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Energy consumption and thermal comfort assessment in retail stores: monitoring and dynamic simulation applied to a case study in Turin

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Abstract

Maintaining suitable microclimate internal conditions in retails store is of great importance, because thermal comfort needs to be satisfied for both customers and employees.
In the present work, energy consumptions and microclimate quality assessment of a retail store are shown. Buildings dynamic simulation tool, and energy and environmental monitoring were both used for the building climate quality and energy efficiency investigation. The paper shows how monitoring data, combined with dynamic simulation, allow to improve the correct system control increasing energy efficiency, and enhancing moreover the indoor thermal comfort in retails.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: energy monitoring, environmental monitoring, dynamic simulation, retails, energy saving

1. Introduction

Building energy consumptions represent a relevant sharing of the total energy cost at global level. Energy uses in buildings are several and cover specific areas, as lighting, appliances, heating and air conditioning. The last two aspects, in particular, represent a portion that is not negligible and on which it is fundamental to investigate to reduce energy wastes.

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In order to understand the energy behavior of a building, various types of monitoring systems have been recently installed in dwellings, offices, and other kind of buildings. Collecting and analyzing data about the energy uses is of great importance to detect bad management of the energy fluxes; moreover, it gives the possibility to program specific interventions to correct the emerged errors and problems. Sensors and related apparatus are helpful also to understand the level of microclimate quality provided inside a building. The indoor climate quality detection is important especially when it is necessary to assure certain comfort conditions to the occupants.

Previous research about energy and climate assessment focuses the attention on various types of buildings: dwellings [1], schools [2], shopping mall [3], offices [4], etc. Less information are given on what concerns retail environments, where the satisfaction of both workers and customers requires a strictly control of the environmental conditions. Also in this kind of environments, the interactions between occupants and building-plant system are not negligible since they affect the energy consumption. The instruments to evaluate the two interrelated aspects, and in general the energy performance of a building, are essentially two: the energetic and environmental monitoring through which the real situation is shown, and the dynamic simulation of buildings through which a reference situation is created. The real time monitoring requires the physical installation of environmental and energy sensors in specific and representative points of the building. This aspect assumes particular relevance in the case of retail stores, where often the right location of sensors is in contrast with the necessity of the rules of sale. In selling areas, in fact, it is not only important the presence of occupant in itself: most important is the interaction between people and product on sale. For this reason it is necessary to avoid any obstacle which can affect the observation of customers around the shop. The installation of sensors to measure micro climate parameters, like temperature sensors, becomes difficult, because often the best location for monitoring purposes is not compatible with the exigencies of customers. In these cases it is necessary to find alternative locations and take into account the consequences on results.

In the present work, after a brief introduction on the relevant themes discussed, a case study is presented. The building considered is a retail store involved in an energetic and environmental monitoring plan. After the analysis and comparison of monitoring data during the winter season, a part dedicated to the energy simulation of the building is introduced. From the comparison between real data and simulation results some relevant conclusions about the energy performance of the building are presented.

2. Methodological approach: Measurements and Dynamic simulation

The study here presented deals with the detection of energy consumptions and microclimate conditions in a case study building. The analysis is performed through the combined use of two instruments: monitoring and building dynamic simulation.

The methodology adopted for the study consisted in the following steps:

- *Survey phase*. During this phase relevant information about energy systems, architecture, and occupation of the analyzed site have to be collected. During this time, spot measurements and questionnaires for the environment subjective occupation by occupants need to be performed too, in order to design the monitoring plan identifying the position in which install the monitoring probes.
- *Monitoring phase*. The second step consists on the analysis of the monitored data. Energy and environmental data are elaborated in order to figure out the actual building behavior, accent moreover critical situations to be solved.
- *Dynamic simulation phase*. In parallel to the monitoring, a model of the analyzed building needs to be done and to be calibrated through the support of a dynamic simulation tool. The aim of this operation is to compare real trends of energy and real comfort levels, collected through the monitoring, with the results of the simulations, on which systems control and occupation are defined by schedules.
- *Energy retrofitting phase*. The comparison between expected results (from simulation) and real monitoring could allow to put in evidence systems inefficiency, errors in the building-plant system management, etc. During this phase specific interventions have to be identified and implemented.
- *Monitoring post intervention phase*. Last step is the monitoring data analysis after the refurbishment, for to put in evidence the positive effect in terms of energy and comfort of the entire process.

3. Case study

The analyzed building is a phone retail store located in Turin, Italy (45°4'41"16 N latitude - 07°40'33"96 W longitude). The store is involved in an environmental and energetic monitoring plan together with other similar buildings of the same retail chain, located in other cities in Italy. The building is one floor above the ground structure: at the ground floor there is a big selling area, with two large glazed surfaces (North and West exposed), a small waiting customer room and a back office where the entrance is allowed only to employees, while a large warehouse and the plants rooms are situated in the basement (**Error! Reference source not found.**).

Functional area	Floor Surface		Employees	
	m^2	% on the totality	Nr	% on the totality
Selling area	120	26%	7	77%
Back office	30	6%	2	23 %
Warehouse	292	60%	0	0%
Plant area	40	8%	0	0%

Fig. 1. First floor and basement with identification of functional areas

The store is opened from Monday to Friday from 10:00 AM to 7:30 pm with an hour of closing at 1:00 pm, while on Saturday the opening hours are from 10:00 am to 12:00 am, for a total of 40 weekly hours.

All the energy in the building is provided by electricity. The conditioning is performed through the use of two heat pumps located in the basement of the building. The carrier fluid feeds:

- the thermal exchange batteries of two air handling units with heat recovery system, which provide new fresh air both for the selling area and for the back office,
- two heat exchange units located in the selling area and
- three direct expansion heat exchange units positioned in the back office.

The DHW is provided through an electric boiler. The control of the system is manual (through a zone thermostat): during the working hours the employees can switch on and off the conditioning system according to their needs.

3.1. Monitoring system

The wireless monitoring system installed in the building collects both environmental and energy data and send them to a web platform, where they are registered and from where collected information can be easily downloaded and processed. Data are available hourly for the selected interval, but the acquisition timestamp is 5 minutes.

The monitoring system consists of :

- 6 TLH sensors, which measure Air Temperature, Illuminance and Air Relative Humidity in different part of the selling area, in the back office and outside. The monitoring points have been defined through a spot monitoring campaign, whose allowed to identify areas homogeneous in terms of operative temperature.
- 5 Power Meters, installed in correspondence of the electrical panels, which measure Current (A), Electric Power (W) and Voltage (V) of the whole building, and in specific of the conditioning system, of the lights, of the appliances and of the services.
- 5 Bridges for the connection of the sensors to the network
- 1 Radio Repeater with a routing function
- 1 Gateway, with coordination role, which allow the communication of the whole apparatus with the central server.

1.1. First monitoring results

First measurements in the building were performed during the period of time January-March 2012.

For what concern energy measurement, data demonstrate that lights, services and appliances did not present anomalies in functioning, while the conditioning system highlighted many irregularity. In particular, the collected data put in evidence the absence of an automatic control of the systems and shown how the energy consumptions varied according with the occupants manual system control. In Fig.2, for example, where conditioning power is represented, is it not possible to distinguish working days from retail closing days, or daily hours from nights hours. Moreover, the values of the energy power are very different day by day.

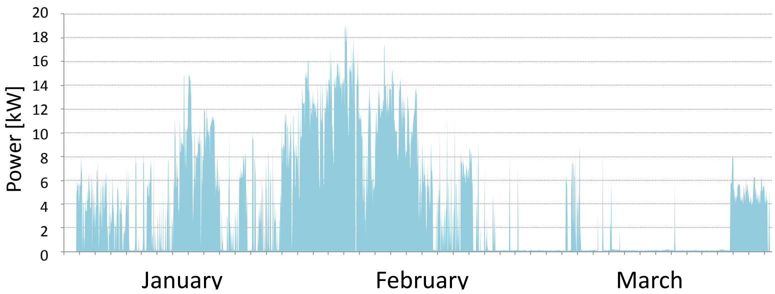

Fig. 2. Conditioning Power profile during the winter season 2012.

During the same time, the monitored data highlighted difference of air temperature between adjacent areas higher than 4°C, evidencing the bad mixing of the air in the selling area. Moreover, the temperature analysis showed that averagely, for the 40% of the time, the air temperature inside the room was higher than what expected, using as comparison parameter the operative temperature ranges[2] given by the standard EN ISO 15251 [5]. According with the standard, for this kind of building use, the best range of comfort (Category I) in wintertime goes from 21 to 23 °C.

Lastly, values of illuminance confirmed what previously denounced by employees through subjective questionnaires, that is that the direct solar radiation on the West glazed wall caused discomfort.

1.2. Implementation and calibration of a dynamic simulation model

After the monitoring data elaborations, hypothesis of refurbishments were considered to solve the emerged criticalities. For to evaluate the positive effects of the interventions, both in terms of comfort improvement and energy savings, a model of the building was built and studied through the use of EnergyPlus v7.1 dynamic simulation tool. Information about geometry, surfaces, exposition, lights, occupancy, equipment and energy systems were used as input data, and then the model was calibrated using the monitored data, in particular the indoor average air temperature. When the inputs coming from the survey were not sufficient or not complete, available information from literature were used[3].

Once created a reliable model, new schedules were created according to the desired microclimate conditions inside the building. The values chosen as set point in the rooms were $22°C$ for winter season, and the operational hours of the system were scheduled with a regular and logical control. The effects of hypnotized energy refurbishment were then evaluated, and the most effective intervention were selected to be actuated in the building. In particular the most relevant interventions concerned the regulation of the conditioning system and the relocation of the temperature sensors. Then, also the distribution of the air of the ventilation system was modified, in order to reduce the difference of temperature in adjacent areas highlighted by the monitoring.

[2] In this case study the air temperature has been assumed as reference for the evaluation of the thermal comfort, considering the mean radiant temperature equal to the air temperature. This assumption derive from results of spot monitoring, in which operative temperature and air temperature were both measured and compared in different point of the building.

[3] The model was validated using two statistical indexes, the Monthly Bias Error (MBE) and the Coefficient of Variation of the Root Mean Square Error (CV(RMSE)). In both cases results were acceptable: -0.2% and 29% (the tolerances are $\pm10\%$ and $\pm30\%$ respectively).

Simulations results evidenced the possibility, with the refurbishment, to reduce the conditioning energy consumption during the analyzed period of time of about 38%.

4. Results

Second measurements, effectuated in 2013, demonstrated that the intervention actuated on the building gave results not so far from the ones expected by the simulation. As shown in Fig.3 a chrono-regulation of the heat pumps operating time allowed to have a quite regular distribution of the employed power. Peaks of power rarely exceeds 10 kW, while in 2012 they reached 18 kW, and night and day are easily identifiable in the graph. The positive effect of the intervention is then clear just comparing Fig.2 with Fig.3.

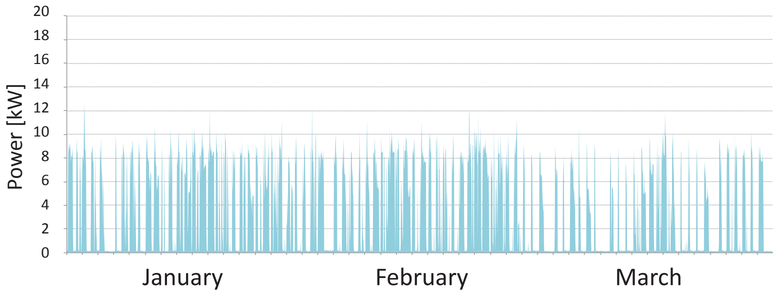

Fig. 3. Conditioning Power profile during the winter season 2013.

The total amount energy for conditioning saved in the considered period of 2013, respect to 2012, and normalized according with the real Heatig Degree Days, has been of about 34%, and this is illustrated in Fig.4(a). The difference between the value obtained with the simulation (38%) depend by the fact that during the day the set point temperature in the building was manually controlled by the occupants, while the model uses constant set point scheduled as input. Employees were in this way free to choose higher or lower temperature in the rooms, determining different operating time of the heat pumps respect to the EnergyPlus model.

The total energy reduction for the whole building, in 2013, was of about the 24%, as this is shown in Fig 4 (b).

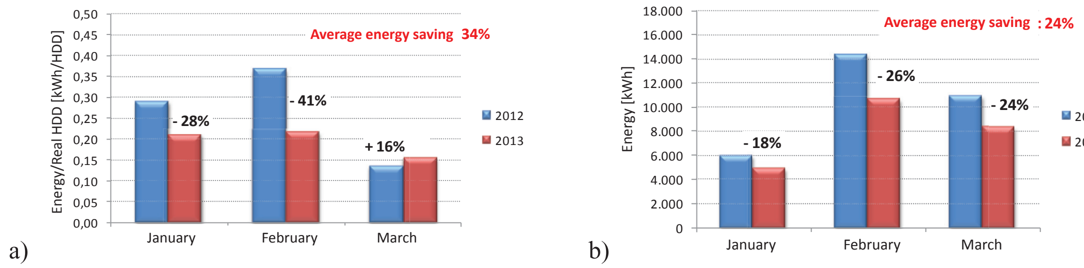

Fig. 4. a) Energy for conditioning normalized according the real Heating Degree Days. b) Energy for the whole building

Also the thermal comfort improved inside the store. The temperature difference between adjacent room decreased from frequent peaks higher than 4°C to rare peaks of maximum 1,8 °C. This means that the intervention on the ventilation system produced the expected results. The lower was the temperature difference, the lower were the peaks of high and low temperature in the rooms, and the more constant was the operating of the heating system.

Averagely the level of thermal comfort increased, and as it is shown in Fig.5, the temperature in the selling area during the occupation hours stayed in comfort zone for longer time.

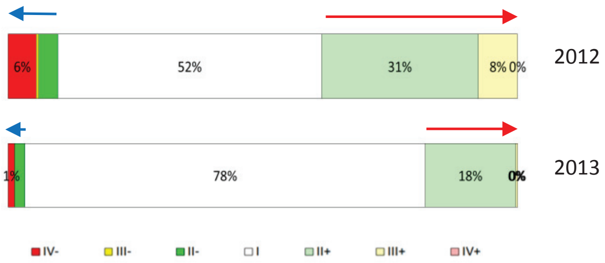

Fig. 5. Thermal comfort evaluation in winter season before and after energy refurbishments.

As previously specified, for the 20% of the time the temperature were still out of the comfort range Category I, correspondent to the supposed set point. Moreover, also if spot measurements results allowed the assumption “ air temperature ~ mean radiant temperature”, the air temperature in the selling area, in particular during the first hours of the day, was probably affected by the radiant temperature, and for to keep comfort in the rooms occupants set the set point temperature on the zone thermostat higher than during the rest of the day.

5. Conclusions

A retail store building was analysed through the use of monitoring and dynamic simulation. The first phase of the work was aimed at detecting problems and irregular systems functioning. Then some retrofit actions were implemented (before in the EnergyPlus model and then in reality). The final part of the work consisted in analysing the efficacy of retrofit actions and comparing the obtained results with the expected ones.

The first relevant aspect is the fact that the implemented measures lead to a significant modification, especially for what concerns the energy consumption profiles. One of the critical points was the regulation of the conditioning system that, apparently, did not answer to any logic scheme. After the examination of the first results and the introduction of the retrofitting measures, the operation systems is now regular and respect the retail opening and closing hours, reducing the quote of energy consumption for conditioning of a significant part, that was associated to a waste. This demonstrate that often “Zero Capital” intervention allow to save a lot of energy and, for this reason, they are the first kind of “refurbishment” to take in account in case of buildings energy saving design. It is important to observe, however, that despite the improved operation of the conditioning system, what happens in reality, and emerges from monitoring analysis, is still a bit different from the output of the model, which represents the reference situation.

Improving the energy system operation also the thermal comfort in the spaces improved. Difference of temperatures between adjacent areas was strictly reduced and the monitored air temperature respected for longer time the thermal comfort zone. However, sometimes in order to maintain an acceptable operative temperature in the internal environment it is necessary to set a higher set-point air temperature. This means that the Mean Radiant Temperature is not negligible and that the Temperature of the surrounding surfaces can influence the microclimate quality inside the building. This put in evidence an important fact: almost the totality of the instruments nowadays used in commerce for thermal comfort evaluation in rooms measure just air temperature and do not take in account the influence of the radiant temperature, returning incorrect thermal comfort assessment results.

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