference
RESIDENCE	Indoor environmental quality benefits of apartment energy retrofits	Noris et al.	2013	Build. Environment, vol. 68
RESIDENCE	Valuing improvements in comfort from domestic energy-efficiency retrofits using a trade-off simulation model	Clinch and Healy	2003	Energy Econ., vol. 25
SCHOOL	The sustainable school: effective and energy efficient ventilation in the classroom, and the question of educational performance and well-being	Wheeler	2014	World Conf. Sustain. Build.
SCHOOL	Ventilation rates in schools	Clements-Croome, et al.	2008	Build. Environment, vol. 43
SCHOOL	Daylighting in schools, an investigation into the relationship between daylight and human performance	Heschong	1999	California Board for Energy Efficiency
SCHOOL	Effects of classroom acoustics on performance and well-being in elementary school children: a field study	Klatte, et al.	2010	Environ. Behav., vol. 42
OFFICE	Proposal for a modified cost-optimal approach by introducing benefits evaluation	Becchio, et al.	2015	Energy Procedia, vol. 82
OFFICE	Benefits of improving occupant comfort and well-being in buildings	Brager	2013	4th International Holcim forum for sustainable construction
OFFICE	Review on visual comfort in office buildings and influence of daylight in productivity	De Carli, et al.	2008	11th International Conference on Indoor Air Quality and Climate
OFFICE	Indoor climate and productivity in offices	Wargocki, et al.	2006	Rehva Gb, vol. 6
OFFICE	Cost-Benefit Analysis of improved air quality in an office building	Djukanovic, et al.	2002	9th International Conference on Indoor Air Quality and Climate
OFFICE	Effect of temperature on task performance in office environment	Seppänen, et al.	2006	5th International Conference on Cold Climate HVAC
OFFICE	Control of temperature for health and productivity in offices	Seppänen, et al.	2005	ASHRAE Transactions, vol.111
OFFICE	A procedure to estimate the cost effectiveness of the indoor environment improvements in office work	Seppänen and Fisk	2006 (a)	Creating the productivity workplace (Book)
OFFICE	Method for cost-benefit analysis of improved indoor climate conditions and reduced energy consumption in office buildings	Jurelionis, et al.	2013	Energies, vol. 6
OFFICE	Benefits and costs of improved IEQ in U.S. offices	Fisk, et al.	2011	Indoor Air, vol. 21
OFFICE	Health-related costs of indoor ets, dampness and mold in the united states and in California	Fisk	2005	10th International Conference on Indoor Air Quality and Climate
OFFICE	Some quantitative relations between indoor environmental quality and work performance or health	Seppänen and Fisk	2006 (b)	HVAC&R Res., vol. 12
OFFICE	Estimate of an economic benefit from investment in improved indoor air quality in an office building	Wargocki	2003	7th International Conference on Healthy Buildings
OFFICE	Review of health and productivity gains from better IEQ	Fisk	2000	International Conference on Healthy Buildings
OFFICE	Influence of indoor air temperature variation on office work performance	Valančius and Jurelionis	2013	J. Environ. Eng. Landsc. Manag., vol. 21
OFFICE	Providing better indoor environmental quality brings economic benefit	Fisk and Seppänen	2007	9th REHVA World Congress

Cost-Benefit Analysis methodology

An analysis based on Cost-Benefit Analysis (CBA) approach was proposed in order to identify the optimal temperature setting scenario that allows obtaining benefits while preserving energy savings. According to European Commission (2014), CBA is a systematic approach used in investment decisions in order to assess the welfare changes attributable to alternative projects and to select the most profitable in terms of the society's convenience (Becchio et al., 2018). It is developed through the following five steps: 1) identification of costs and benefits of the project; 2) estimation of the monetary values; 3) distribution of the estimated costs and benefits over the time and construction of the cash flow; 4) definition of the discount rate; 5) calculation of the performance indicators.

In the present study, a Benefit-Cost Ratio (BCR) was used to determine the economic efficiency of the different scenarios analysed. The following formula (1) presents the ratio between discounted economic benefits and costs:

$$\frac{B}{C} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+r)^t}} \qquad (1)$$

where *n* is the analytic horizon, *t* represents the cash flow period, B_t is the cash flow of benefits, C_t is the cash flow of costs, and *r* is the discount rate.

Application

The methodological approaches presented in the previous section were applied to an existing building in the centre of Turin (Italy), the Hotel Residence L'Orologio.

The main input data are presented in the Table 2.

Table 2: Input data of the analysis.

Occupation rate (short-stay)	25% (average 2013-2014)
Occupation rate (overnight-stay > 1 month)	50% (average 2013-2014)
Floors number	6
Total heated floor area	1,138 m^2
Total heated volume	3,845 m^3
Total rooms surface	874 m^2
Rooms number	20
Beds number	78

Three main environments (guest rooms, service areas and common areas) and two different typologies of indoor requirements (by clients and by employees) were identified and discussed in the following sections. This paper was intended to represent a first attempt to monetize the benefits expected from an improvement in indoor thermal conditions considering two different variables. On one hand, the comfort needs of the client were evaluated through the implementation of the questionnaire presented in Buso et al. (2017) in terms of WTP; on the other hand, the needs of the employee by estimating the economic benefits of a comfort improvement based on his productivity. The evaluation was done in relation to the winter season from 15 October to 15 April (182 days), with regard to the heating energy consumption. The economic benefits were quantified in €/(winter season*m^2) and obtained from the difference between the proposed scenario and the state of art (equal to 20°C inside the three environments).

Guest rooms

Monetary evaluation of comfort conditions in guest rooms was estimated by the co-benefits of employing the results coming from a Contingent Valuation Method (CVM) survey concerning the results conducted by Buso et al. (2017). In the survey, the guests were asked the extra price per night they would be willing to pay for better IEQ in the room. The results of the questionnaire have shown that about 18% (40 people) were not willing to pay an additional price because the room rate per night of 80 €/night (on average hotel rates in the centre of Turin, Italy) was perceived as enough elevated. The rest of the respondents (184 people) were demonstrated a WTP of about 14% more than the base room rate. Subsequently, the percentage (14%) was applied on the average room price of the Hotel Residence L'Orologio (117 €/night for short-stay and 83 €/night for overnight stay), quantifying the guests' willingness to pay as 16.38 €/night and 11.62 €/night more than the base room rate, respectively for short and overnight stay. Finally, considering only the winter season (182 days), the occupation rate in Table 2 and the WTP of clients only for improved the thermal comfort (25%), the total WTP an extra cost results equal to 10.31 €/(winter season*m^2). This economic benefit corresponds to an optimum indoor temperature of 22°C. In Table 3, the economic benefits obtained from the customer's willingness to pay for different temperature settings in the room were summarized.

Table 3: Economic benefits from the guests' WTP in room.

Temperature [°C]	Benefit [%]	Δ Benefit [€/(winter season*m^2)]
21 (+ 1°C)	10 % increase in the room rate	7.36
22 (+ 2°C)	**14 % increase in the room rate**	**10.31**
23 (+ 3°C)	10 % increase in the room rate	7.36
19 (- 1°C)	-14 % decrease in the room rate	-10.31
18 (- 2°C)	-14 % decrease in the room rate	-10.31
17 (- 3°C)	-14 % decrease in the room rate	-10.31

Service areas

Hotel Residence L'Orologio service area was represented by a single office (11 m^2) occupied by the Director. The estimation of the monthly salary of the employee is acquired by the "Contratto Collettivo Nazionale del Lavoro" (CCNL, 2008) equal to 2,514 €/month (13.6 €/h). The study considered that the Director works 8h per day, excluding Sunday, reaching a total of 156 working days. Based on these input data, the manager's salary results equal to 16,972 €/winter season. Since the workplace was characterized by the presence of the employee, quantifying the economic benefits of better thermal comfort was associated with increased productivity. The relation between air temperature and work performance is shown in Figure 1, as follow (2):

$$RP_t = 0.1647524 \times t_c - 0.0058274 \times t_c^2 + 0.0000623 \times t_c^3 - 0.4685328 \quad (2)$$

where RP_t represents the relative performance and t_c is the indoor temperature in °C.

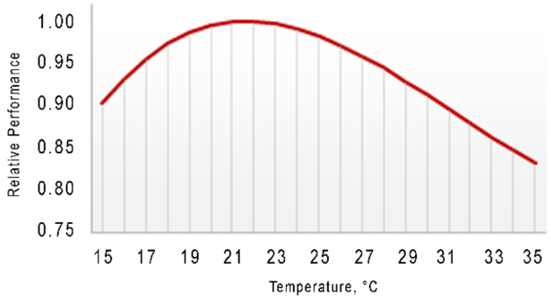

Figure 1: Relative performance in relation to the indoor temperature.

Figure 1 was based on the results from 24 studies, conducted by Seppänen (2006), investigating the effects of temperature on office work performances. The curve suggests that work performance is maximized when the indoor air temperature is about 22°C. For each variation (increase or decrease) of 1°C, compared to the optimal temperature (22°C), a reduction of performance by about 1% occurs. The economic benefits were obtained from the difference between the proposed scenario and state of the art (20°C). Table 4 summarizes the economic benefits coming from the various temperature settings in the office.

Table 4: Economic benefits from the various temperature settings in the office.

Temperature [°C]	***Benefit [%]***	***Δ Benefit [€/(winter season*m²)]***
21 (+ 1°C)	0.46 % increase in work performance	7.09
22 (+ 2°C)	**0.51% increase in work performance**	**7.86**
23 (+ 3°C)	0.23 % increase in work performance	3.54
19 (- 1°C)	0.9 % decrease in work performance	- 13.88
18 (- 2°C)	2.2 % decrease in work performance	- 33.94
17 (- 3°C)	4 % decrease in work performance	- 61.71
(*) Employee salary = 16,972 €/winter season = **1,542 €/(winter season*m²)**		

Common areas

The common area of Hotel Residence L'Orologio was represented by the reception (16 m²) on the ground floor and occupied by two employees, the receptionists.

The estimation of the monthly salary of an individual employee is acquired by the CCNL (2008) equal to 16,180 €/month (8.79 €/h). The study considered that the employee works 6h per day, excluding Sunday, reaching a total of 156 working days (the receptionist's salary was 8,227 €/winter season). Table 5 summarizes the economic benefits coming from the various temperature settings in the reception.

Table 5: Economic benefits from different temperature settings in the reception.

Temperature [°C]	***Benefit [%]***	***Δ Benefit [€/(winter season*m²)]***
21 (+ 1°C)	0.46 % increase in work performance	4.73
22 (+ 2°C)	**0.51% increase in work performance**	**5.24**
23 (+ 3°C)	0.23 % increase in work performance	2.36
19 (- 1°C)	0.9 % decrease in work performance	- 9.20
18 (- 2°C)	2.2 % decrease in work performance	-22.62
17 (- 3°C)	4 % decrease in work performance	- 41.13
(*) Employee salary = 8,227 €/winter season = 514 €/(winter season*m²). Two employees: **1,028 €/(winter season*m²)**		

The approach used to evaluate the economic benefits was the same for the service areas presented in the previous section. In this case, in order to obtain a correct evaluation of the reception area it was necessary to consider the presence of clients. Based on the hypothesis that the client went through the reception about 4 times a day and the average of his/her stay was 10 minutes, the customer's Willingness To Pay for better comfort conditions in the reception was equal to 1.16 €/(winter season*m²) associated with an optimal indoor temperature of 21°C.

Energy consumption and costs

In order to monetize the energy consumption, a quantification was necessary, which in the present study required an energy simulation that refers to the Energy Audit Report (SiTI, 2015). The total energy consumption (97.46 kWh/(winter season*m²) and the equivalent energy costs (6.32 €/(winter season*m²) of the Hotel Residence L'Orologio were referred to the only winter season and therefore to the heating consumption of the building, considering the state of art of 20°C. Table 6 shows the economic benefits for different temperature scenarios (± 3°C) for power consumption/energy savings. Each upward (or downward) variation of 1°C of temperature with respect to the state of art (20°C) results into a 7% increase (or decrease) of the energy cost. The economic benefits were quantified in €/(winter season*m^2) and obtained from the difference between the energy costs of the proposed scenario and the energy costs of state of the art (6.32 €/(winter season*m^2).

Table 6: Economic benefits in terms of energy for different temperature settings.

Temperature [°C]	***Benefit [%]***	***Δ Benefit [€/(winter season*m^2)]***
21 (+ 1°C)	7% increase in energy costs	0.44
22 (+ 2°C)	14% increase in energy costs	0.88
23 (+ 3°C)	21% increase in energy costs	1.32
19 (- 1°C)	7% decrease in energy costs	-0.44
18 (- 2°C)	14% decrease in energy costs	-0.88
17 (- 3°C)	21% decrease in energy costs	-1.32

Results and discussion

The following section identifies all the indoor temperature settings combined for the three distinct areas: guest rooms, office and reception. The different scenarios were assumed for all temperature combinations, excluding those at 17°C and 18°C because, for the winter reference season, they are outside from PPD=10%. Therefore, the temperature setting considered are 19°C, and from 21°C to 23°C; as a consequence, there were 64 possible scenarios. For each of them, the energy cost and the overall economic benefit in terms of €/winter season were calculated. The evaluation of the relationship between benefits and costs will allow to identify the optimal scenario represented in Table 7 and characterized by a temperature inside the three environments equal to 21°C.

Table 7: Scenario 21°C-21°C-21°C.

		[€/(winter season]	
Costs	Office	4.84	
	Reception	7.04	
	Rooms	384.56	
	TOT	396.44	
Benefits	Office	77.99	
	Reception	94.24	
	Rooms	4,824.48	
	TOT	4,996.71	
Benefits/Costs Ratio (BCR)			**12.60**

As shown in the Table 7, the setting of 21°C in office, reception and guest rooms correspond to a BCR of 12.60. In this scenario, the ratio between benefits and costs was maximized. It is possible to notice that while not reaching the optimal set-point of 22°C the benefits were optimized at the indoor temperature of 21°C; as a matter of fact, despite the overall economic benefit of the presented scenario was lower than that of the scenario at 22°C, the costs related to energy consumption for heating were much lower.

Table 8 shows the scenario at the set-point temperature of 22°C in all environments; this temperature guarantees the maximum benefit from both the customer, who was Willing To Pay 14% more on the price of the room, and the employee, who maximizes his/her work performance.

Table 8: Scenario 22°C-22°C-22°C.

		[€/(winter season]	
Costs	Office	9.68	
	Reception	14.08	
	Rooms	769.12	
	TOT	792.88	
Benefits	Office	86.46	
	Reception	96.96	
	Rooms	6,758.20	
	TOT	6,941.62	
Benefits/Costs Ratio (BCR)			**8.75**

As shown in Table 8, the temperature scenario of 22°C corresponds to a cost-benefit ratio of 8.75; this result is lower than the scenario above (Table 7) despite representing the optimal set-point temperature in terms of expected economic benefits. As a matter of fact, it can be seen that the total benefits are much higher, but at the same time, the 2°C increase of the temperature (with respect to the state of art of 20°C) results in the improvement of heating energy.

Conclusion

The research work gave the possibility to identify the optimal method of monetization of thermal comfort in the hotel sector. This paper represents a first attempt to monetize the benefits expected from an improvement in indoor comfort conditions through the analysis of two variables: on one hand, the comfort needs of the client were evaluated by an implementation of the results obtained from Buso et al. (2017) in terms of Willingness To Pay, on the other hand the needs of the employee by estimating the economic benefits of a comfort improvement based on his productivity. The final objective was to identify, through a CBA, the optimal scenario that guarantees the best economic benefit to the hotel owner. The results of the analysis showed that the optimal scenario was identified at a temperature of 21°C inside all three considered areas, which corresponds to a benefit-cost ratio of 12.60; these conditions allow to maximize the thermal comfort in relation to a high energy saving for heating. The application to the case study concerned the hotel sector but the approach identified can be applied to different uses (Becchio et al., 2019). Furthermore, it is necessary to underline that the analysis was exclusively about the evaluation of thermal comfort. For this reason, it would be interesting to investigate on visual and acoustic comfort, and indoor air quality in order to give a complete view of the benefits deriving from the improvement of the indoor environmental conditions.

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