Retrofitting Hospitals: A Parametric Design Approach to Optimize Energy Efficiency

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Abstract. Despite many progress have been done in the renovation of the existing stock, retrofitting hospitals and other strategic buildings still represent a very challenging issue both for their complex articulation and for the need to maintain acceptable operational level. The paper reports a research activity, run at the Department of Architecture in cooperation with S. Orsola Hospital in Bologna, aimed at investigating innovative strategies for retrofitting to meet the highest energy efficiency standards at national level. The main goal of the administration was to set a renovation plan – taking into account some limitations concerning the existing building features and the budget availabilities – able to remarkably reduce energy demand while creating the minimum disruption for end users. The starting position of the research was to preserve the historical image of the building while defining a strategy to insulate it from inside. The novelty of design approach lied in defining a basic working unit which was associated to the typical room of the stay division that was used to analyse the starting conditions (indoor comfort and environmental parameters) and simulate via software modelling the potential improvements. This led to define a step by step strategy that was translated into global intervention scenarios while the basic working unit was properly re-designed and validated. This approach allowed to define a parametric strategy able to predict the impacts of renovation on each floor, on each wing and on the system as a whole while assigning a specific unit cost and a reliable renovation timing.

1. Introduction
Retrofitting hospitals often represents a quite challenging initiative when the existing building owns particular features of historical interest which have been mixed with more recent ones due to the need of adapting the venues to during the time to new requirements and functions related both with medical purposes and with energy savings issues.

The huge amount of energy demand for heating, cooling, operating, etc. as well as the connected management activities require effective monitoring and diagnostic strategies that may benefit of the use of Building Performance Simulation to define use profiles and drive more tailored retrofitting measures. The study reported in this paper was originated by the request of an hospital administration to define a speedy methodology to assess the potential effect of different design option for a renovation plan. It takes into account some limitations concerning the existing building features and budget availabilities while aiming to remarkably reduce energy demand with the minimum disruption for end users. As requested in the brief, the starting position of the research was to preserve the historical image of the building while defining a strategy to insulate it from inside. The main goal is to reduce energy demand as energy costs are embedded in the general budget provided to the hospital by the National Health Service and therefore high energy costs reduce the residual availability for medical and health purposes.
As well documented in the scientific literature by Hirest’s and others [1–3] pioneering studies, “hospitals are the most energy-intensive building in the commercial sector” and this makes the topic of relevant interest considering the scope. In addition, conventional renovation strategies usually operate extensive insulation of the building envelope from the outside both to strongly reduce thermal bridges and the interaction hospital everyday activities. However in the specific case it is not possible to insulate the façades from the outside which are listed by the preservation agency. Past research experiences of the research team involving public administrations [4–7], management [8–11] and wider groups of interest demonstrated that technical information and data must be adequately and easily communicated to properly address renovation actions.

2. Goals
The main scope of the reported study is to support the decision makers, taking into account the complexity of the site, in selecting the best retrofitting option according to the needs and budget availabilities. In a first phase, the study focuses on creating a model of the basic room in its current status which is then, in a second phase, compared with several retrofitting options to assess the deriving outcomes. This approach allows to easily replicate and scale the process defined for a specific sector onto the building as a whole associating some retrofitting scenarios that can be compared according to the initial brief, premises and parameters.

Therefore the typical hospital room [12, 13] is assumed as the basic unit to be parametrically replicated for modelling each single sector till the impacts on the whole building can be predicted, adjusted, managed and finally achieved according to a scheduled sequence of works sector by sector.

3. From room to hospital: the case study of S.Orsola Malpighi Hospital in Bologna
The research is applied to a specific case study: the S. Orsola-Malpighi polyclinic hospital in Bologna (figure 1 and 2). The whole complex is split in several pavilions (each devoted to a specific medical division) embedded in a wide green area of the city quite closed to the historic center.

Each pavilion was built in different period of time and has different architectural layout and characters. The investigated one, dedicated to the obstetric/gynaecologic division and erected in 1934 according to a neoclassic design, is a listed building by the preservation agency. The pavilion is a three storey building (with relevant floor to floor height) with an H shape to which an extension was added in 1997 to connect the two edges of the main wings creating two courtyards.

The main constructive features of the building can be listed as follows:

- Composite concrete floor slabs ($U_{av} = 1.43$ W/m²K);
- Structural bearing clay masonry, cm 29 and cm 42 thickness ($U_{av} = 0.98$ W/m²K);
- Double glazed timber framed window ($U_{av} = 2.20$ W/m²K).

Figure 1. Pavilion 4 general view
4. Novelty of design approach

The novelty of the design approach lies in defining a basic working unit that - in the specific case associated to the typical room of the stay division - is used to analyse the starting conditions (indoor comfort and environmental parameters) and simulate, via software modelling, the potential improvements. According to the functional layout the basic unit can be replicated in most parts of the typical floor and this intermediate unit can be scaled to each wing being replicated at any single level. This process allows to obtain a certain level of accuracy in studying the basic unit and then parametrically extend the outcomes to the building as a wall within an acceptable range of approximation considering the scope. An energy saving simulation was conducted comparing the improvements coming from each renovation scenario on the whole building with the starting position.

Several solutions can be explored according to different retrofitting scenarios (the case study includes three options that are compared and investigated) keeping an eye both on the effectiveness of the energy saving measure and the deriving comfort conditions which are assumed as a key aspect for the patients. Typical retrofitting interventions on the basic unit include a number of actions: partition and existing services removal, insulation (rock wool $\lambda = 0.038$ W/mK) of external wall through a inner drywall 13.5 cm thick, replacement of the existing window with a more performing PVC one ($U_w = 1.2$ W/m²K) including shading system, integration of new services and equipments (lighting, safety sensors, Heating, Ventilation and Air Conditioning [HVAC] unit), creation of a suspended plasterboard insulated ceiling with acoustic properties.

All these actions provide a contribute at building level which is parametrically calculated and replicated. The energy performance of the building was calculated according to UNITS 11300 [14] using Termolog Epix 8 software and adopting a steady-state model. Retrofitting actions are simulated according to three scenarios corresponding to different renovation intensities and expected savings:

Scenario 1 – Only roof insulation (Roof insulation with rock wool $\lambda = 0.036$ W/mK;) is considered and the works do not create any impact on the pavilion activities and patients stay;

Scenario 2 – Roof insulation is combined with façade insulation and window replacement in order to obtain an extensive improvement of the building envelope as a whole (Roof insulation with rock wool $\lambda = 0.036$ W/mK; + Replacement of existing wooden framed windows with high performing PVC ones ($U_w = 1.2$ W/m²K) + External wall insulation (rock wool $\lambda = 0.038$ W/mK) through a inner drywall 13.5 cm thick). Works requires to rotate patients in the beds sector by sector altering the usual pavilion activity;
Scenario 3 – Services and equipment replacement are added to scenario 2 (Roof insulation with rock wool $\lambda = 0.036 \text{ W/mK}$; + Replacement of existing wooden framed windows with high performing PVC ones ($U_w = 1.2 \text{ W/m2K}$) + External wall insulation (rock wool $\lambda = 0.038 \text{ W/mK}$) through a inner drywall 13.5 cm thick + Integration of new services and equipment including Controlled Mechanical Ventilation [CMV] and replacement of existing radiator with fan coils.) requiring patients are re-allocated in a different sector while works are completed.

Basing on the parametric cost generated on the single basic room unit an estimation of costs for each scenario has been provided.

Figure 3 reports and compares intervention costs, yearly cost savings, Simple Pay Back [SPB] value, works duration, impacts and energy performance level associated to each scenario.

Figure 3. Graphic representation of Scenario outcomes and comparison.
5. Energy saving results

Based on the speedy parametric methodology, Table 1 provides a synthetic report of the energy performance level, the payback time, the yearly energy savings and the cost per square meter of each scenario.

Table 1. Comparison between the scenarios outcomes.

| Scenarios | EP index (kWh/m²/year) | SPB (years) | Energy bill saving (€) by year | Building cost (€/m²) |
|-----------|------------------------|-------------|-------------------------------|----------------------|
| 0 (starting position) | 298.84 | - | - | - |
| 1 | 297.35 | 9.2 years | 13,730 €/year | 40 €/m² |
| 2 | 181.62 | 18.1 years | 76,431 €/year | 203 €/m² |
| 3 | 40.82 | 12.1 years | 113,913 €/year | 238 €/m² |

Even if the investment is quite limited (making the solution feasible for the administration), scenario 1 produces very limited impact on energy performance level (EP index) and energy savings. Scenarios 2 and 3 are more expensive and time consuming but ensure to achieve relevant improvements. With an increase of cost around 8% compared to scenario 2, scenario 3 allows to reduce the EP index of 75% representing the most convenient and effective combination of retrofitting actions. This is due to the integration of CMV that is the key element to achieve the described benefits while ensuring adequate indoor comfort conditions.

In the case of very complex buildings, such as hospitals, the achievable energy savings are not the only parameter to be taken into account: the perceived comfort conditions by end users, the minimum disruption for patients during the renovation process, the chance to ensure the continuity of the medical activities may become more relevant in a global perspective. That said, the hospital administration has launched an ambitious renovation plan investing the whole area started with the replacement of the old energy system with a new tri-generation system (combined heat cool and power [CHCP]) to which the new and the renovated pavilions will be connected. Despite this initiative aims to significantly increase energy savings it is not directly connected with the single buildings refurbishment and equipment replacement, thus it is important to provide a speedy methodology to support decision makers in addressing the investment on each single renovation intervention coherently with the general scope of the plan.

The most relevant barriers to the application of the reported methodology are related to the need to consider non-technical priorities, budget availabilities, intervention schedule over the time taking into account the disruption for the patients and users.

6. Conclusion

The proposed methodology ensures to address priorities and choices within a transparent and easy to understand framework that usually makes the process fluid allowing a participated process among the involved subjects and avoiding relevant amendments can arise during the following implementation phase.

The parametric approach was chosen according to the initial brief of the hospital administration and took carefully into account the constraints and limits of the existing building as well as of the administration plans. The described methodology is quite flexible especially in the phase dedicated to scenario creation and evaluation. It requires an initial investment in modelling with a good level of detail the interventions on the basic unit and its proper definition but this effort is then balanced by a speedy and quite easy to understand way to describe the benefits of each design options. Simplified graphs or visualization become the tools to facilitate the impacts understanding to a non technical audience during the decision making process.
Acknowledgment

The authors express their sincere gratitude to the S. Orsola-Malpighi polyclinic hospital administration and management division for cooperation offered during the study and particularly to Eng. Daniela Pedrini for her kind help and support.

Nomenclature

- CHCP: Combined Heat and Cool and Power
- CMV: Controlled Mechanical Ventilation
- EP: Energy Primary index
- HVAC: Heating, Ventilation and Air Conditioning
- SPB: Simple Pay Back
- $U_{av}$: Transmittance average (measured in W/m$^2$K)
- $\lambda$: Thermal conductivity (measured in W/mK)

References

[1] Hirst E 1982 *Analysis of hospital energy audits* vol 10 pp 225–32
[2] Ascione F, Bianco N, De Masi R F and Vanoli G P 2013 Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates *Energy Build.* 60, 125–38
[3] Balaras C A, Dascalaki E and Gaglia A 2007 HVAC and indoor thermal conditions in hospital operating rooms *Energy Build.* 39 454–70
[4] Gaspari J, Fabbri K and Lucchi M 2018 The use of outdoor microclimate analysis to support decision making process: Case study of Bufalini square in Cesena *Sustain. Cities Soc.* 42 206–15
[5] Bertone E, Steward R A, Sahin O, Alam M, Zou P X W, Buntine C and Marshal C 2018 Guidelines, barriers and strategies for energy and water retrofits of public buildings *J. Clean. Prod.* 174 1064–78
[6] Méndez C, San José J F, Villafruela J M and Castro F 2008 Optimization of a hospital room by means of CFD for more efficient ventilation *Energy Build.* 40 849–54
[7] Silenzi F, Priarone A and Fossa M 2018 Hourly simulations of an hospital building for assessing the thermal demand and the best retrofit strategies for consumption reduction *Thermal Science and Engineering Progress* 6 388–97
[8] Ascone F, Bianco N, De Stasio C, Maur G M and Vanoli G P 2018 5.21 Energy Management in Hospitals *Comprehensive Energy Systems* 5 857–54
[9] Garcia-Sanz-Calcedo J and Gomez-Chapparro M 2017 Quantitative analysis of the impact of maintenance management on the energy consumption of a hospital in Extremadura (Spain) *Sustain. Cities Soc.* 30 217–22
[10] Gonzale A G, Garcia-Sanz-Calcedo J and Salvado D R 2018 A quantitative analysis of final energy consumption in hospitals in Spain *Sustain. Cities Soc.* 36 169–75
[11] Thinate H, Wongkapai W and Damrongsk D 2017 Energy Performance Study in Thailand Hospital Building *Energy Procedia* 141 255–59
[12] King M F, Noakes C J and Sleigh P A 2015 Modeling environmental contamination in hospital single- and four-bed rooms *Indoor Air* 25 694–707
[13] Buonomano A, Calise F, Ferruzzi G and Palombo A 2014 Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings *Energy* 78 555–72
[14] UNITS 11300 part 1: 2014 Energy Performance of Buildings – Part 1: Evaluation of Energy Need for Space Heating and Cooling