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Urban Heat Island Effect on the Energy Consumption of Institutional Buildings in Rome

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Abstract. The urban heat island (UHI) effect is constantly increasing the energy consumption of buildings, especially in summer periods. The energy gap between the estimated energy performance - often simulated without considering UHI - and the real operational consumption is especially relevant for institutional buildings, where the cooling needs are in general higher than in other kind of buildings, due to more internal gains (people, appliances) and different architectural design (more transparent façades and light walls). This paper presents a calculation of the energy penalty due to UHI in two institutional buildings in Rome. Urban Weather Generator (UWG) is used to generate a modified weather file, taking into account the UHI phenomenon. Then, two building performance simulations are done for each case: the first simulation uses a standard weather file and the second uses the modified one. Results shows how is it necessary to re-develop mitigation strategies and a new energy retrofit approach, in order to include urbanization ad UHI effect, especially in this kind of buildings, characterized by very poor conditions of comfort during summer, taking into account users and occupant-driven demand.

1. Introduction

Institutional buildings like: offices, universities, schools, hospitals, etcetera, constitute a very important part of the building stock. In Italy, Many of these buildings were built in the XIX and in the first half of the XX Century, without specific measures to reduce energy consumption. As a result, the institutional buildings are responsible of almost the 20% of the total building stock energy demand in the country (REF IS NEEDED). Moreover, the consumption profile of institutional buildings is different from the residential buildings stock: in 2008 institutional buildings consumed more electricity than residential buildings (39% versus 22% of the total consumption) due to more intensive use of air conditioning (19% versus 1%), appliances and lighting (9% versus 3%) [1]. Italy has today a good share of renewable energy contribution to electricity production (about 40%). However, the high demand of electricity that institutional buildings have poses a challenge for energy demand and urban sustainability.

As required by the European norms [2], buildings have to be renewed accomplishing with law. For this reason, an intensive process of refurbishment has been started, firstly regarding educational buildings (schools and universities) following the national norms derived from the European Directive [3]. This process has already generated an important amount of information on energy demand at both professional and academic level [4,5,6,7] which aligns with other international experiences [8,9,10]. However, due to climate change it is possible that the requested interventions would not be calibrated on the weather conditions the renewed buildings will face in their life-time [11]. Climate change (CC) and urban heat island (UHI) effect are increasing present-day urban temperatures, and the phenomenon will worsen in the future [12, 13]. In this work, an evaluation of the current overheating risk in two institutional buildings of the University Campus of the "La Sapienza" University is done. The methodology includes 2 assessments, considering and excluding the UHI in the weather file associated with the building performance simulation (BPS), which was conducted with TRNSYS © tool [13]. The reduction of heating due to UHI is also assessed with the same methodology.

2. Methodology

The influence of the UHI effect on the energy consumption of institutional buildings was calculated using a three step work-flow methodology: 1) first, the urban parameters corresponding to the situation of the Rome University Campus "La Sapienza" is done by using GIS techniques; 2) then, a Urban Weather Generator simulation is run out to obtain a modified weather file to be used in BPS and; 3) finally, two sets of BPS are done, one using the weather for Ciampino airport meteorological station and other using the UWG generated weather file in epw format.

Urban weather generator © (UWG) is a tool developed at MIT in 2008 by Bueno [14]. The tool couples an atmospheric mode with an energy-plus based model for BPS. To estimate the UHI effect, UWG needs some parameters of the urban form, the materials and the buildings operational conditions in the selected city sector. Sensitivity studies [15,16,17] show that the most influencing parameters are the anthropogenic heat generation (basically by cars), the urban morphology (built-up surface, façade surface, green areas) and the materials' optical properties (emissivity and albedo).

In the first step, the urban environment surrounding the University Campus was analyzed by using Google Earth and Google Street View tools (Figure 1). The urban parameters and the materials of soils, walls and roofs were assessed (Table 1). Other parameters, like anthropogenic heat and building operation, were obtained by literature research [18,19].

Figure 1: La Sapienza University Campus, urban context

Table 1: Urban parameters used in UWG simulation

CITY RADIUS (m)	6,500
URBAN MORPHOLOGY	
Average Building Height	16,4
Site coverage ratio	0.29
Facade-to-site ratio	0.87
TREE COVERAGE (%)	12
ANTHROPOGENIC HEAT FROM TRAFFIC (W/m^2)	8
Day time **COOLING SET POINT** (ºC)	25
Nigh time **COOLING SETPOINT** (ºC)	28
HEAT RELEASED TO CANYON (%)	50
WALL CONSTRUCTION	
layers material	plaster-masonry-plaster
thickness (m)	0.02-0.5-0.01
conductivity (W/mK)	1.0-0.72-1.0
volumetric heat capacity (J/mc K)	14 -1,612,800-1,400,000
SURFACES' ALBEDO AND EMISSIVITY	
wall	0.35/0.95
road	0.08/0.96
roof	0.25/0.95

Site coverage ratio is obtained by the equation (1):

$$site\ coverage = \frac{\sum A_{bldg}}{A_{site}} \tag{1}$$

Where A_{bldg} is the footprint of each building in the site and A_{site} is the total site area.

Façade to site ratio is obtained by the equation (2):

$$facade\ to\ site\ ratio = \frac{\sum Ph_{wtd}}{A_{site}} \qquad (2)$$

Where P is the perimeter of each building in the site, h_{wtd} is the weighted building height (by footprint) and A_{site} is the total site area.

In the second step, UWG simulation was ran. The result is a modified weather file to be used in building performance simulation. In the third step, BPS was conducted on two buildings of the Campus (Figures 2 to 4). Parameters used in BPS are resumed in Table 2.

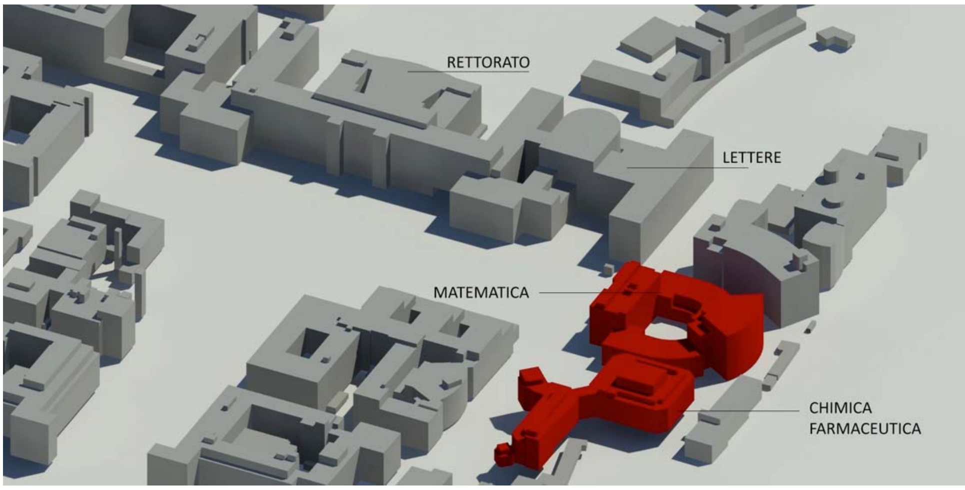

Figure 2: location of analyzed buildings in the university campus

Math Faculty building is an historical example of the Italian architecture of the Fascist period: designed by G. Ponti in 1935, was modified in the space distribution to adapt it to new didactical functions, but conserves the original structure of bricks and metal frameworks on the windows.

Figure 3: Math Faculty building

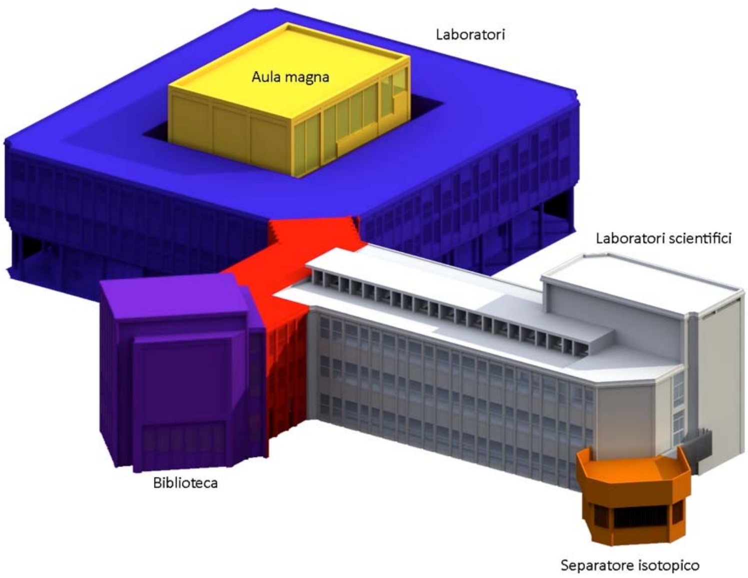

Figure 4: Chemistry Faculty building

Chemistry Faculty building was constructed in 1962. It can be observed a clear division between the didactical area and the scientific area, with more controlled conditions in terms of temperature and humidity (laboratories). The structure is made of reinforced concrete blocks, whilst windows are single glazed with aluminium frameworks.

Table 2. Building Performance Simulation parameters

Occupancy schedule	8 - 18
Infiltration air renewal (1/h)	1
Ventilation air renewal (1/h)	0.2
Heating set point (ºC)	22
Cooling set point (ºC)	22
Construction elements thermal transmittance (W/m^2K) – Math building	
walls	1.5
roofs	1.2
floors	2.7
windows	5.4
Construction elements thermal transmittance (W/m^2K) – Chemistry building	
walls	1.3
roofs	1.3
floors	2.7
windows	5.8
Percentage of glazed surface	
Math building	25 %
Chemistry building	40 %

3. Results and discussion

Results of simulations show an increase in the cooling needs of about 10% and a decrease in heating needs of about 5% for both analysed buildings. Due to the set points used (22 ºC for both heating and cooling), the total net energy demand considering UHI is slightly less than the energy demand without considering it. However, it has to be considered that free-running building are normally evaluated by considering a comfort range of 18-26 ºC. Nowadays, the two studied buildings have only a heating system and resolve the summer comfort by natural ventilation. Heating is often used to maintain the internal temperature at more than 22 degrees Celsius. User behaviour still remains one of the most important strategies to resolve the winter problem.

Figures 5 and 6 show the external temperature in rural and urban environment for a winter and a summer week. It could be noticed that UHI effect in Rome is higher in winter (up to 7 degrees versus 2 degrees in summer) and is principally a night effect (during the day, even a negative UHI could be observed). The percentage of heating reduction is, however, less than the increase in cooling demand. In absolute terms, the two effects are balancing (in the operational condition evaluated, 22 ºC), as shown in Figures 7 and 8 for both studied buildings.

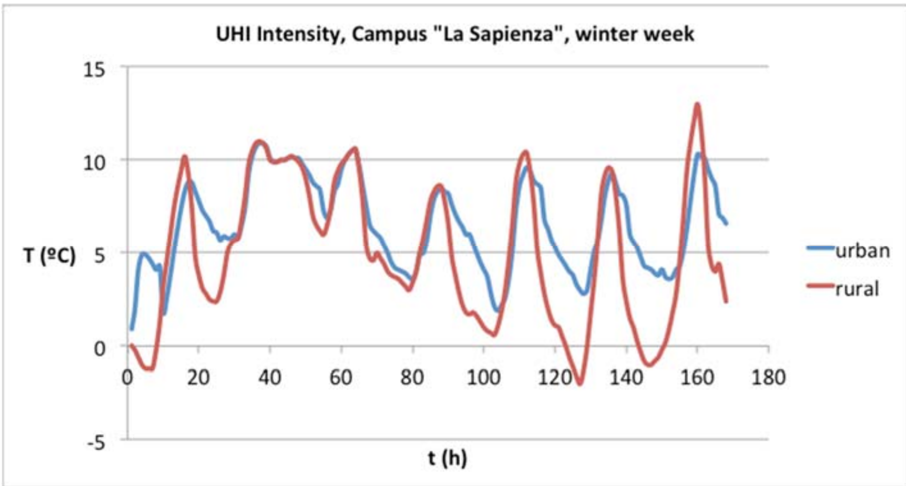

Figure 5: external temperatures for urban and rural scenarios, winter week

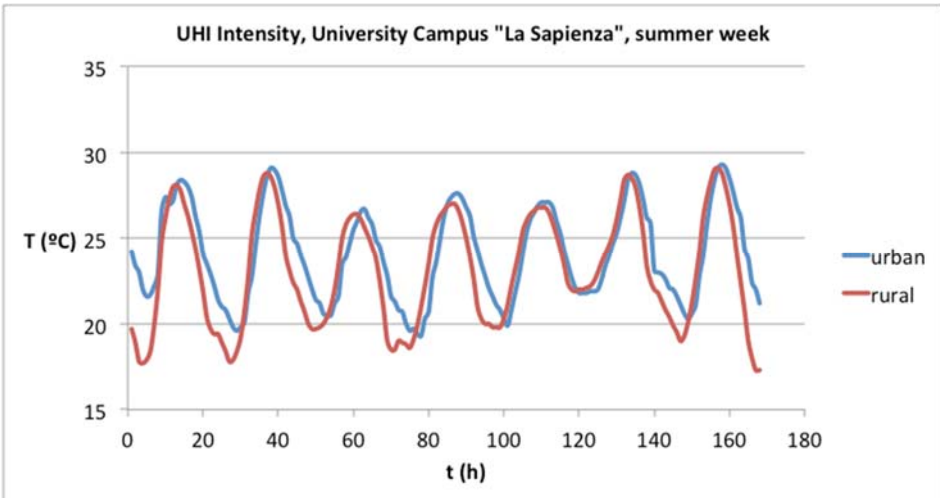

Figure 6: external temperatures for urban and rural scenarios, summer week

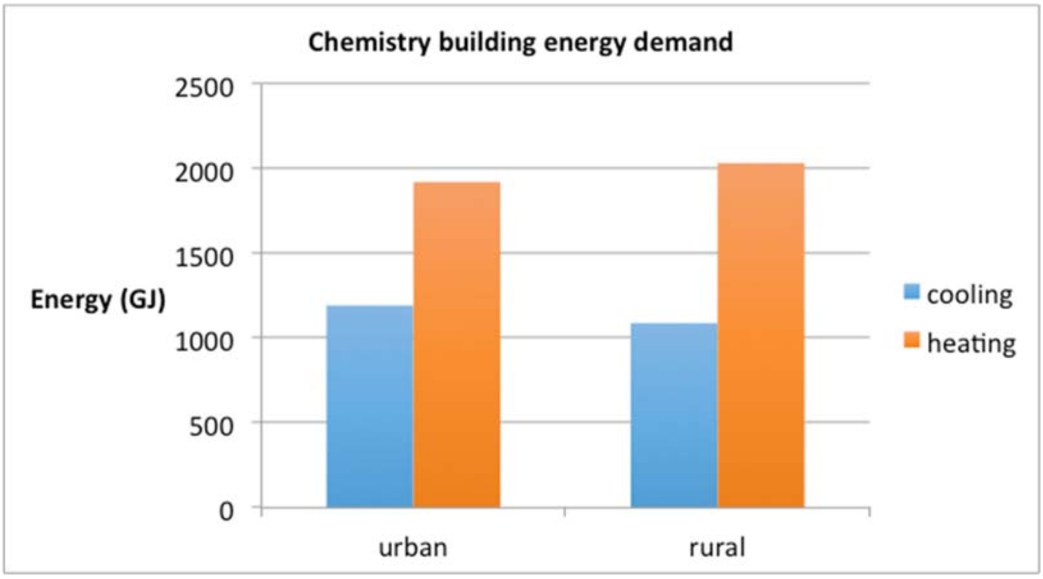

Figure 7: cooling and heating energy demand for chemistry building

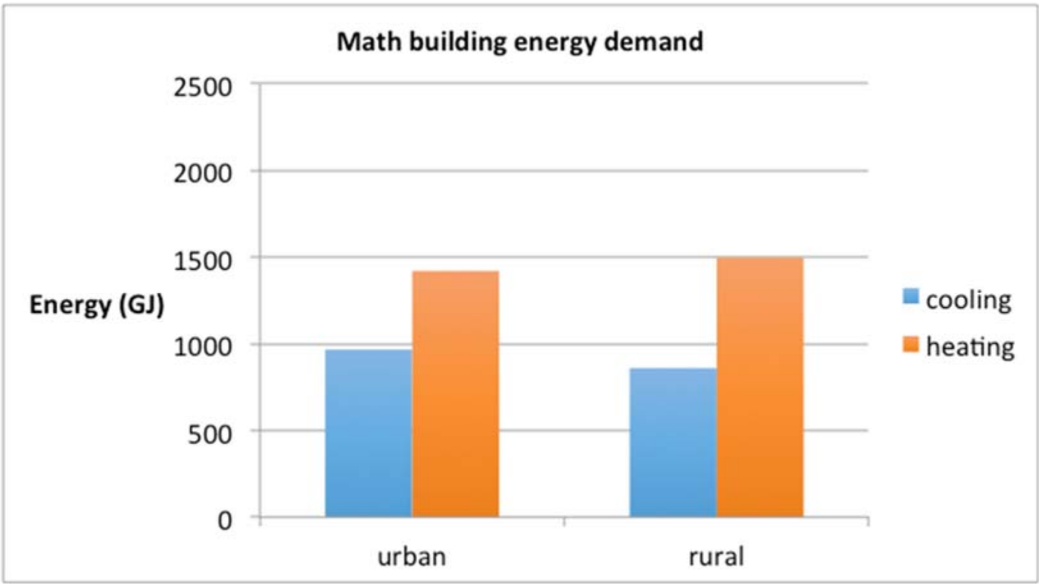

Figure 8: cooling and heating demand for math building

Energy performance of Math building is a little better, as observed previously [20]. The older building presents a 30% less heating demand and about 20% less cooling demand. The absolute value of energy needed by the two building is, however, enormous. The impact of the electricity consumption on the total budget of the "La Sapienza" Campus is one of the priorities to be resolved in the near future at the University of Rome.

4. Conclusions

This research focused on the energy penalty introduced by UHI in building performance simulation. Results confirm that estimated cooling needs increase by about 10% whilst heating needs decrease by 5%. Math building, older and whit higher thermal mass, performs better than the other building. This is in line with similar previous evaluations [21, 22]. However the sensitivity to UHI effect seems to be the

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same. The final energy demand is a bit lower when considering the UHI effect, but this occurs in a context whit an enormous difference between heating and cooling systems management. Even if, like in Italy, the renewable share of the electricity generation sector is quite high, cooling appliances are generating the pernicious snow ball effect: the more the consumption, the more the heat released to the environment and vice versa. Moreover, many standards should be reconsidered if urban climate is different than the supposed one. Researches conducted in other world regions tend to confirm the poor summer performance of buildings that should have a near-zero energy performance in theory [23]. In this sense, mitigation strategies should be re-developed as "adaptigation" strategies [24], that is, mitigation strategies for a scenario adapted to the UHI and other anthropogenic impacts on the environment.

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