ENERGY SAVINGS IN MULTI-FUNCTIONAL BUILDINGS: AN HISTORICAL CONTEXT FOR A CASE STUDY IN ROME

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ABSTRACT

The historical headquarter of Italian Ministero degli Esteri (Ministry of External Affairs) in Rome named as "Palazzo della Farnesina" is a very large (about 700.000 m^3 of volume) and complex multi-functional building. The objective of present study, commissioned by Ministry of Environment, is to evaluate different energy saving strategies in this building achievable by the implementation of retrofit actions. At first, the seasonal energy consumption obtained by the existing cooling and heating systems has been estimated. Further, the aim was to evaluate the appropriate alternative technologies which contributes to lower energy consumption according with a non-intrusive building rehabilitation both with a more efficient plant, including various hypotheses of co-generation energy production and a desiccant cooling system. An extensive use of daylighting-control strategies have also been tested. Building energy performances have been assessed using DOE-2 simulation software. All the actions have been evaluated according to their economic, energy and environmental performances.

KEYWORDS

Buildings, energy saving strategies, co-generation, desiccant cooling, simulation, DOE-2.

BUILDING DESCRIPTION

The building "Palazzo della Farnesina" considered in this study reveals the extreme functional and occupational characteristics distributed over more than 700000 m^3 volume. This 9 story building with the average presence of 3500 persons is having around 120000 m^2 effective floor area with 20800 m^2 of total roof surface. The height of the building is 46 m from the ground and apart of 5 m is situated underground.
Building structure is quite massive and the thickness of the external wall is more than 1 m. The flat-roof is constructed with brick holes and concrete without insulation. The single glass windows with bad designed iron frame (increases infiltrations) installed in the building results negative effect on the thermal performance.
The building is equipped with gas-fired water boilers for heating with radiators and thermo-convectors. For summer cooling several kind of systems has been used e.g. the central HVAC's, fan-coil and split systems.

ENERGY SIMULATIONS

The energy simulations have been carried out using DOE-2 model (1). The input data used for DOE-2 simulations are taken from the actual data available on building construction, plants, equipments and the occupancy profile. Figure 1 shows the 3-dimensional building model.

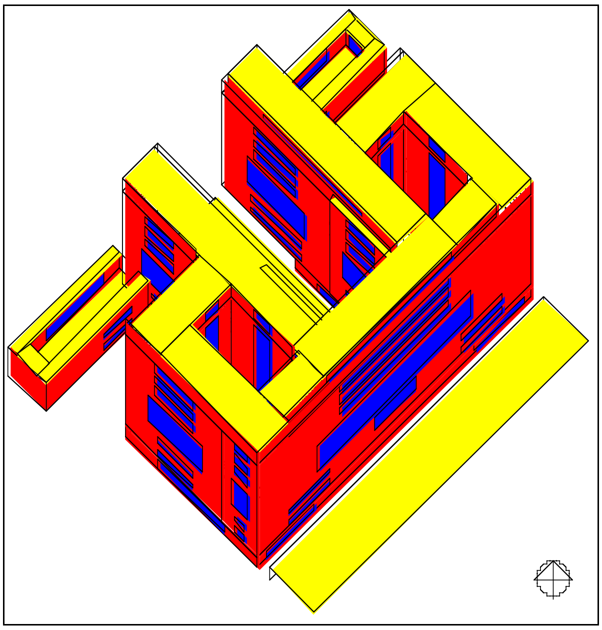

Figure1: 3D view of building

The DOE-2 model has been validated against the average actual annual energy consumption data (electrical 7328 MWh, thermal 23352 GJ). The electrical energy consumption pattern (in percentages) has been shown in Figure 2.

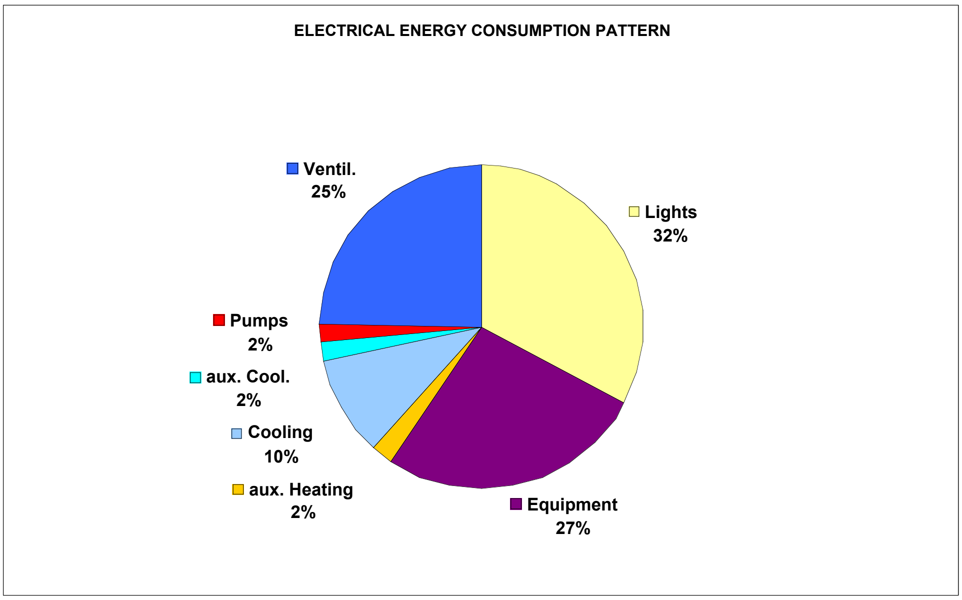

Figure 2: Electrical energy consumption pattern for end-use.

In this study, starting from conventional techniques, several different (non conventional) strategies have been analysed and evaluated in respect of energy saving in this building. The economical evaluations are based on the extra-cost resulted by applying non conventional solutions.

Energy saving strategies on building envelope

The first conventional strategy considered in this study is the replacement of existing windows by double glass windows with aluminium thermal break frames. Further, double glass windows with in filled Argon, with low-emissivity and selective coats have been tested for better winter and summer performances. The above strategies obtained best performance results throughout the year: use of selective glass for NE and NW exposition and low-e glass for SE and SW exposition. The thermal and optical characteristics of various type of glass considered in the simulations are shown in Table 2.

TABLE 2: Thermal and Optical characteristics of Glass

	Single	**Double**	**Selective**	**Low-e**
DOE-2 cod.	**1000**	**2004**	**2665**	**2615**
U (W/m^2k)	6.31	2.74	1.30	1.67
Solar Trans.	0.84	0.60	0.34	0.53
Sol. Refl.	0.08	0.11	0.31	0.13
Absorptance	0.08	0.29	0.35	0.34
Vis. Trans.	0.90	0.78	0.68	0.72

The other energy saving strategy considered in respect of the use of insulation on the top-roof. This shows the opportunity of energy saving during maintenance of roof asphalt : a layer of insulation material can be mounted below the new layer of asphalt. In this case, 6 cm. thick panel of polystyrene (thermal conductance, $\lambda = 0.035$ W/mK) has been considered.

The last strategy considered on the control of artificial lighting based on the availability of natural day-lighting in the building. The first estimation on electrical energy consumption patterns (see figure 1) of building clearly verified that the control of artificial lighting is very critical in respect of energy saving, as most of the offices uses artificial lighting throughout the day and in full scale. In the simulation, the daylight sensors has been considered to control the functioning of artificial lighting when necessary.

The results of the simulation on energy savings in percentage obtainable using the different strategies with respect to actual conditions have been shown in figure 3. The coefficient of primary energy conversion used in the simulations is taken as 0.39 for electrical energy, and the evaluation of CO_{2_eq}. are based on the values referred by AIRES (2).

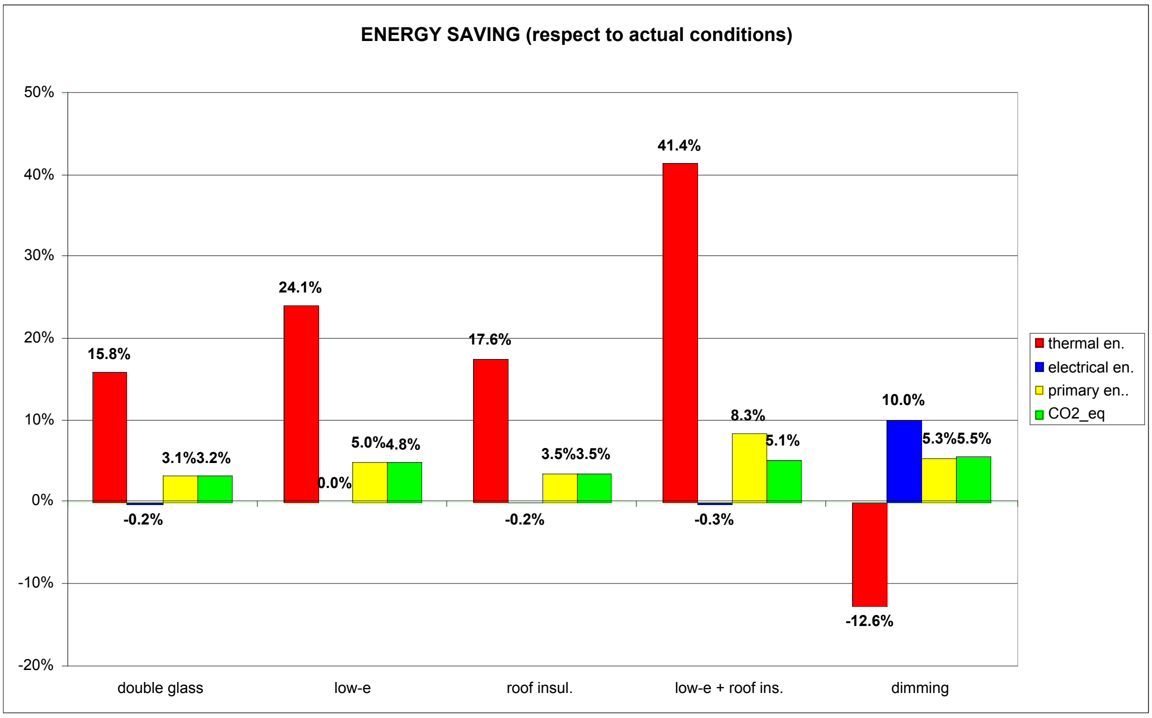

Figure 3: energy savings using the different strategies on building

Energy saving strategies on building energy systems

The conventional simulated strategy for the new air conditioning system is seen as a number of VAVS systems of secondary level with localized post-heating and heat recovery from air change corresponding to each thermal zone. Among them, the VAVS is served by conventional boilers and electrical chillers with cooling tower (primary level) in respect of cooling and heating. This scheme is considered as a reference case for comparing different energy saving strategies.
The following strategies have been considered at primary and secondary levels. Results are shown on figure 4.

- **Alternative n° 1 – Desiccant cooling**

At the secondary level, the desiccant rotor has been introduced in each of the thermal zone in addition to other existing plant in reference case. Moreover, one air-to-air heat-exchanger between supply air and the air for the regeneration of desiccant rotor. This heat-exchanger is used for cooling the dry and hot air from the desiccant, simultaneously for heating the returning air used for the regeneration.

- **Alternative n° 2a – Electrical Chiller with heat recovery system from the hot coil.**

In this case, the total heat recovery is not possible because the presence of heating load.

- **Alternative n° 2b – Endothermic Generator Chiller with heat recovery system from the engine water loop and from the chiller hot coil.**
- **Alternative n° 3 – Reversible heat pump**

This substitute the chillers and the boiler of the reference case.

- **Alternative n° 4a – CHP (natural gas) based on electrical loads and single phase absorber chiller (at primary level).**
- **Alternative n° 4b – CHP based on thermal loads and single phase absorber chiller.**
- **Alternative n° 4c – CHP based on electrical and thermal loads (whichever is higher) and single phase absorber chiller**
- **Alternative n° 5 – CHP based on thermal loads and conventional electric chiller.**

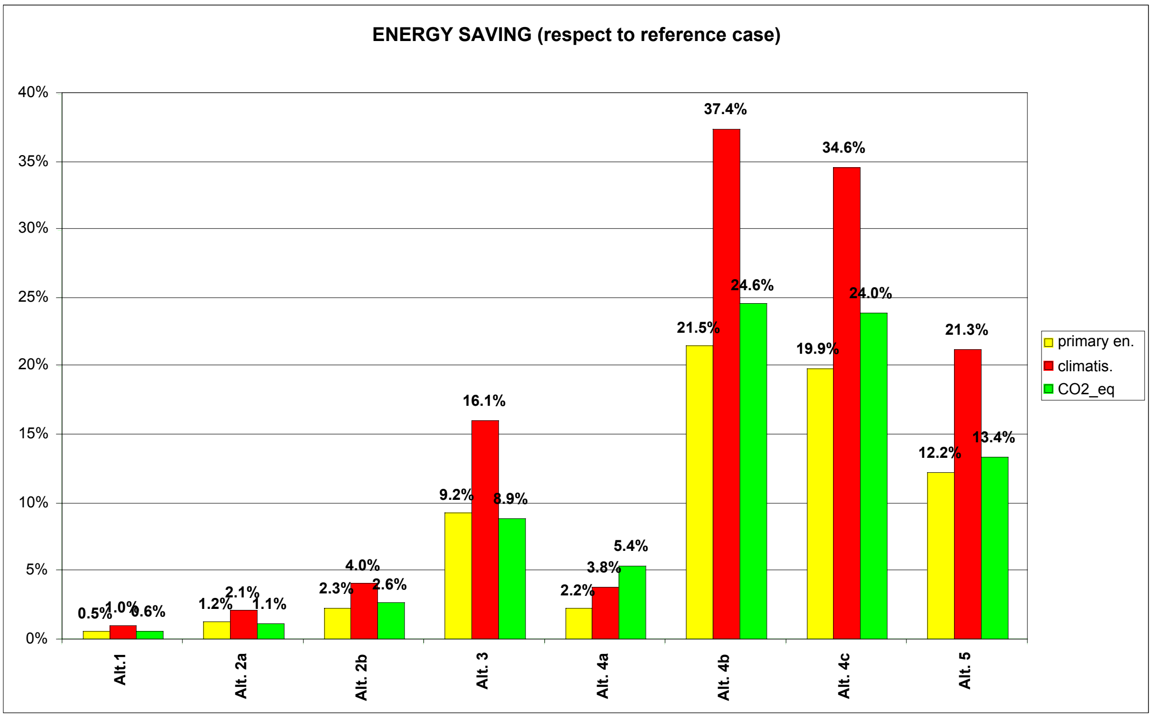

Figure 4: energy savings using the different strategies on energy system

CONCLUSIONS AND ECONOMICAL EVALUATIONS

Simulation results for the first energy saving strategy on automatic control of artificial lights show that during winter the heating demand increases as there is a less heat obtained from the artificial lights, however during summer the scenario is opposite. In total, there is a considerable electrical energy saving (both for the lighting and air conditioning) is foreseen with additional advantage of less emissions. As a result, there is a less annual primary energy consumption.

For the combined case of efficient windows and roof insulation, there is a significant contribution has been seen for annual thermal energy savings (around 41% less in respect of the actual conditions). As far as the concern of electrical energy, in this case, does not change significantly because of the following reasons.

It has been observed that during the nights of the summer season, and a part of the days in the intermediate seasons (autumn and spring), the external air temperature is lower than the set point of internal building. In these periods, the cooling energy loads are higher if the building envelope is heavily insulated, because of the heat loss from building to the environment.

In general, with the selective glass the solar heat gains are lower so the cooling energy loads decrease. However, for this case, the peculiar positions of the windows in the thick walls, gives an extraordinary natural shading for the sun, and there is a little scope to get advantages from any kind of the glass. This has been seen clearly from the simulation results.

For the present case, it has been seen that the use of selective glass has not a significant contribution in energy savings. The extra cost for selective glass is quite higher in respect of the glass with low-e (the extra cost for selective glass is around 60000 ITL/m^2, while for glass with low-e is around 30000 lire/m^2). Therefore, for economic point of view, it is not suggested to use the selective glass.

However, in the economic point of view, the energy saving strategy considered in respect of the use of insulation on the top-roof has been found advantageous (extra cost 16000 lire/m^2).

In case of the control of artificial lights, the average extra cost is estimated as 1 million lire for each office room. It is evident from the figure that the strategy contributes significantly in indirect energy savings as a result of less $CO_{2\text{-}eq}$ emissions, however, is not found feasible economically.

In case of various energy saving strategies on building energy systems considered in this study, the following observations have been made.

In point of view of primary energy consumption as well as $CO_{2\text{-}eq}$ emissions, the best strategy has been obtained from the simulation is the CHP based on thermal loads and single phase absorber chillers.

The percentage reduction in CO_{2_eq} are not directly proportional to the primary energy savings because of the mix of electrical and thermal consumption for all the individual solutions considered.

The extra cost of the best strategy was estimated as a difference between the costs of electrical chillers and the absorber chillers in addition to the cost of cogenerator (4 MW_e). It has been further observed that the electrical energy production from cogenerator is only not limited to satisfy the electrical demand but the surplus has been seen as the additional energy saving. On the other hand, for the operation of cogenerator, the gas is consumed, results an additional cost, however with lower price because of the national policy in respect of the use of gas for cogeneration.

The cost of energy saving has been estimated around 157 ITL/kWh which is less than the cost of electrical energy 170 ITL/kWh. It shows the economical feasibility to implement the appropriate (best in our case) energy saving strategy.

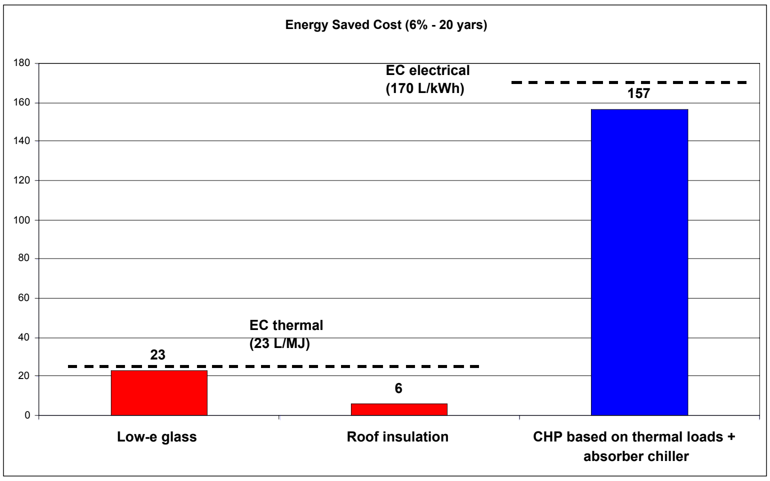

Figure 5: Energy Saved Cost in comparison to Energy Cost

At the last, the retrofit solutions considered in the present study show the significant reduction in $CO_{2\text{-}eq}$ emissions without modifying the original architectural aspects of present famous historical building.

References

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