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Possible Control Strategies for Energy Savings Through ICT Based Control and Monitoring Systems

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Abstract

The paper addresses the topic of energy savings in existing public buildings by designing an intelligent ICT-based service to monitor and control environmental conditions, energy loads and plants operation. A set of demonstrator buildings of the Politecnico di Torino and an interoperable web-based software and hardware solution for real-time monitoring and control are being implemented. So, lighting, heating, ventilation and air conditioning services, through both wired and wireless sensors networks will be connected and the running optimized.

New control rules have been designed and tested in order to properly balance energy savings and comfort issues. The test cases have been modeled in DAYSIM (lighting simulations) and TRNSYS (thermal simulations). A combination of daylight harvesting and occupancy detection was proposed as lighting control strategies. For the thermal control presence detection and occupancy planning are used. In order to reach the best compromise, the time necessary to reach the set point temperature is estimated based on ambient conditions.

First simulation results presented here show that it is possible to maintain user thermal and visual comfort while reducing the HVAC annual energy demand up to 13 % (for the presented cases) and the lighting electric consumption up to 50 %.

Keywords – ICT, thermal simulation, lighting simulation, comfort, control

1. Introduction

“Smart Energy Efficient Middleware for Public Spaces” (SEEMPubS European project) specifically addresses reduction in energy usage in

existing public buildings by implementing an intelligent ICT (Information and Communications Technology)-based building monitoring and managing system. The project will implement, in a set of demonstrator buildings of the Politecnico di Torino, an interoperable web-based software and hardware solution for real-time monitoring and control of lighting, heating, ventilation and air conditioning services, through both wired and wireless sensors networks.

Control rules were designed and tested in order to properly balance energy savings and comfort issues. The test cases have been modeled in DAYSIM [1, 2, 3] (lighting simulations) and TRNSYS [4] (thermal simulations) and several control rules have been implemented and tested.

To evaluate the achievable energy savings, the rooms selected for the project (six pairs of similar rooms, heated and cooled individually with fan coils) were simulated as they are now, with the existing plants and control systems (Reference cases) and after applying the proposed control strategies (Test cases). Some obtained results, presented here, outline potentials but also limitations of the control approaches.

2. Energy Conservation Strategies for HVAC

The economic advantage of intermittent use of heating systems in intermittently-occupied buildings (e.g. schools, office buildings) is no longer in doubt. Nevertheless, optimal energy consumption requires that the heating restart time shall be defined with great precision. In many cases, to avoid risks, the lowering of the temperature during non-occupancy period is limited, which leads to reductions in energy savings.

An intermittent heating controller allows the internal temperature to be lowered during non-occupancy periods, while maintaining the desired temperature during occupancy periods, when these periods are clearly defined. For the SEEMPubS project it was assumed to go further by having a detection of the occupancy. A schedule is always defined allowing turning off the heating when the room is unoccupied, unless a presence is detected. Nevertheless, the user can always act on the system by changing the set point temperature of the fan coils with individual switcher. In fact, a lot of classrooms or offices are not used during all the time of the scheduled period. If no presence is detected, the heating is stopped after a little delay.

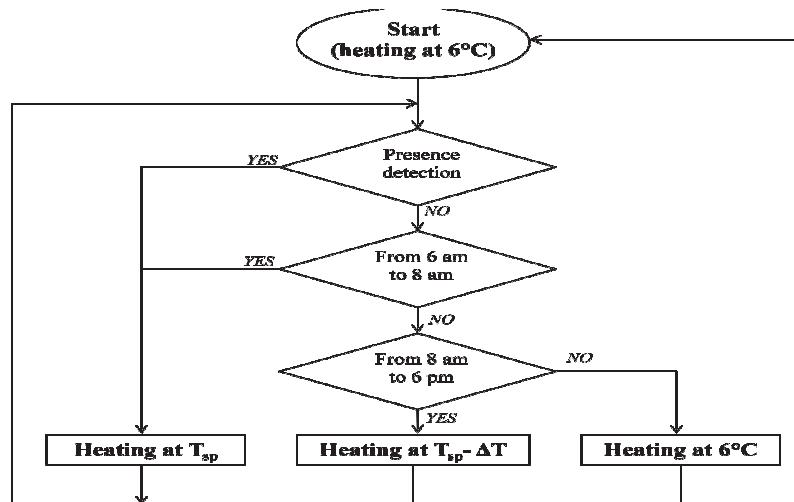


Fig. 1 Heating strategy for offices

The strategies we have tested are divided in two parts depending on the information we have access for the room:

- For the room in which a presence prediction is impossible (for example a teacher office), we imagine a scenario (presented on Figure 1.) which permit to heat the room the whole day at a base level to ensure an internal comfort if the user comes. Nevertheless, this strategy allows energy savings if there is no presence during a day because, in this case, the office will be heated at a lower set point temperature.

- The Other case is an algorithm of thermal strategy for the room in which we can predict the presence by the utilization of a schedule (a meeting room, a classroom for example or an office with regular occupation). The possibility of knowing the presence or not in the room allows anticipating the heating start to have a sufficient user comfort when people arrive, and also anticipating the heating stop to perform energy saving if the room is empty after the occupation. The paper focuses on Δt for start of the heating only, however, the same principle has been applied at the end of the occupation period (switching off heating in advance) but this solution lead to discomforts and very low savings, and isn't developed there.

For summer, similar algorithms are defined.

These strategies also rely on better management of the fan coil speed by automating their selection. Longer the indoor temperature approaches the set point temperature the more the blowing velocity is reduced. In this manner the power of the fan coil varies with the speed and is better adapted to the energy needs of the room as in summer than in winter.

3. Energy Conservation Strategies for Lighting

According to the information on the room features, some lighting control logics have been proposed [5]. In particular, for spaces with high daylight availability and medium/high users absence probability, a combination of daylight harvesting and occupancy control was proposed. For

spaces with low daylight availability, a lighting control based on occupancy sensing was proposed, while a particular solution was planned for large classrooms with no daylight: students absence probability during the day is very low, but the classroom area could be only partially occupied when a small number of students attend the lectures. In this case it was supposed to use several occupancy sensors to dim the light to a minimum in correspondence to the unoccupied parts of the classroom.

For some rooms a time switching strategy is planned, whereas in all cases the possibility to override the automatic control via manual command is provided.

Based on these assumptions some recurrent combinations of lighting control strategies [6] were proposed for the selected rooms:

- *Time switching, occupancy detection for personal light and manual control*; This mix of control strategies is proposed for the Student Offices of the Valentino Castle where daylight availability is very low and the general lighting is provided by means of High Pressure Metal Halide lamps, which cannot be switched on and off instantaneously and cannot be dimmed.
- *Daylight harvesting, occupancy detection and manual control*; This combination of control strategies is proposed for Diter offices, Administrative offices and Dauin single offices. In these cases the automatic dimming of lights based on a daylight harvesting control strategy could be applied successfully thanks to the high daylight availability and it could be useful to control lights on the basis of room's occupancy too, as a medium absence probability could be supposed for these offices (Fig.2)

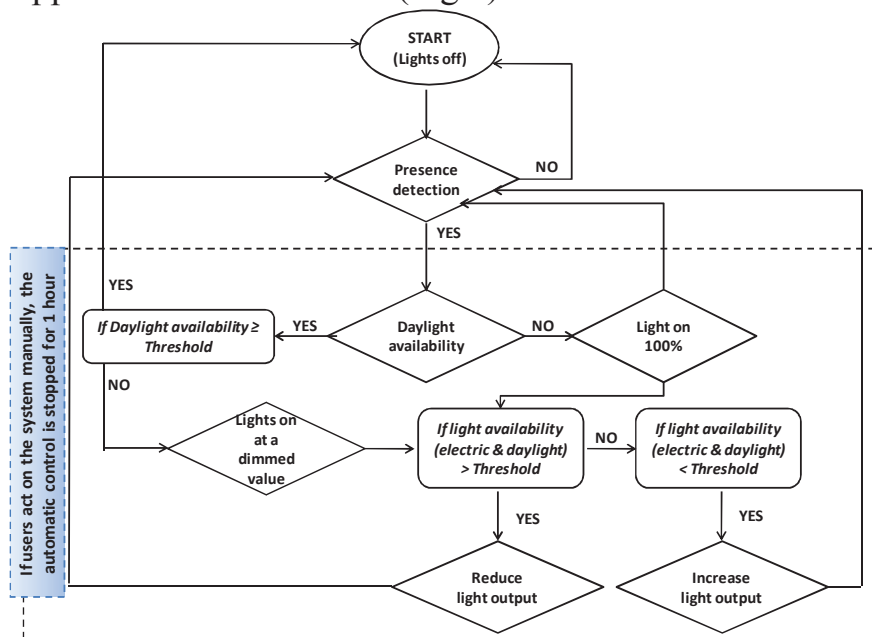


Fig. 2 Flow chart of the control rules for the lighting systems for Diter, Administrative and Dauin offices

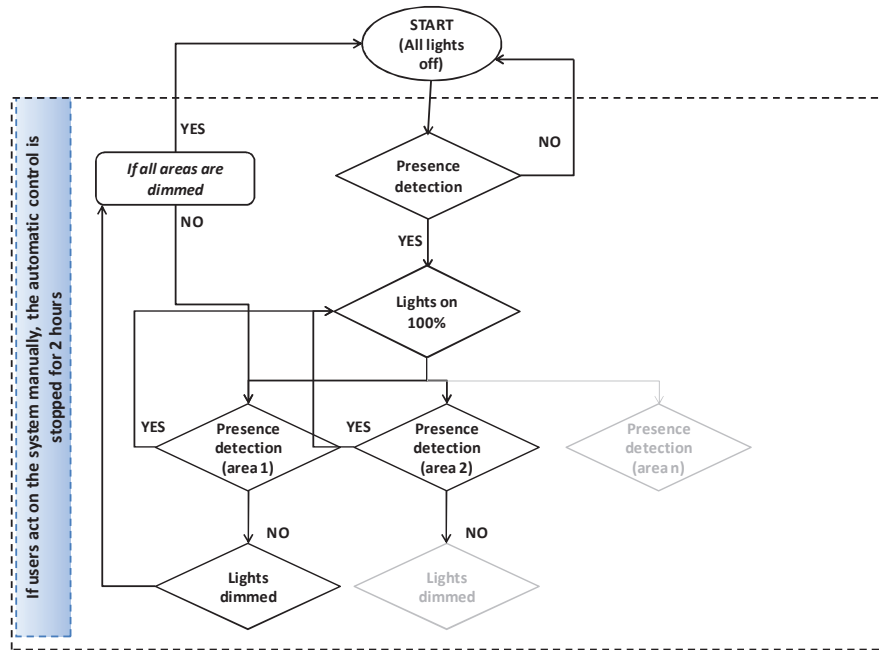


Fig. 3 Flow chart of the control rules for the lighting systems for classrooms

- *Occupancy detection and manual control*; This control strategies is proposed for Classrooms 1&3 and for Dauin open plan offices as daylight is not allowed to enter the rooms (in classrooms) or is quite low due to the glazing characteristics and the external obstructions produced by the structure of the double façade in the Dauin open plan offices (Fig. 3)
- *Shading device control based on outdoor illuminance or solar radiation*; This control strategy is proposed for Diter offices, where motorized blinds are installed on the roof lights, to control overheating and glare due to solar radiation.

4. Evaluation, Through Software Simulations, of the Energy Conservation Strategies for HVAC

Only results on presence detection (DITER Offices) will be presented in this paper. The simulations carried out with Trnsys are based on the annual weather data for Torino Results of different strategies will be presented in terms of energy savings and comfort:

- Test case 1: Presence detection with two set point temperatures
 - $T_{sp} = 21^{\circ}\text{C}$ in occupation
 - $T_{sp} - 3^{\circ}\text{C} = 18^{\circ}\text{C}$ in unoccupation
- Test case 2: Test case 1 + optimization of the recovery time

The occupation schedule considered in all cases is presented in figure 4.

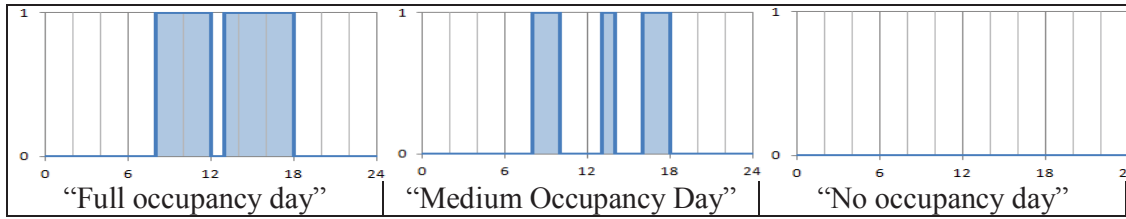


Fig 4 Typical occupancy schedules used in the simulation

Mondays and Fridays are supposed to be “Full occupancy days”, Tuesdays and Wednesdays are supposed to be “Medium occupancy days” and Thursdays are supposed to be “No occupancy days”. It means that the real occupancy considered in the simulation is 56 % of the theoretical occupancy (44 % of vacancy).

In order to reach comfort condition, the set point temperature of the HVAC system is 21°C in early morning during heating season. The set point temperature reduction (18°C) applies only during theoretical occupancy (from 8:00 am to 6:00 pm Monday through Friday and from 8:00 am to 3:00 pm on Saturday) when occupation is not detected.

a. Optimisation of Recovery Time Δt

For Test Case 2, we have proceeded to the calculation of Δt (recovery time necessary to reach the set point temperature each day) on an annual simulation for the building. A correlation has been found between the recovery time Δt and temperature difference ΔT between the set point temperature and the indoor temperature when the heating system is turned on. Results are displayed on Figure 5.

The Monday morning case has been separated from the others days. Indeed, on Monday mornings the temperature of the building structure is low while on the other hand, on the week the inertia of the building allows to save time to achieve the set point temperature and so reduce Δt .

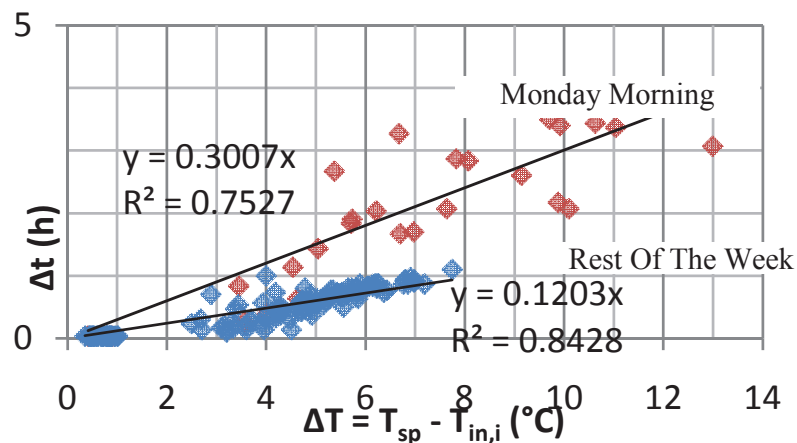


Fig. 5 Correlation between Δt and ΔT (DITER offices)

This strategy has been implemented for the heating period on the DITER offices with the following simple correlation in heating mode:

$$\begin{cases} \Delta t = 0.3 \Delta T \text{ on monday mornings} \\ \Delta t = 0.12 \Delta T \text{ during the rest of the week} \end{cases}$$

where Δt is the recovery time (time needed to reach the set point temperature) and ΔT is the temperature difference between the set point temperature and the indoor temperature at the moment when the HVAC system is turned on. In cooling period, no recovery time is necessary as there is usually no comfort issue in the early morning.

b. Energy Saving Results

First results are displayed on table 1 and show that this strategy allows energy reduction up to 12.5 % (12.4 % on heating and 13.0 % on cooling).

Table 1. Heating and Cooling energy consumption using our control strategy (DITER offices) and Corrected values for test case 2

<i>kWh/m².y</i>	<i>Ref</i>	<i>TC1</i>	<i>Savings</i>	<i>TC2</i>	<i>Savings</i>
Heat	57.3	46.3	19.3%	50.3	12.4 %
Cool	20.0	17.5	12.3%	17.4	13.0 %
Total	77.3	63.8	17.5%	67.7	12.5 %

The fact that the building warm up is the same in the reference room and in the test room, and that the set point temperature is simply reduced (as opposed to a control strategy where the HVAC system would completely turn off while vacancy) explains why there is only a 12.5 % reduction on energy consumption when the room is unoccupied 44 % of the theoretical occupancy schedule.

c. Comfort Results

Comfort is already an issue particularly during early hours in the existent strategy (reference room) and in the investigated strategy as shown in figure 6. We can see that there are still numerous hours when indoor temperature is far from the set point temperature during occupancy. This is probably due to the fact that the HVAC system is turned on at 6:00 am every weekday morning regardless of the outside and ambient temperature. When outside temperature is very low or when the HVAC system has been turned off for a long time (typically on Monday mornings), the time necessary to reach the set point temperature is longer.

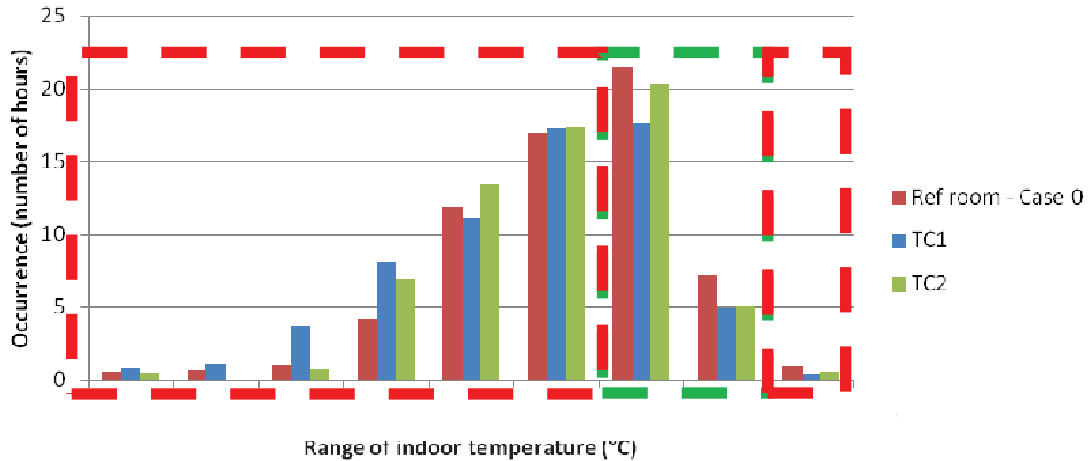


Fig. 6 Indoor temperature distribution during heating season between 8:00 and 8:30 (DITER offices) for Test Case 1 (TC1) and Test Case 2 (TC2)

Comfort results are much better in test case 2 because there is a fewer number of hours when indoor temperature is more than 2°C lower than the set point temperature. The set point temperature is more often reached on time. Nevertheless, there are still numerous hours when set point temperature is not reached. This is due to the fact that the correlation found is not really accurate (standard deviation of 12 minutes for Monday mornings and 32 minutes for the rest of the week). A better correlation would lead to better results without necessarily causing an increase of energy consumption.

5. Evaluation, Through Software Simulations, of the Energy Conservation Strategies for Lighting

In this paper the first results on lighting energy demand for single offices (Diter offices), are presented.

Annual electric energy demand for lighting [7], in a building or room, depends on several factors, mainly related to the indoor daylight availability, the building usage (occupancy profile, required illuminance), the user's behavior with respect to both electric and daylighting systems and the lighting plant characteristics (installed electric power density and adopted lighting control system).

The simulations carried out with Daysim are based on the annual weather data for Torino, on the offices occupancy profile and lighting requirement (target illuminance of 500 lux) and on stochastic user behaviour models implemented in Daysim to mimic how building occupants interact with manual controls of lighting plants or shading devices [8, 9]. For lighting an active or an equal mixed of active and passive behavior can be selected. For blinds an active behavior is considered which may depend on the user's need to avoid direct sunlight on work plan or to avoid discomfort glare. In general, Daysim defines as "active" the user who operates the electric

lighting taking into account the indoor daylighting conditions, opening the blinds in the morning, and partly closing them to avoid visual discomfort. While, it defines as "passive" the user who keeps the electric lighting switched on for all working hours and keeps the blinds lowered throughout the year.

In the following some first results of lighting energy demand for Diter single offices are presented. Offices receive daylight through northwest oriented rooflights, with internal motorized blinds.

Inputs for simulation are:

- occupancy profile: from 9,00 a.m. to 6,00 p.m., with lunch and intermediate breaks;
- lighting requirements: target illuminance of 500 lx,
- user behavior: mix of active and passive behavior for electric lighting and active behavior for blinds, depending on the user's need to avoid direct sunlight on work plan;
- lighting control systems: the initially proposed control solution for the office was a combination of switch on/off based on occupancy detection and dimming based on photosensor.
- blind control system: both manual and automatic control for blinds were simulated.

The calculated electric energy demand for test and reference office and the energy savings resulting by applying the proposed control strategies are reported in figure 7.

The calculated energy saving ranges between 14% and 30%, depending on the type of blind control (manual or automatic).

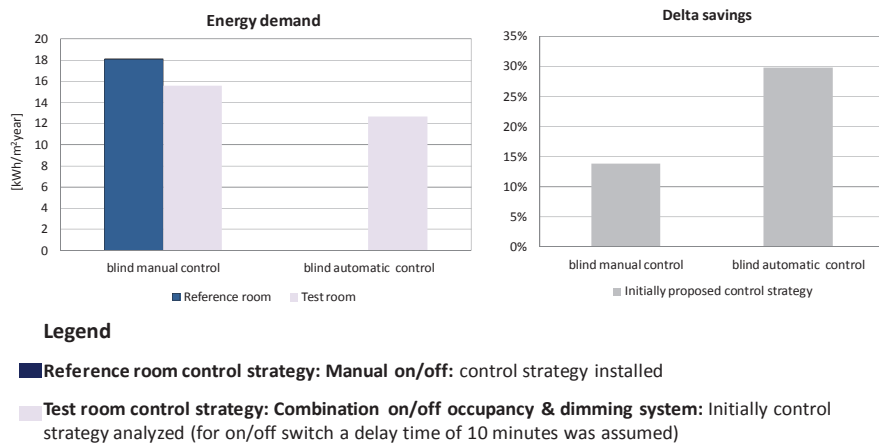


Fig. 7 Electric lighting energy demand and savings for Diter offices

Analysing the results achieved from these first lighting simulations (figure 7), whose goal was to verify the effectiveness, in terms of energy saving, of the proposed control strategy, it was observed that obtained energy savings were below the expectations. The initially proposed control

strategy was based on switching lights on and off as a consequence of users presence detected by the occupancy sensors, and on the automatic dimming of lights as a consequence of daylight availability, considering both manual and automatic control of shading devices. In this first hypothesis the mixed active and passive behavior user's behaviour was considered.

A further series of lighting analysis was carried out changing the electric lighting control strategy. In particular it was supposed to use a combination of dimming based on daylight availability and switch off based on occupancy detection, while letting the user the task to switch lights on manually when necessary [10].

The results obtained with Daysim demonstrate that, for this room, this is the most effective control strategy. In this case in fact energy savings for the test room, where the new control strategy will be implemented, rise up respectively to 29% and 48% depending on the type of blind control (manual or automatic). Energy demands and savings are shown in figure 8.

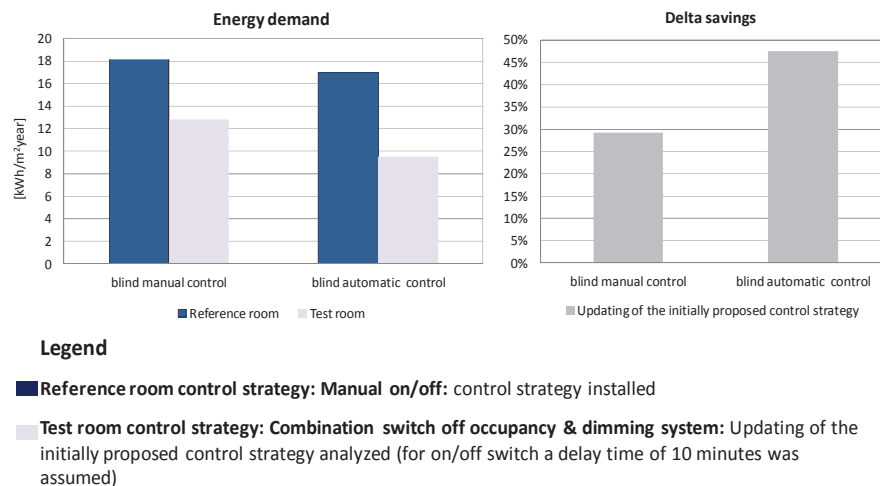


Fig. 8 Electric lighting energy demand and savings for Diter offices

6. Conclusions

For the control of HVAC services, the simulation results outlined that, taking into account the characteristics of the Politecnico plants (centralized heating and cooling system with independent fancoils in each room), the best control strategies are the one based on presence, detected by occupancy sensors (offices) or predicted by occupancy scheduling (classrooms) made possible by room reservation. In the presented Test Case 2 (better for thermal comfort), we can reach 13% in energy savings for a whole year (heating and cooling) in comparison with the reference room.

Nevertheless the control strategy that will be implemented in the Link Smart system should take carefully into account the necessary balance between energy savings and thermal comfort conditions. It was in fact

demonstrated that higher energy savings can be achieved on detriment of comfort conditions, in particular at the beginning of the working time.

For the control of electric lighting, the simulation results outlined that the most effective control solution is a mix of manual and automatic control. In fact, the hypothesis of switching on and off lights based on the users presence detected by occupancy sensors, provided quite low energy savings with respect to the existing manual control solution (from 5% to 30%). On the other hand, the simulations carried out in Test 1 demonstrated that using the occupancy sensors only to switch the lights off could increase significantly the energy savings (from 27% to 49%).

For the control of electric lighting, the simulation results outlined that the most effective control solution is a mix of manual and automatic control. In fact, the hypothesis of switching on and off lights based on the users presence detected by occupancy sensors, provided quite low energy savings with respect to the existing manual control solution (from 14% to 30%) respectively with blinds manually and automatically controlled, while it could increase significantly (from 29% to 48%) when another hypothesis, based on switching off lights thanks to the occupancy sensor, is considered.

7. Acknowledgment

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