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BUILDINGS' HEAT OUTPUT AND URBAN CLIMATE

M SEPRŐDI-EGERESI[1] and A ZÖLD[2]

[1]*Department of Environmental Economics, Budapest University of Technology and Economics*
Magyar tudósok krt. 2. 1117 Budapest, Hungary, E-mail: egeresi.marta@gmail.com
[2]*Faculty of Technology, University of Debrecen, Ótemető u. 2-4. 4028 Debrecen, Hungary*

Summary: Both winter and summer "the buildings heat the street". In the typical design procedures the mutual interrelations between the buildings and the environment are neglected, the environment is supposed to be a sink of unlimited capacity. Nevertheless, the heat output of the buildings – a component of the anthropogenic heat load – has considerable effect on the urban microclimate. Mechanical cooling (air conditioning) launches a harmful self-generating process. Adequate urban design facilitates the slowing down or cease of this process and at the same time provides acceptable summer thermal comfort conditions. Dispensable mechanical cooling promotes mitigation. The effect appears on both urban and global scale.

Key words: Urban heat island, heat output of buildings, mechanical cooling, urban green areas

1. INTRODUCTION

When calculating the energy consumption of buildings, the set indoor temperature (the desired or the tolerated value) and the parameters of the environment are taken into account. The aim of the calculation is to determine the energy flux and its cumulated value. It is supposed that the environment is a sink of unlimited capacity. In other terms the energy flux from, or to, the environment does not cause any change in its parameters such as external air temperature.

These steady state balance equations are the base of the typical design procedures: the mutual interrelations between the buildings and the environment are neglected.

In reality not only the environment affects the energy balance of buildings but vice versa, the buildings influence the environment too. It's interesting that this relationship is better known on the global than on the local scale.

Knowing the scenarios of global climate change it is expected that the frequency and length of the hot periods and/or the summer temperature will be higher, thus in the temperate zone of Europe in a few decades the external conditions in summer will be similar to those of the Mediterranean area nowadays (IPCC 2007). This is why the study and the implementation of architectural solutions, the experience of vernacular architecture in the Mediterranean zone is becoming step by step the subject of interest of long-term thinking architects and engineers. In other terms it means the adaptation of the buildings to the expected new conditions.

Global climate change is the consequence of such activities of mankind as the heat and pollution emission of the building sector.

Climate change can already be felt on the local scale in urban areas where the density of buildings is high. Here the complexity of the parameters of the environment surrounded by real and virtual boundaries considerably depends on the building sector: the effect of the buildings on the environment can be felt. This is the microclimate on urban scale, the well-known phenomenon of the urban heat island (UHI) (Sümeghy and Unger 2004).

The UHI is the consequence of many factors. The albedo (the reflected fraction of the solar radiation) differs from that of rural areas. Therefore a higher fraction of the incoming solar radiation is trapped. At the same time, the incoming radiation is less, due to the higher air pollution. Considerable difference can be found in the intensity of the long-wave infra-red radiation towards the sky since the sky view factor of the rural areas is high, while that of the urban surfaces (building envelope, street etc.) is limited as the buildings obstruct the mutual visibility between the urban surfaces and the sky. This effect is augmented by the above-mentioned fact, namely the more polluted air over the cities.

It is evident that the thermal characteristics of the building envelope have some effect on the radiation balance. The interrelation of the albedo of the surface and the surface temperature is obvious, the importance of the thermally light colours and the cool roofs is well known. The buildings have a considerable heat storage capacity. The heat accumulated during the day is released after sunset.

The buildings influence air movement: they accelerate or slow down the wind depending on their height and layout, the width, depth and orientation of the streets and the direction of the wind. These effects form the passive role of the buildings in the development of the UHI.

Besides the radiant heat exchange there is a great difference between urban and rural areas regarding the latent heat exchange. Due to the restricted green areas in the cities the evapotranspiration of the vegetation does not represent a significant component in the energy balance.

The sewage system and the cleaning of the streets means that the melted snow and the channelling of rainwater further decrease the evaporative cooling in urban areas.

The urban heat island is intensified by the anthropogenic heat output. The heat output of the industry and traffic seems to be obvious however the heat output of buildings must not be forgotten: it should be considered as the “active role of the buildings” in the development of UHI.

2. THE ACTIVE ROLE OF THE BUILDINGS

Certainly it is not the building itself that is active, but the anthropogenic heat output due to buildings is spoken of. It is to be understood that the buildings heat the street in both winter and summer. In winter it is due to the heat loss. In summer the mechanical cooling of buildings is equivalent to the heating of the street since mechanical cooling systems extract the heat from the building and release it just nearby via the condensers on the façades and the roofs, the cooling towers on the roof and next to the building.

In both cases we have to consider the internal gains in the buildings due to the household devices, lighting, metabolic heat, etc. these are transferred to the environment as heat loss (even in summer!) or with mechanical cooling (Egeresi 2009).

The significant and basic difference between the winter and summer situation can be seen at the first glance. In winter a dynamic balance is achieved: the higher the heat loss, the more intensive the UHI is, and the more intensive UHI decreases the heat loss, thus an equilibrium state will develop. In summer a catastrophic self generating process develops: the more heat is extracted from the building, the more intensive is the UHI and as a consequence even more mechanical cooling will be needed (Santamouris 2001).

In order to compare the heat output of the buildings and the most important "natural" component of the energy balance we attempted to estimate the active role of the buildings in a case study of a downtown district of Budapest.

3. CASE STUDY

The effect of the urban heat island peaks above the city centre (Probáld 1974). The 5th District is a well-known area in Hungary in the centre of Budapest. Table 1 contains the basic parameters of the 5th District and other areas of the city.

Table 1 Population, area and density in conurbation of Budapest (www.studiometropolitana.hu 1998)

	5th District	**Budapest, total**	**Outskirts**
Population (person)	27 732	1 860 000	620 000
Area (km^2)	2.59	525	2013
Density of population (person/km^2)	10 666	3544	309

The number of flats is 19180 in the 5th District and the total floor area of flats is 1.3 million m^2. Besides residential buildings there are a lot of offices, hotels and other service areas. The total floor area of the buildings in this district is 6.5 million m^2. The ratio of built-up areas and the total area of the district is 80%. In order to estimate the specific heat output of the buildings per unit urban area the following data and approximations have been made. The ratio of the floor area and urban area is 2.52 m^2/m^2 (Table 2).

Table 2 Built-in areas in the 5th District of Budapest (2009)

Ratio to each m^2 of urban area	**m^2/m^2**
total built-in floor area	2.52
road or covered surfaces	0.36
park or green area	0.07

Taking an average ceiling height the specific heated volume of the buildings is 7.5 m^3/m^2. Taking into account the typical surface to volume ratio of the buildings (block of flats, hotel, office) in the downtown the exposed surface of the buildings per unit urban area is 4.5 m^2/m^2 (Table 3). The ratio of the cooling surface and the heated volume (A/V) determines basically the energetic quality of building. Considering the age of this building stock the heat loss coefficient of walls, roofs, windows and the transparent ratio of the building envelope, the average U value is 1.6 W/m^{2}K.

The estimated air change rate is one 1/h in winter – higher than the regulation value, because of the poor air tightness of old buildings. The internal heat gain is 5 W/m^2 floor areas, according to the design value (prescribed in the regulation) for calculation of building energy needs. 0°C external and 20°C indoor temperatures have been taken into account as the average for January. With this input data set the calculation shows that the heat output of this building stock is 4.716 kWh/d for 1 m^2 horizontal area.

Table 3 Data of different built-in areas in Budapest

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
built-in ratio (%)	80	50	30
A/V (m^2/m^3)	0.6	0.8	1
floor surface per unit urban area (m^2/m^2)	2.5	0.8	0.1
built-in volume per unit urban area (m^3/m^2)	7.5	2.4	0.3
building envelope superficies A (m^2)	4.5	1.92	0.3
windows and doors (N or obstructed) (%)	75	50	25
windows and doors (E-S-W, insolated) (%)	25	50	75

The incoming solar radiation in a clear day in January is 1.45 kWh/d for 1 m^2 horizontal area. (Szabó and Tárkányi 1969) Thus the specific heat output of this building stock is not only comparable with the incoming solar radiation on an average winter day but considerably exceeds it (Fig. 1). The same calculation has been carried out for the other areas of the city as we can see in Table 4.

Table 4 Heat surplus data of different built-in areas in winter

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
Solar radiation pro day ($kWh/m^2/d$)	1.450	1.450	1.450
Heat output of heating ($kWh/m^2/d$)	4.716	1.878	0.281

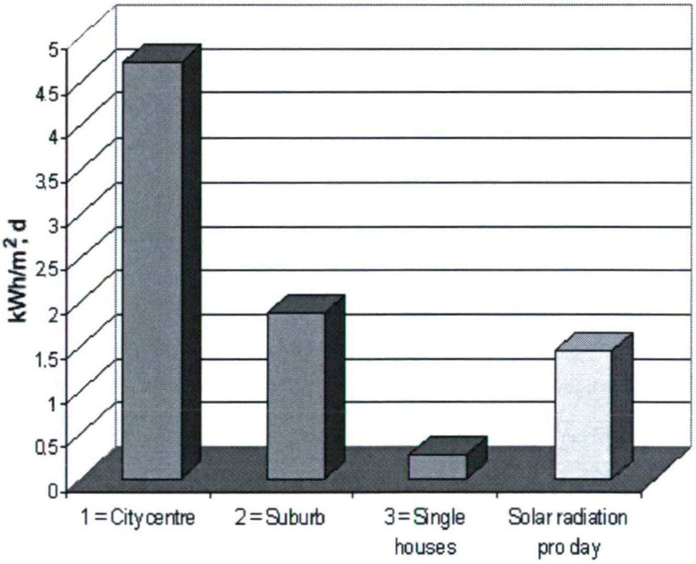

Fig. 1 Daily heat output of buildings on an average winter day and the incoming radiation

Soon a new thermal mapping system will be available covering winter-time heat loss data on Budapest and the 5th District. EnergyCity is a European-funded project aiming the reduction of energy consumption and CO_2 emission of towns and cities in Central Europe (www.energycity2013.eu). High resolution airborne infrared pictures will support the analysis of heat losses from buildings (among others) – one of the target areas will be the here investigated district of Budapest.

For summer the following conditions have been taken into account: the geometry and topology of the buildings is the same. Mechanical cooling is applied to maintain an indoor set temperature of 24°C, which coincides with the design value of the daily mean external temperature. The internal gain remains unchanged: 5 W/m^2. Whilst calculating the solar gain the total radiant energy transmittance of the windows (the *g* value) is 0.8. With regard to the high density of buildings in the downtown area it is supposed that 75% of the windows are obstructed, thus only the diffuse radiation can be taken into account. The remaining 25% (mainly on the top floors) has solar access and is evenly distributed for different orientations (Table 3). The input data set can be seen in Table 5.

Table 5 Heat surplus data of different built-in areas in summer

	1 = City centre	**2 = Suburbs**	**3 = Single houses**
Solar radiation pro day (kWh/m^2,d)	7.300	7.300	7.300
Heat output of cooling (kWh/m^2,d)	1.080	0.385	0.053

The mechanical cooling extracts the cumulated gain, the sink is the outdoor air. The results are shown in Fig. 2 with the daily heat output of buildings on an average summer day and the incoming radiation.

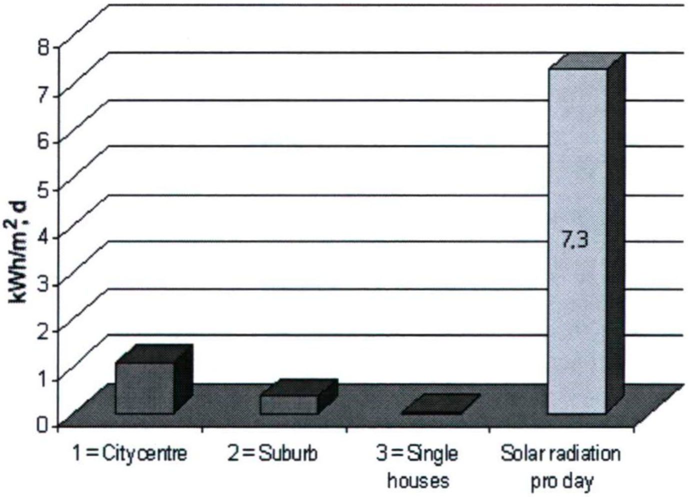

Fig. 2 Daily heat output of buildings in an average summer day and the incoming radiation

All data relates to the daily energy balance. Certainly at a given time the ratios may considerably differ from the daily average and around sunset and the evening hours the buildings' heat output exceeds the actual value of the radiation.

4. THE WAY OUT

If the buildings and the urban environment are adapted to the more severe summer conditions energy consumption and emission will decrease, mitigation may be realised. Here the interrelation shows a "positive feedback", the better the buildings are adapted, the better the mitigation is.

On an urban scale a well-proven solution is the vegetation. Among other favourable effects the cooling potential of the vegetation is very high.

Fig. 3 illustrates the temperature distribution in the neighbourhood of the City Park of Budapest (Gábor and Jombach 2006).

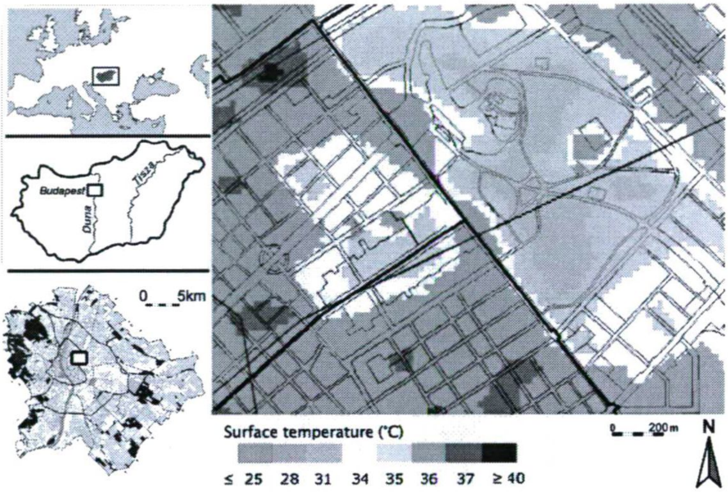

Fig. 3 The city Park of Budapest (Gábor and Jombach 2006)

One can see that the temperature in the park is low. The cooling effect can be observed around the buildings, the perimeter of the park and along the axis of the two main roads: the latter two channel the air movement, and by having trees along them, the shading and evaporative cooling effect is improved.

It is to be emphasized that the positive effects of the green areas can not only be felt within the park itself but in the buildings around the green area, too.

As a cooler part of the city a green area generates air movement: the urban breeze, which affects the surrounding buildings. In Szeged, Hungary, Gulyás (2005) reported another light-breeze measurement in which the magnitude of breeze was 0.5-1.5 m/s at a height of 1.1 m and 0.5-2 m/s at a height of 30 m. We can estimate the parameters of urban breeze with simulation tools. In the following results are shown from a PCI (Park Cool Island) examination. This research studies an average park in 1 ha and the surrounding buildings with the help of computational tools (FLUENT).

In Fig. 4 it can be seen, that even a modest temperature difference between the park and the built-in area can generate the expected light breeze mainly due to the high surface temperature of roofs and surrounding facades. The vertical component is the consequence of the buoyancy effect and has a maximum along the vertical edges at the buildings' corners. Nevertheless the horizontal components achieve a maximum of 0.7 m/s at the corners of the park and in the street – parallel with the street axis the velocity is 0.82 m/s (Egeresi and Zöld 2009).

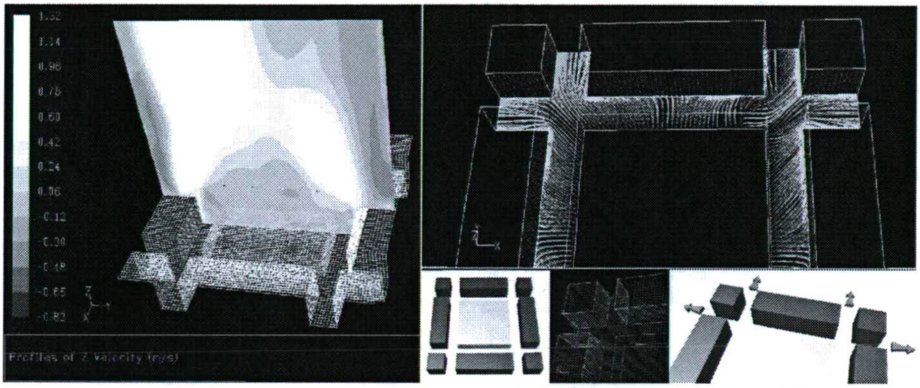

Fig. 4 PCI effect in a computational model (FLUENT) (Egeresi and Zöld 2009)

The air movement parallel with the facades is less intensive in the middle of the edge of the park, and increases approaching the corners. Comparing the different forms of the park it can be stated that a more intensive air movement is expected if the park layout is elongated.

The breeze from the park towards the built-in area has different effects. Although the internal and solar gain remains unchanged the cooling load of the building will be less since the temperature of the incoming air is lower, thus even if mechanical cooling is applied, the energy consumption will be less.

More important is the possibility of natural ventilation. In this respect two facts should be considered: on the one hand the temperature of the outdoor air is lower, and on the other hand the air movement along the facades intensifies the air movement inside the buildings. The higher air change rate accompanied with lower temperature may fulfil the expected thermal comfort conditions without mechanical cooling. Even if only a small decrease of temperature is realized, the effect of 1-2°C difference may be dramatic in the interval of 26-29°C. Last but not least the street comfort improves.

5. CONCLUSIONS

The interrelation of heat output of buildings in winter and the UHI is well-known, however the same phenomenon in summer is worthy of much more interest due to its self-generating character.

The harmful self-generating process of energy consumption and climate change on urban and global scale can and should be slowed down or prevented not only by adapting buildings to the more serious summer conditions but with conscious urban design. Urban green areas decrease the need in mechanical cooling. Without mechanical cooling the heat output of the buildings is less. Providing all buildings are air conditioned the cumulated daily heat output in dense urban area may be comparable with the daily energy income from the solar radiation.

A better adaptation of buildings and urban areas results in the mitigation of harmful emission, there is a "positive feedback" between them.

Obviously it is not disputable that there are buildings where mechanical cooling is inevitable even if the design and the urban environment is energy conscious. In some cases the technology or the high internal gains make air conditioning necessary, e.g. in a theatre, or in a hospital, but a well designed residential building in a well designed urban environment will provide acceptable thermal comfort conditions in summer without mechanical cooling.

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