MOBO – An experimental network for urban heat island analysis in a green district of the Middle-East

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16 April 2015

Abstract

Masdar hOBO (MOBO) is a three-year long experimental effort to evaluate the efficiency of Masdar Institute (UAE) in mitigating the urban heat island. During this campaign, a network of temperature and relative humidity loggers was installed over the campus. In addition to that, a weather station was installed to measure open desert conditions. In this paper, we analyze the summer urban heat island effect measured during the MOBO campaign. Using measurements of summer temperature, we calculate the average and average maximum temperature difference between HOBO loggers and the open desert station. According to the MOBO experiment, the urban heat island effect in Masdar Institute is insignificant compared to that reported in other Asian and Australian cities.

1. Introduction

The Urban Heat Island (UHI) effect is a phenomenon that has been carefully studied since the advent of low-cost computer modeling and reliable autonomous data acquisition systems coinciding with expansion of urbanized areas. Several experimental campaigns have been undertaken throughout the world to analyze the behavior of temperature differences between an urban and a rural area. According to Asimakopoulos et al. (2001), the UHI effect mainly has a significant impact on the energy demand due to the consumption of air conditioning systems. In cities located in the Middle-East, the demand in air conditioning can reach 60% of the total consumption over the year (Radhi and Sharples, 2011). Shading, insulation, vegetation, and natural ventilation are among the most used techniques in this region of the globe to mitigate the impact of the UHI effect on cooling consumption (Haggag and Elmasry, 2011). The amount of information regarding UHI effect of the Middle-East is relatively small compared to what has been done in Europe or North America (Asimakopoulos et al., 2001).

Nasrallah et al. (1990) report properties of the UHI effect in Kuwait City (Kuwait) based on 23-year long air temperature data. For this purpose, three weather stations were installed around Kuwait city: one rural station (Al-Roudatain), and suburban station (Al-Shuwaikh), and one urban station (Kuwait International Airport). As main result, they evaluated the trend[1] between 0.07 and 0.12 °C per decades. Consequently, Kuwait City has a relatively low warming effect compared to North American cities also surrounded by a hot and arid climate.

A deeper study on UHI effect was led by Charabi and Bakhit (2011) in Muscat (Oman) who, like Nasrallah et al. (1990), used a rural station (Al-Amerat), a suburban station (Muscat International Airport), and an urban station (Mina Sultan Qaboos) to measure the significance of temperature differences in Muscat. In addition to these three weather stations, they recorded mobile measurements of dry-bulb temperature and relative humidity all over the city. Considering temperature measured by Mina Sultan Qaboos station and Al-Amerat station, Charabi and Bakhit (2011) conducted that the average urban heat island intensity between these two weather stations is about 2.4 °C over the year.

In this study we describe an experimental campaign carried out at Masdar Institute, a small low-energy urban district. From data collected during this experiment, we evaluated two measures of the UHI effect: the mean and the peak daily average UHI intensity. These values were then compared to the ones obtained in other cities of Asia and Australia (Santamouris, 2015).

[1] The trend corresponds the increase of temperature differences between an urban and a rural area per period of time.

2. Experimental network

Masdar Institute is a new research center located in Masdar City (Abu Dhabi, UAE). The campus consists of two kinds of buildings: student residences and laboratories. To provide high resistance to outdoor extreme temperatures, facades of student residences are provided with shading grilles. According to Martin et al. (2015), the residential façade U-value is about 0.24 W / (m^2-K). Laboratories were also built with highly insulated and air tight facades with a U-value around 0.26 W / (m^2-K). Streets have an height-to-width ratio between 2 and 3 to benefit from shading as much as possible, especially during summer times. Paved surface is made up of terracotta with a measured albedo of 0.4. Vegetation and soil are also covering streets of the campus at a ratio of 11%. Fig. 1 illustrates Masdar Institute seen from the library building.

Fig. 1 Masdar Institute (left) with student residences (left) and laboratories (right)

To reduce the outdoor temperature inside the campus, Masdar Institute has a unique a facility providing fresh and humid air: the wind tower. Louvers were installed at the top of this facility to capture upper-level winds and conduct air downward to its base. Louvers are operated by sensors detecting wind direction to automatically open exposed louvers (and close the others). Inside the polytetrafluoroethylene membrane tube, the captured wind may be adiabatically cooled to saturation by mist generators injecting water droplets. A technical schema of the Masdar wind tower is shown in Fig. 2.

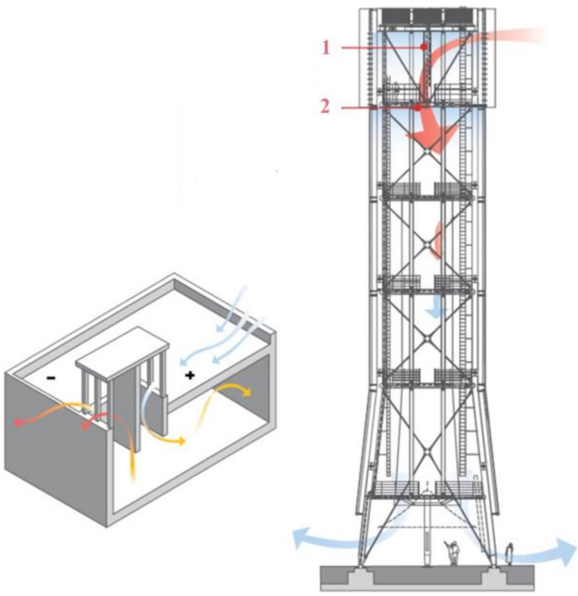

Fig. 2 Masdar wind tower

The MOBO experimental campaign began in April 16th 2011 with the installation 72 temperature and relative humidity loggers (HOBO Onset U12) over the campus, 18 at each of four heights: 3, 7, 11, and 15 meters above street level. HOBO loggers were programmed to measure urban temperature and humidity with a sampling rate of 15 min. A first level of loggers was installed at the angle of each concrete column of the ground level. The other loggers were fixed behind the façade covering each balconies. Fig. 3 illustrates how we installed temperature and relative humidity loggers throughout Masdar Institute.

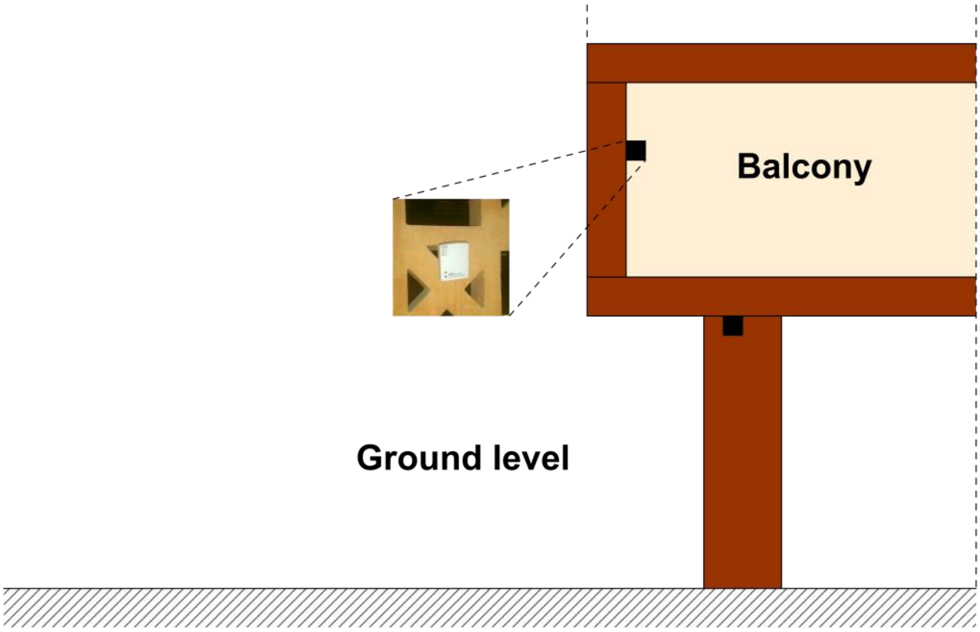

Fig. 3 Typical HOBO logger (dark square) installation

The Masdar Field station is a meteorological station that was installed at 600 m. away from the center of the campus to measure open desert conditions. Dry-bulb temperature and relative humidity are measured at 2 m. and 10 m. with probes (Vaisala HMP60). A 3-cup anemometer (Met One 014A) and a wind monitor (Met One 034B) were installed at 5 m. and 10 m., respectively, to measure wind speed. The Masdar Field Station also measures pressure by using a barometric sensor (Vaisala CS106) at ground level. A picture of the Masdar Field Station is shown in Fig. 4.

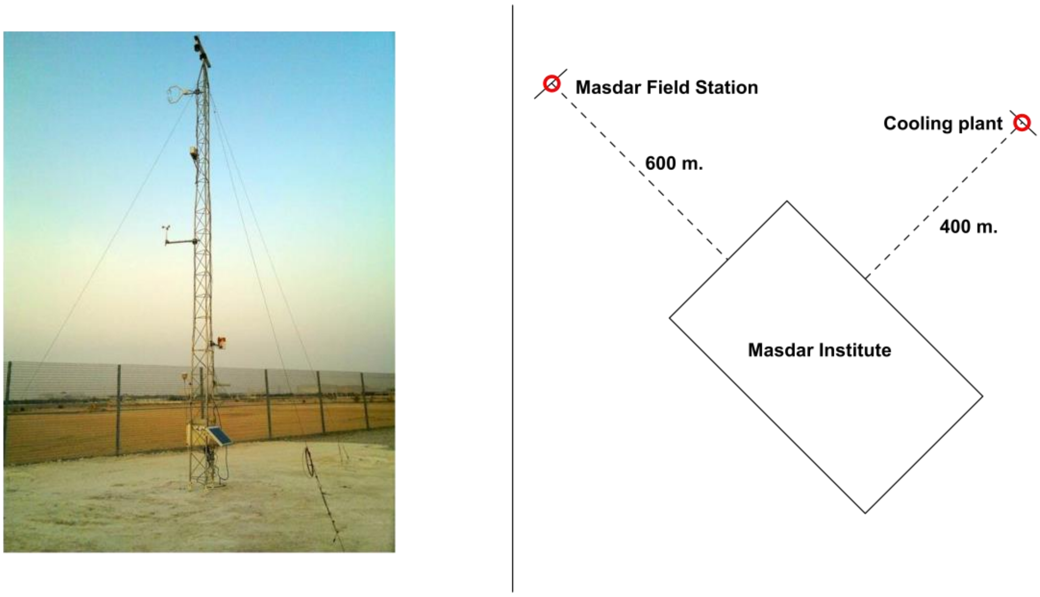

Fig. 4 Location of Masdar Field Station

4. Data analysis

Among the set of 72 HOBO loggers we run in Masdar Institute between 2011 and 2013, we decided to focus our analysis on the 8 loggers installed inside the campus at ground level (i.e. 3 m.). Due to their location, these loggers provide us a better evaluation of the thermal outdoor comfort felt by pedestrians in Masdar Institute. During the MOBO campaign, we unfortunately lost measurements of temperature recorded by ground loggers from 2012. To estimate summer UHI effect in Masdar Institute, ground loggers continuously measured urban temperature from August 13th to September 31st 2011. Fig. 5 illustrates the locations and IDs of the 8 ground HOBO loggers we used for analyzing the UHI effect in Masdar Institute.

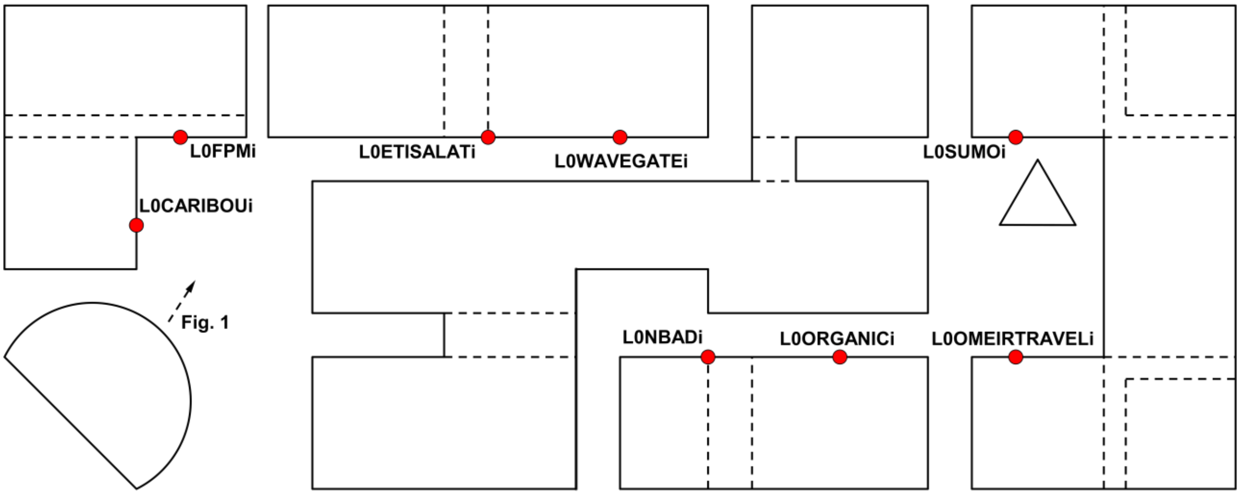

Fig. 5 Location of ground level HOBO loggers used for UHI effect analysis in Masdar Institute

5. Urban heat island effect

Fig. 6 illustrates measured urban temperature and UHI intensity at Masdar Institute from August 13th to September 31st 2011. By UHI intensity, we mean the temperature difference between HOBO logger and Masdar Field Station measurements. During the period under analysis, a clear heating effect (i.e. positive UHI intensity) appears at nighttime while a significant cooling effect (i.e. negative UHI intensity) can be seen at daytime.

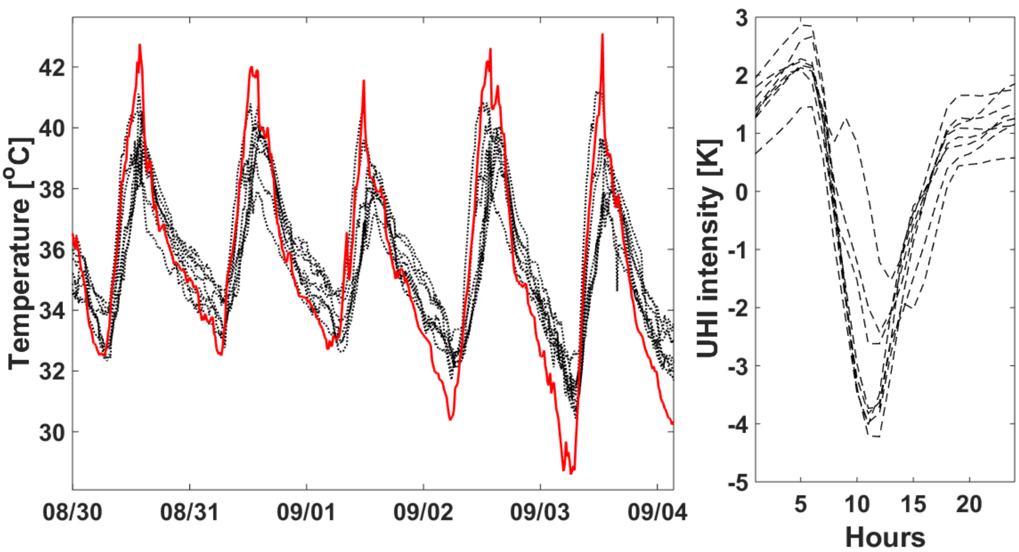

Fig. 6 Urban (black) and open desert (red) temperature (left), and average diurnal cycle of UHI intensity (right) measured at Masdar Institute from August 13th to September 31st 2011

Table 1 shows the average and average maximum UHI intensity computed from the 8 ground level HOBO loggers between August 13th and September 31st 2011. During this period, we can observe that the average UHI intensity did not go over 1 K. Some measurement points like L0NBADi and L0ORGANICi recorded temperatures below open desert ones on average over August and September 2011. It is not surprising to observe that the two hottest points (i.e. L0CARIBOUi and L0FPMi) compared to open desert temperature are the one which are located the furthest from the wind tower. The average maximum UHI intensity varies from 1.4 and 2.9 K. The proximity to the wind tower does not seem to have an influence on this value.

Table 1 Average and average maximum UHI intensity reported from the 8 ground level HOBO logger measurements from August 13th to September 31st 2011

HOBO ID	Average UHI intensity [K]	Average Max. UHI intensity [K]
L0CARIBOUi	0.55	2.28
L0FPMi	1.04	2.24
L0NBADi	-0.54	1.45
L0OMEIRTRAVELi	0.15	2.13
L0ORGANICi	-0.11	2.17
L0ETISALATi	0.32	2.86
L0WAVEGATEi	0.22	2.66
L0SUMOi	0.30	2.10

Fig. 7 illustrates the summer UHI intensity we assessed from the MOBO experiment compared to the average annual UHI intensity recorded in other Asian and Australian cities (Santamouris, 2015). With a summer average UHI intensity of 0.24 K., Masdar Institute reaches the 6th of 34 cities in terms of annual average UHI intensity. In other words, the measured average UHI intensity between August 13th and September 31st 2011 is four and eleven times lower than the mean and the maximum, respectively, average annual UHI intensity of Asian and Australian cities under study (including Masdar Institute).

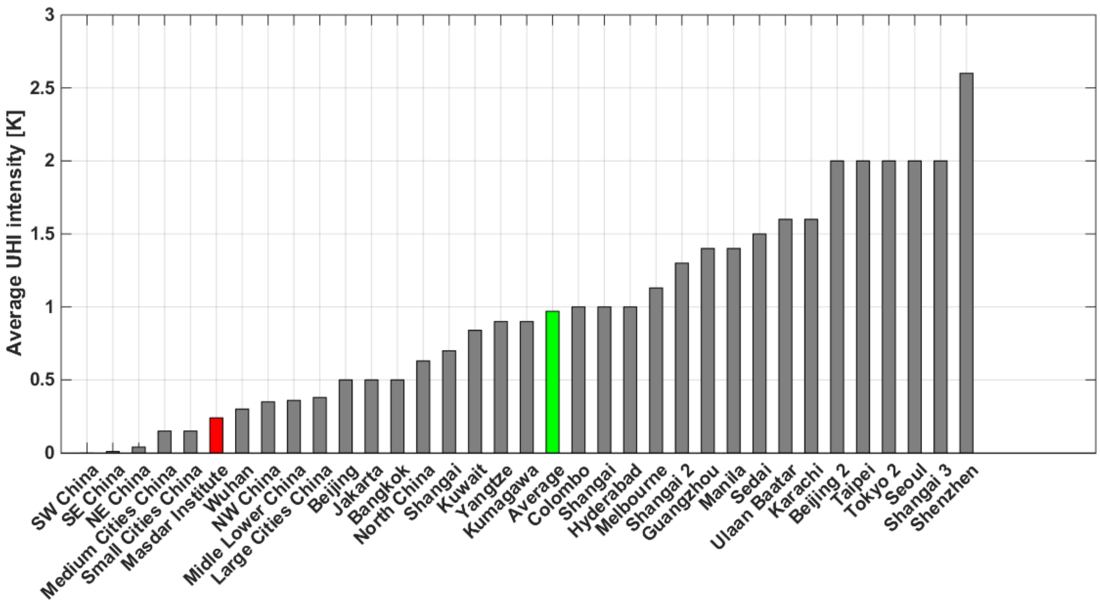

Fig. 7 Summer average UHI intensity at Masdar Institute (red) compared to the average annual UHI intensity of other Asian and Australian cities (gray)

According to measurements from August 13th to September 31st 2011, Masdar Institute has a maximum average UHI intensity of 2.84 K as shown in Fig. 8. It means that the recorded average maximum UHI intensity in summer 2011 is almost equal to the mean average maximum UHI intensity of the 22 cities under study (including Masdar Institute). Nevertheless, we can observe that the measured average maximum UHI intensity is about two times lower than Muscat and Bahrain, which are located near UAE.

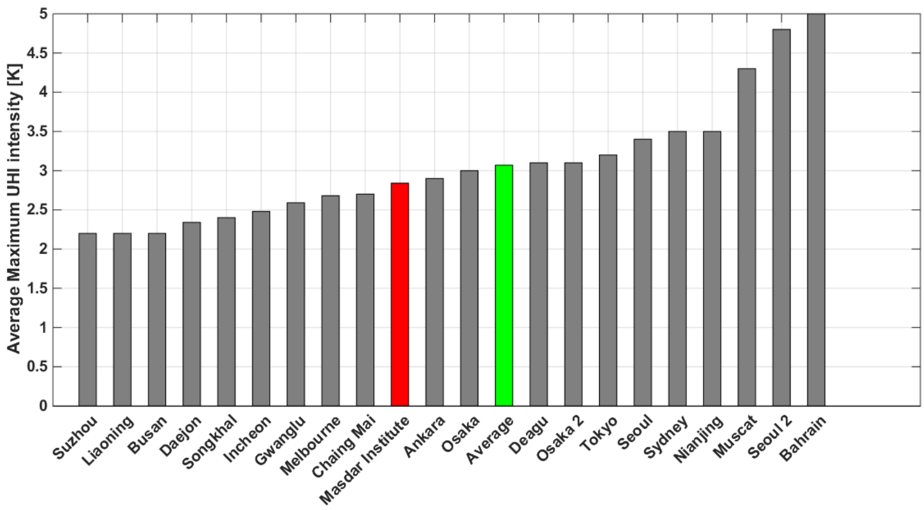

Fig. 8 Summer average maximum UHI intensity at Masdar Institute (red) compared to the average maximum UHI intensity of other Asian and Australian cities (gray)

6. Conclusion

In this study, we introduced the facilities installed during the MOBO experimental campaign to analyze the urban heat island effect in Masdar Institute. As a result of this experiment, we observed that the summer urban heat island effect in Masdar Institute is less significant than that taking place in most of Asian and Australian cities. A number of factors may contribute to this small number. First, Masdar Institute has very little anthropogenic heat (as cars). Then, the built up area has small scale of 80x160 m. or 160x220 m. After that, the waste heat caused by air conditioning consumption is rejected 400 m. away from the campus. Finally, an optimal orientation from North (about 37^o) was chosen to build the campus. In the future, it would be interesting to proceed to a similar experiment in Abu Dhabi downtown, and compare the results to what we obtained in Masdar Institute.

Acknowledgment

This work was funded under the Cooperative Agreement between the Masdar Institute of Science and Technology, Abu Dhabi, UAE and the Massachusetts Institute of Technology, Cambridge, MA, USA, Reference Number 02/MI/MIT/CP/11/07633/GEN/G/00. In addition to this, we would like to acknowledge Muhammad Tauha Ali, Marwan Mokhtar, Marte Fekkes, Omer Qureshi, Ali Almasabai, Alex Niswander, Ragini Kalapatapu, Akaml Khusanov, and Jemal Adem for their assistance during the MOBO experiment. We also want to thank Prof. Mattheos Santamouris (msantam@phys.uoa.gr) for helping us in defining the significance of the urban heat island effect in several Asian and Australian cities.

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