UNIVERSITÀ DEGLI STUDI
DI GENOVA

Energy saving room scheduling system for smart hotels

Ernesto Denicia, Emanuele Sansebastiano, Rocco Caravelli

1. Abstract

The energy consumption is probably the most important aspects engineers have to take into account when they project a robot case or plan the action sequence to make it do. Generally, this problem is handle by optimal path research and optimal decision analysis. There are infinitive application in robotics regarding optimal storage strategy, for instance, manipulators managing storehouse have to decide where they have to store the packs according to shortest time spend, force and velocity they can apply on the pack (fragile or not), and best storage location according to the specifics of the object: the robot do have to put milk in a fridge, not in a hoover. Our analysis deals with this last case: where I do have to put something which must stay in specific temperature bounds. In particular, we analysed how the customers are placed in hotel room according to their needs, at first, the maximal revenue the hotel owner can get and the minimal energy usage to keep the temperature feasible to live by law. In this paper we are going to analyse the Winter period, but the identical approach can be used to find the optimal distribution during Summer.

2. Introduction and proposal

This paper deals with the necessity of reducing the energy loss in hotels related to the usage of heat sources (radiators, heat pumps, etc..). Since a hotel has to provide a fixed minimum in every room used to host of 20 ± 2 °C by the norm DPR n° 412/1993, during Winter, at least in Europe, hotel managers need to turn on heaters. Assuming the buildings we are observing have the possibility to turn on and off the heat sources of each room independently from the other ones we wonder if the usage of the heat source is just dependent on the dimension of the specific room or if the other rooms will contributes to reduce the energy required to heat up the considered room. Moreover, we assume that if none booked a room on a day, that heater is not active in that room on that specific day. In order to see check it we made a lumped parameter model of the hotel using a on/off controller, having heat pumps as heating (and cooling) system source. These heat pumps directly blow wormed air in the room (forced convection), so they are very fast, and easy to control by an on/off control. The figure 1 shows that, thanks to the fact the room located on the first floor (blue line) is occupied on the days 2, 4, 5 and the room located on the third floor (blue line) is occupied on the days 2, 4, 6, the room located on the second floor (red line), which is in the middle, receives a consistent heat flux from the other two. That room is never booked on the mentioned period, but its temperature is almost always above to minimum temperature required to keep the heat pump off (18.5 °C). Finally, we have the proof the temperature of a room influences the one of the other and vice verse. Thus, we want to formulate and optimal decision algorithm, which takes in consideration all the rooms in their complexity, to accept, at first, the best requests combination among the ones we have, and then, optimize the distribution of the accepted costumers in the rooms available.

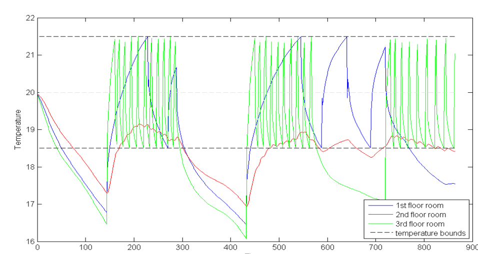

Figure 1: *Temperature of three rooms located one over the other having various customers along 6 days.*

3. State of the art

In order to understand the algorithms already used we decided to perform a market analysis asking to specific hotels, located in Genoa, chosen according to they class of quality (number of stars) to explore every kind of quality service provided: the quality service is a valid index to check the possible price of

a room, and so the possible revenue coming from each room. In particular we asked if they make forecasts on the demand according to their own customers and/or the Genoa statistics, and if they use software to manage the demand. Surprisingly, we found out the just the 20% of the hotel manager interviewed use to check the demand statistics and they take more into consideration the agencies' forecasts more than looking at their past customers.
On the other hand the usage of computer to manage the whole hotel is a common layer. It bursts all the paper work and the customer distribution could not wait for a different fate. However, none uses a software which optimizes the room booking, most of the software just uses a first list/first choice or a random choice. The internet sources reveal some software which are sponsored as optimization software, but they do not have the algorithm available because of industry secret. The hotel manager must pass to the software the parameters of the rooms like price and grade of priority. These kind of software, instead, tend to optimize the revenue management (schedule an offer campaign and the optimal room price) more than optimize the room booking.
Thanks to researches we are confident that the algorithm (based of the energy consumption) we want to propose is not already present on the market. Since it is strictly related to topology of the hotel (room adjacencies), we strongly think companies doing building energy analysis could be interested in offering this kind of service to their clients.

Anyway, the algorithm we are proposing for this specific problem is largely versatile to solve every placing and/or storage optimization.

4. Previous heat and control analysis

In order to analyse the heat fluxes governing the heat transmission of a building there are two ways to proceed: taking blueprints of the building and, knowing all the material properties, making a heat analysis of every room, or taking the temperature of every room and identify the parameters to know the behave of heat fluxes. Because both approaches lead to the solution, we decided to make two independent previous analysis.
Each procedure is based on the equivalence having on the left side the summation of heat fluxes at a specific time instant and on the right side the variation of the internal energy from an instant to the following one:

$$q_{tot_t} = \Sigma q_{k_t} + \Sigma q_{h_t} + \Sigma q_{vent_t} + \Sigma q_{sun_t} + q_{pump_t}$$

$$q_{tot_t} = \rho V c_p \frac{dT}{dt}$$

Where:

q_k is the thermal convection;
q_h is the thermal conduction;
q_{vent} is the ventilation flux according to the norm UNI/TS 11300;
q_{sun} is the sun radiation took from weather forecast;
q_{pump} is the heat flux coming from the heat pump (if activated);
$\rho V c_p \frac{dT}{dt}$ is the time derivative of the internal energy.

4.1. Blueprint analysis strategy

Since the used scenarios must be realistic we planned three kind of room according with their price and structure (25 m^2, 50 m^2, 75 m^2) and the same amount of customer kinds. Every wall is made by common bricks (density: 2000 $\frac{kg}{m^3}$; heat capacity: 0.9 $\frac{kJ}{kgK}$; thermal conduction: $8e^{-4}$ $\frac{kJ}{smK}$); the exterior wall thickness is 0.4 m, while the interior one is 0.1 m. Every room have at least a window and one door on the corridor. The windows are made by common glass (density: 2400 $\frac{kg}{m^3}$; heat capacity: 0.84 $\frac{kJ}{kgK}$; thermal conduction: $9.6e^{-4}$ $\frac{kJ}{smK}$), and its thickness is 0.04 m, while the doors are assumed to be like the interior wall for their heat behaviour. To run these initial set of experiments we decided to use real heat pumps (any other kind of heat source do not change the result) taken by the commercial catalogue Daikin Industries, in particular we used the heat pump called 'FTXZ35N'.

Due to the fact computer cannot handle continuous domain, the heat transfer equation must be discrete:

$$q_{tot_t} = \rho V c_p \frac{dT}{dt} \qquad --> \qquad \frac{q_{tot_t}}{\rho V c_p} = \frac{T_{t+1} - T_t}{timegap}$$

Then, we can rewrite the equation:

$$K_{i,j}(T_{i,t} - T_{j,t}) = \frac{C_i}{timegap}(T_{i,t+1} - T_{i,t})$$

Where:

$K_{i,j}$ is the heat transfer coefficient from the room j to i;
$C_{i,j}$ is the capacitance of the room i;

4.2. System identification strategy

The practise requires the temperature of the air of each room at each instant of the analysis

E-plus

bla bla

4.3. P control vs. ON/OFF control

map of the hotel

different curves for the temperature depending on floors

gap-time

Assumptions on the hotel (temperature in - out, sun)

5. analysis of the problem

maximize revenue

minimize costs

reject request

Optimized software used is Gurobi
?formulas?

6. Results

6.1. Revenue

6.2. Random assigning vs. optimized assigning

7. Conclusion