Applied Energy 95 (2012) 102–110

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Influence of air conditioning management on heat island in Paris air street temperatures

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ARTICLE INFO

Article history:
Received 14 September 2011
Received in revised form 6 February 2012
Accepted 8 February 2012
Available online 13 March 2012

Keywords:
Air conditioning
Heat island mitigation
Urban heat island
Paris heat wave

ABSTRACT

Projections of future climate suggest increases in extreme temperatures particularly in mid latitudes. In addition, the effect of heat waves, which are becoming a major "summer killer", is exacerbated in urban areas owing to the heat island effect. Air conditioning (*A*/*C*) is a key parameter for health problems in case of heat waves since, on one hand, it reduces mortality but, on the other hand, depending on the heat management, it can increase street temperature therefore increasing the air cooling demand. Results of a meso-scale meteorological model (MESO-NH), coupled to an urban energy balance model including a simplified building model (TEB), are used. Simulations based on a realistic spatial cartography of air-cooled chillers and cooling towers in the city of Paris and surroundings have been performed. The simulation period corresponds to the extreme heat wave in Paris: 9–13 August 2003. Five scenarios will be discussed: firstly a baseline without air-conditioning (NO-AC scenario); secondly the actual situation including individual air dry coolers, wet cooling towers and an urban cooling network relying on free-cooling (water-cooled *A*/*C* with the river Seine) (REAL scenario). A third scenario will assume that all the heat is rejected as sensible heat in the atmosphere (DRY AC scenario). Two other scenarios correspond to a prospective where *A*/*C* is doubled. Scenario 4 assumes that all the heat is rejected as sensible heat in the atmosphere (DRY ACx2 scenario). On the opposite, scenario 5 assumes that all the heat is rejected underground or in the river Seine (NOREJ scenario). Results show that *A*/*C* affects the UHI depending on its management. A detailed analysis on selected districts shows that the local temperature variation resulting from heat island is proportional to the sensible heat rejected locally by *A*/*C*, indicating that a clever *A*/*C* management is all the more important to provide comfort and to mitigate heat island. Moreover, the incidence of the sky view factor is also discussed.

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1. Introduction

Air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country, and this phenomenon is known as "heat island". The urban heat island phenomenon results from the altered nature of urban land use (asphalt pavement, buildings) and energy consumption related to human activity (residences and commercial buildings, transportations, industries). For example, in Athens, the mean heat island intensity exceeds 10 °C but in the very central Athens area, the heat island intensity may reach 15 °C [1].

Heat wave impact on mortality, especially in densely areas in big cities, is a major issue and the National Weather Service, in US, claims that heat wave is becoming a "major killer". In France, the 2003 heat wave killed 14,802 persons [2]. Tan et al. [3] studied the 1998 and 2003 heat waves impacts on mortality in Shanghai. Interestingly, the authors note that the mortality was much more pronounced during the 1998 heat wave although the 2003 one was slightly warmer than the 1998s. Amongst the reasons for less mortality in 2003, the authors note that there was an increase in air-conditioning use, larger living spaces and a higher coverage of urban green space. Between 1998 and 2003, the number of air conditioners in Shanghai jumped from 68.6 to 135.8 per 100 households. In that case, the authors claim that air conditioning (*A*/*C*) undoubtedly lessens heat stress, protecting large portions of the population from the heat wave.

This heat island results not only in an increase in the ambient temperature but presents also other important consequences such as a modification of the energy consumption in buildings. For example, in Athens, the peak electricity load for cooling in summer is tripled due to a cooling demand which is doubled and to the COP

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doi:10.1016/j.apenergy.2012.02.015

of the chillers which is reduced up to 25%. On the opposite, energy consumption for residential heating in winter is reduced up to 30–50% [1]. Smog production is observed in summer in some cities like Los Angeles where, at temperatures above 35 °C, practically all days are smoggy [4].

However, the role of A/C on heat waves is subject to controversy. On one hand, it protects from heat stress inhabitants who are in coolers spaces but, on the other hand, it can contribute, depending on the A/C management, to increase the street temperature if air-source A/C, which discards condensing heat into the air, is used. Due to that effect, several authors [5,6] suggest to use ground-source or water (river, lake or sea) cooled A/C so as to evacuate the condensing heat elsewhere than into the air.

Last but not least, there exists two trends which could contribute to UHI extension. The first one is global warming which suggests that within a few decades, the extreme temperatures observed in France during the August 2003 heat wave should no more be an exception. The second trend is the emergence of many mega cities, favourable to UHI, in countries like China. It is the reason why UHI mitigation corresponds to an important present challenge. Some authors developed numerical models to understand the influence of air-conditioning on air temperature. Wen and Lian [7] developed a box model to quantitatively determine the rise in outdoor air temperature caused by using domestic air conditioners in Wuhan, China. The variation in temperature may reach 2.56 °C. Hsieh et al. [8] discussed the penalty of heat rejection to the cooling load during the night-time, in Taipei city. The temperature rise obtained through numerical modelling, was found to reach 1.89 °C. In Tokyo, the heat resulting from air conditioners usage increased the air temperature by 1–2 °C or more on weekdays, in the office district [9].

These results demonstrate the importance of considering the heat resulting from energy consumption with air-conditioning on the energy balance.

Beside individual A/C, there are urban cooling networks that manage the heat rejection differently, as is the case for Climespace in Paris which use either wet cooling towers or the river Seine. The present paper presents the consequences of such managements on the street temperatures in Paris in the case of the severe heat wave which occurred in August 2003. First some results on global influence of air conditioning in Paris and the 25 km surroundings are presented and secondly a local analysis is performed for some district within inner Paris.

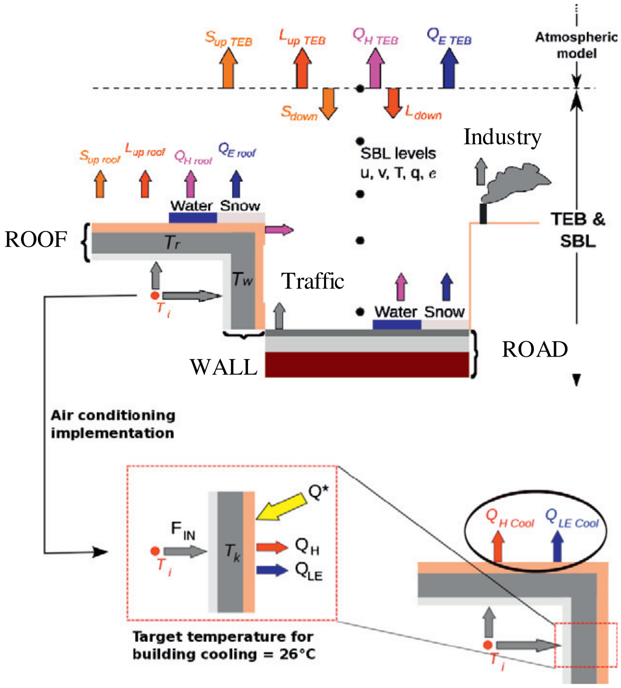


Fig. 1. Simplified description of TEB model implemented with A/C [13].

2. Methodology

MESO-NH, a meso-scale meteorological model developed by Lafore et al. [10] and Stein et al. [11] was used to reproduce meteorological conditions for the 2003 heat wave (9–13 August). The exchanges of energy (momentum, convection, radiation) are computed using a tiling approach splitting the surface between 4 major types of land use that are natural or agricultural covers, seas, inland water and urban areas. For the latter surfaces, the Town Energy Balance (TEB) is used [12]. It is a single layer urban canopy model that has been evaluated on various cities and climate [13–15]. Within TEB, the urban landscape is simplified as an isotropic network of street canyons. TEB simulates exchanges of momentum, heat and water for three generic surfaces: road, wall and roof that interacts directly for radiative fluxes and with the street canyon air volume for convection fluxes. Implementation of A/C within TEB was based on the heat released by A/C and an indoor target temperature of 26 °C for buildings with A/C (Fig. 1). The other inputs for the model are the surface building fraction, the ratio between the buildings' height and the streets width (H/W), the building height, the thermal and radiative properties of roads, walls and roofs. The simulations realised for this study use specific parameters computed for the urban area of Paris by the Urban planning agency of Paris-APUR, Agence Parisienne d'Urbanisme-from digital maps. For example, Fig. 2 presents the H/W parameters for the streets of Paris. This parameter, used in the model to calculate the road and wall sky view factors, is critical for the computation of the solar and infrared radiation trapping inside the canyon. It can be observed some high values in the city centre of Paris or in building office area like La Défense in the northwest of the city whereas this number decreases in the suburbs areas.

For the estimation of heat released, A/C systems can be classified in three categories:

(1) Evaporative cooling towers discharging latent waste heat to air. Their inventory was facilitated by the legal requirement imposed on them to declare their power and localisation to the authorities due to the sanitary hazard that they might carry. In terms of heat discharge, the waste heat is assumed partitioned into 95% latent heat and 5% sensible heat (based on the manufacturers' data).

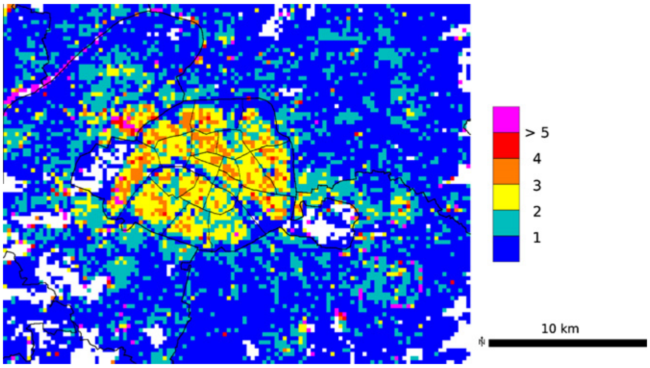


Fig. 2. Ratio between the buildings' height and the streets width (H/W).

(2) Large dry cooling towers (data centre, commercial centre, hotels…). The estimation of the heat released was undertaken based on a visual inventory via open source satellite images for roof condensers.
(3) Small dry cooling systems (from 6 to 70 kW per unit). Visual inventory of these small condensers was first carried out within inner Paris on a sub-sample of five districts (ground surfaces between 742.10^3 and 260.10^3 m^2) representative in building type and dwellings or business diversity, using both open source satellite images for roof condensers and Google Street View for front condensers. The cooling power of the small dry condensers observed yielded two levels (i.e. baseline ratio) of dry waste heat intensity for these five districts: 8 and 34 W/m^2_{land}.

After this inventory, a baseline ratio is assigned to each grid cell of the simulation domain: for a residential mesh, the low ratio is assigned and the high ratio for a business district, for example. Then, the waste heat associated with the large dry cooling towers was added to each grid cell according to the number and the power of the installations observed during the visualisation phase. Then, in addition to the sources of AC waste heat themselves, the thermal discharge of the power transformers supplying the AC systems was accounted for amounting to 3% of the electrical power requested by the AC systems identified. This is the REAL scenario.

Another present-time scenario is the DRY AC scenario: all the heat released is converted to sensible heat. The overall heat released over the simulation domain is the same as for the REAL scenario.

Two other scenarios correspond to a future situation where *A*/*C* is doubled : one assumes that all the heat is rejected as sensible heat in the atmosphere (DRY ACx2 scenario), the other, on the contrary, even if based on the DRY ACx2 scenario, assumes that all the heat is rejected underground or in the river Seine (NOREJ scenario).

For the DRY ACx2 scenario, to avoid a non-realistic case, a heat rejection limit of 126 W/m^2_{floor} (corresponding to a ratio of 90 W_{cold}/m^2_{floor}) is imposed into the model. Furthermore, the 10.32 GW of sensible heat reject is distributed with 68% in Paris and 32% outside of central Paris.

All scenarios are compared to a baseline (NO-AC scenario) referring to a situation without air-conditioning.

This paper presents and analyses some results of this model. All validations, boundary conditions and sensitivity tests are presented in [16].

3. Results

3.1. Global impact on street temperatures

When compared to the NO-AC scenario without *A*/*C*, the three scenarios considered in Fig. 3 show an increase in 2 m street temperatures which is greater at night than during day time. Compared to the NO-AC, temperature elevation at night in Paris is about 0.5 °C, 1 °C and 2 °C for the REAL, DRY AC and DRY ACx2 scenarios respectively. The average temperature variation is about +0.25 °C, +0.5 °C and +1 °C outside of Paris.

As expected, temperature in central Paris is more influenced by *A*/*C* than outside, due to a strong concentration of air-conditioned buildings in Paris. The future projection scenario (DRY ACx2) impacts wider zones in the city.

3.2. Impact on urban heat island (UHI)

Fig. 4 represents for a cross section an average night-time street temperature profile for four scenarios including the baseline (NO-AC). This figure shows the influence of air-conditioning on the heat island in Paris, especially on the spatial expansion and the intensity. For the NO-AC scenario UHI amplitude reaches 3.75 °C and it increases to 4.5 °C for DRY AC and 5.5 °C for DRY ACx2.

For the REAL scenario corresponding to an actual situation of the air-conditioning development in Paris and its surroundings, the amplitude of the UHI is not modified notably compared to the baseline. However, this scenario shows that *A*/*C* still influences the temperature profile with an increase in temperature in the hottest areas in central Paris.

3.3. Local variation of street temperatures

Figs. 3 and 4 show that UHI is not at all constant. To analyse the impact of *A*/*C* on local street temperature variation some districts within inner Paris have been selected to look at the influence of the local management of *A*/*C* on the street temperatures: type of air-conditioning (dry or wet unit, individual or connected to the Climespace network, the urban cooling network in Paris), density of *A*/*C*, type of buildings… For a local comparison of the influence of AC management, four meshes of 250 × 250 m^2 localised in four different districts in central Paris are studied. Descriptions of these meshes for the REAL scenario can be found below (Table 1).

Fig. 5 presents local variations of air temperatures at 2 m during 5 days in August 2003 for meshes *A*, *B C* and *D* respectively and for the four scenarios. For all districts (i.e. meshes), the maximum temperature variation is around the 11 August 2003 and reaches up to +3.5 °C for the mesh *B* and the DRY ACx2 scenario.

For mesh *A*, with a low *A*/*C* ratio, the impact of *A*/*C* is not marked except on the 11 August afternoon at 16 pm, with a maximum of +1.5 °C (DRY ACx2 scenario). For REAL and DRY AC scenario, figure shows some small negative values (less than 1 °C). This result could be associated with the natural variability of temperature and especially the turbulence (different positions of the convection cells between baseline and scenario creating occasionally colder zones).

In the case of mesh *B* with high density of dry air *A*/*C*, the temperature increases in the REAL case reaches 2.3 °C and not be much affected by the DRY AC management but the DRY ACx2 case would yield a strong enhancement of the local temperatures. In that case, *A*/*C* management without heat rejection in the ambient air (NOREJ) results with a small mitigation of the heat island (negative effect on the temperature variation). Compared to mesh *B*, mesh D, with higher heat releases, have an average temperature during the 5 days higher than *B* but the maximum temperature is quite similar than *B* for all scenarios.

For mesh *C*, the large part of district cooling present in the REAL scenario avoids the temperature increase which is observed with the DRY scenario. Consequently the districts which can use district cooling are less affected by heat waves than those which use air cooled *A*/*C*.

In districts with a lot of air-conditioned buildings, if all buildings use units discharging dry waste heat to air, temperatures could be impacted and should increase between 0.7 °C and 2.5 °C. The impact could be as high as 3.5 °C/4 °C for the DRY ACx2 scenario.

For all meshes, the NOREJ scenario (buildings are air-conditioned and *A*/*C* waste heat is released to ground or the Seine river) cancels temperature increase and, punctually and locally, decreases air temperatures and slightly the heat island.

From the total 9000 meshes (250 × 250 m^2) in Paris simulation domain, 12 have been selected for a local analysis. Over the heat wave period, the maximum temperature difference (ΔT_{max}) between the daily average temperature of a scenario and that of the reference was extracted for each mesh and each scenario. Taking these 12 meshes with 3 scenarios with heat rejection due

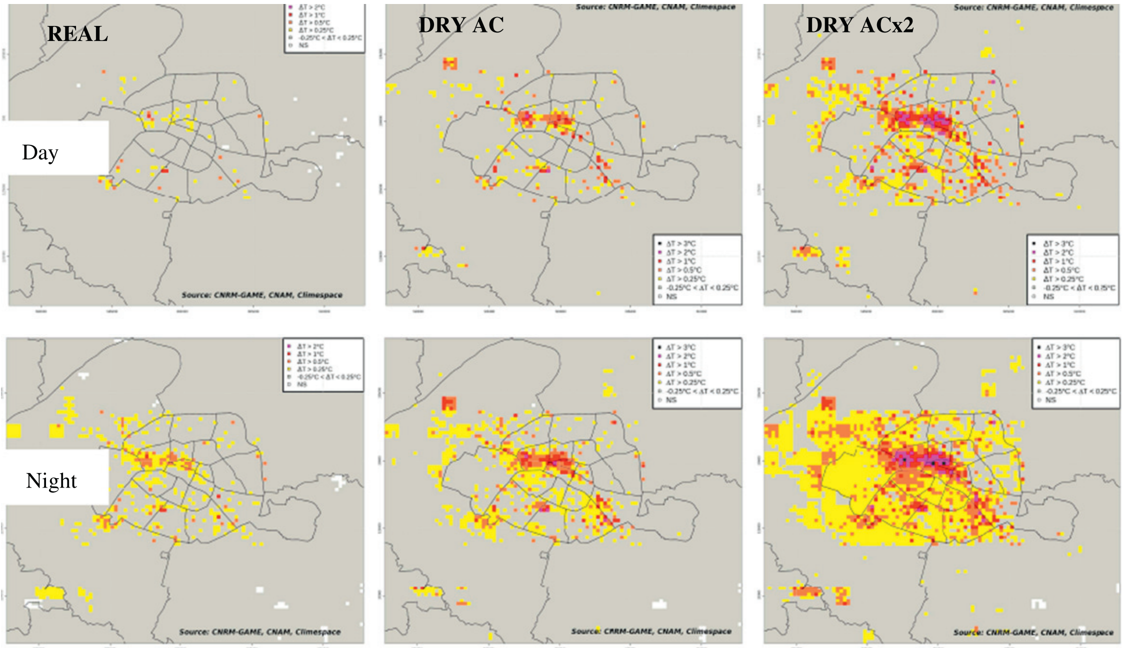


Fig. 3. Average variation of temperature at 2 m for 3 *A*/*C* scenarios at daytime and night-time [16].

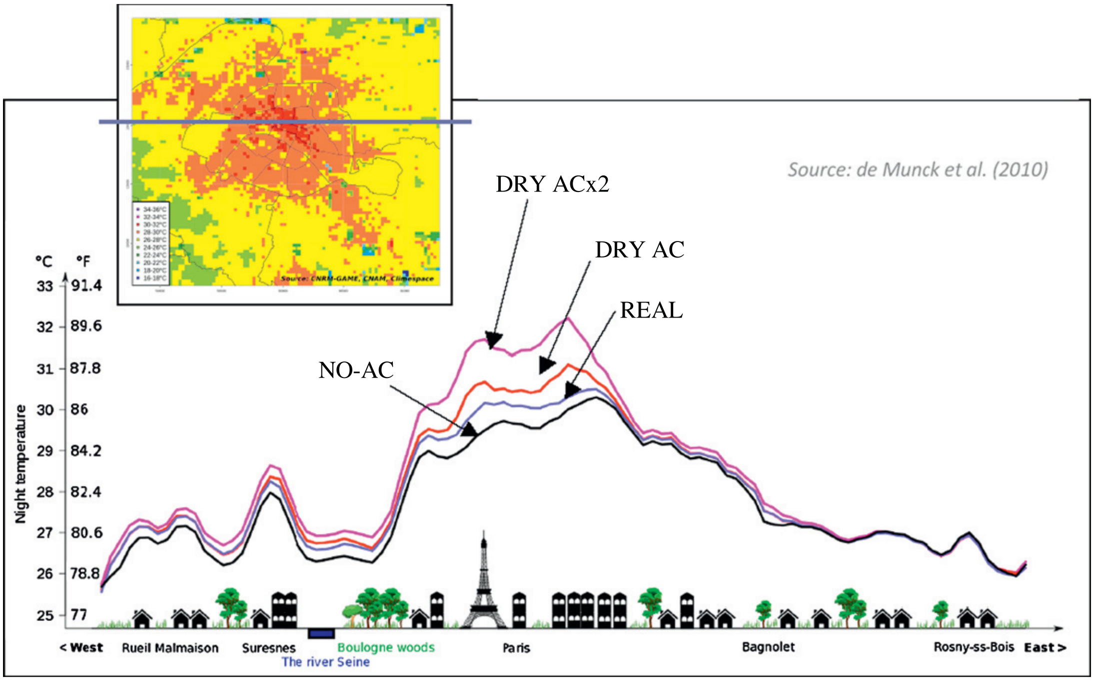


Fig. 4. Temperature profiles at night-time for a West-to-East cross section [16].

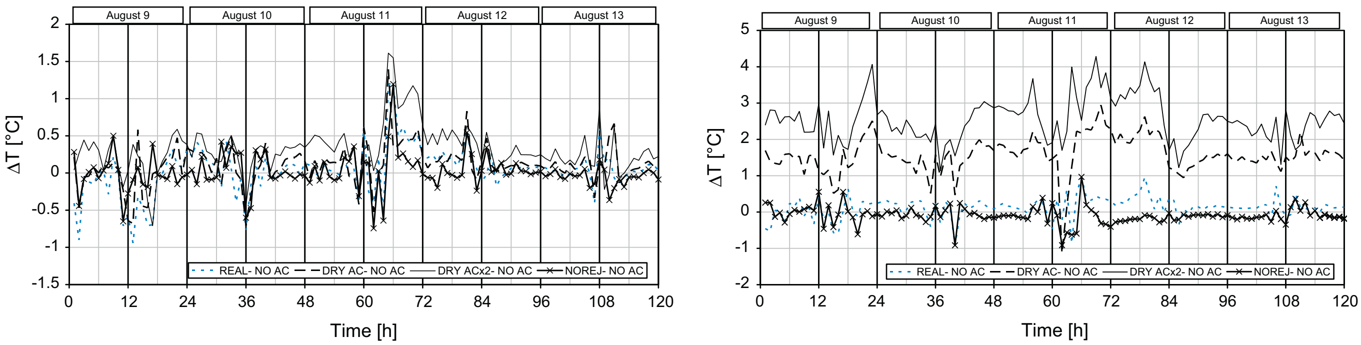
to *A*/*C*, 36 points were obtained. Results of that maximum temperature difference ($\Delta T_{\max}$) are presented in Fig. 6 for each mesh under each scenario.

Interestingly, a linear variation of the temperature increase due to *A*/*C* versus the sensible heat rejection is obtained. This tends to prove that the local street temperature increase due to *A*/*C* depends, to the first order, on the heat rejection. Note that for zero heat rejection, we do not get zero temperature increase. This could prove that, in densely areas, even without heat rejection due to *A*/*C*, a mesh experiences a temperature increase due to the next meshes where *A*/*C* may exist.

Calculated as a function of the ground surface, the ratio of maximal street temperature variation is about: $5\,\mathrm{K\,m^2_{land}\,kW^{-1}_{heat}}$. Kikegawa et al. [17] reported temperature differences, in Tokyo, due to *A*/*C* reaching 0.6 or 1.15 °C depending on the sky view factor. More recently Kikegawa et al. [18] claim that the sensitivity of downtown air temperature, in Tokyo and Osaka, to anthropogenic heat is $7\text{–}9\,\mathrm{K\,m^2_{land}\,kW^{-1}_{heat}}$ which is of the same order of magnitude as the $5\,\mathrm{K\,m^2_{land}\,kW^{-1}_{heat}}$ reported herein. In the model developed herein, the heat is assumed to be rejected on the roof (which corresponds to the most important fraction of heat released by *A*/*C* in Paris) but Kikegawa et al. [5] note that when the heat is rejected to

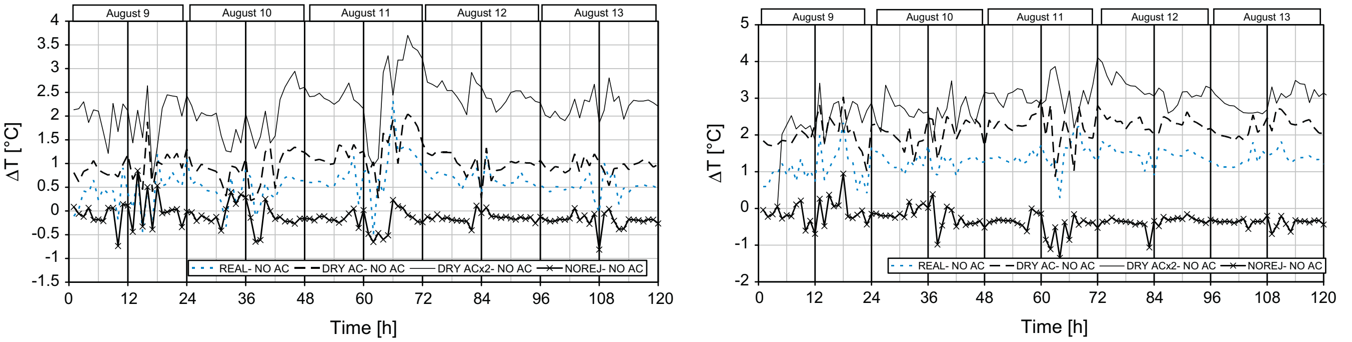
Table 1
Description of the studied meshes (250 × 250 m^2).

	Localisation	Main description	Sensible/latent heat releases (kW)	A/C ratio (W_{heat}/m^2_{floor}; W_{heat}/m^2_{land})	%$_{power}$ of buildings connected to the Climespace network
Mesh *A*	North East	Residential	549/427	6.5; 9	0
Mesh *B*	West Paris	Commercial district, top-of-the-range hotels	6131/1843	24.9; 98	<1%
Mesh *C*	Centre	Commercial district, museum	580/926	5.7; 9	91
Mesh *D*	North West	Business	20628/8620	81; 330	0



(a) Mesh A

(c) Mesh C



(b) Mesh B

(d) Mesh D

Fig. 5. Local temperature variation between each *A/C* scenario and the baseline for mesh *A* (a), *B* (b), *C* (c) and *D* (d).

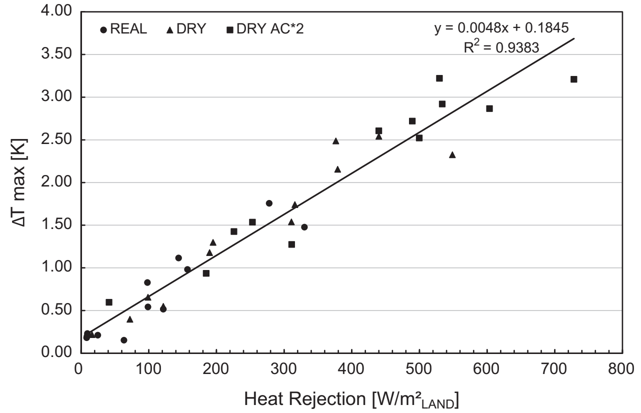


Fig. 6. Variation of local temperature as a function of sensible heat rejection for a subset of 12 meshes.

the ground levels rather than from the rooftop, the daily surface-air temperature increases by 0.62 °C. This could explain the difference between the results herein and the data by Kikegawa et al. on the sensitivity of air temperature to anthropogenic heat.

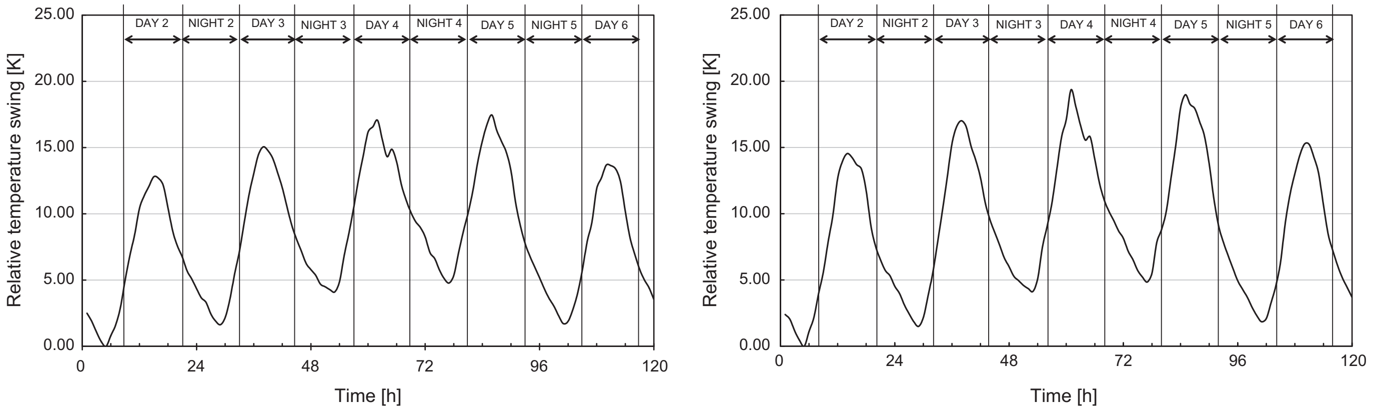
The analysis of the results shown on Figs. 4 and 6 suggest that in the NO-AC scenario, the UHI is mainly due to the impact of the urban structure (including the disappearance of green spaces) whereas, in the other scenarios, the heat rejected plays a major role. The results show that the extra UHI due to heat rejected by *A/C* may be as high or even more than the structural UHI when air cooled *A/C* is intensively used. This proves the challenge for a clever *A/C* management to avoid UHI pockets intensification in districts with a high *A/C* level.

Four typical meshes have been selected to present their relative hourly street temperature variation, in the REAL scenario (Fig. 7), and their average excess temperature due to *A/C* (Fig. 8) during the heat wave period. As observed on Fig. 6, the trend for the temperature swing is the same for all the meshes but the relative temperature swing between day and night is not the same for the four meshes and it can reach and even overpass 15 °C. For all the meshes, the minimum temperature during night time goes through a maximum on the same night during the heat wave peak. The meshes *A*, *B* and *D* experience a smaller temperature swing than mesh *C*.

On Fig. 9, the average excess temperature due to *A/C*, for day time and night time on periods of 12 h, is now presented for each

(a) Mesh A

(c) Mesh C



(b) Mesh B

(d) Mesh D

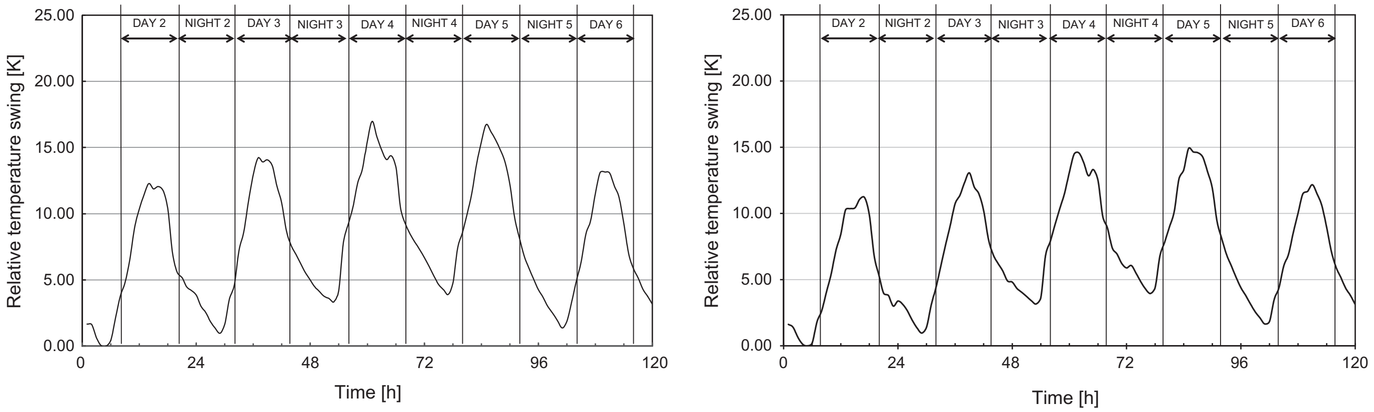


Fig. 7. Relative hourly temperature swing deduced from the REAL scenario for meshes *A* (a), *B* (b), *C* (c) and *D* (d).

mesh as the temperature difference between a given scenario and the reference scenario. Doing so, the main focus is put on the effect of the *A*/*C* management as it was performed on Fig. 6. In the mesh D where *A*/*C* is very important, the sensible heat released by *A*/*C* is high (330 $\mathrm{W/m^2_{land}}$ in the REAL scenario). The temperature increase spans between 1.5 (REAL) and 3.5 °C (DRY ACx2). On the contrary, mesh A corresponds to a residential popular district where very little *A*/*C* exists (9 $\mathrm{W/m^2_{land}}$ sensible heat rejected in the REAL scenario). The temperature increase is very small, between .3 (REAL) and .7 °C (DRY ACx2). Mesh *C* corresponds to case where district cooling represents more than 90% of the *A*/*C*. With district cooling, the REAL scenario does not show significant temperature increase with respect to the NO-AC scenario because the sensible heat released is very low. But, when the condensing heat is rejected into the mesh, as depicted by the DRY scenario, a temperature increase between 1.5 °C and 3 °C, with respect to the reference, is observed.

Note that in meshes *B* and *C* , the temperature increase due to the heat rejected due to *A*/*C* is higher during the night as should be expected from the analysis presented on Fig. 3 whereas in mesh *A* and *D* there is no significant difference between day and night.

From Fig. 8, we can deduce the local augmentation of temperature between $t = 36$ h and $t = 72$ h, which seems important for health (Table 2). As expected influence of DRY ACx2 scenario is higher than the other scenarios. Mesh D, with a large heat release is not more affected than mesh *A*. Influence of architecture or urbanism could explain this.

From those data, important conclusions can be drawn:

- The local street temperature increase is strongly, and linearly, dependent on the sensible heat released through *A*/*C* and UHI pockets do exist.
- Dry air cooling *A*/*C* represents a strong penalty in districts where *A*/*C* is highly used since it induces temperature increase which can reach 2.5 °C in the DRY scenario.
- Areas where district cooling is mainly used are not subject to significant temperature increase due to *A*/*C* preventing UHI pockets.

In Fig. 6 some dispersion on the points was observed and in Fig. 7, it was noted that the temperature swing between day and night differed significantly depending on the meshes. The influence of other parameters than heat rejection was analysed to find if some could play a role. Herein, the influence of the sky view factor (SVF) is reported. SVF indicates the relationship between the visible area of the sky and the area covered by urban structures and is dependant of the ratio H/W (Fig. 2). For that purpose, the temperature swings observed in Fig. 7 were analysed in more detail. The temperature swing between the average temperature of a half day and that of the following half day has been extracted and is presented on Figs. 9–11, for three different sequences during the heat wave, versus the sky view factor of the mesh (which varies from 0.126 to 0.68 for the 12 meshes). Note that the information contained in those figures differs strongly of that contained in Figs. 6 and 7. In the previous figures, the temperature difference was that existing between the scenario with *A*/*C* under study and the reference one without *A*/*C*. That means that the existing temperature swing of the reference case was subtracted. Therefore, effects due to parameters like architecture or urbanism were excluded. On the opposite, the results shown, in the REAL case, on Figs. 9–11 include not only the effect of heat released by *A*/*C* but also the characteristics of the mesh (architecture, urbanism, etc.). For the 4 meshes under study, all the scenarios yield typical similar results

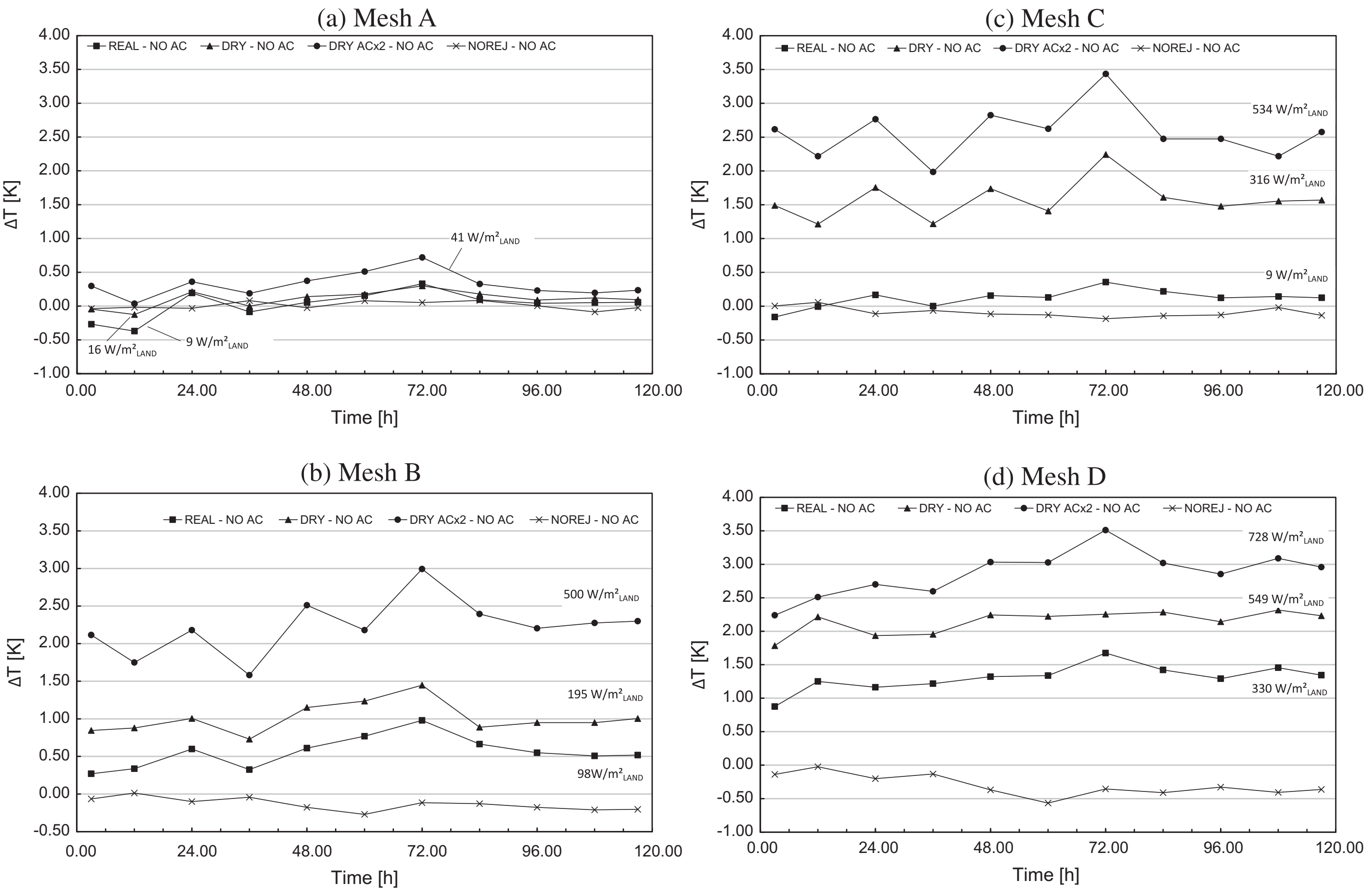


Fig. 8. 12 h-average temperature difference between each scenario with *A*/*C* and the reference without *A*/*C* for meshes *A* (a), *B*(b), *C*(c) and *D*(d).

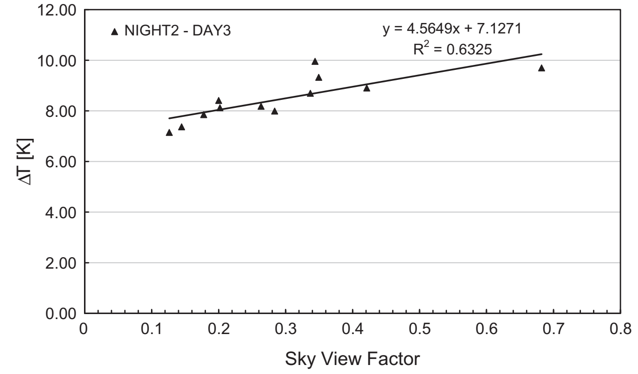


Fig. 9. Absolute temperature swing between the average temperature of the second night and the third day of the heat wave for the REAL scenario and the12 meshes versus their sky view factor.

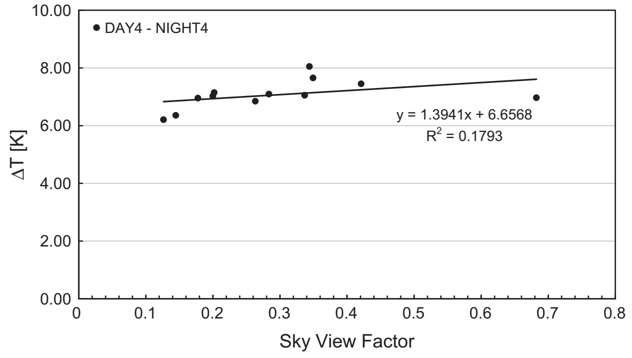


Fig. 10. Absolute temperature swing between the average temperature of the fourth day and the fourth night of the heat wave for the REAL scenario and the12 meshes versus their sky view.

Table 2
Variation of local temperature difference between time 36 and time 72 h. for the four meshes.

	REAL – NO AC	DRY – NO AC	DRY ACx2 – NO AC
Mesh *A*	0.42	0.30	0.53
Mesh *B*	0.65	0.72	1.41
Mesh *C*	0.35	1.02	1.45
Mesh *D*	0.46	0.30	0.91

as those reported herein on Figs. 9–11 for the REAL scenario. The temperature swing between day and night increases linearly versus the sky view factor from 8 °C to 10 °C at the beginning (Fig. 9) or 8 °C to 12 °C at the end (Fig. 11) of the heat wave. It is reduced to 7 °C and does not show any significant dependence on the sky view factor when the heat wave is the strongest (Fig. 10).

Coming back to Fig. 7, the temperature swing was noted to be smaller for mesh D. The explanation could be that the sky view factor of mesh *D* equals to 0.126 is smaller than that of meshes *A*, *B* and *C* which equals respectively to 0.263, 0.202 and 0.349.

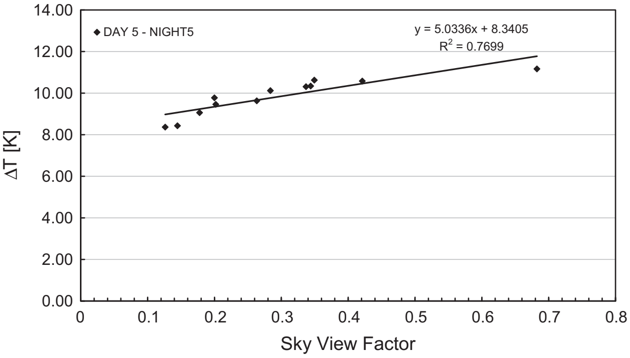


Fig. 11. Absolute temperature swing between the average temperature of the fifth day and the fifth night of the heat wave for the REAL scenario and the12 meshes versus their sky view.

Results shown on Figs. 9–11 tend to prove that the urban characteristic of the mesh plays a role, as well as heat released, on the temperature increase and confirms that the sky view factor is a pertinent parameter to take into account for UHI. Areas with higher sky view factor experience higher temperature swings, which is favourable for the health. But when the effect of the heat wave is the highest, the influence of the sky view factor seems to be reduced.

The NOREJ scenario whose results are shown for the four selected meshes on Fig. 8 corresponds to the case when the heat released by *A*/*C* is the same as in the DRY ACx2 scenario except that, now, the heat is rejected elsewhere than in the air (in Paris, it can be underground or in the river Seine). In that case, the air temperature is found to be less than in the reference scenario for all meshes except mesh *A* where very little *A*/*C* does exist so that the external cooling load of the buildings is negligible and does not interact with the street. For mesh *B*, influence of *A*/*C* without discharging to air, is marginal. But for meshes *B* and D, NOREJ *A*/*C* results in a slight cooling with respect to the reference scenario without *A*/*C*. For mesh D, the maximum cooling effect reaches −0.5 °C as depicted on Fig. 8 and −0.25 °C for mesh *B*.

Although small, according to the model, that effect does exist and contributes to mitigate slightly UHI. Interestingly, the mitigation effect is more important in areas where intensive *A*/*C* with heat released elsewhere than into the air is used. Obviously, district cooling rejecting condensing heat in a river or underground (or using the heat for domestic hot water) could be the appropriate technology to reach that goal of slightly cooling the city through *A*/*C*.

4. Conclusion

Heat waves will be reinforced due to climate change. In France, more probably, the temperatures observed during the August 2003 heat wave will be very frequent after 2050. Therefore, the need for *A*/*C* in large cities will be required to protect populations sensible to heat stress since it is proven that *A*/*C* can contribute to reduce mortality during heat waves. However, it is, as well, known that *A*/*C* can reinforce UHI. Therefore a clever management of *A*/*C* constitutes an important present challenge.

This study, based on a model using actual meteorological data [15], shows that, in Paris, the global UHI depends on the heat released by the *A*/*C* management. Moreover, this study also shows that, in densely areas, the local temperature variation due to *A*/*C* depends linearly on the sensible heat rate released by *A*/*C*. In districts where air cooled *A*/*C* is very intensive, the extra UHI due to *A*/*C* may be of the same order of magnitude as the structural UHI. This proves the importance of the challenge of a clever *A*/*C* management to avoid extra UHI.

In densely areas, dry air cooling *A*/*C* with heat rejection into the air represents a bad solution since it contributes to increase strongly the temperature creating UHI pockets. The districts more affected are those where the *A*/*C* is strongly developed. Doubling *A*/*C* as compared to the present situation, should produce, in some areas, local temperature increases due to *A*/*C* which should reach 2.5 °C. The districts where very little dry air cooling *A*/*C* exist are far less affected but, nevertheless, are a little affected (a few 0.1 °C) through coupling with nearby districts with dry air cooling *A*/*C*.

Wet towers *A*/*C* represent a much better solution than dry air cooling from the point of view of temperature variation since the sensible heat released is small, but the problem of Legionella must not be neglected.

However, the best solution is undoubtedly ground source or water cooled *A*/*C* in which the heat is released elsewhere than into the air (NOREJ scenario). Some cases of that technology do exist, in Paris for example where the river Seine is used for district cooling by Climespace. With the NOREJ scenario, *A*/*C* should contribute to slightly mitigate heat wave. The mitigation should be higher in areas where *A*/*C* is more developed.

The influence of the sky view factor has also be noted. A high sky view factor is more favourable for the existence of large temperature swings between day and night which is favourable for health. However, during the warmest period of the heat wave, the influence of the sky view factor on temperature swing seemed to disappear.

In this work, the impact on energy consumption due to *A*/*C* was not addressed but further studies will develop this point since it is known that energy consumption due to *A*/*C* increases when the street air temperature increases [5,16]. Therefore, another advantage to dissipate the heat of condensation elsewhere than into the air will be energy saving.

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