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MODELING THE GLOBAL WARMING EFFECT ON INDOOR TEMPERATURE PEAKS AND COOLING SYSTEMS CONSUMPTION

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ABSTRACT

This study is a part of the research project MEIGEVILLE driven by IRSTV (Research Institute on Cities) in which our laboratories are partners. The general objective of the project is to take into consideration local climatic data of cities in building thermal behaviour simulation and to set up a coupling between these two kinds of simulation. At first, climatic data will be processed in order to obtain the input data at a city scale. Our project will focus then on the urban microclimate, to predict overheating periods within the studied location, in two cities. This part will involves a G.I.S. method to convert geographical maps into digital database.
In this study, the morphological analysis approach is depicted to clarify different district areas in one city from G.I.S. data. This investigation takes into account the buildings architecture by the calculation of different morphological parameters. In a second part, the methodology for the urban microclimate simulation is exposed, based on the first par results. Finally, the global warming data, obtain from a specific meteorological model is used for the building simulation. The obtain results for different years until the year 2100 highlight a regular increase of assessed building energy consumption and indoor air temperature peaks. At last, the coupling of the urban heat island and global warming effects with the building simulation is outlined.

INTRODUCTION

Urban structures in terms of morphology and of thermal and radiative properties of the artificial surfaces modify the climate at both city scale and local scale. The main influence of the cities on microclimate is the heat island caused by radiative trapping inside dense canopies and heat storage in the urban materials. (Adolphe 2001).

In this context, understanding of the interaction between buildings and urban fabric should drive us to a better management of building energy consumption.

Building uses are an important part of the global energy use thus a good conception of these systems is essential.

The aim of this study is the analysis of this interaction *building – urban fabric* and of the impact of the building mass on the surrounding unban fabric.

Two cities will be studied in this project. The first is Nantes, showed on *Figure 1,* the second one is La Rochelle. As shown on the figure, the studied district of Nantes, called Pin sec, is cut in five zones according to its building types. On the site, we find block of flats as well as dwelling houses. The age of buildings varies between 50 years and recent constructions. For this reasons it is hard to define a “building type” which is representative for the whole district.

In first time, we decided to study two typical buildings in Nantes and one at La Rochelle. The first building in Nantes is a block of flats, the second is an individual dwelling and the third one at La Rochelle is an office building. At this stage of the project, a first building simulation has been completed for the building at La Rochelle. Both buildings at Nantes were built around 1960, while the office block is a recent construction.

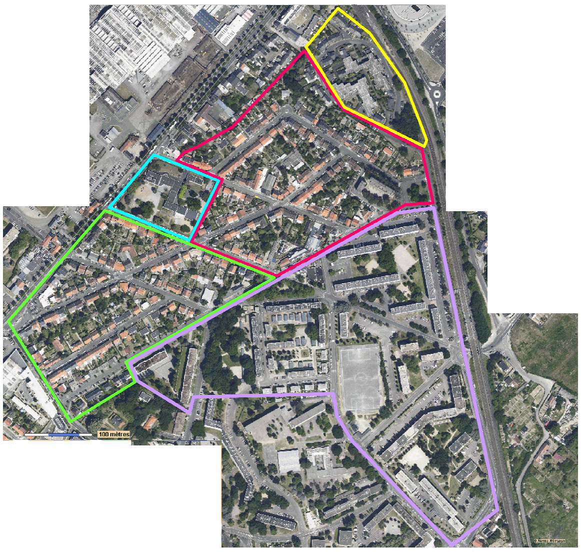

Figure 1 Presentation of the studied area, Pin Sec, Nantes, France

The morphological description of a city can be achieved by a distinction of different district type (Adolphe 2001). But the most usual way is to determine a mesh that cut into equal parts the town and then users can determinate needed parameters on this mesh size (Long 2003). The first step of this process is a conversion of geographical maps into digital database. This group of data is then analysed by a GIS program. The aim of this study is to introduce city parameters in climate model. We need characteristics which modify the urban wind context and the fluxes between atmospheric boundary layer and the surface. This modification is considered via the surface roughness length (Oke 1987). In usual model of roughness length, the average building height and the built density appear directly by the zero plane displacement. (Raupach 1994, Bottema 1996, Macdonald 1998). Other input to microclimatic models is weather data. Several database and simulation tool are available for climatic study on France. Measurement data are also available, but for simulation of global warming effect, climatic models are needed. Arpège Climat of Météo-France applies two scenarii according to demographic evolution. It has a 50 km resolution on a global scale. Aladin Climat (developed in the ENSEMBLES European project) has a 20 km resolution and gives data for the Mediterranean zone. It covers the 1950-2050 period. A third simulation tool is available also, LMD-Z, which was developed by French laboratories. As a part of microclimate studies, the urban energy contribution to the atmospheric energy balance has been widely studied (Masson, 2000; Dupont and Mestayer, 2006). All these models are based on the description (more or less detailed) of the morphological characteristics of the urban fabric to evaluate the surfaces energy budget and to deduce the heat transfers between the canopy and the atmosphere. Roofs and inside canopy surfaces are treated separately, the SM2U model (Dupont & Mestayer, 2006) considers walls and roads as a unique surface while TEB model consider it separately. The SM2U model has the advantage of a unique model for both rural and urban soils so that the vegetation influence on microclimate, that may be important in peri-urban neighbourhoods, can be taken into account.

Woloszyn and Rode (2008) presented the available simulation tools of building behaviour simulations. For thermal studies several codes (commercial or open source) are available. Bozonnet (2005) used a zonal model to define the interactions between urban microclimate, buildings and its air conditioning energy demand, by simulation of heat and mass transfer in the typical case of an urban street canyon. Recently Zmeureanu (Zmeureanu et al. 2008) showed the capabilities of TRNSYS on building analyse in a climatic context.

We divided this study in three parts: the first part concerns the morphological analysis of a studied city; the second, the climate study methodology of the same city, this includes a meteorological database as input information; the third one is a building study that includes a dynamical analysis of building thermal behaviour exposed to global warming effect. Each part developed separately will be coupled in the final study, which is ongoing.

The objective of MEIGEVILLE project is to set up this coupling between urban microclimate and the thermal behaviour of buildings.

DISCUSSION AND RESULTS

Urban Morphology

To take into consideration the morphological parameters of chosen cities, first we have to process a geographical analysis on available data. We have at our disposition the French National Geographical Institute's (IGN, France). Topographical database (BD Topo). It contains a numerical model of the topography with meter precision. The database contains several layer-composed files. The most sophisticated file contains the building description with more than one hundred layers. The building height is stored as an attribute. Hydrographical information and vegetation description files are also available.

Then this database is analysed by the open source GIS software, OrbisGIS, developed in the IRSTV research federation.

The real urban fabric appears in microclimatic model by aerodynamic roughness length of logarithmic wind profile. Here we applied the method of Bottema (1996):

$$z_0 = (h - z_d)\exp\left(-\frac{\kappa}{\sqrt{0.5C_{dh}\lambda_f}}\right)$$

where z_d is the "in plane" displacement height within a building row, model sheltering parameter [m], κ is the von Kármán constant (0.4), C_{dh} is the drag coefficient of an isolated roughness element is a low roughness approach flow and λ_f is the frontal area density.

We need to calculate h, average roughness element height, on the database. We used a quadratic mesh of 200 m size. Building average height is pondered by building surface in order to obtain a representative average value. The obtained value corresponds to one cell in the urban fabric.

For the drag coefficient, C_{dh}, we took 0.8 as it was suggested by Bottema.

For calculate λ_f, we need to know the building surface ratio in the wind direction, to calculate this density.

Microclimatic approach

The used model (Soil Model for submesoscales, urbanized version – SM2U) evaluates the turbulent energy, moisture and radiative fluxes at the urban canopy – atmosphere interface (Dupont and Mestayer 2006). With this, one can calculate directly street canyons energy budget. An exhaustive presentation of this model can be find in Dupon and Mestayer (2006) and Leroyer (2006).

For SM2U we need two kinds of input data: meteorological and morphological. In the next, the needed data list is presented.

The asked meteorological data are:

- Air temperature,
- Air specific humidity,
- Wind velocity,
- Precipitation,
- Atmospheric radiation (infra red atmospheric radiation),
- Global radiation (sum of direct and diffusive solar radiation).

For morphological description, we need:

- Soil occupation mode (urban cover/vegetation and natural cover)
- Canyon aspect ratio,
- Surface of buildings
- Height of buildings
- Total roughness length.

In addition, some parameters describing other soil occupation modes (such as roads, vegetation, bare soil fraction, etc...) are demanded. To take into consideration buildings contribution to energy balance, SM2U uses:

- Roof roughness length, albedo and emissivity,
- Roof and wall layers characteristics: thickness, heat storage capacity and thermal conductivity.

The same thermal parameters for other surfaces (roads,...) are necessary. For city description, the previously described data obtained from OrbisGIS is added.

The code uses the following model of street:

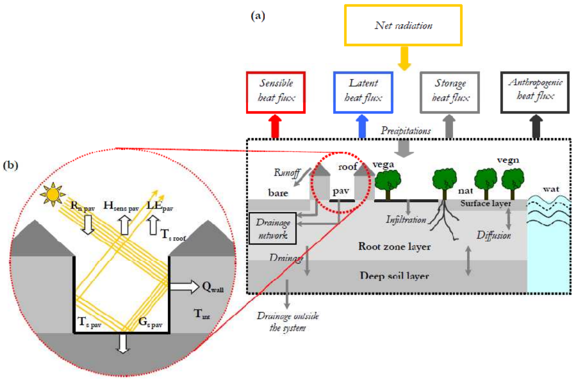

Figure 2 (a) Scheme of the SM2-U energy and water budget models with 7 surface types (pav, bare, nat, roof, vega, vegn, wat) and 3 soil layers. (b) Energy budget of paved surfaces. (Dupont and Mestayer, 2006).

The street is modelled as one surface, so the road and the building facade have the same temperature. SM2U separates eight soil type (Figure 2.) in each computational cell.

Global warming data

The used meteorological data come from Météo-France simulations, which called Arpège Climat. In this model two scenario are available: the moderated and the intensive. In the first case a moderated demographic growth is supposed while in the second one a more important demographic evolution and regional disparities are present. In Arpege Climat the France is cut in 360 zones, with 5 indicators for each zone: maximum, minimum temperature, precipitation, solar radiation and soil humidity.

In spite of clear effect of green house gases on global warming, we cannot say that the warming will be linear, and each year will be warmer than the precedent. So that is why we cannot take the year 2099 as the most representative, because it is not so.

For the following building study, hourly weather data are needed. Then a sinusoidal daily variation was built on the basis of the weekly data from Arpège Climat.

Building Study

It is a preliminary building study of an office building made by CoDyBa software. It supplies a prediction of temperature values and energy uses for a determined period for hourly time step. Thus, the input weather data is required in hourly period also.

The used climatic values by the code are the solar exposition, ambient and sky temperature and air humidity. Building materials' characteristics are given as well.

Six climatic scenarios were involved. The first one is peculiar to CoDyBa with its own values, which are representative of the standard climate of the studied location. The second one is based on the same data, with a simplified daily evolution based on the mean daily temperatures, in order to have consistent comparison with the future meteorological data that are available on the same time step. The next 4 simulation are based on a 100 years database (Arpège Climat) from 2000 to 2100; the 4 studied cases are: actual weather data, the year 2050, and the year 2075 and the last one for 2099. To obtain the highest temperatures in the year, 12 weeks during the summer period (July – September) were simulated.

Two series of simulation are done according to the heating installation. The first one is without any regulation. The second one contains air-conditioning regulation, maintained to 25 °C maximum, during office hours.

A simulation with night ventilation was also done with recent climatic conditions and with future ones (2099).

The studied building characteristics are: an average room of 5.25x7m, 2.80m height under ceiling. The external walls are constituted by 20 cm concrete, 10 cm isolation (glass wool) inside and plasterboard (1.3 cm) as finishing layer. Inside walls are made by 5 cm isolation (glass wool) between two plasterboards of

1.3 cm. The slab is in concrete with plasterboard downside and usual surface finishing upside. Doors have 0.93x2.04m dimensions while windows constitution is 30% frame and 70% double glazing, with 4-16-8 dimensions. Visors of 0.6 m dimension are installed on facades in building long.

The chosen building has several floors from that only one makes subject of our analysis.

To set up a simulation one need to describe using scenarios in the studied building. During the daily use, two periods were determined while during a week a working period and a weekend period are fixed.

The air change rate was fixed in 1 [h^{-1}] for every simulation. Air-conditioning is switched on only for cases where 25 °C is exceeded.

Simulated cases

For each simulation an average, a minimum and a maximum temperature as well as power using were calculated.

The first simulation, done with CoDyBa weather data, serves as a base for comparison between this one and the second simulation (with corrected weather model). So in this one regulation connected to air-conditioning was not used.

In the second simulation, we used our sinusoidal correction on CoDyBa's weather data in order to estimate its performance as this correction will be used for the other simulations with modelled weather data.

We obtained an average temperature of 19.14 °C with the first, and 19.53 °C with the second simulation. It represents 2% of difference. On the other hand, difference between minimal temperatures is around 8.5% while between maximal temperatures is around 2.2%. The comparison of the temperatures of the coldest and the hottest room on the floor, the differences are 0.5 and 1.16%.

The two simulations concerning air-conditioned building give the next values: 3.5% difference between minimal average temperatures and 0.8% for the maximal average temperatures. For the coldest room it is 2% and for the hottest is 2.36%.

These four simulations demonstrate the quality of our mathematical approximation. The values are not identical between CoDyBa's and fitted model, but the difference stays lower than 9%. Thus, we accept this sinusoidal approximation for further simulations.

Temperature evolution and energy consumption

From this section, we used simulated weather data with sinusoidal correction. The chosen four years are the same as it was mentioned before. The temperature is analysed in the coldest and in the warmest room as well as an average value for all rooms on the floor.

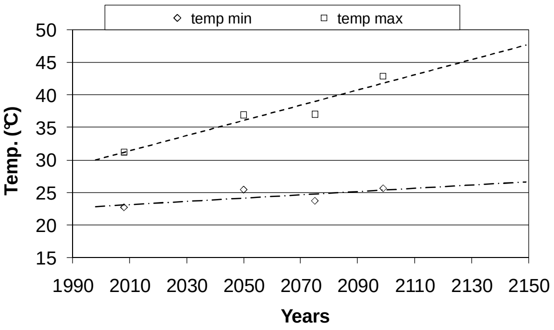

Figure 4: Temperature peak values in the coldest room (without air conditioning)

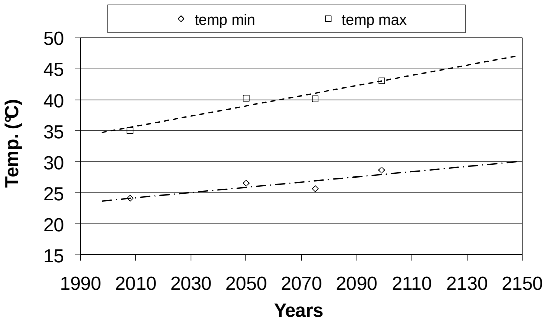

Figure 5: Temperature peak values in the warmest room (without air conditioning)

On *Figure 4* and *5* the trend curves show a net increase of temperatures. The tendency is more evident for the maximum temperatures than for the minimum. The year 2075 seems to be a little bit colder than the others are, but it does not influence the increasing tendency. It means that around 2100 the minimum temperature will be around 26 °C and the maximum around 43°C. Our city is next to the ocean so temperatures in a continental city should be higher than these values. But we can remark that temperature is elevated, and surely energy consumption will be too important.

The air-conditioned coldest room case is presented on the next two figures. In these analyse the regulation is added to the building model, which ensure the maximum temperature at 25 °C during work hours and outside of this period there is no regulation.

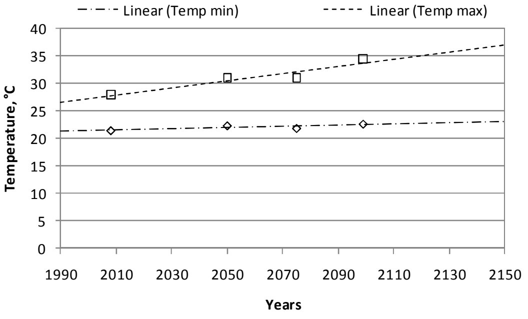

Figure 6: Temperature peak values in the coldest room (with air conditioning)

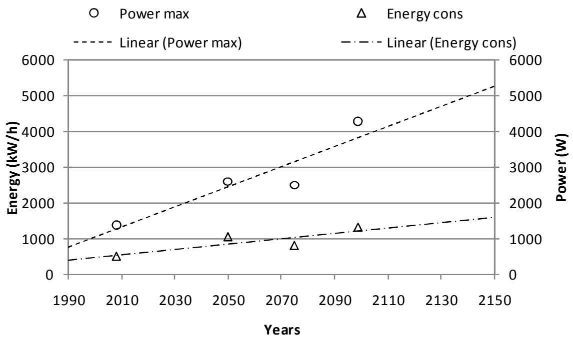

Figure 7: Energy consumption and power use peak values in the coldest room (with air conditioning)

The energy consumption and power maximum were simulated with the air-conditioning. The values show that the average of energy consumption on three month will be third times more in 100 years at only 7°C increase of maximum temperature. As for minimum temperatures, the increase is around 1°C, which let us search some supplementary solution to decrease it, such as night ventilation. It could be effective with not too much energy demand. This question will be regarded in further paragraphs. One has to remark that maximum demanded power increase rapidly in time. As during weekend period the temperature could increase at any level, the Monday morning values of this power level are high. These two effects are linked; the increasing temperatures lead to increasing power levels of air-conditioning installations.

The warmest room shows the same tendency. The temperature increase and it leads to increasing energy use and higher power level of air-conditioning installations. In this case, the augmentation of maximum temperatures is less important than the coldest room, and the energy demand stays less important in comparison with the coldest room. This difference should come from the Monday restarts of air-conditioning machines. In the warmest room, the temperature difference, between week and weekend, remains less than in the coldest room.

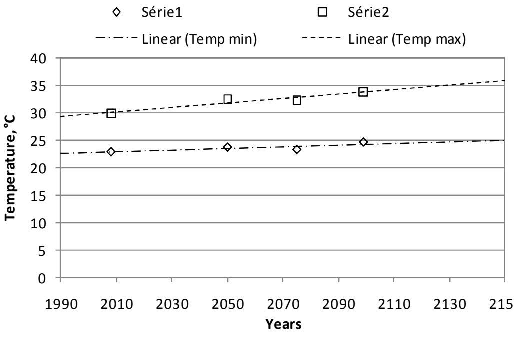

Figure 8: Temperature peak values in the warmest room (with air conditioning)

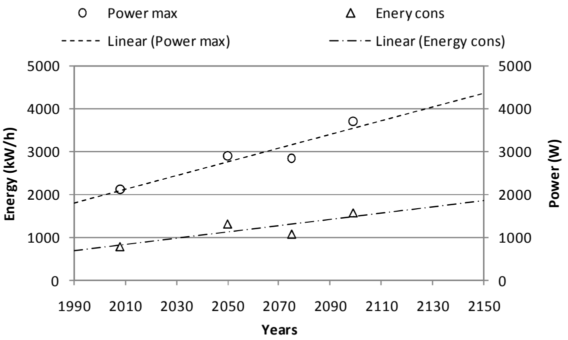

Figure 9: Temperature peak values in the warmest room (with air conditioning)

This relation between extreme temperature and building energy consumption's peak was find in whole building analyse also. Building average temperatures show the same tendencies as the coldest and the warmest room, and power use trend is the same. So we have to remark that in the future a well pronounced demand will be done in energy consumption due to restart of air-conditioning machines, so peak values are very important. This fluctuation in energy consumption must be taken into consideration as in 100 years the value of used energy will be third times more elevated. Total building values are presented on *Figure 10* and *11.*

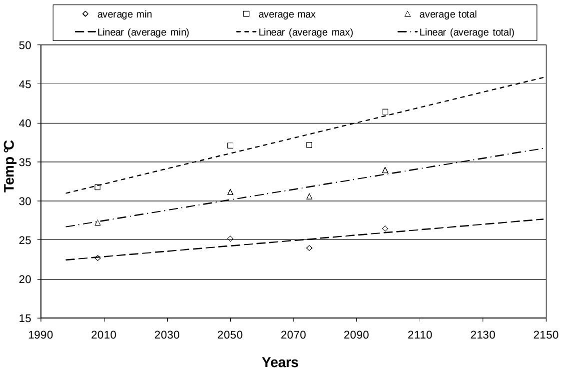

Figure 10: Whole building average temperatures

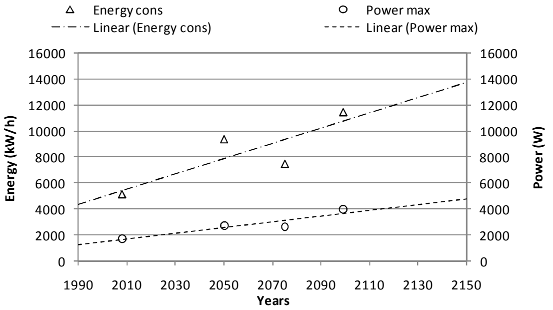

Figure 11: Whole building energy consumption and maximal power

Intensive night ventilation is a well-known tool to decrease temperature in buildings. To study the impact of this ventilation on energy use, a four times higher air change rate during the night was applied in the next simulations. We studied the years of 2008 and 2099. In both cases, the coldest and the warmest rooms are analysed. The case of 2008 shows a clear benefit in temperature in the warmest and the coldest room too. The maximum day temperature falls with 1.5°C and the minimum night temperature with 4°C. As for the total building temperature, the value drop about 5°C. On the energy consumption, the gain is around 45 % while the average sensible power is lower with 28 %. These values demonstrate the efficiency of intensive night ventilation in heat evacuation in 2008. If we look the year 2099, the coldest room values follow the same tendency. However, the warmest room temperatures are different. The minimal temperature drop 3°C but the maximal temperature augments 1°C. It means that the night ventilation is no more beneficial, as the night temperatures in 2099 are higher than the regulation temperature in our building. The used energy in 2099 with night ventilation stays lower, than energy use without this ventilation, but the earnings are less important than in 2008. It is about 11 % for the total building. It put in evidence the importance of other parameters such as room orientation or ventilation scenario, which should play an important role in the energy economisation.

CONCLUSION

Building indoor temperature evolution and energy consumption analysis was presented in this paper. An analysis of available simulated climatic data was performed. A simplified building energy study showed that with climate change, building energy consumption could be three time more important in one hundred years. A part of this study emphasis that the night ventilation would not have the same beneficial effect on energy consumption in the future. It was showed that the conventional ventilation techniques could not be able to compensate the temperature increase. At this stage of our analysis, it seems necessary to take into consideration local climatic data during building thermal simulation.

In perspective of our project, a morphological analysis of two French cities by a GIS treatment allows us to take into consideration city's characteristics in climatic models. The coupling between the climatic model and the building simulation is planned. For this, another building simulation code will be applied, TRNSYS, to simulate the buildings of Nantes city at their current and 1960 state.

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