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Energy conservation by control systems: a diagnosis in Politecnico di Milano University Campus

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ABSTRACT

Main aim of the present work is to underline the importance of local equipments management by advanced control systems and techniques for energy saving strategies in buildings sector and especially in public buildings.

In the framework of a relevant research about the evaluation of the energy and environmental performances of building stock in the Campus Leonardo-Bassini-Bonardi of Politecnico di Milano, an experimental diagnosis has been carried out.

Due to the detailed diagnosis on the sample building it has been possible to evaluate the different conditions of usage and management of working spaces and also main environmental parameters of thermal and visual comfort (temperature, solar radiation, lamps-on, electricity consumption and luminance). In fact, several times people unintentionally over-use the energy supplies and the effects are often significant in terms of energy wastes. The amount of energy wastes are related, on one hand, to the carelessness of the people behavior and, on the other hand, to the absence of any equipment dedicated to perform specific controls.

In addition, also results from scientific literature in the field of energy savings due to control systems have been taken into account in the definition of the energy benefits due to application of control strategies in Campus Leonardo-Bassini-Bonardi. At the end, several scenarios of interventions have been defined and their effects have been extended to the other buildings of the Campus. Final results could represent a benchmark to estimate the potential of improvement both for existing and for new similar buildings, in Italy and abroad.

RIASSUNTO

Tramite efficienti strategie di controllo e gestione delle apparecchiature di erogazione energetica presenti nei singoli ambienti si possono evitare inutili sprechi di energia, in particolar modo negli edifici pubblici, dove l’utenza non ha a diretto carico i costi di bolletta. Spesso, infatti, per soddisfare le condizioni di comfort ambientale (luce, caldo e freddo) gli utenti si avvalgono dei terminali di erogazione energetica in modo
sconsiderato (per noncuranza) o, comunque, inappropriato (per mancanza di opportuni sistemi tecnologici che ne consentano una gestione più oculata), abusando delle risorse energetiche oltre il necessario.

A tal proposito, nell’ambito di una più ampia ricerca sulle prestazioni energetico-ambientali degli edifici costituenti il Campus Leonardo-Bassini-Bonardi del Politecnico di Milano, è stata condotta una diagnosi sperimentale sugli usi energetici di alcuni ambienti di un edificio campione. L’indagine ha consentito di evidenziare le modalità di utilizzo degli ambienti di lavoro e i principali parametri energetico-ambientali connessi agli aspetti di comfort termico e luminoso (temperature, radiazione solare, attivazione delle lampade, consumi elettrici e livelli di illuminamento). Sulla base degli esiti dell’indagine e dei dati desunti da esperienze analoghe, riportate nella letteratura scientifica, per tutti gli edifici del Campus Universitario sono stati stimati diversi scenari di risparmio energetico associati all’adozione di sistemi di controllo e gestione efficienti.

I risultati dello studio possono costituire un confortante riferimento per contemplare tra le azioni di risparmio energetico e di riduzione delle emissioni di gas serra, sia per gli edifici esistenti che per le nuove costruzioni, quelle relative al contenimento degli sprechi energetici.

1. INTRODUCTION

Energy conservation has become a must and involves every action of our life. Politecnico di Milano is the biggest university in Italy where new generation of engineers and architects are trained and, for this reason, it is one of the most relevant place for disseminating a correct life style and design approach to energy saving; to that end, it could be very effective to transfer energy and environmental consciousness working directly in classrooms, laboratories and offices in which students usually spent the most part of their time.

At the moment, the campus considered in this study includes 27 buildings (built in several ages, occupied at 80% with offices and supplied by a district heating system fuelled by a central heating generator), for a total of about 3700 zones (classrooms, offices and other common spaces). Saving measures applied to such a big spaces could give relevant and easily communicable results. Further, it could be possible to test the effectiveness of each energy saving measures and to define the most promising field of application, also for starting up similar experiences in other campus.

2. METHODOLOGY

The survey about the energy performance of the buildings began with a large investigation of the main characteristics of the 3700 zones in terms of main destination, solar protection devices, lighting layout and activation, equipments for HVAC and control systems. During the investigation, in addiction, other data about the buildings to which zones belong have been collected; these data are mainly related to envelopes (age, dimension, shape, orientation, transparent surface percentage and distribution etc). After that, also available data of energy consumption have been considered.
One of the explored buildings has been selected as test-building and in 6 office-rooms of it a first screening monitoring campaign has been carried out.

Another kind of survey has been also carried out on the basis of analogous experiences and considering data and energy potential results reported in scientific papers. These results are very important because permit to easily find the most promising interventions, in term of retrofit and building automation, in order to reduce wastes of energy.

2.1. Survey

As mentioned before, the first step regarded the acquisition of the main buildings characteristics in order to set the energy audit. A lot of efforts have been invested in collecting and recording data of the rooms, located in the buildings that belong to Campus Leonardo-Bassini-Bonardi of Politecnico di Milano.

Final database contains the collection of more than 100 fields for each zone describing main characteristics of orientation, lighting layout and activation, heating and cooling devices and controls, alarms, windows, shading devices, destination etc, as well as main characteristics of the building in which the room is located.

Due to this survey, it could be possible to observe that:

- windows have low performances: 50% of them are single glazing with old frames; others are double glazing
- shading devices are not suitable for having a correct solar radiation control
- there is no automation for shading devices management; this means that solar protections are activated in case of annoyance, but then not opened when the glare effect not subsists
- there is no lighting control system for a correct integration of daylighting and artificial lighting: usually all the lamps are turned on with the same button at the same time
- there is no lighting control system for turning off lights when are not needed (after a defined time step or in absence of persons)
- there are no control on demand or other local control devices for heating and cooling systems except manual on/off switches where fan coils are installed (depending on the building, heating and cooling are provided using water or air as carrier)
- almost buildings have been realized in the second half of the last century; there are 9 heavy-envelope buildings (group A), realized in the period 1927-1936; 8 light-envelope buildings (group B), realized in the period 1958-1978; and other 10 buildings (group C), with peculiar features
- shape, orientation of buildings and opaque/transparent surface distribution are quite random and don't follow a bioclimatic approach.

These features let preview a large potential for energy saving. It is possible to imagine a reduction of energy consumption as consequence of a better integration of daylighting and artificial lighting, of solar protections automation, of correct management of windows (solar protection and ventilation) in order to reduce heating and cooling demand. Further, considering the available data about energy consumption (we have only the overall electricity and gas consumption of all the Campus Leonardo-
Bassini-Bonardi), we can find not only high specific value (roughly 200 kWh/m²y and 150 kWh/m²y for electricity and gas, respectively) but also high overall value during the night, the week ends and holidays (August), when the buildings are almost empty (fig. 1 and 2).

**Figure 1. Trend of overall electricity loads of the campus during the week**

**Figure 2. Trend of total electricity loads of the campus in different periods**

### 2.2. Monitoring

The first monitoring campaign has been carried out due to the collaboration between the two research units mentioned above (BEST and CUEPE), with the aim of screening the customary management and the behaviours of users into the rooms. To that end, a building of the group C (see list reported above) has been selected and 6 rooms (5 faced South and 1 faced North) of the first floor have been monitored: sensors for the measures of temperatures, presence, lamps on/off, windows opened/closed and status of shading devices have been installed.
This monitoring has been very low cost and easy to implement. The campaign started in winter 2006 and will end in autumn 2007. Despite of limitations related to the simple monitoring appliances, looking at the colleted data, it is possible to observe that artificial lighting is turned on also when rooms are empty and/or when daylighting is enough for an adequate visual comfort level. Looking at the time steps in which lamps are turned on but no occupants are in the rooms, it has been possible to evaluate that, for example, a simply timer, able to turn off lamps after 30 minutes of non occupation, could permit to cut the electricity wastes for lighting of about 60%. Figure 3 represents the percentage distribution of different time steps in which lamps are turned without occupants in the rooms: it is possible to see that time steps above 30 minutes are relevant.

Looking at the temperature trends measured in offices faced North and faced South, it is not possible to find out general correlations. In fact, sometimes temperatures in offices faced North are higher than temperatures in offices faced South, measured at the same time. This effect could depend on presence of personal additional heating equipments (that means that winter comfort conditions are not satisfied by the central system) and/or on the activation of the shading devices in South faced offices (in order to avoid glare effect), that means to not benefit from solar gains.

Looking at the lux levels measured in a particular point of the rooms, it is possible to find out that often artificial light are turned on also when natural light (lux outside measured by climatic station) could be sufficient for visual comfort inside. This effect could depend on the activation of the shading devices in South faced offices, in order to avoid glare effect.

It is also possible to observe that windows are usually opened for more than half hour during the day, without switching off heating system, with relevant heat wastes.

Obtained results foster to continue in the near future with a more deep, systematic and professional monitoring, extended also to other buildings and rooms.

Figure 3. Percentages of the time steps in which there are no occupants and lights are on
2.4. Saving potential due to control systems

Another kind of survey has been also carried out on the basis of analogous experiences and considering data and energy potential results reported in scientific literatures. These results are related to actual interventions on control systems carried out in the last years in commercial (mainly) and residential buildings or by ad hoc simulations and permit to easily find the most promising interventions, in term of building automation, in order to reduce wastes of energy.

According to the mentioned literatures, average values of energy savings for the considered control strategies have been taken into account.

Taking into account monitoring results and also data from the survey mentioned above, it has been possible to preview energy saving percentages deriving from different control actions, separately and combined. In particular, following control devices were considered both applied separately and combined, where possible:

- opening windows detectors
- presence sensors
- differed activation of internal shading devices
- daylight sensors (dimming)
- daylight sensors (on/off)
- differed activation of artificial lighting
- thermostatic valves
- timers (for lighting).

The effects of the control devices listed before were evaluated on heating consumption, cooling consumption and electricity consumption for lighting. At the end, 39 possible configurations of interventions were obtained, depending on the features of the zones as reported in the mentioned final database.
Table 1. Definition of the configurations of control strategies

<table>
<thead>
<tr>
<th>Code</th>
<th>Control Strategy description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>opening windows detectors</td>
</tr>
<tr>
<td>2.a</td>
<td>presence sensors</td>
</tr>
<tr>
<td>2.b</td>
<td>presence sensors (only room with FAN-COIL)</td>
</tr>
<tr>
<td>3</td>
<td>daylightsensors (dimming)</td>
</tr>
<tr>
<td>4</td>
<td>daylightsensors (ON-OFF)</td>
</tr>
<tr>
<td>5</td>
<td>timers (for lighting)</td>
</tr>
<tr>
<td>6</td>
<td>presence sensors + presence sensors</td>
</tr>
<tr>
<td>7</td>
<td>presence sensors + daylightsensors (dimming)</td>
</tr>
<tr>
<td>8</td>
<td>presence sensors + daylightsensors (dimming) (only room with FAN-COIL)</td>
</tr>
<tr>
<td>9</td>
<td>presence sensors + daylightsensors (ON-OFF)</td>
</tr>
<tr>
<td>10.a</td>
<td>presence sensors + differed activation of internal shading devices</td>
</tr>
<tr>
<td>10.b</td>
<td>presence sensors + differed activation of internal shading devices</td>
</tr>
<tr>
<td>11.a</td>
<td>presence sensors + daylightsensors (dimming) (only room with FAN-COIL)</td>
</tr>
<tr>
<td>11.b</td>
<td>presence sensors + daylightsensors (ON-OFF)</td>
</tr>
<tr>
<td>12.a</td>
<td>presence sensors + daylightsensors (ON-OFF) (only room with FAN-COIL)</td>
</tr>
<tr>
<td>13.a</td>
<td>presence sensors + differed activation of artificial lighting</td>
</tr>
<tr>
<td>14.a</td>
<td>differed activation of internal shading devices + daylightsensors (dimming)</td>
</tr>
<tr>
<td>15</td>
<td>differed activation of internal shading devices + daylightsensors (ON-OFF)</td>
</tr>
<tr>
<td>16</td>
<td>differed activation of internal shading devices + differed activation of artificial lighting</td>
</tr>
<tr>
<td>17</td>
<td>daylightsensors (dimming) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>18</td>
<td>daylightsensors (ON-OFF) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>19.a</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (dimming)</td>
</tr>
<tr>
<td>19.b</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (dimming) (only room with FAN-COIL)</td>
</tr>
<tr>
<td>20.a</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (ON-OFF)</td>
</tr>
<tr>
<td>20.b</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (ON-OFF) (only room with FAN-COIL)</td>
</tr>
<tr>
<td>21.a</td>
<td>presence sensors + differed activation of internal shading devices + differed activation of artificial lighting</td>
</tr>
<tr>
<td>21.b</td>
<td>presence sensors + differed activation of internal shading devices + differed activation of artificial lighting (only room with FAN-COIL)</td>
</tr>
<tr>
<td>22.a</td>
<td>presence sensors + daylightsensors (dimming) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>22.b</td>
<td>presence sensors + daylightsensors (dimming) + differed activation of artificial lighting (only room with FAN-COIL)</td>
</tr>
<tr>
<td>23.a</td>
<td>presence sensors + daylightsensors (ON-OFF) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>23.b</td>
<td>presence sensors + daylightsensors (ON-OFF) + differed activation of artificial lighting (only room with FAN-COIL)</td>
</tr>
<tr>
<td>24</td>
<td>differed activation of internal shading devices + daylightsensors (dimming) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>25</td>
<td>differed activation of internal shading devices + daylightsensors (ON-OFF) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>26.a</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (dimming) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>26.b</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (dimming) + differed activation of artificial lighting (only room with FAN-COIL)</td>
</tr>
<tr>
<td>27.a</td>
<td>presence sensors + daylightsensors (ON-OFF) + differed activation of artificial lighting</td>
</tr>
<tr>
<td>27.b</td>
<td>presence sensors + differed activation of internal shading devices + daylightsensors (ON-OFF) + differed activation of artificial lighting (only room with FAN-COIL)</td>
</tr>
</tbody>
</table>
3. RESULTS

3.1. Assumptions

By applying percentages of energy saving, for different energy final uses, corresponding to different control strategies, it has been possible to evaluate the overall reduction of consumptions of electricity and gas among all the buildings of Campus Leonardo-Bassini-Bonardi, where electricity savings regard both lighting and cooling, while gas savings regard only heating. To that end, a queries system has been implemented using MS-Excel's macros, in order to apply different control systems to zones with appropriate characteristics and considering proper surfaces. By this system it is possible to calculate the cascade-effect of different control strategies, taking into account the actual energy demand on which each control strategy operates, when in series energy savings are previewed.

Analogous results have been evaluated in terms of CO₂ emissions reduction due to the application of the control systems.

Results have been obtained according to following data:

- national mean efficiency for electricity generation: 36%
- average thermal efficiency for heating generation into all the zones of the Campus: 55%
- average coefficient of performance for cooling generation: 2.5
- equivalent CO₂ emission factor for electricity generation: 670 g-eq-CO₂/kWh_el
- equivalent CO₂ emission factor for thermal generation: 200 g-eq-CO₂/kWh_Th, gas
- typical occupations of different zones, according to academic calendar and standard periods of work and holiday
- effects of defined interventions on cooling needs are related to all the zones in which cooling devices are present or heating devices are adaptable as cooling suppliers (i.e. fan coils or primary air vents).

3.2. Overall saving potential for energy consumptions and CO₂ emissions reduction

Looking at obtained results (figures 4-7), it is possible to observe that:

- in offices, about 60% of the defined interventions are possible due to the features of the spaces; the most effective strategy correspond to the adoption of presence sensors both simple or coupled with daylight sensors and with a better activation of lighting
- in classrooms, almost all the defined interventions are possible due to the features of the spaces; presence sensors represent an important intervention, both simple or coupled with others, but also shading devices controls and better activation of lighting permit conspicuous energy savings
- in passageways, half of the defined interventions are possible due to the features of the spaces; presence sensors represent an important intervention, both simple or coupled with others, but also shading devices controls, daylight sensors and better activation of lighting permit conspicuous energy savings
in technical rooms, only few interventions are recommended due to the features of the spaces; also in this case presence sensors represent the most important intervention. Obtained results in terms of energy and CO$_2$ emissions conservation are more important than how it seems. All control strategies are defined in order to reduce electricity waste (electricity is the most important energy consumption in commercial buildings; in Campus Leonardo-Bassini-Bonardi electricity consumption are almost 4 times more than natural gas consumption in term of primary energy); the only control strategy dedicated to natural gas saving is represented by thermostatic valves, even if, actually, the main effect of these device is to improve comfort condition. For all the other strategies, natural gas consumption reduction could be considered as a collateral effect of controls dedicated to electricity savings. Further, the percentage of the electricity savings is calculate as ratio between energy savings in the different rooms (on which control strategies have effects) and the overall electricity consumption of the campus that includes also needs on which control strategies could not have any effects (external lighting, auxiliary pumps for district heating, elevators, etc). This means that, if electricity saving percentage was calculated on the actual electricity consumption on which control strategies have effects, its value would be larger. Furthermore, it should be also remember that a conservative approach has been assumed during the calculations.

Despite all these considerations, overall electricity and natural gas conservations in Campus Leonardo-Bassini-Bonardi reach about 17% (795 TEP as primary energy) and 13% (165 TEP as primary energy) respectively; while avoided CO$_2$ emissions are about 2230 tCO$_2$-eq and 384 tCO$_2$-eq due to electricity and natural gas savings, respectively.

Following figures (figures 4-7) describe in details the effect of the control strategies on different typical rooms, where typical room (table 2) is the average sized room for each destination (the size of a typical room is defined, for each kind of destination, as the ratio between the overall surfaces dedicated to that destination and the number of zone with the same destination). In particular, figures 5-8 describe saving potentials in terms of primary energy and CO$_2$-eq emissions, in relation to the maximum achievable value for each typical room.

**Table 2.** Main characteristics of each typical room; maximum reductions are referred to the most effective control strategy (among whose reported in table 1) for each room

<table>
<thead>
<tr>
<th>Typical room</th>
<th>Size [m$^2$]</th>
<th>MAX CO$_2$-eq reduction [kg]</th>
<th>MAX Primary Energy reduction [tep]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>22</td>
<td>722</td>
<td>0.26</td>
</tr>
<tr>
<td>Classroom</td>
<td>70</td>
<td>2459</td>
<td>0.91</td>
</tr>
<tr>
<td>Passageway</td>
<td>50</td>
<td>2710</td>
<td>0.97</td>
</tr>
<tr>
<td>Technical spaces</td>
<td>50</td>
<td>2492</td>
<td>0.89</td>
</tr>
</tbody>
</table>
Energy conservation by control systems: a diagnosis in Politecnico di Milano University Campus

Figure 4. Effects of the different control strategies on offices (percentages respect to the maximum achievable value)

Figure 5. Effects of the different control strategies on classrooms (percentages respect to the maximum achievable value)
4. FURTHER DEVELOPMENTS: THE NEW MONITORING CAMPAIGN

Due to the relevant results obtained from mentioned elaborations, a set of activities has been preview in the next future. Main aims of these activities are to collect more precise information about heating and cooling systems, to calibrate the elaborations with direct measures and to evaluate also economic aspects of different interventions, in order to introduce innovative control strategies in the program for buildings conservation and renovation of the campus. To that end, a detailed monitoring campaign has been planned and will take place, from autumn 2007 to summer 2008, in the same building offices.
already monitored (see paragraph 2.2 Monitoring) and, in addition, also other zones like classrooms and common spaces will be monitored, in order to have useful results about the effectiveness of defined control strategies with different kind of spaces destinations.

The second monitoring campaign previews the installation of professional control systems including windows opening detectors, daylight sensors, presence sensors, CO$_2$ sensors, temperature sensors coupled with terminals of heating and cooling systems and electric plant modifications in order to obtain a better integration of artificial lighting and daylighting due to a smarter activation of the lamps.

Results obtained at the end of the second monitoring phase will be the basis for putting in practice the most cost and energy effective control strategies and for adopting buildings automation systems.

5. CONCLUSIONS

Considering the priorities of energy policy at European level, the ever growing energy costs and the importance of public sector in energy saving applications, a lot of efforts have been made in defining retrofit priorities for improving performance of envelopes, systems and plants in buildings.

Looking at the results of this study it is possible to underline that also occupants behaviour and buildings management has a very important role in order to promote a more rational use of energy. The analysis and the elaboration of recorded data suggest strategies for avoiding wastes of energy not only at technical levels but also at decision-making and operative levels.

Despite the elaborations have been conducted with a conservative approach, obtained results in terms of energy and CO$_2$ emissions conservations are conspicuous and could bring also economic benefits. In particular, electricity and natural gas conservations result about 17% and 13% respectively and, actually, could be higher if a less conservative approach would be assumed.

For this reason, low energy strategies in buildings should involve not only interventions on envelope and/or plants, but also in the field of control systems and automation.

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Tiziana Poli, Meteorological Station of Dept. Building and Environment Science and Technologies (BEST), Politecnico di Milano, Italy.
7. REFERENCES


