ICT in Building Design Course, Master Degree in ICT4SS, Politecnico di Torino

Internal Heat Capacity in an office

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Abstract

This paper analyses the quantity of thermal energy needed to reach a comfortable temperature in an office, in both summer and winter conditions. The analysis has been carried out on three different scenarios, considering low, medium and high insulation levels. For each scenario, we investigated how the change in Internal Heat Capacity (IHC) leads to a change in heating/cooling energy needed.
Keywords: Internal Heat Capacity; Energy consumption;

1. Introduction

Knowing the characteristics of a building is necessary to manage and control its use, and knowing the energy that is needed for thermal reasons is fundamental to estimate the energy profile of the building and to forecast expenses.

In this paper we examine three different cases, considering an old-style building with nearly no insulation, a medium insulated building and a final one with good insulation. For each scenario, we ran several simulations, accounting for different material specifications, to investigate the relationship between Thermal Energy and IHC.

2. Methodology

2.1. Model of the Building

The building that we are considering in our paper is an office prototype described as a 3D model in Building Design. Even though the office is made of several units, we will consider the building as a whole for our purposes, taking into account external walls and windows only for sake of simplicity. Considering internal walls or the roof would just have added mathematical computations, without changing the core of the study.

2.1.1. Building occupancy

The presence of people in the building is both the reason for and the disturbance element of thermal energy used for heating and cooling: every person affects the building energy balance, adding some heating to the system.

In our work, people presence is the noise added to the building characteristics. This presence is modeled as a random Gaussian noise, where the medium value is the average occupancy for offices and corridors, with a proper variance.

The average value that we used is the 0.111 [people/ m^2], the standard deviation is 0.001

With those values, it is very unlikely to get a negative value for building occupancy, but anyway we decided to take the absolute value of the number of people to avoid this problem.

2.1.2. Scenarios

We modeled our office in three different configurations:

- Not insulated building: very thin insulating layer, representing an old-style building
- Medium insulated building: average insulating layer, reaching the current threshold for insulated building in Piedmont region
- Highly insulated building: thick insulating layer, well above the law requirements.

The considered values are reported in the following table

Table 1: Parameters definition for the different scenarios

SCENARIOS	EPS thickness [mm]	Walls U-Value [W/M^2*K]	Windows U-Value [W/M^2*K]
Low insulation	8	1.596	5
Medium insulation	103	0.298	1.8
High insulation	180	0.180	1

2.2. IHC calculation

The internal heat capacity does not depend on the insulating layer, but only on the inner layers of the building.

$$IHC = \rho * C * d \qquad [kJ/(m\char`^2 * K)]$$

Where:

ρ is the density,
C is the specific heat
D is the thickness

Of each wall material between the insulating layer and the internal air[1]

The concrete that we consider for our model has a specific heat C = 1 [kJ / (kg*K)]
Moreover, the thickness of concrete layer does not change and is 0.3m. What does change is its density, which becomes the true driving variable of our investigation.
For all three scenarios, we ran 120 simulations, having IHC value in range 300-2100 [kJ / (m^2*K)], therefore having the concrete density in range 1000 – 7000 [kg/m^3].

3. Simulation

3.1. Generation of .idf and E+ simulation

After setting specifications for U-value in Design Builder, for each of the three scenarios we created an .idf file, which is a compatible format for Energy Plus, the software we used for energy simulation.
Using a python script we managed to create and simulate on E+ 3*120 .idf files, each one of them with different concrete density for all scenarios. Moreover, we added to all of them a rondomized people occupancy, as previously discussed.
All the .idf files have been simulated in E+ with appropriate weather conditions, for both summer and winter period, getting in return the used thermal energy.

To perform further analysis on the obtained results, we implemented a linear regression algorithm using the Minimum Square Error (MSE) method. This procedure has been repeated for both heating and cooling energy estimation.

[1] SBEM Technical Manual, http://www.uk-ncm.org.uk/filelibrary/SBEM-Technical-Manual_v5.2.g_20Nov15.pdf | pag 63 (@ bottom)

3.2. Data analysis and linear regression

The obtained data are affected by the random noise due to the variable number of people present in the building during the study period.

To get rid of this disturbance we implemented a python code for linear regression, using MSE method. We used our 120 simulations to be the training set, and then we apply the algorithm firstly to our set again, for double check, then to a new set of values of density, more spaced and independent.

Analyzing the result, we decided that a first order linear regression fitted well the results, having therefore:

$$y(x,w)= w_0 + w_1 x_1$$

In Order to find out the *w* coefficients we applied, with a python script, the matrix estimation:

$$\underline{\boldsymbol{w}} = [\boldsymbol{X}^T\boldsymbol{X}]^{-1}\boldsymbol{X}^T\boldsymbol{y}$$

3.2.1. MSE implementation

To approximate the building behavior we used our simulated samples as a training test, and then created a new test set, with different densities.

Our aim was to get comparable mean square error for both sets, aiming to get similar approximation.

As can be seen from the graphs, the approximation lead to similar values for both known and estimated values, proving the well-functioning of the algorithm

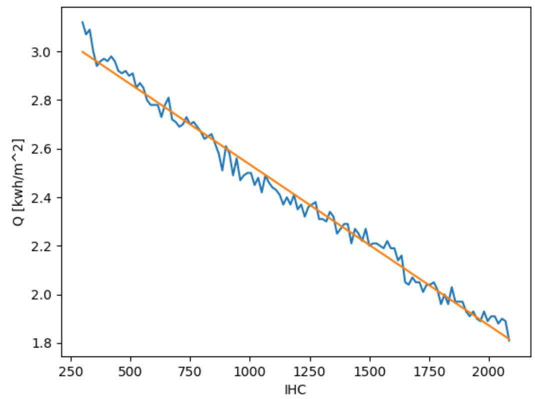

Figure 1: Linear regression for train data

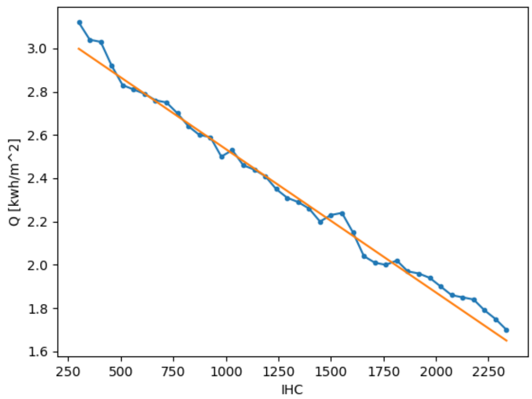

Figure 2: Linear regression for test data

4. Results and discussion

The final result of our simulation is a graph for cooling and heating required energy over concrete density, that in our case is directly proportional to IHC.

1st scenario: no insulation

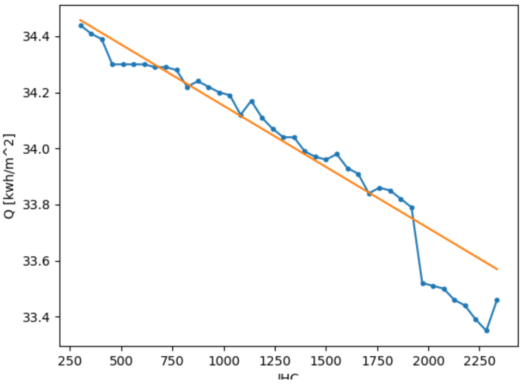

Figure 3: Cooling Energy vs IHC

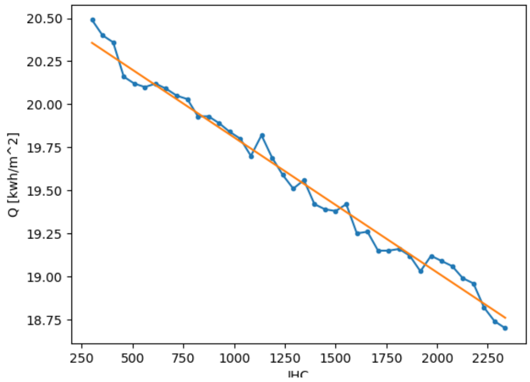

Figure 4: Heating Energy vs IHC

2nd Scenario: average insulation

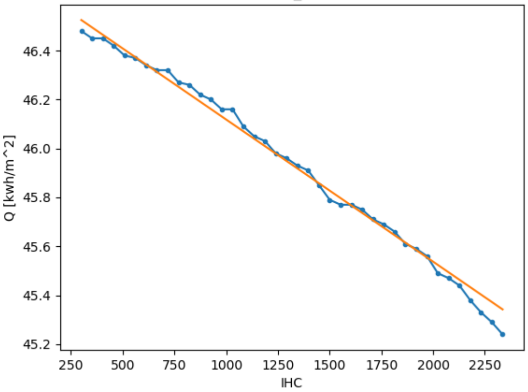

Figure 5: Cooling Energy vs IHC

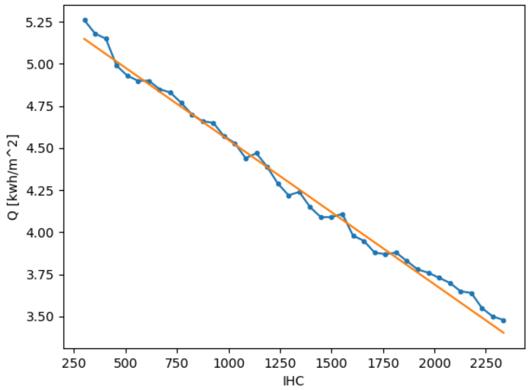

Figure 5: Heating Energy vs IHC

3rd Scenario: high insulation

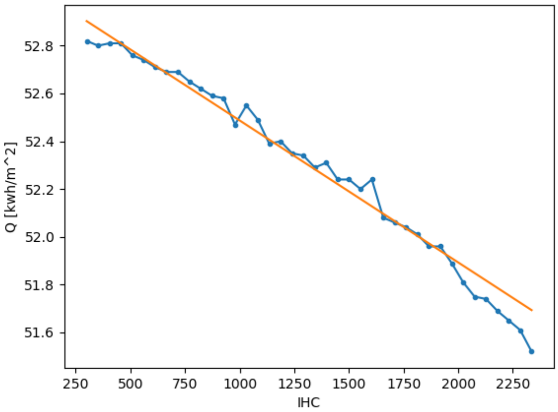

Figure 7: Cooling Energy vs IHC

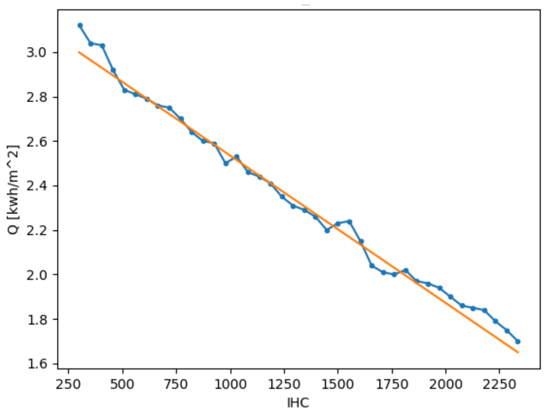

Figure 8: Heating Energy vs IHC

As can be seen from the graphs, the linear regression line is a good approximation of the general trend. For all scenarios, it is clear that buildings with higher IHC lead to thermal energy savings for both heating and cooling. This is reasonable, as higher IHC means longer time for temperature changing, so the building can keep longer the warm (in winter) and cool (in summer) temperature.

About energy consumption, the general trend is that for heating, having an insulated building is much better and can lead to save up to 80% of the power.

On the other hand, something for us unexpected happens on the cooling side: It seems that the better-insulated building needs more energy to keep a cool temperature.

To try explain this unexpected phenomenon, we can say that while in wintertime the heating system is on all-day, in summer the air conditioning in turned on and off according to the given time table. This, combined to natural ventilation, makes so that the internal temperature raises during AC off periods, which leads to higher energy use to get back quickly to the cooler comfort temperature.

5. Conclusions

The simulation that we performed shows that have better energy efficiency in winter, and worse in summer, even if the result is probably affected by the fact that we have used just one ACS program.

More precisely about the focus of our work, we can say that buildings with higher IHC have better energy efficiency, as they manage to keep for a longer time the desired temperature.

Of course different would be the case, which is not, of a building used for very few hours a day. In that case it would probably be more convenient to have a lower IHC, so to get faster to the desired temperature without feeding the system with unnecessary energy.