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Sensitivity analysis of Urban Heat Island parameters based on Urban Weather Generator model

Análisis de sensibilidad de los parámetros que influyen en la Isla de Calor urbana con el modelo Urban Weather Generator

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Abstract

Rural exodus leads to fill cities and consequently to develop and boost urbanization. Until now, effects of climate were not sufficiently considered. More and more, decision makers examine situations on this side. Scientists highlight the effects of urbanization on comfort based on temperature and humidity. They underlined the Urban Heat Island (UHI) effects and the linked parameters. Through 10 parameters, we accomplished a sensitivity analysis of the UHI using the Urban Weather Generator (UWG) to model the climate. Results showed the significance of Albedo but mainly of building height and building density. Those two last parameters have a great impact on the UHI Intensity (UHII). We observed a significant change on the temperature and humidity affecting the comfort of city dwellers with staggering figures near to the state of medical emergency with certain scenarios. Consequently, we can assume that urban planners and decision makers must focus on it. Despite the urban sprawl, this analysis supports this theory. One of the alternatives could be to use factors interacting together with sharpness and to adjust the parameters in order to obtain a resilient city.

KEY WORDS: URBAN HEAT ISLAND; SENSITIVITY ANALYSIS; URBAN PLANNING; URBAN WEATHER GENERATOR; RESILIENT CITY; TEMPERATURE AND HUMIDITY; MODEL; CLIMATE CHANGE

I. Introduction

This master thesis provides additional support and comes in hand with the other master thesis I write simultaneously about local smart grids. In fact, it hinges on the local electricity production to make territories resilient. And then, unlike this one wondering on solution validity, this master thesis theme serves to study the parameters and put forward a line of thinking for solutions. My sensitivity about climate change issues and the way to build the future has lead me to look for a topic in advance, to contact a laboratory in order to work together and to propose it to the responsible of the master's in construction, research, technology and management in Europe.

During my academic career, I studied civil engineering but this last year leaned towards research, technologies was also really instructive regarding the environmental aspects. We broached many subjects and learnt many ways to treat and go on it.

Global warming is for sure the most significant issue of the 21st century and as Malraux said, "the 21st century will be spiritual, or it will not be". Hence, it is necessary to proceed on global change to wake up the collective unconsciousness. This master thesis is therefore a way to demonstrate more deeply, justify and communicate the acting importance. Following that principle and regarding our position, it is interesting to think about the risks on future cities that can affect citizens. Urban Heat Island (UHI) is one of them. It is caused by many factors considered in this study and correlated to other that are, for sure, necessary to identify and examine.

Those factors like the albedo or the urban planning influenced the UHI and can be modeled on the Urban Weather Generator (UWG) tool, using rural meteorological station data and a district file.

Consequently, we may wonder in what extent the variation of the UHI parameters impacts on the temperature increase in cities. Based on a sensitivity analysis, we will tackle the problematic and purpose a thought process. Nevertheless, we will moderate our purpose by framing the scope and introducing limitations. The problematic and the objectives will be reminded in the next part.

First of all, we will wonder and analyze previous work on the topic through a state of the art in order to establish the scope and identify the key factors. Then, we will develop a methodology to answer the problematic. The methodology is composed of 2 different analysis in order to insure the relevancy of the results. Thus, we will analyze the results, mitigate the analysis through external issues and venture way of research. Finally, we will conclude on the topic.

II. Objectives

The objective of this master thesis is to answer the following question: In what extent the variation of the UHI parameters impacts on the temperature increase in cities ? The major goal of this master thesis is to propose strategies for urban planners to make cities more resilient to climate change.

In order to answer this question, we will proceed to a definition of the different characteristics of the topic through a state of the art made from the literature. These definitions introduce briefly key concepts. The objective is to describe and analyze works done before and reflect on it, and develop a point of view. To reduce the scope, we will define specific reference measurement that will be reminded in the methodology. It will be a real expectation to find tools to evaluate the results and specifically for the comfort. Also, it will be necessary to describe the origin of the issue to adapt our approach.

From this, the objective becomes:

- To develop a rigourous and relevant methodology to bring out results demonstrating our hypothesis.To adapt our methodology gradually.
- To compare through two analysis: Minitab and Morris analysis.

Then, the objective is to analyze clearly with a 3D consideration the results. It is necessary to extract odd values not adapted to our problem. The goal is to obtain a relevant analysis and to consider as much as possible element to extract results. However, focusing on specific element is necessary. That is why we will consider only Morris plot, interaction plot and the box plot.

III. State of the art

1) Global situation

The rural exodus was a real phenomenon that is continuing nowadays. Because of the resources given by the economic growth, the rural exodus was unavoidable. Economic opportunities, health care, education and transportation remain the frequent reasons of this transition keeping many ways of mobility. But it also happens for local conflicts and lack of resources (Santamouris, 2001) and it will persist with the future and the concerns of the global warming. Two-thirds of the world's population will live in cities from now until 2030 and we will reach the 9 billion humans around 2050 (UNFPA, 2007). Population movement and rise lead to a gathering of people in the cities and all the attached consequences. Unfortunately, living in the city provokes health problems and the quality of life decrease because of anthropogenic pollutants (Lawrence, et al., 2007). Adding increased temperature, caused by the Urban Heat Island (UHI) phenomenon, cities become hostile place. By focusing on it later, we will reduce the scope.

Current cities use up to ¾ of the resources and contribute to ¾ of the world greenhouse gas emission. Thus, challenges for the cities of the futures will be to home more inhabitants but also to provide solution for ecological, social and economic challenges (UNFPA, 2007). Also, it would be necessary to well use the resources as water (Haase & Nuissl, 2007) and then to fight against that issue of heat waves which provoked tens thousands of premature deaths in Europe (EEA, 2012). Regarding the following definition, we can highlight that cities have to be planned in a more resilient way. The IPCC describes resilience as:

> "The ability to absorb disturbances, to be changed and then to reorganize and still have the same identity (retain the same basic structure and ways of functioning). It includes the ability to learn from the disturbance. A resilient system is forgiving of external shocks. As resilience declines the magnitude of a shock from which it cannot recover gets smaller and smaller. Resilience shifts attention from purely growth and efficiency to needed recovery and flexibility (IPCC, 2007). "

Inhabitant's position and climate change forced us to think and seriously study how to build cities in a resilient way. It means to design the city with sufficient tools to survive and tackle incomfortable phenomenon as heat waves, lack of energy and so on. The concept of resilient city is more and more used in science as a guideline for research and helping for decision making. Therefore, to tackle UHI is a huge element to build resilient city.

2) Urban Heat Island

As a definition, the urban heat island intensity (UHII) is the effect describing the temperature difference between an urban site and a surrounding rural site (Oke, 1982; Arnfield, 2003; Grimmond, 2007; Mills, 2008). Consequently, we can observe that cities and towns are warmer, especially at night, in urban areas due to the absorption of the sun's radiation by buildings and urban coating namely "grey surfaces".

Heat island concept was first introduced in 1820 by Luke Howard comparing simple observations of the air temperature evolution in London. The real magnitude of the heat island phenomena was actually scientifically recognized 150 years later, in the 1970s (Oke, 1973; Howard, 2007). UHI appeared because of industrialization with a change in the structural and land cover. Many factors can affect the city and create a UHI such as : sky view, surface albedo, altitude, vegetation height, average height to floor area ratio or canyon geometry, city size, proximity to the sea, wind velocity (Giridharan, et al., 2007; Oke, 1973; Oke, 1981; Li, et al., 2016). Nowadays, it is a continuous challenge because of climate change and urbanization (Rizwan, et al., 2008; Stewart & Oke, 2012). In relation with the previous elements, those phenomena will still continue increasing and provoking health disasters. In Moscow, an increase in the average UHI effect was observed : from 1.0-1.2°C at the end of the 19th century, to 1.6-1.8°C at the end of the 20th century (Lokoshchenko, 2017). Every city and even every village creates a heat island effect (Stewart & Oke, 2012). Considering the current UHI as an increase of 5-11°C warmer in cities than in the surrounding rural areas, dehydration, heat stroke, cardiovascular and respiratory diseases associated to UHI will have significant consequences on the humankind (Campbell-Lendrum & Corvalan, 2007).

Therefore, the higher temperatures caused by the UHI lead to an intensified use of cooling systems and electrical devices like fans, both energy consumers and spreading hydro fluorocarbons and greenhouse gases into the atmosphere. It creates a vicious circle because the warmer the environment is, the more people tend to use air conditioning, the warmer it becomes and according to de Munck, et al. (2013), the future air-conditioners will provoke an increase of 2°C during heat waves. In fact, air-conditioning released heat to cool the buildings. Moreover, emitted or wasted heat from electricity consumption in the building sector is an anthropogenic contribution to the UHII (Boehme, et al., 2015). Therefore, during heat waves people feels a real discomfort outdoor because of the additional 2°C and need solution. They need more resilience to better live in city.

3) Human thermal comfort

Heat waves have a strong impact on humans who live in cities, as the heat island effect is exacerbated. (Scherer, et al., 2013; Gabriel & Endlicher, 2011; Kovats & Hajat, 2008). During the summer 2003 in France, 15,000 people died during the period of the heat waves(Kopper, et al., 2004) (Valleron & Mendil, 2007). In Australia, it is estimated that on average 1 100 heat-related deaths happen every summer (McMichael, et al., 2002). With temperatures higher than usual, the photochemical process of the atmospheric pollutants happens faster and can generate smog in the city.

In Pakistan, severe heat waves were observed in 2015 causing more than 800 deaths within 10 days because of a 45°C temperature combined to a high humidity (Salim, et al., 2015).Human thermal comfort is a complex mechanism between temperature, humidity, wind and solar radiation. In this study, we will analyze the impacts of temperature and humidity on thermal comfort. Wind and radiation will not be considered because of the model's limitations, the scope focuses on temperature and humidity. Temperature is considered in the study but as it was mentioned before, the humidity is also considered as a significant parameter on the comfort.

Regarding the humidity (presence of water in the air), the literature is globally unvarying and considers the relative humidity (rate of water compared to the maximum water possible) comfortable between 40% and 60 % in indoor environments ? (Morini, et al., 2018). Out of this range, the air is too humid, or too dry for the humans to be "comfortable". On one hand, if too humid the air becomes unhealthy and can bring cardiovascular and pulmonary diseases as reported in numerous scientific papers (Bouchama & Knochel, 2003; Goggins, et al., 2001; Abrignani, et al., 2012; Ivey, et al., 2003; Bartkova-Scevkova, 2003). On the other hand, a low humidity can also have negative effects such as eyes and mucous irritation, dryness and symptoms related to sick building syndrome (SBS) (Nagda & Hodgson, 2001; Gruen, et al., 2012). Consequently, it has to be considered because of sanitary reasons that are different than irradiation and wind, which bring a different perception in the comfort. Another important factor to notice is that a high humidity rate with an increasing temperature has a real impact on the human comfort (Tsutsumi, et al., 2007; Jing, et al., 2013). At the same temperature, 30°C for example, a 40% RH will be more bearable than a 70% RH. And that is the principle of UHI in the case of heat waves as it was observed in July, 2019 in France. Temperature was not extreme but the high humidity made it uncomfortable. Also, during the night, as the air becomes cooler than during the day, the relative humidity is always lower than during the day. With the UHI keeping the heat at night, the environment becomes uncomfortable even if during the day it was tolerable.

To evaluate the comfort of the city dwellers, we will use the discomfort index described by (Thom, 1959). In terms of humidity and temperature it corresponds to Equation 1 : Thom's discomfort equation in correlation with the Table 1 : Discomfort index related to the Thom's discomfort equation :

$$DI = T - (0.55 - 0.0055RH)\,(T - 14.5)$$

Equation 1 : Thom's discomfort equation

Where:

DI: Discomfort Index
T: mean hourly temperature in (°C)
RH: mean hourly relative humidity of air (%)

Table 1 : Discomfort index related to the Thom's discomfort equation

Condition	DI
No discomfort	< 21
Under 50% of population feels discomfort	21-24
Over 50% of population feels discomfort	25 - 27
Most of population suffers discomfort	28 - 29
Everyone feels stress	30 - 32
State of medical emergency	> 32

The thermo hygrometric human comfort index (THI) from national weather service of the USA (Table 2) is also interesting and bring comparable results but it is based on feelings, as the precedent equations, but without mathematical expression. Consequently, the previous tool is more convenient, and the results are similar. It is relevant and interesting to attach the following chart because it reminds the real proportion between temperature and humidity. As mentioned before, with high humidity the temperature becomes less tolerable. For instance, at a temperature of 32°C and a relative humidity of 45%, the heat index is about 34°C. At the same temperature and a relative humidity of 75%, the heat index becomes about 43°C which is much higher.

Table 2 : National Weather Service Heat Index Chart (National Weather Service, s.d.)

HEAT INDEX (°C)													
	RELATIVE HUMIDITY (%)												
Temp.	40	45	50	55	60	65	70	75	80	85	90	95	100
47	58												
43	54	58											
41	51	54	58										
40	48	51	55	58									
39	46	48	51	54	58								
38	43	46	48	51	54	58							
37	41	43	45	47	51	53	57						
36	38	40	42	44	47	49	52	56					
34	36	38	39	41	43	46	48	51	54	57			
33	34	36	37	38	41	42	44	47	49	52	55		
32	33	34	35	36	38	39	41	43	45	47	50	53	56
31	31	32	33	34	35	37	38	39	41	43	45	47	49
30	29	31	31	32	33	34	35	36	38	39	41	42	44
29	28	29	29	30	31	32	32	33	34	36	37	38	39
28	27	28	28	29	29	29	30	31	32	32	33	34	35
27	27	27	27	27	28	28	28	29	29	29	30	30	31

4) Urban solutions

Urban planners and architects considered more and more solutions to counterbalance the urbanization and handle the different parameters as much as possible and necessary. They tried to model the landscape by modifying materials properties, morphological characteristics and so on. For a better climate regulation and more appropriate climate in cities, they vary the use of light and reflectivity with the materials color (Santamouris, 2001; Kolokotsa, et al., 2013), greeneries (Potcher, et al., 2006; Shashua-Bar, et al., 2009) and building albedo (Harazono, et al., 1991; Wong, et al., 2003).

To counterbalance urban heat island, two main solutions can be highlighted:

- Increasing solar reflectance: increasing the material reflectance, namely the albedo, it is an efficient way to reduce the UHI. In Italy, Morini, et al. (2018) demonstrated that it has an impact on up to 4 ° C daytime and up to 1 ° C nights time during summer. The principle is that urban surfaces absorb heat because of the color. Clear colors reflect more than dark. The change of albedo can be applied on roofs, pavements and walls. Globally, it is more efficient on roof because of the emission rate received. At local scale, albedo materials solution were tested for UHI reduction as thermochromic materials (Doulos, et al., 2004), directional materials (Hooshangi, et al., 2015) and retro-reflective materials (Rossi et al., 2015a, 2016; Morini et al, 2017b).

- Increasing evapotranspiration: As vegetation is often little in the city, shading is lacking. Consequently, concrete surfaces absorb the temperature and release it slowly. However, plants go through the process of evapotranspiration when they are warm, which has a direct and localized cooling effect (Clements & Casani, 2009). Vegetation has a real impact on the UHII as it was demonstrated in a study of Susca, et al., (2011). They showed a difference of 2°C according to the district of New York city because of the albedo difference. Many others studies worked on vegetation and its effects (Akbari & Konopacki, 2005; Imhoff, et al., 2010; Takebayashi & Moriyama, 2007), so we can consider it as a solution to include in the design of future cities. On that basis, we can highlight the works of de Munck, et al., 2018, demonstrating the impact of green scenarios. Most of them have a negative correlation with UHI, especially green roofs adaptable to the different seasons and a good way to reduce energy consumption. Hence, green roofs increase evapotranspiration and improve insulation of building for summer and winter reducing energy consumption.

The negative correlation between vegetations and urban heat island is sure and was demonstrated in many cases as in Beijing, where Zhang, et al. (2010) demonstrated their strong link. In Manchester the UHI could add 2.4 K in average and 8 K punctually to the urban temperature because of the green space’s reduction (Levermore, et al., 2018). Knowing that urbanization is increasing from the rural exod, it is interesting to observe the effect on humidity:

it decreases (Adebayo, 1991). Vegetation release water vapor around their position and it increases humidity and decreases temperature (Barradas, 1991). Consequently, in a dry and warm city which is significantly uncomfortable, this effect is a real regulator. Additionally, albedo and greeneries have a direct impact on reducing the cooling energy demand, which has an amplificatory effect on the UHI (Gros, et al., 2016; Gros, et al., 2014).

5) Physical model

To model the UHI, four different ways can be underlined: climatology models, empirical models, computational fluid dynamics models and statistical regression methods (Kolokotroni, et al., 2010). In our case we will use a computational model made by Bueno, et al. (2012): The Urban Weather Generator.

Using a computer to handle a numerical simulation has become a relevant and efficient solution to solve calculations with large databases. Many researchers adopted programming features that allow the computer to perform their numerical calculations and gain a precious time (Kusaka, et al., 2001). In particular the modeling methods to assess the UHI according to the scale are determining (Bozonnet, et al., 2015).

Many parameters influence the UHI and make the model more and more complex and in-depth. Building performance simulation software were developed these last 30 years such as Energy plus© (Crawley, et al., 2001), TRNSYS© (Beckman, et al., 1994) and Esp-r© (Strachan, 2000). These softwares can predict building energy demand using input weather files. At the district or at the city scale, we can find, on the same principle, the Urban Weather Generator taking into account urban climate conditions (Bueno, et al., 2012). In order to use the UWG, an input weather file from a rural meteorological station is required. The model UWG will then transforms this weather file into an urban weather file based on the characteristics of the city or the district modeled. We described the urban landscape through a parameter file. This file highlights the principle of the urban canyon, which is a place where the street is flanked by buildings on both sides (Figure 1). This street setting has an effect on wind, temperature and the air quality. The UWG uses energy conservation principles and a bottom-up building stock model. Based on several Urban Heat Island parameters, we will do a sensitivity analysis to highlight and prioritize the most sensitive and determining elements. The UWG model will modify the parameter of temperature and humidity in the weather file, considering the climate conditions in the city. Many parameters are considered and will be described below in the methodology, while some of them will be selected for the analysis. Python is a good tool to compute repetitive experiments and to use Minitab is also a recognized way to analyze results (Jato Espino, 2019).

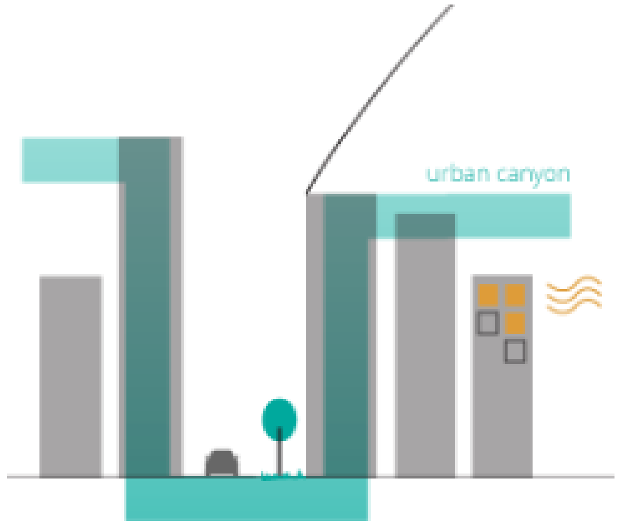

Figure 1 : Urban canyon model principle in the Urban Weather Generator (Bueno, et al., 2012; Norford & Reinhart, 2013)

Also, it is necessary to understand the spatial scale of the city to appreciate correctly the urban climate. Latitude, continentality, topography or proximity to water can be real factors that influence not only the design of the city, but also the consequences on the climate (Grimmond, et al., 2010). The scale is significant according to the surroundings. In fact, considering the whole city could lead to obtain an average; however, basing a study on an area too small affected by the surrounding but not included in the parameters cannot be representative. Numerous studies were done at global and regional scales (Huth, et al., 2000; Chauvin & Denvil, 2007; Vautard, et al., 2007). In this study, we are at the local scale, around 70,000 m², namely the neighborhood scale of La Rochelle, France.

Our study aims to give an additional support from scientific experiments to urban planners, architects and decision makers. Determining the influence of parameters and analyzing the sensitivity will allow underlining the relevant way to act. The next section will describe the methodology we developed, and the different parameters chosen. Then, we will analyze and discuss the results in order to underline some relevant parameters for the UHI.

IV. Methodology

In this part, the global principle of the methodology will be described in order to go deeply on each topic subsequently. Figure 2 illustrates the different steps:

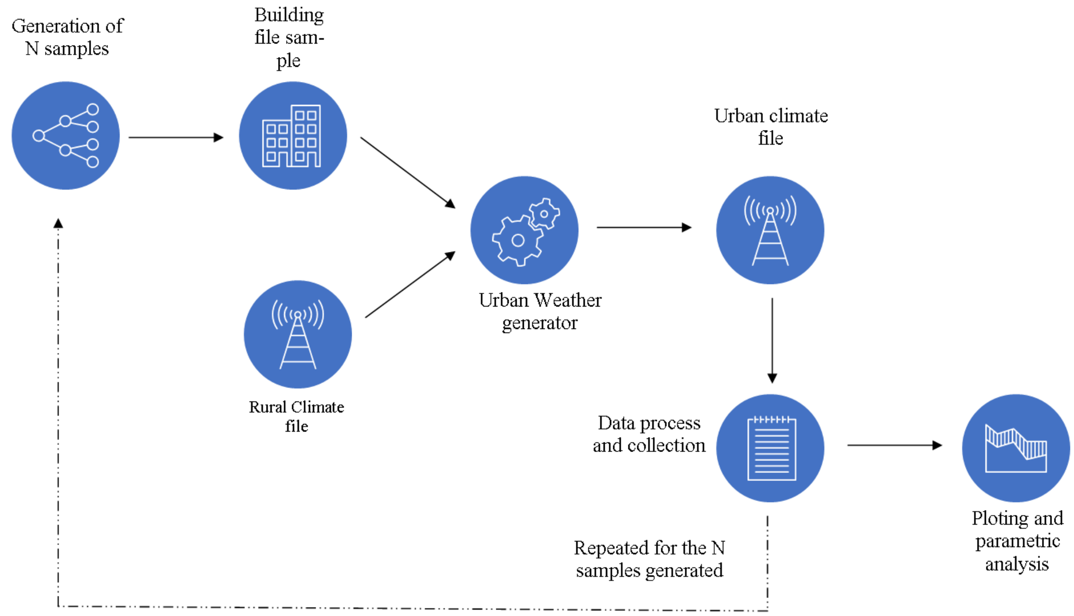

Figure 2 : Methodology process to generate values leading to the analysis

The process generated N different samples varying the tens parameters. Then, we processed the N files one by one. Thus, we introduced the building file sample and the rural climate file in the urban weather generator. It generated an urban climate file forecasting the weather in the city. Then, we collected the results of each simulation. And finally, we were able to analyse and discuss on it.

The methodology was used to evaluate the UHI effect and the significance of some parameters through a sensitivity analysis. It considered numerous scenarios in order to compare and generate values for the analysis. From Minitab and Python code, we will illustrate our purpose.

1) Urban model
   a. Geographical scale

In this scientific consideration, we have chosen to be at the scale of the district in different cities: Paris and La Rochelle, France. This choice is enough in order to evaluate the different scenarios and develop our analysis. It will correspond to a city district like La Rochelle, France with building or a housing scheme. Comparing the different parameters defining the district as well as the meteorological file results, such as the temperature and the humidity, it will allow to suggest urban planning scheme.

b. Temporal scale

The temporal scale is extended to one year in order to observe the effects on the whole year and specifically on summer because eventually UHI is problematic for human life during this period, especially during period of heat waves. By adding the Cooling Degree Hours (CDH), we will consider the whole year. This approach offers a mitigation on the summer consideration.

c. Temperature and humidity

As we mentioned before, temperature is the main parameter observed for the UHI. Humidity will be considered in correlation with the temperature based on the discomfort index described before. We will observe the sum and average of temperature higher than 0 on the year compared to the rural temperature and to 26°C as a sample value.

$$Si\ T > 0°C, \Delta T = T - T_0$$
$$Si\ T < 0°C, \Delta T = 0$$

Equation 2 : Temperature calculation

As previously stated in the state of the art, humidity is a determining factor and will be observed in the same way. By applying the formula purposed by Thom (1959) we will be able to compare the number of uncomfortable days between urban and rural scenarios but also according to the scenarios.

d. Position

In this study, we will consider the city of La Rochelle, France. This city, through chosen district is known and was modelled with a Sketchup model. We could work on different cities, but we will reduce the scope on this, and especially for the analysis.

e. UWG simulation

UWG will allow us to generate an output file that we will develop below from the previous described files. As we underlined it in the state of the art, UWG is a model of reference.

For each scenario, we will run the UWG while changing different input parameters. It generates a new climate file (.epw) and allows carrying out the data processing described below.

f. Input data

In this file, it is included every parameter defining the studied district. We can find the different global parts describing the district:

- Urban characteristics
  - Some parameters can be affected, but in order to reduce the factors, the scope and to increase the level of accuracy, we decided to consider some parameters and not others. For example, the albedo is more relevant than the pavement thickness.

Table 3 : Urban characteristics choice of parameters

Considered values	Unconsidered values
• Average building height (m) • Urban area building plan density • Urban area vertical to horizontal ratio • Road albedo	• Fraction of building HVAC • Dimension of a square that encompasses the whole neighborhood • Road pavement thickness • Road pavement conductivity • Road volumetric heat capacity • Non-building sensible heat at street level

- Climate zone
  - Climate is not considered because we cannot have a direct impact on it. The position of the street can not be changed and consequently, the climate is unchangeable.
- Vegetation parameters
  - As previously, vegetation and tree can be affected but the natural phenomena are not relevant to be considered because of their unalterable characteristics.

Table 4 : Vegetation parameters choice

Considered values	Unconsidered values
• Vegetation coverage • Tree coverage	• The month in which vegetation starts evapotranspiring • The month in which vegetation stops evapotranspiring • Fraction of the rural ground covered by vegetation • Heat absorbed by grass that is latent • Heat absorbed by trees that is latent

- Traffic schedule
  - Being difficult to estimate and considered, this factor is removed.
- Fraction of building stock
  - Considered implicitly in the building height, its impact is not really relevant. And, with our model, it is not sufficiently accurate.
- Optional urban parameters
  - Solar heat gain coefficient is not taken into consideration because of the impossibility to change it contrary to the other that are real urban planning parameters.

Table 5 : Optional urban parameters choice

Considered factors	Unconsidered factors
• Roof albedo • Fraction of the roofs covered in grass/shrubs • Glazing ratio • Wall albedo	• Solar heat gain coefficient

- Simulation parameters
  - Time scale and time step cannot be managed. Thus, they were not considered
- Heating, Ventilation and Air-Conditioning (HVAC) system and internal loads
  - HVAC factors are notified for information purposes only, because we will not consider them. They are more related to internal building factors.

Table 6 : HVAC systems and internal loads choice in parameters

Considered factors	Unconsidered factors
	• Auto size HVAC • Sensible heat per occupant • Latent heat fraction from occupant • Radiant heat fraction from occupant • Radiant eat fraction from equipment • Radiant heat fraction from light

- Urban climate parameters
  - Urban climate factors are notified for information purposes only, because we will not consider them. Being natural elements, we have a low efficiency to handle the climate as an urban planning element.

Table 7 : Urban climate parameters choice

Considered factors	Unconsidered factors
	• Ubl height – day (m) • Ubl height – night (m) • Inversion height (m) • Temperature height (m) • Wind height (m) • Circulation coefficient (default=1.2; per Bruno (2012) • Exchange coefficient (default = 1; per Bruno (2014)) • Max day threshold (W/m²) • Max night threshold (W/m²) • Min wind speed (m/s) • Rural average obstacle height (m)

This file is a key element of the input parameters for the good performance of the simulation. The urban parameters were obtained by the Sketchup model proper to the district and its specific areas. It will be described below.

In those groups, we can eliminate the traffic schedule, which is difficult to influence and estimate for the future. Also, the climate zone is impossible to change. The fraction of building stock is difficult to moderate because it will not be a helpful consideration to the whole urban planning. The other parameters representing the global urban planning are sufficient to estimate the future way to build. Simulation parameters do not change because they are related to the time scale. HVAC and internal loads are not considered because of the lack of data on the topic and the difficulty to control the use of these systems. And finally, the urban climate parameters cannot be changed because they are related to the meteorological data.

g. The input climate file

Climate files originate from measures of local meteo whith meteo France as a reference at the French scale. Files are arranged according to the daily data of the year detailed at the hour and available on the Energy plus website (National Renewable Energy Laboratory (NREL), 1996). We can find inside numerous meteorological data's as:

- Date
  - Year, Month, Day, Hour, Minute
- Temperature(°C)
  - Dry Bulb Temperature (°C), Dew Point Temperature (°C)
- Relative Humidity (RH) (%)
- Atmospheric Station Pressure (Pa)
- Radiation
  - Extraterrestrial Horizontal Radiation (Wh/m²)
  - Extraterrestrial Direct Normal Radiation (Wh/m²)
  - Horizontal Infrared Radiation Intensity (Wh/m²)
  - Global Horizontal Radiation (Wh/m²)
  - Direct Normal Radiation (Wh/m²)
  - Diffuse Horizontal Radiation (Wh/m²)
- Illuminance
  - Global Horizontal Illuminance
  - Direct Normal Illuminance
  - Zenith Luminance
- Wind
  - Wind Direction
  - Wind Speed (m/s)
- Sky Cover
  - Total Sky Cover
  - Opaque Sky Cover
- Visibility
- Ceiling Height (m)
- Present Weather Observation
- Present Weather Codes
- Precipitable Water (m)
- Aerosol Optical Depth
- Snow Depth (m)
- Day Since Snowfall

- Albedo
- Liquid Precipitation
    - Liquid Precipitation Depth (m)
    - Liquid Precipitation Quantity (m^3)

In this study, the only modified parameters by the UWG model will be temperature and humidity.

This file is necessary as an input. We will not execute any adjustment and will finally only describe the weather at the rural meteorological station.

2) Criteria analysis
    a. General

As we previously described, the district file included numerous parameters. Consequently, it is necessary to sort them for this study in order to make it relevant. In fact, we defined the parameters impacting the most the UHI in order to handle them for future urban planning. Therefore, we can rule out unchangeable and hard predictable parameters. Moreover, in order to be in a worst-case situation, it is essential to conserve significant and impacting parameters. Also, we avoid taking into account the parameters which are difficult to forecast for the future. For example, the traffic can be handled but it is difficult to estimate the results of the future mobility policy. Consequently, on the list of parameters described previously, we will consider 10 of them:

- Average building height
- Urban area building plan density
- Urban area vertical to horizontal ratio
- Road albedo
- Fraction of the urban ground covered in grass/shrubs only
- Fraction of the urban ground covered in trees
- Roof albedo
- Fraction of the roofs covered in grass/shrubs
- Glazing ratio
- Wall albedo

Below, we will proceed to a description of each parameter. We will add the range for the simulation.

b. Average building height

The average building height (bldHeight) of all the buildings of the district. We obtained it from the Sketchup model. For the simulation we will consider a range from 5 to 30 meters. It represents most of the different buildings we have in our different districts and it is a sufficient range allowing seeing the variation and the impact of this parameter. It is a way to evaluate the future urban planning with a vertical or horizontal urbanization. Common values are 26 m for

Singapore, 15 m for Bazel (Switzerland) or 20 m in Toulouse (France) (Norford & Reinhart, 2013).

c. Urban area building plan density

The urban area building plan density (bldDensity) is the ratio of surface used by the buildings in the considereddistrict. The range is between 0.1 and 0.9, that are the extreme values available on the UWG notice. It is relevant because it allows us seeing the real difference between rural and urban areas.

d. Urban area vertical to horizontal ratio

The urban area vertical to horizontal ratio (verToHor) depends on the area and the height of the buildings. The range is from 0.1 to 0.9. It offers the possibility to see the influence of the global percentage of urbanization on an area. This ratio has a real impact on the way to urbanize.

e. Road albedo

The road albedo (albRoad) can vary in the future depending on the innovation. For example, we can find coverage based on the biomimetics of the zebra crossings, which mix black and white and change the albedo. Also, red albedo has an influence. Consequently, a range of 0.1 to 0.9 is a way to test the influence. The albedo is a reflection coefficient. It is the ratio of reflected radiation from the surface to incident radiation upon it, it affects the sensible heat flux into boundary layer.

f. Roof albedo

The roof albedo (albRoof), with a range of 0.1 to 0.9, is the influence of the color of the different roof in the city. Depending on the colors, it will influence the UHII. It has a direct impact on the irradiation. It has a direct link with photovoltaic technologies and their effectiveness. Consequently, it is a way for us to estimate the impact of technologies on the UHII.

g. Wall albedo

The wall albedo (albWall) is like the roof albedo. We can see in Mediterranean countries the colors on the walls : For instance on Greek islands, all walls are white in order to reflect heat from the sun and therefore reduces the cooling demand. The range is also from 0.1 to 0.9. As general values, we will consider 0.1 for concrete, 0.2 for brick, 0.05 for soil and 0.55 for cool roof (Norford & Reinhart, 2013).

h. Fraction of the urban ground covered in grass/shrubs only

The fraction of the urban ground covered in grass/shrubs only (vegCov) is directly linked to the albedo and mitigate the percentage of the grey area. It is the quantity of green areas directly on the ground such as grass. Changing this parameter will modify the evapotranspiration factor as well. The large range of 0.1 to 0.9 is logical in the case of each extreme choice (Norford &

Reinhart, 2013). As typical values, we generally consider 1 for green roof and 0 for bituminous surfaces.

i. Fraction of the urban ground covered with trees

The fraction of the urban ground covered in trees (treeCoverage) is the percentage of trees on the area. This parameter mostly influences the shadows, the evapotranspiration factor and the wind factor. The range chosen is from 0.1 to 0.9. Usual values are 0.19 for Singapore, 0.16 for Bazel (Switzerland) and 0.08 for Toulouse (France) (Norford & Reinhart, 2013).

j. Fraction of the roofs covered with grass/shrubs

The fraction of the roofs covered in grass/shrubs (vegRoof) allows considering green roofs. In fact, as we demonstrated in the state of the art, i is significant and mitigates the effect of a conventional roof. The range is from 0.1 to 0.9 too.

k. Glazing ratio

The glazing ratio (glzR) is the ratio of glazed area to total façade surface. We will consider 0.1 to 0.9 for the simulation with a typical U-value for a double-glazed of 2.2 W/m²K. The typical values are from 0.2 to 0.4. The real effect of the window glazing on the city UHI is related to the thermal mass that can keep the temperature and release it at night increasing the UHII. Glazing, contrary to brick wall, does not have a significant thermal mass that is positive for UHI. However, it also affects the thermal insulation of buildings and, consequently, the energy consumed and released (Kolokotroni, et al., 2005).

3) Sketchup

From Sketchup, we can achieve the different city profiles. It provides specific values and allows join the attached scenarios. It will allow us to identify the problematic of the city and to apply our analysis to real cases. Thanks to Sketchup, we obtained the following values:

- Average building height
- Urban area building plan density
- Urban area vertical to horizontal ratio
- Fraction of the urban ground covered with grass/shrubs only
- Fraction of the urban ground covered with trees
- Fraction of the roofs covered with grass/shrubs

This model on Sketchup is simplified and is based on cube and parallelepiped shape (Figure 3 and Figure 4), which is enough for the required parameters of the study, even if the level of definition is not extremely accurate as we can see it below.

Figure 3 : SketchUp model with a 3D vision

Figure 4 : SketchUp model with a 2D vision in the x/y plan

From the model, we can define ranges of values. It is a tool to complete and compare the results.

4) Criteria analysis
    a. Parametric analysis method

By using the software Minitab, we have generated 161 scenarios. We can find in Annex 2 : Minitab Data's all the scenarios. Those scenarios considered as samples In the analysis are sufficient to describe all the parameters in different situations and to obtain a relevant description of each parameter. We varied each parameter from min to max, also choosing mean values. Each parameter could have these 3 different values in order to create a combination of input district combined with all the other changing parameters. By choosing a Box-Behnken response surface with 10 center points, we obtained 161 different scenarios with those 3 values. We have decided to use the Box-Behnken process because we wanted a model curvature in our data. It is a "light" analysis compared to a central composite design which would require to generate many more sample. However, we do not need a precise equation and therefore a full quadratic model.

Table 8 : Values affected to each parameter with Minitab

Parameters	Min	Mean	Max
Average building height (m)	10	20	30
Urban area building plan density	0.1	0.5	0.9
Urban area vertical to horizontal ratio	0.1	0.5	0.9
Road albedo	0.1	0.5	0.9
Fraction of the urban ground covered in grass/shrubs only	0.1	0.5	0.9
Fraction of the urban ground covered in trees	0.1	0.5	0.9
Roof albedo	0.1	0.5	0.9
Fraction of the roofs covered in grass/shrubs	0.1	0.5	0.9
Glazing ratio	0.1	0.5	0.9
Wall albedo	0.1	0.5	0.9

Maximum and minimum are not equal to 0 or 1 for the ratio in order to avoid convergence issues. Otherwise, in the manual, we can find that parameters can vary from 0 to 1.

The Morris methodology is a method used on Python to undertake a sensitivity analysis (Annex 1: Morris analysis code). It generates samples as we described previously with Minitab and, from this, compares the correlation between the variation of the results and the changes in the parameters. It is the same principle. It allows comparing 2 methodologies and with python, it is faster to run many samples. It uses the SALib and Pandas library in order to code it easily. Based on the results, the analysis will be detailed later. Morris analysis considered the mean and dispersion effects in order to obtain the sensitivity and the interactions (Looss, 2012).

b. The output climate file

From the simulation, an output climate file was generated. This meteorological file is exactly the same as the one from Meteo France but modified and implemented with the results of the simulation. It allows, after handling, to interpret the data's. Thanks to those results, we will be able to compare the temperature change over the year between the rural and the urban area.

c. Criteria analysis

In order to analyze the data from a global point of view, we will make the **parameters vary** and **observe the correlation** with the output meteorological file. Thus, it will be necessary to handle the changing data impacting the UHII. We have chosen criteria in order to analyze the impact of our different strategies (changing parameters) on the UHI.

The chose criteria are the **Cooling Degree Hours** (CDH). In order to obtain them, we have to calculate the difference between the urban and the rural temperature. With this difference, we can do the sum of all the values superior to 0. And this sum will represent the CDH of the year. This value is relevant because it is the measure of the global effect of UHI on a city. Consequently, we can know the global effect and highlight main effective parameters to change.

$$Si\ RH > 0°C, \Delta RH = RH - RH_0$$
$$Si\ RH < 0°C, \Delta RH = 0$$

Equation 3 : Relative humidity calculation

For the **UHII**, the calculation is the same, but we have chosen to compare the new urban temperature to 26°C instead of the rural temperature. This value is interesting because it focuses on the heat waves period and shows the effect especially during the summer, when the temperature is higher and the situation favorable to UHI. It confirms and refines the measure simultaneously done. 26°C is also the main limits in the French climate to be comfortable.

To compare the values, we have summed the average values for both the CDH and the UHII. It is another indicator of the phenomenon.

To evaluate the humidity, we have used the same calculation. We will be able to estimate the **evolution of humidity** and the main factors affecting this element. We considered the superior value in one calculation and the inferior value in another to evaluate the positive or negative variation of the humidity. It allows us to evaluate the impact on humidity on the UHI. Also, as previously with the CDH and the UHI, we considered the average value, because it gives an order of magnitude of the global impact.

Finally, with the **discomfort index**, it will be possible to assess the effect on humans and to add a relevance assessment to our analysis. For this, we choose to calculate the average value of the discomfort to estimate the evolution according to the parameters of the comfort. However, this does not help to assess the real impact. Consequently, we have calculated the maximum value in order to assess the evolution on the temperature during the heat waves. Moreover, in order to estimate the duration of the discomfort period, we calculated the number of days with a discomfort index superior to 21 (Table 1), which is the limitation value.

Thanks to this data processing, we obtained box plots and interactions plots. Box plots show the distribution of the results and the trend of the parameters. Interaction plots represent the relationship between one categorical factor and a continuous response. The less parallel the lines are to each other, the greater the interaction is. Otherwise, it presents the real impact of a factor on another.

d. Summary

Finally, the general goal was to change the parameters of the city influencing the urban planning in order to observe how sensitive the output meteorological file is to changes in the inputs. Simulation after simulation, we obtained a database with all the results, allowing us to observe and analyze the results based on all the different scenarios generated by the Morris code and by the software Minitab.

V. Analysis and mitigations

This analysis is made from the plots displayed in Annex 4: Interaction plots and Annex 5: Box plots. Those plots were generated with Minitab and Python. They represent the influence of each factor and try to answer the situation identified at the very beginning. Results are relevant comparing to the analysis of Jato Espino (2019). We will try to demonstrate it as precise as possible.

a. Interaction plot

Before anything else, we can see that interaction plots are more or less the same according to the factor. Consequently, we will do a global description. In the box plot analysis, we will consider only one result because it will not be relevant to consider each response. For this reason, we inserted the results as annex to compile all the results with Minitab. Figure 5 shows the main trend of the interaction plots to interpret the results. However, we can find in Annex 4: Interaction plots, the rest of the interaction plots.

It is interesting to see the high influence of the combination of building density and building height. Those 2 factors together have a significant impact on the UHII. Also, we can see that the building density is a high factor against the other. We can see that, moving up a notch, UHII is considerable.

Regarding specific interactions, we can underline:

- Building height and vegetation coverage

It means that with a high or low building height (10 or 30 meters), a mean vegetation coverage (0.5) will be more adapted than extreme vegetation coverage (0.1 or 0.9). For a mean height (20 meters), mean vegetation coverage is more adapted.

- Vertical to horizontal ratio and vegetation roof

For high vertical to horizontal ratio, a high ratio of vegetation roof will have a negative impact on the UHII because of solar radiation on those zones. It is the same for opposite values. For mean values of vertical to horizontal ratio, a high and a low percentage of vegetation roof will be interesting to reduce UHII, but a mean value will not be effective.

- Road albedo and glazing ratio

The link between albedo and glazing reflection seemss to be sensitive. We can observe that a mean road albedo will be interesting with high orlow glazing ratios. And for a low or high values of road albedo, a mean glazing ratio would be preferred because of the impact on insulation.

It is attractive to examine the effects of roof and wall albedo that generally, with an adequate adaptation to the situation, can be effective to drop off the UHII.

Regarding relative humidity, we can underline some high interactions:

- Building density with vertical to horizontal ratio and vegetation roof

Globally, the relationship is linear but with a high building density and a high vertical to horizontal ratio, the humidity rate increases seriously. Those results represent clearly the effect of the urban canyon because of the significant radiation arriving on the roof which are directly impacted and without shading zone.

- Vertical to horizontal ratio, roof albedo and vegetation roof

Lines are parallel and do not present any interaction. But for high values of roof albedo and vegetation roof, the RH skyrocket. It is more visible with the vegetation roof. It has a real impact on the humidity rate, which is the evapotranspiration mentioned in the state of the art. The vegetation roof, because of the high radiation received, is a good solution to solve the consequences of the urban canyon.

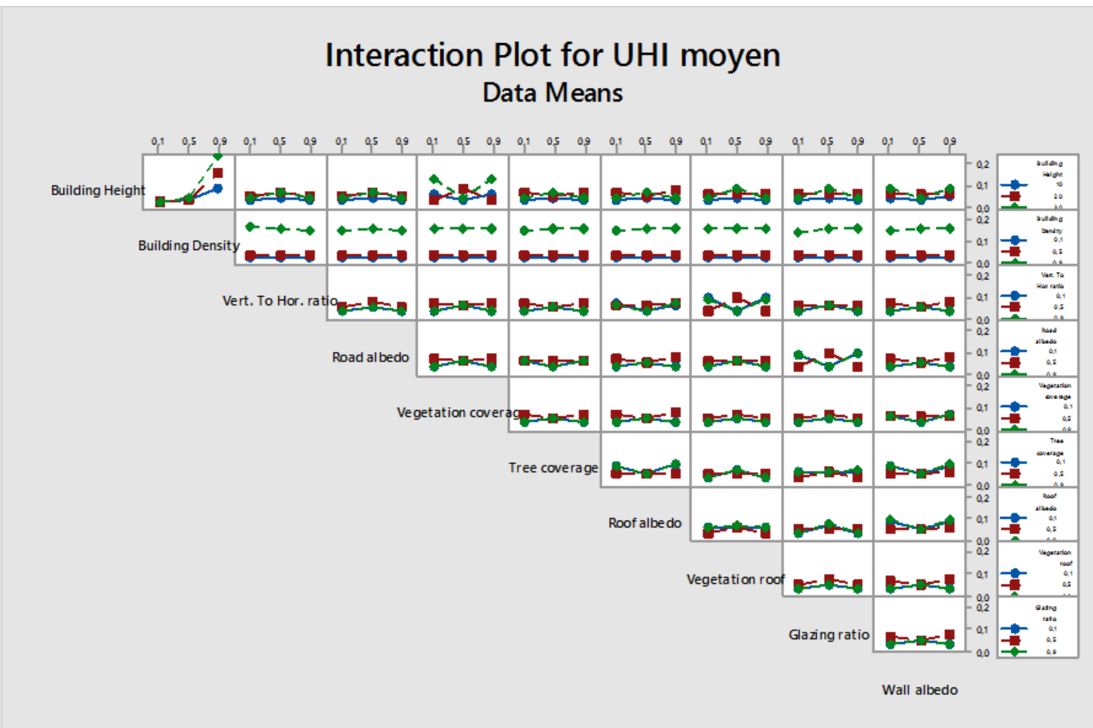

Figure 5 : Interaction plot for average UHI

Also, we can observe that compared to the other responses, RH goes down. It means that urbanization decreases the humidity rate (Adebayo, 1991). Consequently, in the city we have a dry air and high temperature during heat waves. However, it happens that the cloudy weather makes it uncomfortable. Building density increases the UHII but decreases seriously the RH out of the interaction.

To conclude on the interaction plots, we can observe that a well-used vegetation roof can have a significant impact on the urban climate. Building density and building height have a serious impact on the urban climate and combinedtogether, it creates an urban canyon impacting significantly the temperature. Values will be detailed later with the boxplot and the discomfort index.

b. Box plots

As previously mentioned, interaction plots show that results are similar according to the response. Results of the box plots are similar. Consequently, the analysis will be restricted to UHII box plots. Figure 6 and Figure 7 represent global trends to interpret the results. The other graphs are available in Annex 5: Box plots.

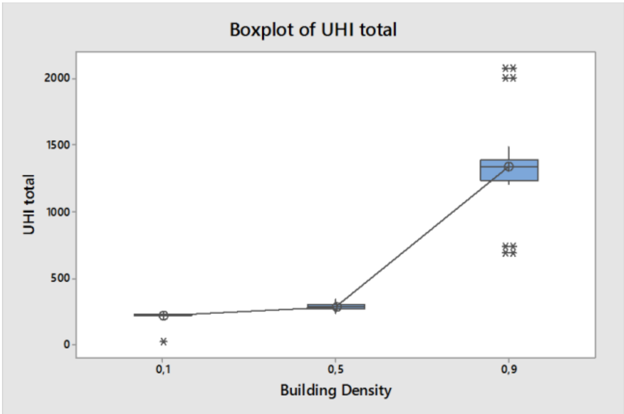

Figure 6 : Boxplot of UHI total with building density

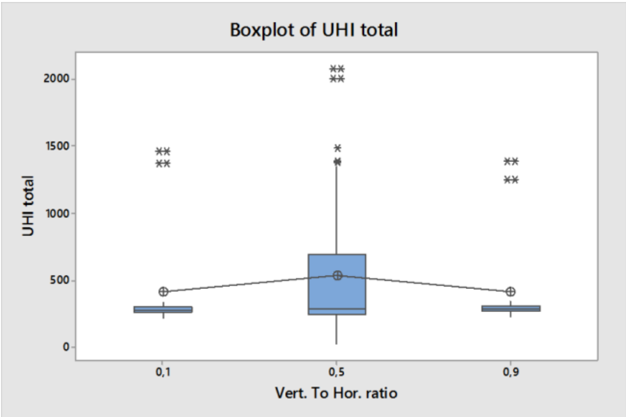

Figure 7 : Box plots of UHI total with ver. To Hor. Ratio

Regarding the mean values, we can see they increase in the building height and the building density which are the most significative ones. For the remaining variables, the UHII stays at the same level of value. It means that building density and height are the most sensitive values to change. This is linked to the urban canyon: The higher and denser the urban canyon, the more intense the UHII. When a critical value in building height is reached, the UHI is at his maximum. Regarding other trends, it is difficult to extract specific conclusions.

We can also analyze specific points: We can see on the box plots that some points are out. It is always related to the same experiments which are the 19, 20, 23, 24, 26, 27, 29, 30, 32, 36, 38, 40, 42, 44 and 46 experiments.

It corresponds to the interaction between factors as presented before or principally to the building height or building density.

c. CDH and UHII

As we described before, some parameters are more sensitive and now, we will observe some specific values. The mean variation of UHI is not significant but it is compared to 26°C, which is important and the higher limits to a comfortable situation. Regarding the real variation between rural and urban areas based on the CDH, we can observe a high variation of the temperature until 3.2 K and a mean value of 1 K.

d. Morris analysis

In the Morris analysis, we have measured the average of the effects and the dispersion. The average value μ measures the sensitivity and shows the significant effects. Results evolve depending on the input variations. The dispersion is a measure of the interaction and will measure the effects between values. By creating 3 groups of points. At the down left side, there are negligible values, whilst values on the other side are linear. The global scatter plot is for the non-linear values and/or with interaction. In our graph, we can see directly that the building height and the building density are isolated on Figure 8 and Figure 9. It shows their linear influence as we explained before. Therefore, both analyses yield to the same results.

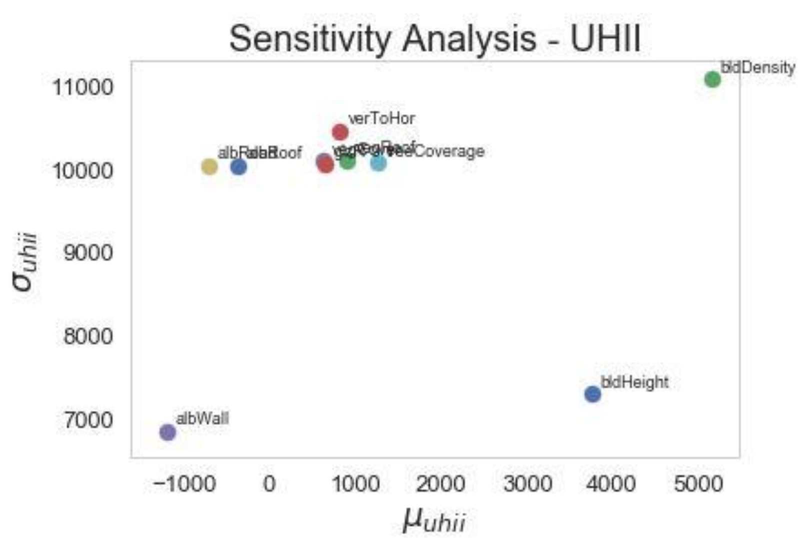

Figure 8 : Sensitivity analysis UHII from the Morris analysis on Python

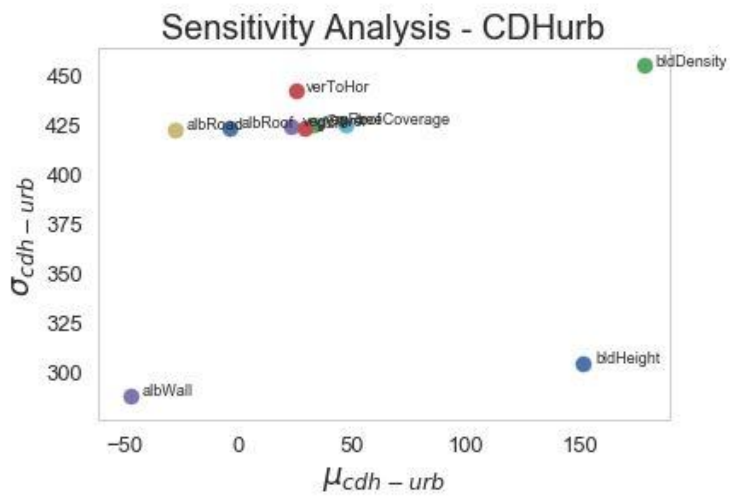

Figure 9 : Sensitivity analysis CDH from the Morris analysis on Python

e. Relative humidity

On the one hand, we have the variation of inferior values and on the other hand, we have the variation of superior values. We can see that urbanization leads to a reduction in the relative humidity as we mentioned before (Adebayo, 1991). UHI generates a RH reduction of 5.2 % with a maximum value reaching 14.7 % whereby the air is dryer. According to Table 2, a dryer air is more comfortable when the temperature is high. However, we will see in the next paragraph that the increase in the discomfort hours is still there.

f. Discomfort

Analyzing the discomfort, we can observe that the range is large: 615 to 1657 hours during the year are judged as being uncomfortable according to our discomfort index. Judging that it is mostly during summer, a number of discomfort hours increase of around 1000 is enormous. With 12 hours of abnormal heat by day/night, it is equivalent to 83 days in discomfort position.

Regarding the maximum discomfort index, we obtain 30.2 that corresponds to everyone feeling heat stress. A mean value of 27.9 on the index means that a significant part of the population is not in good conditions.

g. Mitigations

With global warming, we can imagine that temperature will increase and that mean values and discomfort hours will increase significantly. With 5 K of increase expected, the sensitivity will be exacerbated.

The effect of the urban canyon is significant when we know the sensitivity to building height and density. Using the UWG offers a real tool to think about how to design cities and how to find compensatory measures.

Regarding the initial scope, there are still some limitations in the model. Wind and sun radiation are not taken into account in the model, these are elements impacting on the comfort and it would be interesting to model it as well. Especially the influence of a urban canyon on the UHI with low or high wind speed and shadows would be really interesting to analyze.

Also, we did not take into consideration some parameters of the UWG: the traffic, the heat emission of cooling devices or the exact type of building, which surely have an impact on UHII.

We can also underline the scale of our study. We chose a districtbecause it is sufficiently large to be representative; however, with a large factor by proximity, the ambient conditions in the district can be changed quite a lot. For example, the presence of the sea nearby, such as in La Rochelle, can impact the results. It depends on the region and the climate.

In consequence, reducing building height and density seems to be a good way to think of a more resilient city to heat. A mitigation appears with the urban sprawl. More and more, we are building cities avoiding this phenomenon. Decision makers try to reduce this effect and to densify the urban place. This problematic is also important regarding the use of agricultural land. It could be interesting to study it in the current context.

One of the solutions could be to work on the interaction at the global scale. The Morris analysis and the interaction plots demonstrated the interaction between factors. Regarding the actual urban planning, the principle would be to adapt the urban landscape with the interacting factors. We can underline the huge impact of vegetation on UHI combined with other parameters. Thus, the architectural point of view is necessary to be innovative and imagine solutions for the future city.

VI. Conclusion

In our study, we introduced temperature and humidity parameters to examine their sensitivity to Urban Heat Island. We used these two parameters to calculate a discomfort index in order to know the impact on city dwellers thermal comfort. Considering the current situation and the next future, this analysis provides an idea of the sensitive factors. Figures are staggering for the future. Thus, it is necessary to find ways to change our habits and specifically in this context, our way to build. It revealed how to act on a city landscape.

Through the methodology using the UWG and two methods of analyzing the results, we developped an analysis demonstrating the huge impact of the urban canyon (Figure 1 : Urban canyon model principle in the Urban Weather Generator). Our methodology used 161 samples simulating different scenarios and demonstrating the impact of UHI parameters. Based on a Morris analysis, interaction plots and box plots, we could see the impact of building height and density. Moreover, we can highlight positive and negative interaction bearing the effects.

Thus, in order to plan a city in the next few years in a way to make it more resilient to heat, it is necessary to consider reducing the building height and the building density. Currently, it is not the trend and it would be really difficult to implement this approach in an ancient district with protected buildings. However, for new buildings, a new architecture approach could be considered. Finally, it is the role of architects, urban planners and decision makers to think about the interactions between buildings and landscapes, especially vegetation roof and coverage.

It is necessary to act because of the global warming and its consequences on health. Road albedo, tree and vegetation coverage, vegetation roof and so on are factors interacting with each others. We chose them because of our capacity to influence directly their values.

We observed a real impact of the UHI on the relative humidity and the temperature with maximum values of 3.6 K of increase and 14.7 of reduction for a district in La Rochelle, France. In the city, the air revealed to be dryer than in the countryside. Moreover, we observed a non-negligible increase on discomfort hours in certain conditions. It reveals the necessity to take into consideration these parameters.

The analysis is interesting because of the relevance of the results and the practical approach. However, we can underline the lack of parameters used and the accuracy of the 3D model we used. It could be interesting to go further through a GIS model allowing to introduce more precise parameters and to introduce future landscape linked to global warming as sea level. Moreover, considering the traffic, pollution and HVAC impacts could be relevant for an analysis of the comfort. Taking into account these factors would probably add a negative effect of the urban heat island. Nowadays, the city mobility is a real problematic and it should be studied with a transversal analysis including city dwellers feelings and comfort, pollutions, global warming, urban sprawl and so on.

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Annex 1: Morris analysis code

The python code below proceed to a parametric analysis and allow to generate the Figure 8 and Figure 9. It was done in collaboration with the LaSie quoted in the Acknowledgments.

```
import pandas as pd
import numpy as np
import fileinput
import seaborn as sns
import tkinter
import matplotlib.pyplot as plt
from matplotlib import gridspec
import os
from uwg import uwg
from tkinter import *

#---------------------------------------------------------------------------------
# Définition des chemins absolus
#---------------------------------------------------------------------------------
dossier_parametre = 'C:/Users/smarti04/Desktop/uwg-master/utiliser_uwg/resources/parameters/'
dossier_epw = 'C:/Users/smarti04/Desktop/uwg-master/utiliser_uwg/resources/epw/'
dossier_epw_uwg = 'C:/Users/smarti04/Desktop/uwg-master/utiliser_uwg/resources/epw_uwg/'
nom_fichier = 'FRA_Strasbourg.071900_IWEC'
nom_initialize = 'initialize'

#---------------------------------------------------------------------------------
# Entrées des paramètres de simulation
#---------------------------------------------------------------------------------

vector_texttoreplace = [

    #-----------------------------------------------
    # Paramètres de la ville
    #-----------------------------------------------
              '10',    # Hauteur moyenne des bâtiments
              '0.5',   # Densité urbaine
              '0.8',     # Ratio vertical/horizontal des surfaces bâtiments
              '1',        # Fraction de la chaleur des HVAC envoyé vers la canopée urbane
              '1000',   # Longueur caractéristique de la zone d'étude
              '0.1',      # Albédo de la route
              '0.5',        # Largeur des routes (m)
              '1',        # Conductivité thermique de la route (W/mK)
              '1600000',       # Capacité calorifique de la route (J/m3K)
              '20',     # Energie dégagée par le reste de la rue (W/m2)
              '1',         # Choix de la zone
```

```
    #-----------------------------------------------
    # Paramètres de la végétation
    #-----------------------------------------------
              '0.4',     # Fraction de la zone recouverte par de l'herbe
              '0.1', # Fraction de la zone recouverte par des arbres
              '4',     # Mois à partir duquel la végétation évapotranspire - début
              '10',       # Mois à partir duquel la végétation évapotranspire - fin
              '0.25',       # Albedo de la végétation
              '0.9',  # Fraction du sol urbain recouvert par la végétation
              '0.4',      # Fraction latente de la chaleur absorbée par l'herbe
              '0.6',      # Fraction latente de la chaleur absorbée par les arbres
   #-----------------------------------------------
   # Typologie des bâtiments
   #-----------------------------------------------
        # 0 Restaurants - Full Service Restaurant
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 1 Hôpital - Hospital
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 2 Hôtel - Large Hotel
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 3 Grands bureaux - Large Office
              '0',            # pré-1980s
              '0.4',            # 1980s - present
              '0',            # Neuf
        # 4 Bureaux de taille moyenne - Medium Office
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 5 Appartements - Mid Rise Apartment
              '0',            # pré-1980s
              '0.6',            # 1980s - present
              '0',            # Neuf
        # 6 Urgences - Outpatient
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
```

```
        # 7 Ecole primaire - Primary School
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 8 Fast-food - Quick Service Restaurant
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 9 Collèges - Secondary school
              '0',            # pré-1980s
              '0',            # 1980s - present
              '0',            # Neuf
        # 10 Petits hôtels - Small Hotel
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
        # 11 Petits bureaux - Small Office
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
        # 12 Epicerie - Stand-alone retail
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
        # 13 Centre commercial - Strip mall
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
        # 14 Supermarché - Super Market
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
        # 15 Entrepôt - Warehouse
              '0',           # pré-1980s
              '0',           # 1980s - present
              '0',           # Neuf
   #-------------------------------------------------
   # Caractéristiques aditionnelles du quartier
   #-------------------------------------------------
              '0.05',      # Albédo des toits
              '0.1',         # Fraction des toits recouverts par des toitures végétalisées
              '',      # Rapport de vitrage
              '',      # Pourcentage de gains solaires
              '0.05',       # Albédo des parois
```

```
#------------------------------------------------
# Caractéristiques de la simulation
#------------------------------------------------
     # Paramètres de simulation
           '1',        # Mois de début de simulation (1-12)
           '1',          # Jour de début de simulation (1-31)
           '365',         # Nombre de jours simulés
           '300',        # Pas de temps de la simulation (s)
           '3600',    # Pas de temps du fichier météo (s)
     # Paramètres des systèmes dans le bâtiment - HVAC
           '0',     # Autodimensionnement des systemès HVAC (0 = non, 1 = oui)
           '100',       # Energie sensible dégagée par chaque occupant (W)
           '0.3',       # Energie latente provenant des occupants
           '0.2',        # Rayonnement provenant des occupants
           '0.5',    # Rayonnement provenant des équipements
           '0.7',    # Rayonnement provenant de l'éclairage
     # Paramètres du climat urbain
           '1000',        # Hauteur de la couche limite le jour (m)
           '80',        # Hauteur de la couche limite la nuit (m)
           '150',        # Hauteur de la couche de cisaillmement (?)
           '2',        # Hauteur de la couche limite "température" (m)
           '10',        # Hauteur de la couche limite "vent" (m)
           '1.2',        # Coefficient de recirculation
           '1',        # Coefficient d'échange convectif (?)
           '150',        # Seuil de déclenchement de l'éclairage en journée (W/m2)
           '20',      # Seuil de déclenchement de l'éclairage en nuit(W/m2)
           '1',      # Vitesse minimale du vent (m/s)
           '0.1'         # Hauteur moyenne des obstables urbains (m)
          ]
```

```
nom_fichier_resultat = nom_fichier+('_UWG')
init_txt = nom_initialize + '.txt'
init_uwg = nom_initialize + '.uwg'

#----------------------------------------------------------------------------------
# Génération du fichier initialize.txt
#----------------------------------------------------------------------------------
reponse = '# ===================================================\n# Sample UWGv4.2 simulation initiali:
fichier= open("init0.txt","w")
fichier.write(reponse); # Ecris la réponse qui a été tapée.
fichier.close()

#----------------------------------------------------------------------------------
# Remplacement de toutes les variables
#----------------------------------------------------------------------------------

vector_texttofind = [

    #------------------------------------------------
    # Paramètres de la ville
    #------------------------------------------------
              'xxbldHeight',    # Hauteur moyenne des bâtiments
              'xxbldDensity',   # Densité urbaine
              'xxverToHor',     # Ratio vertical/horizontal des surfaces bâtiments
              'xxh_mix',        # Fraction de la chaleur des HVAC envoyé vers la canopée urbane
              'xxcharLength',   # Longueur caractéristique de la zone d'étude
              'xxalbRoad',      # Albédo de la route
              'xxdRoad',        # Largeur des routes (m)
              'xxkRoad',        # Conductivité thermique de la route (W/mK)
              'xxcRoad',        # Capacité calorifique de la route (J/m3K)
              'xxsensAnth',     # Energie dégagée par le reste de la rue (W/m2)
              'xxzone',         # Choix de la zone
    #------------------------------------------------
    # Paramètres de la végétation
    #------------------------------------------------
              'xxvegCover',     # Fraction de la zone recouverte par de l'herbe
              'xxtreeCoverage', # Fraction de la zone recouverte par des arbres
              'xxvegStart',     # Mois à partir duquel la végétation évapotranspire - début
              'xxvegEnd',       # Mois à partir duquel la végétation évapotranspire - fin
              'xxalbVeg',       # Albedo de la végétation
              'xxrurVegCover',  # Fraction du sol urbain recouvert par la végétation
```

```
            'xxlatGrss',      # Fraction latente de la chaleur absorbée par l'herbe
            'xxlatTree',      # Fraction latente de la chaleur absorbée par les arbres
#-------------------------------------------------
# Typologie des bâtiments
#-------------------------------------------------
     # 0 Restaurants
            'x01',            # pré-1980s
            'x02',            # 1980s - present
            'x03',            # Neuf
     # 1 Hôpital
            'x11',            # pré-1980s
            'x12',            # 1980s - present
            'x13',            # Neuf
     # 2 Hôtel
            'x21',            # pré-1980s
            'x22',            # 1980s - present
            'x23',            # Neuf
     # 3 Grands bureaux
            'x31',            # pré-1980s
            'x32',            # 1980s - present
            'x33',            # Neuf
     # 4 Bureaux de taille moyenne
            'x41',            # pré-1980s
            'x42',            # 1980s - present
            'x43',            # Neuf
     # 5 Appartements
            'x51',            # pré-1980s
            'x52',            # 1980s - present
            'x53',            # Neuf
     # 6 Outpatient
            'x61',            # pré-1980s
            'x62',            # 1980s - present
            'x63',            # Neuf
     # 7 Ecole primaire
            'x71',            # pré-1980s
            'x72',            # 1980s - present
            'x73',            # Neuf
     # 8 Fast-food
            'x81',            # pré-1980s
            'x82',            # 1980s - present
            'x83',            # Neuf
     # 9 Collèges
            'x91',            # pré-1980s
```

```
            'x91',          # pré-1980s
            'x92',          # 1980s - present
            'x93',          # Neuf
        # 10 Petits hôtels
            'x101',         # pré-1980s
            'x102',         # 1980s - present
            'x103',         # Neuf
        # 11 Petits bureaux
            'x_111',         # pré-1980s
            'x_112',         # 1980s - present
            'x_113',         # Neuf
        # 12 Epicerie (stand-alone retail)
            'x_121',         # pré-1980s
            'x_122',         # 1980s - present
            'x_123',         # Neuf
        # 13 Centre commercial
            'x_131',         # pré-1980s
            'x_132',         # 1980s - present
            'x_133',         # Neuf
        # 14 Supermarché
            'x_141',         # pré-1980s
            'x_142',         # 1980s - present
            'x_143',         # Neuf
        # 15 Entrpôt
            'x_151',         # pré-1980s
            'x_152',         # 1980s - present
            'x_153',         # Neuf
    #-------------------------------------------------
    # Caractéristiques aditionnelles du quartier
    #-------------------------------------------------
            'xxalbRoof',    # Albédo des toits
            'xxvegRoof',    # Fraction des toits recouverts par des toitures végétalisées
            'xxglzR',       # Rapport de vitrage
            'xxSHGC',       # Pourcentage de gains solaires
            'xxalbWall',    # Albédo des parois
    #-------------------------------------------------
    # Caractéristiques de la simulation
    #-------------------------------------------------
        # Paramètres de simulation
            'xxMonth',      # Mois de début de simulation (1-12)
            'xxDay',        # Jour de début de simulation (1-31)
            'xxnDay',       # Nombre de jours simulés
            'xxdtSim',      # Pas de temps de la simulation (s)
            'xxdtWeather',  # Pas de temps du fichier météo (s)
        # Paramètres des systèmes dans le bâtiment - HVAC
            'xxautosize',   # Autodimensionnement des systemès HVAC (0 = non, 1 = oui)
            'xxsensOcc',    # Energie sensible dégagée par chaque occupant (W)
            'xxLatFOcc',    # Energie latente provenant des occupants
            'xxRadFOc',     # Rayonnement provenant des occupants
            'xxRadFEquip',  # Rayonnement provenant des équipements
            'xxRadFLight',  # Rayonnement provenant de l'éclairage
        # Paramètres du climat urbain
            'xxh_ubl1',     # Hauteur de la couche limite le jour (m)
            'xxh_ubl2',     # Hauteur de la couche limite la nuit (m)
            'xxh_ref',      # Hauteur de la couche de cisaillement (?)
            'xxh_temp',     # Hauteur de la couche limite "température" (m)
            'xxh_wind',     # Hauteur de la couche limite "vent" (m)
            'xxc_circ',     # Coefficient de recirculation
            'xxc_exch',     # Coefficient d'échange convectif (?)
            'xxmaxDay',     # Seuil de déclenchement de l'éclairage en journée (W/m2)
            'xxmaxNight',   # Seuil de déclenchement de l'éclairage en nuit(W/m2)
            'xxwindMin',    # Vitesse minimale du vent (m/s)
            'xxh_ob'        # Hauteur moyenne des obstables urbains (m)
           ]
```

```
#------------------------------------------------------------------------------
# Changer les paramètres du fichier
#------------------------------------------------------------------------------
with open('init0.txt','r') as inputfile:
    filedata = inputfile.read()
    for i in range(len(vector_texttofind)):
        texttofind = vector_texttofind[i]
        texttoreplace = vector_texttoreplace[i]
        fildata = filedata.replace(texttofind,texttoreplace)
        filedata = fildata;


#------------------------------------------------------------------------------
# Génère le fichier initialize.txt modifié
#------------------------------------------------------------------------------
nom_outF = dossier_parametre + init_txt
outF = open(nom_outF, "w")
outF.writelines(fildata)
outF.close()
```

```
# modifier l'extension du fichier
#------------------------------------------------------------------------------\n",
# Générer un fichier uwg",
#------------------------------------------------------------------------------\n",
thisFile = dossier_parametre + init_txt
base = os.path.splitext(thisFile)[0]
os.rename(thisFile, base + ".uwg")


#------------------------------------------------------------------------------
# Récupération des fichiers
#------------------------------------------------------------------------------

epw_filename = dossier_epw + nom_fichier + '.epw'    # .epw file name
param_filename = dossier_parametre + init_uwg            # .uwg file name

# Noms des fichiers météo
#-------------------------
# La Rochelle : FR-La-Rochelle-73150.epw
#-------------------------
# Paris : FR-Paris-Montsouris-71560.epw
#-------------------------
# Singapore : SGP_Singapore.486980_IWEC.epw
#-------------------------
# Bordeaux: FRA_Bordeaux.075100_IWEC.epw
#-------------------------
# Lyon : FRA_Lyon.074810_IWEC.epw
#-------------------------
# Marseille : FRA_Marseille.076500_IWEC.epw
#-------------------------
# Marseille : FRA_Strasbourg.071900_IWEC.epw
#-------------------------



#------------------------------------------------------------------------------
# Lancement de la simulmation
#------------------------------------------------------------------------------
uwg_ = uwg(epw_filename, param_filename)
uwg_.run()
```

```
#-------------------------------------------------------------------------------
# Lecture du fichier de résultat
#-------------------------------------------------------------------------------
# inscrire le dossier dans lequel apparaissent les fichiers résultats
dir_name= dossier_epw
# inscrire le nom du fichier de la simulation à observer
base_filename= nom_fichier_resultat
# extension du fichier
format = 'epw'


#-------------------------------------------------------------------------------
# Lecture du fichier initial
#-------------------------------------------------------------------------------
# inscrire le dossier dans lequel apparaissent les fichiers résultats
dir_name_init = dossier_epw
# inscrire le nom du fichier de la simulation à observer
base_filename_init = nom_fichier
# extension du fichier
format = 'epw'



#-------------------------------------------------------------------------------
# Récupération  des résultats
#-------------------------------------------------------------------------------
results = os.path.join(dir_name, '.'.join((base_filename, format)))
results_init = os.path.join(dir_name_init, '.'.join((base_filename_init, format)))


#-------------------------------------------------------------------------------
# Fichier data - les résultats sont dans la matrice data
#-------------------------------------------------------------------------------
data = pd.read_csv(results,header = None, skiprows=8)
data_init = pd.read_csv(results_init,header = None, skiprows=8)



#-------------------------------------------------------------------------------
#déclaration des variables - fichier UWG
#-------------------------------------------------------------------------------
dry_bulb_temperature = data[6]
dew_point_temp = data[7]
```

```
#-----------------------------------------------------------
#déclaration des variables - fichier UWG
#-----------------------------------------------------------
dry_bulb_temperature = data[6]
dew_point_temp = data[7]
relative_humidity = data[8]
atmospheric_pressure = data[9]
extraterrestrial_horizontal_radiation = data[10]
extraterrestrial_direct_normal_radiation = data[11]
horizontal_infrared_radiation_intensity = data[12]
global_horizontal_radiation = data[13]
direct_normal_radiation = data[14]
diffuse_horizontal_radiation = data[15]
global_horizontal_illuminance = data[16]
direct_normal_illuminance = data[17]
diffuse_horizontal_illuminance = data[18]
zenith_illuminance = data[19]
wind_direction = data[20]
wind_speed = data[21]
opaque_sky_cover = data[22]
visibility = data[23]
ceiling_height = data[24]
present_weather_observation = data[25]
present_weather_codes = data[26]
precipitable_water = data[27]
aerosol_optical_depth = data[28]
snow_depth = data[29]
days_since_last_snowfall = data[30]
albedo = data[31]
liquid_precipitation_depth = data[32]
liquid_precipitation_quantity = data[33]
unknown = data[34]
```

```
#-----------------------------------------------------------
#déclaration des variables - fichier initial
#-----------------------------------------------------------
dry_bulb_temperature_init = data_init[6]
dew_point_temp_init = data_init[7]
relative_humidity_init = data_init[8]
atmospheric_pressure_init = data_init[9]
extraterrestrial_horizontal_radiation_init = data_init[10]
extraterrestrial_direct_normal_radiation_init = data_init[11]
horizontal_infrared_radiation_intensity_init = data_init[12]
global_horizontal_radiation_init = data_init[13]
direct_normal_radiation_init = data_init[14]
diffuse_horizontal_radiation_init = data_init[15]
global_horizontal_illuminance_init = data_init[16]
direct_normal_illuminance_init = data_init[17]
diffuse_horizontal_illuminance_init = data_init[18]
zenith_illuminance_init = data_init[19]
wind_direction_init = data_init[20]
wind_speed_init = data_init[21]
opaque_sky_cover_init = data_init[22]
visibility_init = data_init[23]
ceiling_height_init = data_init[24]
present_weather_observation_init = data_init[25]
present_weather_codes_init = data_init[26]
precipitable_water_init = data_init[27]
aerosol_optical_depth_init = data_init[28]
snow_depth_init = data_init[29]
days_since_last_snowfall_init = data_init[30]
albedo_init = data_init[31]
liquid_precipitation_depth_init = data_init[32]
liquid_precipitation_quantity_init = data_init[33]
unknown_init = data_init[34]
```

```
#-----------------------------------------------------------------------------------------------------
# RESULTATS
#-----------------------------------------------------------------------------------------------------
data[35] = dry_bulb_temperature - 26

liste = []
for i in data[35]:
    liste.append(max(i,0))

data['DeltaT_urb_CDh'] = liste







# COLORS (choose the line) for more colormaps check https://matplotlib.org/users/colormaps.html#list-colormaps
#cmap = plt.cm.viridis
#cmap = plt.cm.inferno
#cmap = plt.cm.Reds
#cmap = plt.cm.Oranges
#cmap = plt.cm.Blues_r
#cmap = plt.cm.Greys
cmap = plt.cm.OrRd
#cmap = plt.cm.afmhot

# STYLES (font size, etc...)
sns.set(context='talk', style='whitegrid')
# style options: 'darkgrid', 'whitegrid', 'white', 'dark', 'ticks'
# context options: 'paper', 'notebook', 'talk', 'poster'

data.index = pd.to_datetime(data.index+1, unit='h') # hourly time step

#To select summer (May-September)
datasummer=data.loc['1970-06-01':'1970-08-31']

# Ajour d'une colonne heure et jour
datasummer['hours'] = datasummer.index.hour
datasummer['days'] = datasummer.index.date

```

```
#-----------------------------------------------------------------------------------------
# Générer
#-----------------------------------------------------------------------------------------
#To create pivot table
piv = pd.pivot_table(datasummer, values='DeltaT_urb_CDh', index=["hours"], columns=["days"])
#print(piv)
pmin_max = pd.pivot_table(datasummer, values='DeltaT_urb_CDh', index=["days"], aggfunc= [min, max]) # get min and max values for each day
#
## To plot heatmap of a single column
label = u'$\ T_{urb}-26$ [°C]'
f, (ax0, ax) = plt.subplots(2,1, figsize=(20,10), gridspec_kw = {'height_ratios':[1, 3], 'hspace':0.1})
ax0.fill_between(pmin_max.index, pmin_max['min','DeltaT_urb_CDh'], pmin_max['max','DeltaT_urb_CDh'],
                 edgecolor=cmap(0.8), facecolor=cmap(0.8), label=label)
ax0.legend(loc='upper left')
ax0.autoscale(enable=True, axis='x', tight=True)
ax0.set_ylim(ymin=0)
ax0.get_xaxis().set_visible(False)
sns.heatmap(piv,vmin=0,vmax=10,xticklabels=30,yticklabels=6,ax=ax, cmap=cmap, cbar_ax=f.add_axes([.92,.13,.01,.5]), cbar_kws={'use_gridspec':True, 'label': label})
ax.invert_yaxis()
ax.set_xticklabels(['01-Jun','30-Jun','30-Jul','29-Aug'])



os.remove(dossier_parametre + init_uwg)
os.remove(dossier_parametre + init_txt)
os.remove('init0.txt')
```

Annex 2 : Minitab Data's

This is the values generated by Minitab. It represents all the samples tested for the experimentations.

N°	Build. Hei.	Build. Dens.	Ver. to Hor.	Road Alb.	Veg. cov.	Tree cov.	Roof Alb.	Veg. roof	Glaz. ratio	Wall alb.
1	17.5	0.1	0.5	0.5	0.5	0.1	0.1	0.5	0.5	0.1
2	17.5	0.9	0.5	0.5	0.5	0.1	0.1	0.5	0.5	0.1
3	17.5	0.1	0.5	0.5	0.5	0.9	0.1	0.5	0.5	0.1
4	17.5	0.9	0.5	0.5	0.5	0.9	0.1	0.5	0.5	0.1
5	17.5	0.1	0.5	0.5	0.5	0.1	0.9	0.5	0.5	0.1
6	17.5	0.9	0.5	0.5	0.5	0.1	0.9	0.5	0.5	0.1
7	17.5	0.1	0.5	0.5	0.5	0.9	0.9	0.5	0.5	0.1
8	17.5	0.9	0.5	0.5	0.5	0.9	0.9	0.5	0.5	0.1
9	17.5	0.1	0.5	0.5	0.5	0.1	0.1	0.5	0.5	0.9
10	17.5	0.9	0.5	0.5	0.5	0.1	0.1	0.5	0.5	0.9
11	17.5	0.1	0.5	0.5	0.5	0.9	0.1	0.5	0.5	0.9
12	17.5	0.9	0.5	0.5	0.5	0.9	0.1	0.5	0.5	0.9
13	17.5	0.1	0.5	0.5	0.5	0.1	0.9	0.5	0.5	0.9
14	17.5	0.9	0.5	0.5	0.5	0.1	0.9	0.5	0.5	0.9
15	17.5	0.1	0.5	0.5	0.5	0.9	0.9	0.5	0.5	0.9
16	17.5	0.9	0.5	0.5	0.5	0.9	0.9	0.5	0.5	0.9
17	5	0.1	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.1
18	30	0.1	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.1
19	5	0.9	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.1
20	30	0.9	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.1
21	5	0.1	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.1
22	30	0.1	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.1
23	5	0.9	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.1
24	30	0.9	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.1
25	5	0.1	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.9
26	30	0.1	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.9
27	5	0.9	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.9
28	30	0.9	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.9
29	5	0.1	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.9
30	30	0.1	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.9
31	5	0.9	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.9
32	30	0.9	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.9
33	17.5	0.1	0.1	0.5	0.5	0.5	0.1	0.1	0.5	0.5
34	17.5	0.9	0.1	0.5	0.5	0.5	0.1	0.1	0.5	0.5
35	17.5	0.1	0.9	0.5	0.5	0.5	0.1	0.1	0.5	0.5
36	17.5	0.9	0.9	0.5	0.5	0.5	0.1	0.1	0.5	0.5

37	17.5	0.1	0.1	0.5	0.5	0.5	0.9	0.1	0.5	0.5
38	17.5	0.9	0.1	0.5	0.5	0.5	0.9	0.1	0.5	0.5
39	17.5	0.1	0.9	0.5	0.5	0.5	0.9	0.1	0.5	0.5
40	17.5	0.9	0.9	0.5	0.5	0.5	0.9	0.1	0.5	0.5
41	17.5	0.1	0.1	0.5	0.5	0.5	0.1	0.9	0.5	0.5
42	17.5	0.9	0.1	0.5	0.5	0.5	0.1	0.9	0.5	0.5
43	17.5	0.1	0.9	0.5	0.5	0.5	0.1	0.9	0.5	0.5
44	17.5	0.9	0.9	0.5	0.5	0.5	0.1	0.9	0.5	0.5
45	17.5	0.1	0.1	0.5	0.5	0.5	0.9	0.9	0.5	0.5
46	17.5	0.9	0.1	0.5	0.5	0.5	0.9	0.9	0.5	0.5
47	17.5	0.1	0.9	0.5	0.5	0.5	0.9	0.9	0.5	0.5
48	17.5	0.9	0.9	0.5	0.5	0.5	0.9	0.9	0.5	0.5
49	17.5	0.1	0.5	0.1	0.5	0.1	0.5	0.5	0.1	0.5
50	17.5	0.9	0.5	0.1	0.5	0.1	0.5	0.5	0.1	0.5
51	17.5	0.1	0.5	0.9	0.5	0.1	0.5	0.5	0.1	0.5
52	17.5	0.9	0.5	0.9	0.5	0.1	0.5	0.5	0.1	0.5
53	17.5	0.1	0.5	0.1	0.5	0.9	0.5	0.5	0.1	0.5
54	17.5	0.9	0.5	0.1	0.5	0.9	0.5	0.5	0.1	0.5
55	17.5	0.1	0.5	0.9	0.5	0.9	0.5	0.5	0.1	0.5
56	17.5	0.9	0.5	0.9	0.5	0.9	0.5	0.5	0.1	0.5
57	17.5	0.1	0.5	0.1	0.5	0.1	0.5	0.5	0.9	0.5
58	17.5	0.9	0.5	0.1	0.5	0.1	0.5	0.5	0.9	0.5
59	17.5	0.1	0.5	0.9	0.5	0.1	0.5	0.5	0.9	0.5
60	17.5	0.9	0.5	0.9	0.5	0.1	0.5	0.5	0.9	0.5
61	17.5	0.1	0.5	0.1	0.5	0.9	0.5	0.5	0.9	0.5
62	17.5	0.9	0.5	0.1	0.5	0.9	0.5	0.5	0.9	0.5
63	17.5	0.1	0.5	0.9	0.5	0.9	0.5	0.5	0.9	0.5
64	17.5	0.9	0.5	0.9	0.5	0.9	0.5	0.5	0.9	0.5
65	5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1
66	30	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1
67	5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.1	0.1
68	30	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.1	0.1
69	5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.9	0.1
70	30	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.9	0.1
71	5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.9	0.1
72	30	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.9	0.1
73	5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.9
74	30	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.9
75	5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.1	0.9
76	30	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.1	0.9
77	5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.9	0.9
78	30	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.9	0.9
79	5	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.9	0.9

80	30	0.5	0.5	0.5	0.5	0.5	0.5	0.9	0.9	0.9
81	17.5	0.5	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.1
82	17.5	0.5	0.9	0.1	0.1	0.5	0.5	0.5	0.5	0.1
83	17.5	0.5	0.1	0.9	0.1	0.5	0.5	0.5	0.5	0.1
84	17.5	0.5	0.9	0.9	0.1	0.5	0.5	0.5	0.5	0.1
85	17.5	0.5	0.1	0.1	0.9	0.5	0.5	0.5	0.5	0.1
86	17.5	0.5	0.9	0.1	0.9	0.5	0.5	0.5	0.5	0.1
87	17.5	0.5	0.1	0.9	0.9	0.5	0.5	0.5	0.5	0.1
88	17.5	0.5	0.9	0.9	0.9	0.5	0.5	0.5	0.5	0.1
89	17.5	0.5	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.9
90	17.5	0.5	0.9	0.1	0.1	0.5	0.5	0.5	0.5	0.9
91	17.5	0.5	0.1	0.9	0.1	0.5	0.5	0.5	0.5	0.9
92	17.5	0.5	0.9	0.9	0.1	0.5	0.5	0.5	0.5	0.9
93	17.5	0.5	0.1	0.1	0.9	0.5	0.5	0.5	0.5	0.9
94	17.5	0.5	0.9	0.1	0.9	0.5	0.5	0.5	0.5	0.9
95	17.5	0.5	0.1	0.9	0.9	0.5	0.5	0.5	0.5	0.9
96	17.5	0.5	0.9	0.9	0.9	0.5	0.5	0.5	0.5	0.9
97	5	0.5	0.5	0.1	0.5	0.5	0.1	0.1	0.5	0.5
98	30	0.5	0.5	0.1	0.5	0.5	0.1	0.1	0.5	0.5
99	5	0.5	0.5	0.9	0.5	0.5	0.1	0.1	0.5	0.5
100	30	0.5	0.5	0.9	0.5	0.5	0.1	0.1	0.5	0.5
101	5	0.5	0.5	0.1	0.5	0.5	0.9	0.1	0.5	0.5
102	30	0.5	0.5	0.1	0.5	0.5	0.9	0.1	0.5	0.5
103	5	0.5	0.5	0.9	0.5	0.5	0.9	0.1	0.5	0.5
104	30	0.5	0.5	0.9	0.5	0.5	0.9	0.1	0.5	0.5
105	5	0.5	0.5	0.1	0.5	0.5	0.1	0.9	0.5	0.5
106	30	0.5	0.5	0.1	0.5	0.5	0.1	0.9	0.5	0.5
107	5	0.5	0.5	0.9	0.5	0.5	0.1	0.9	0.5	0.5
108	30	0.5	0.5	0.9	0.5	0.5	0.1	0.9	0.5	0.5
109	5	0.5	0.5	0.1	0.5	0.5	0.9	0.9	0.5	0.5
110	30	0.5	0.5	0.1	0.5	0.5	0.9	0.9	0.5	0.5
111	5	0.5	0.5	0.9	0.5	0.5	0.9	0.9	0.5	0.5
112	30	0.5	0.5	0.9	0.5	0.5	0.9	0.9	0.5	0.5
113	17.5	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5
114	17.5	0.5	0.9	0.5	0.1	0.5	0.1	0.5	0.1	0.5
115	17.5	0.5	0.1	0.5	0.9	0.5	0.1	0.5	0.1	0.5
116	17.5	0.5	0.9	0.5	0.9	0.5	0.1	0.5	0.1	0.5
117	17.5	0.5	0.1	0.5	0.1	0.5	0.9	0.5	0.1	0.5
118	17.5	0.5	0.9	0.5	0.1	0.5	0.9	0.5	0.1	0.5
119	17.5	0.5	0.1	0.5	0.9	0.5	0.9	0.5	0.1	0.5
120	17.5	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.1	0.5
121	17.5	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.9	0.5
122	17.5	0.5	0.9	0.5	0.1	0.5	0.1	0.5	0.9	0.5

123	17.5	0.5	0.1	0.5	0.9	0.5	0.1	0.5	0.9	0.5
124	17.5	0.5	0.9	0.5	0.9	0.5	0.1	0.5	0.9	0.5
125	17.5	0.5	0.1	0.5	0.1	0.5	0.9	0.5	0.9	0.5
126	17.5	0.5	0.9	0.5	0.1	0.5	0.9	0.5	0.9	0.5
127	17.5	0.5	0.1	0.5	0.9	0.5	0.9	0.5	0.9	0.5
128	17.5	0.5	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.5
129	5	0.5	0.1	0.5	0.5	0.1	0.5	0.5	0.1	0.5
130	30	0.5	0.1	0.5	0.5	0.1	0.5	0.5	0.1	0.5
131	5	0.5	0.9	0.5	0.5	0.1	0.5	0.5	0.1	0.5
132	30	0.5	0.9	0.5	0.5	0.1	0.5	0.5	0.1	0.5
133	5	0.5	0.1	0.5	0.5	0.9	0.5	0.5	0.1	0.5
134	30	0.5	0.1	0.5	0.5	0.9	0.5	0.5	0.1	0.5
135	5	0.5	0.9	0.5	0.5	0.9	0.5	0.5	0.1	0.5
136	30	0.5	0.9	0.5	0.5	0.9	0.5	0.5	0.1	0.5
137	5	0.5	0.1	0.5	0.5	0.1	0.5	0.5	0.9	0.5
138	30	0.5	0.1	0.5	0.5	0.1	0.5	0.5	0.9	0.5
139	5	0.5	0.9	0.5	0.5	0.1	0.5	0.5	0.9	0.5
140	30	0.5	0.9	0.5	0.5	0.1	0.5	0.5	0.9	0.5
141	5	0.5	0.1	0.5	0.5	0.9	0.5	0.5	0.9	0.5
142	30	0.5	0.1	0.5	0.5	0.9	0.5	0.5	0.9	0.5
143	5	0.5	0.9	0.5	0.5	0.9	0.5	0.5	0.9	0.5
144	30	0.5	0.9	0.5	0.5	0.9	0.5	0.5	0.9	0.5
145	17.5	0.5	0.5	0.1	0.1	0.1	0.5	0.1	0.5	0.5
146	17.5	0.5	0.5	0.9	0.1	0.1	0.5	0.1	0.5	0.5
147	17.5	0.5	0.5	0.1	0.9	0.1	0.5	0.1	0.5	0.5
148	17.5	0.5	0.5	0.9	0.9	0.1	0.5	0.1	0.5	0.5
149	17.5	0.5	0.5	0.1	0.1	0.9	0.5	0.1	0.5	0.5
150	17.5	0.5	0.5	0.9	0.1	0.9	0.5	0.1	0.5	0.5
151	17.5	0.5	0.5	0.1	0.9	0.9	0.5	0.1	0.5	0.5
152	17.5	0.5	0.5	0.9	0.9	0.9	0.5	0.1	0.5	0.5
153	17.5	0.5	0.5	0.1	0.1	0.1	0.5	0.9	0.5	0.5
154	17.5	0.5	0.5	0.9	0.1	0.1	0.5	0.9	0.5	0.5
155	17.5	0.5	0.5	0.1	0.9	0.1	0.5	0.9	0.5	0.5
156	17.5	0.5	0.5	0.9	0.9	0.1	0.5	0.9	0.5	0.5
157	17.5	0.5	0.5	0.1	0.1	0.9	0.5	0.9	0.5	0.5
158	17.5	0.5	0.5	0.9	0.1	0.9	0.5	0.9	0.5	0.5
159	17.5	0.5	0.5	0.1	0.9	0.9	0.5	0.9	0.5	0.5
160	17.5	0.5	0.5	0.9	0.9	0.9	0.5	0.9	0.5	0.5
161	17.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Annex 3: Results data

As mentioned in the Figure 2, this is the database obtained at the end. These values represent all the combinations and will be interpreted in the Analysis and mitigations from Annex 4: Interaction plots and Annex 5: Box plots.

N°	CDH tot	CDH moy.	UHI tot.	UHI moy.	RH var. inf. tot.	RH var. inf. moy.	RH var. sup. tot.	RH var. sup. moy.	Max. DI	Moy. DI	DIH
1	4682,7	0,535	218,8	0,025	24051,6	2,746	4617,8	0,527	27,358	13,34	621
2	21197	2,42	1206	0,138	100368,5	11,458	99,5	0,011	29,466	15,015	1295
3	4941,5	0,564	25,7	0,026	25343,3	2,893	3955,7	0,452	27,367	13,381	636
4	21445	2,448	1234	0,141	101349,6	11,57	79,5	0,009	29,453	15,036	1309
5	4681,6	0,534	218,8	0,025	24049	2,745	4613,4	0,527	27,358	13,34	621
6	22207	2,535	1349,4	0,154	104339,9	11,911	35,7	0,004	29,592	15,099	1354
7	4941,2	0,564	226,1	0,026	25339,9	2,893	3931,6	0,449	27,367	13,381	636
8	22487	2,567	1384,8	0,158	105441,1	12,037	28,1	0,003	29,58	15,122	1369
9	4644,3	0,53	218	0,025	23877	2,726	4640,1	0,53	27,358	13,336	618
10	21376	2,44	1240,5	0,142	101033,2	11,533	91,1	0,01	29,453	15,028	1310
11	4939,9	0,564	227,9	0,026	25339,5	2,893	3795,8	0,433	27,367	13,384	637
12	22012	2,513	1317,6	0,15	103538,1	11,819	48,7	0,006	29,496	15,081	1342
13	4642,3	0,53	218	0,025	23870,7	2,725	4636,9	0,529	27,358	13,336	619
14	22358	2,552	1385,3	0,158	104875	11,972	35	0,004	29,58	15,109	1368
15	4942,7	0,564	228,3	0,026	25345,1	2,893	3764,7	0,43	27,367	13,384	637
16	23117	2,639	1481,4	0,169	107825,9	12,309	18,6	0,002	29,659	15,172	1405
17	4764,9	0,544	223	0,025	24449,8	2,791	4143,2	0,473	27,377	13,358	632
18	4958,3	0,566	229,8	0,026	25423,4	2,902	3858,8	0,441	27,414	13,384	640
19	15285	1,745	689,2	0,079	74668,6	8,524	245,4	0,028	28,662	14,477	1034
20	27843	3,178	2001,8	0,229	127215,4	14,522	15,5	0,002	30,17	15,582	1625
21	4634,4	0,529	213,8	0,024	23852	2,723	4792,9	0,547	27,367	13,333	618
22	4842,3	0,553	220,8	0,025	24878,2	2,84	4428,7	0,506	27,377	13,362	631
23	15285	1,745	689,2	0,079	74668,6	8,524	245,4	0,028	28,662	14,477	1034
24	27843	3,178	2001,8	0,229	127215,4	14,522	15,5	0,002	30,17	15,582	1625
25											
26	4963,1	0,567	231,4	0,026	25433,7	2,903	3711	0,424	27,414	13,387	642
27	15732	1,796	739,9	0,084	76457	8,728	184,4	0,021	28,778	14,514	1064
28	28174	3,216	2076,6	0,237	128405,2	14,658	13	0,001	30,208	15,607	1657
29											
30	4800,4	0,548	220,1	0,025	24684,8	2,818	4446,9	0,508	27,377	13,357	629
31	15732	1,796	739,9	0,084	76457	8,728	184,4	0,021	28,778	14,514	1064
32	28174	3,216	2076,6	0,237	128405,2	14,658	13	0,001	30,208	15,607	1657
33	4658,5	0,532	218,3	0,025	23901,8	2,729	4532,3	0,517	27,358	13,338	630
34	22096	2,522	1457,1	0,166	103806,7	11,85	89,4	0,01	29,933	15,082	1336
35	4932,2	0,563	224,2	0,026	25360,6	2,895	4051,7	0,463	27,367	13,38	633
36	21556	2,461	1249,9	0,143	101904,1	11,633	67,7	0,008	29,453	15,05	1303

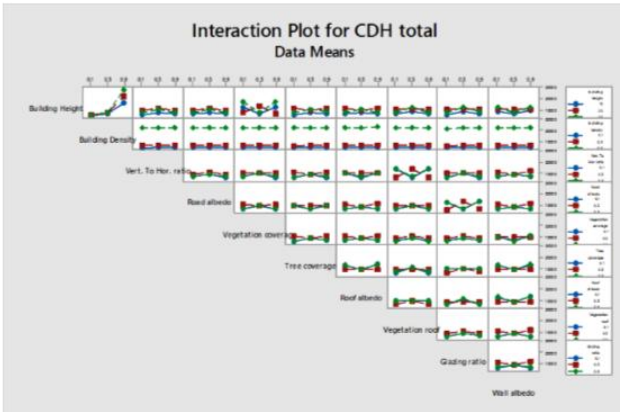
37	4659,4	0,532	218,4	0,025	23905,9	2,729	4509,4	0,515	27,358	13,338	631
38	22851	2,609	1370,1	0,156	107176,2	12,235	33,6	0,004	29,58	15,155	1375
39	4933,5	0,563	224,5	0,026	25365,4	2,896	4035,8	0,461	27,367	13,381	634
40	22521	2,571	1392	0,159	105658,3	12,061	23,9	0,003	29,575	15,13	1358
41	4658,5	0,532	218,3	0,025	23901,8	2,729	4532,3	0,517	27,358	13,338	630
42	22096	2,522	1457,1	0,166	103806,7	11,85	89,4	0,01	29,933	15,082	1336
43	4932,2	0,563	224,2	0,026	25360,6	2,895	4051,7	0,463	27,367	13,38	633
44	21556	2,461	1249,9	0,143	101904,1	11,633	67,7	0,008	29,453	15,05	1303
45	4659,4	0,532	218,4	0,025	23905,9	2,729	4509,4	0,515	27,358	13,338	631
46	22851	2,609	1370,1	0,156	107176,2	12,235	33,6	0,004	29,58	15,155	1375
47	4933,5	0,563	224,5	0,026	25365,4	2,896	4035,8	0,461	27,367	13,381	634
48	22521	2,571	1392	0,159	105658,3	12,061	23900	0,003	29,575	15,13	1358
49	4581	0,523	216,7	0,025	23509	2,684	4724,8	0,539	27,358	13,326	622
50	21241	2,425	1226,6	0,14	100384,1	11,459	86,8	0,01	29,466	15,012	1309
51	4541,5	0,518	210,1	0,024	23326,9	2,663	5348,5	0,611	27,321	13,31	615
52	21270	2,428	1226,6	0,14	100518,1	11,475	94	0,011	29,466	15,015	1308
53	4867,8	0,556	226,1	0,026	24940,8	2,847	3893,9	0,445	27,367	13,372	636
54	21642	2,471	1272	0,145	101969,9	11,64	58,4	0,007	29,508	15,046	1326
55	4796,8	0,548	218,4	0,025	24625,1	2,811	4441,4	0,507	27,367	13,355	630
56	21669	2,474	1271,9	0,145	102085	11,654	63,9	0,007	29,453	15,048	1325
57	4803,6	0,548	225,1	0,026	24661,9	2,815	4087,1	0,467	27,367	13,365	629
58	22076	2,52	1332,1	0,152	103934,1	11,865	45,2	0,005	29,58	15,093	1329
59	4758,3	0,543	220,7	0,025	24464	2,793	4516,9	0,516	27,377	13,352	625
60	22100	2,523	1331,5	0,152	104040,6	11,877	49,2	0,006	29,526	15,095	1329
61	5088,1	0,581	233	0,027	26102,3	2,98	3427,7	0,391	27,404	13,408	644
62	22486	2,567	1379,5	0,157	105542,7	12,048	31,7	0,004	26,575	15,127	1352
63	5011,5	0,572	227,4	0,026	25753,1	2,94	3841,9	0,439	27,367	13,392	636
64	22514	2,57	1379,9	0,158	105658,6	12,061	34,9	0,004	29,58	15,129	1354
65	5648,5	0,645	248,6	0,028	28939,7	3,304	3075,4	0,351	27,473	13,471	665
66	7454,3	0,851	324,4	0,037	37723,6	4,306	1940	0,221	27,702	13,667	734
67	5648,5	0,645	248,6	0,028	28939,7	3,304	3075,4	0,351	27,473	13,471	665
68	7454,3	0,851	324,4	0,037	37723,6	4,306	1940	0,221	27,702	13,667	734
69	5866,9	0,67	255,8	0,029	30120,1	3,438	2763,5	0,315	27,454	13,505	670
70	7655,8	0,874	330,7	0,038	38731,6	4,421	1815,2	0,207	27,692	13,703	734
71	5866,9	0,67	255,8	0,029	30120,1	3,438	2763,5	0,315	27,454	13,505	670
72	7655,8	0,874	330,7	0,038	387313,6	4,421	1815,2	0,207	27,692	13,703	734
73	5496,9	0,628	240,1	0,027	28223,9	3,222	3464,8	0,396	27,409	13,449	658
74	7291,8	0,832	314,8	0,036	36983,9	4,222	2158,7	0,246	27,639	13,658	724
75	5496,9	0,628	240,1	0,027	28223,9	3,222	3464,8	0,396	27,409	13,449	658
76	7291,8	0,832	314,8	0,036	36983,9	4,222	2158,7	0,246	27,639	13,658	724
77	5971,7	0,682	263,3	0,03	30551,9	3,488	2465,7	0,281	27,508	13,52	672
78	7720,7	0,881	337,5	0,039	39015,6	4,454	1634,2	0,187	27,672	13,712	738
79	5971,7	0,682	263,3	0,03	30551,9	3,488	2465,7	0,281	27,508	13,52	672
80	7720,7	0,881	337,5	0,039	39015,6	4,454	1634,2	0,187	27,672	13,712	738

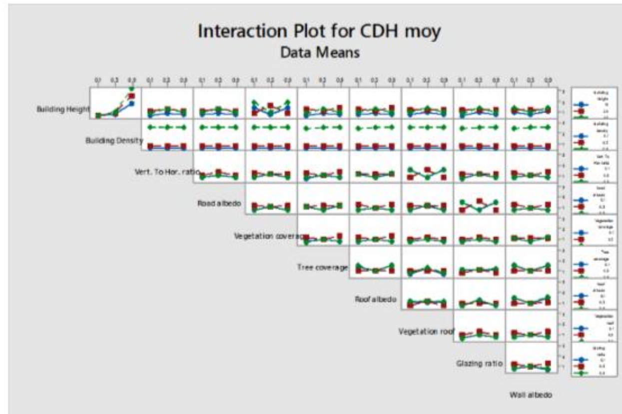
81	6869,6	0,784	293,6	0,034	34884,7	3,982	1797,2	0,205	27,596	13,62	707
82	6898	0,787	294,3	0,034	35095,7	4,006	1612	0,218	27,596	13,626	702
83	6645,7	0,759	278,2	0,032	33898,1	0,87	2473,3	0,282	27,56	13,586	693
84	6854,1	0,782	288,7	0,033	34907,9	3,985	2101,9	0,24	27,605	13,618	699
85	6571,5	0,75	275,4	0,031	33527,5	3,827	2517,8	0,287	27,542	13,579	692
86	6755,4	0,771	284,4	0,032	34451,1	3,933	2125,2	0,243	27,605	13,608	696
87	6600,6	0,753	274,9	0,031	33681,6	3,845	2602,7	0,297	27,56	13,58	693
88	6791,5	0,775	284,4	0,032	34636,8	3,954	2190,4	0,25	27,615	13,61	699
89	6877,5	0,785	293,8	0,034	34918,8	3,986	1782,3	0,203	27,596	13,621	707
90	6984,5	0,797	300,6	0,034	35450,2	4,047	1712,3	0,195	27,649	13,636	709
91	6635,4	0,757	277,4	0,032	33840,2	3,863	2496,2	0,285	27,56	13,585	694
92	6862,8	0,783	292,8	0,033	34903,4	3,984	1970,3	0,225	27,605	13,62	705
93	6558,8	0,749	274,3	0,031	33472,2	3,821	2541	0,29	27,552	13,577	692
94	6748,3	0,77	286,2	0,033	34382,6	3,925	2033,9	0,232	27,596	13,608	694
95	6588,5	0,752	274	0,031	33626,1	3,839	2632,6	0,301	27,56	13,578	694
96	6776,6	0,774	285,2	0,033	34535,1	3,942	2094,1	0,239	27,605	13,61	697
97	5717,6	0,653	251,4	0,029	29293,6	3,344	2952,4	0,337	27,463	13,483	667
98	7491,8	0,855	325,2	0,037	37926	4,329	1927,1	0,22	27,692	13,683	730
99	5752,3	0,657	250,9	0,029	29466	3,364	3024,1	0,345	27,473	13,485	666
100	7530	0,86	325,7	0,037	38117,2	4,351	1983	0,226	27,702	13,686	729
101	5746,5	0,656	254,4	0,029	29424,6	3,359	2753,8	0,314	27,46	13,49	669
102	7546,1	0,861	329,1	0,038	38165,5	4,357	1753,4	0,2	27,689	13,692	732
103	5784,8	0,66	254,2	0,029	29602,9	3,379	2813,5	0,321	27,463	13,493	668
104	7586,5	0,866	328,9	0,038	38371,4	4,38	1804,7	0,206	27,692	13,695	730
105	5717,6	0,653	251,4	0,029	29293,6	3,344	2952,4	0,337	27,463	13,483	667
106	7491,8	0,855	325,2	0,037	37926	4,329	1927,1	0,22	27,692	13,683	730
107	5752,3	0,657	250,9	0,029	29466,5	3,364	3024,1	0,345	27,473	13,485	666
108	7530	0,86	325,7	0,037	38117,2	4,351	1983	0,226	27,702	13,686	729
109	5746,5	0,656	254,4	0,029	29424,6	3,359	2753,8	0,314	27,46	13,49	669
110	7546,1	0,861	329,1	0,038	38165,5	4,357	1753,4	0,2	27,689	13,692	732
111	5748,8	0,66	254,2	0,029	29602,9	3,379	2813,5	0,321	27,463	13,493	668
112	7586,5	0,866	328,9	0,038	38371,4	4,38	1804,7	0,206	27,692	13,695	730
113	6692,3	0,764	282,2	0,032	34080,1	3,89	2229,9	0,255	27,56	13,595	701
114	6628,4	0,757	281,3	0,032	33740,2	3,852	2283,4	0,261	27,56	13,588	702
115	6522,8	0,745	272,4	0,031	33325,6	3,804	2709,2	0,309	27,562	13,57	689
116	6504,1	0,742	273,9	0,031	33214,4	3,792	2502,4	0,286	27,552	13,573	692
117	6761,7	0,772	287,3	0,033	34385,8	3,925	2026,9	0,231	27,605	13,605	703
118	6672,7	0,762	285	0,033	33937,6	3,874	2114,6	0,241	27,605	13,595	702
119	6574,8	0,751	275,4	0,031	33550,4	3,83	2482,7	0,283	27,56	13,579	693
120	6539,7	0,747	277,6	0,032	33358	3,808	2329,7	0,266	27,547	13,579	693
121	6763,5	0,772	285,2	0,033	34429,5	3,93	2154,1	0,246	27,605	13,604	702
122	7140,1	0,815	301,9	0,034	36269,3	4,14	1761,1	0,201	27,659	13,655	709
123	6593,8	0,753	274,2	0,031	33665,3	3,843	2610,9	0,298	27,552	13,579	693
124	7016,3	0,801	294	0,034	35727,5	4,078	1929,4	0,22	27,596	13,641	700

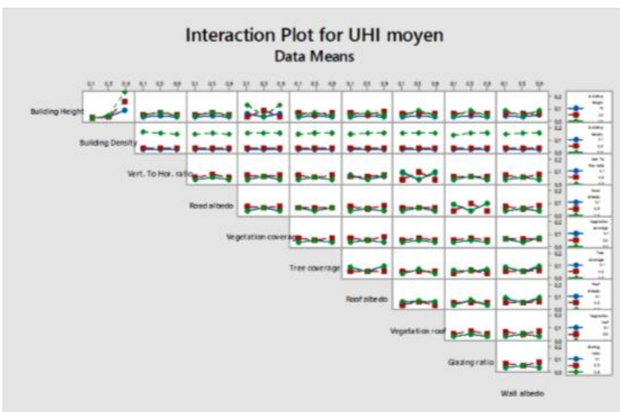
125	6835,3	0,78	291,3	0,033	34750,2	3,967	1954,2	0,223	27,601	13,614	706
126	7197,2	0,822	306	0,035	36506,1	4,167	1615,2	0,184	27,649	13,663	710
127	6649,4	0,759	279,5	0,032	33909	3,871	2397,1	0,274	27,56	13,589	694
128	7057,1	0,806	297,6	0,034	35923,6	4,101	1764	0,201	27,659	13,648	704
129	5328,9	0,608	232,8	0,027	27343	3,121	4229,7	0,483	27,428	13,415	650
130	7086,2	0,809	302,7	0,035	36046,1	4,115	2560,6	0,292	27,649	13,629	716
131	5482,6	0,626	241,2	0,028	28166,3	3,215	3483	0,398	27,412	13,448	659
132	7237,1	0,826	312,1	0,036	36722,8	4,192	2179,4	0,249	27,639	13,652	724
133	5702,8	0,651	249,1	0,028	29182,1	3,331	2939,7	0,336	27,473	13,479	667
134	7542,8	0,861	325,6	0,037	38211,7	4,362	1859,2	0,212	27,702	13,688	734
135	5675,8	0,648	249,1	0,028	29087,9	3,321	2895,4	0,331	27,473	13,479	667
136	7455,8	0,851	324	0,037	37720,8	4,306	1846,4	0,211	27,635	13,68	733
137	5402,6	0,617	236,1	0,027	27720,4	3,164	4019,7	0,459	27,419	13,428	653
138	7149,1	0,816	305,5	0,035	36375	4,152	2479,2	0,283	27,639	13,638	721
139	6052,9	0,691	262,5	0,03	31036,4	3,543	2495,1	0,285	27,517	13,533	672
140	7737,7	0,883	334,8	0,038	39139,4	4,468	1657,8	0,189	27,682	13,716	732
141	5774,6	0,659	252,9	0,029	29542	3,372	2813,8	0,321	27,463	13,49	670
142	7611,9	0,869	328,9	0,038	38539,2	4,399	1803,5	0,206	27,692	13,697	736
143	6241,2	0,712	269,2	0,031	31968,9	3,649	2129,7	0,243	27,508	13,559	675
144	7963,2	0,909	342,4	0,039	40155,4	4,584	1432,6	0,164	27,745	13,742	737
145	6608,4	0,754	287,2	0,033	33621,7	3,838	2120,5	0,242	27,596	13,589	696
146	6516,4	0,744	280,1	0,032	3324,8	3,793	2464,1	0,281	27,56	13,574	693
147	6416,8	0,733	276,1	0,032	32768,9	3,741	2558,5	0,292	27,547	13,563	685
148	6453,9	0,737	275,1	0,031	32942	3,761	2619,2	0,299	27,56	13,566	686
149	6926,4	0,791	299,1	0,034	35130,6	4,01	1689,7	0,193	27,586	13,628	709
150	6805,1	0,777	291,4	0,033	34584	3,948	1975,4	0,226	27,605	13,612	703
151	6695,1	0,764	286,3	0,033	34073,5	3,89	2036,3	0,232	27,605	13,601	697
152	6730,2	0,768	285,7	0,033	34252,8	3,91	2096,8	0,239	27,605	13,603	698
153	6608,4	0,754	287,2	0,033	33621,7	3,838	2120,5	0,242	27,596	13,589	696
154	6516,4	0,744	280,1	0,032	33224,8	3,793	2464,1	0,281	27,56	13,574	693
155	6416,8	0,733	276,1	0,032	32768,9	3,741	2558,5	0,292	27,547	13,563	685
156	6453,9	0,737	275,1	0,031	32942	3,761	2619,2	0,299	27,56	13,567	686
157	6926,4	0,791	299,1	0,034	35130,6	4,01	1689,7	0,193	27,586	13,628	709
158	6805,1	0,777	291,4	0,033	34584	3,948	1975,4	0,226	27,605	13,612	703
159	6695,1	0,764	286,3	0,033	34073,5	3,89	2036,3	0,232	27,605	13,601	697
160	6730,2	0,768	285,7	0,033	34252,8	3,91	2096,8	0,239	27,605	13,603	698
161	6643	0,758	281,9	0,032	33884,9	3,868	2278,5	0,26	27,605	13,591	696

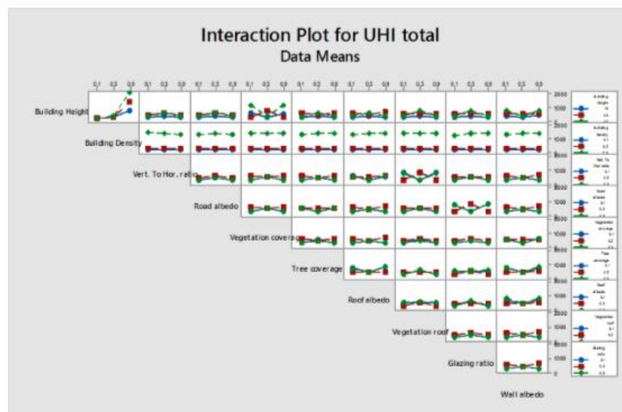
Annex 4: Interaction plots

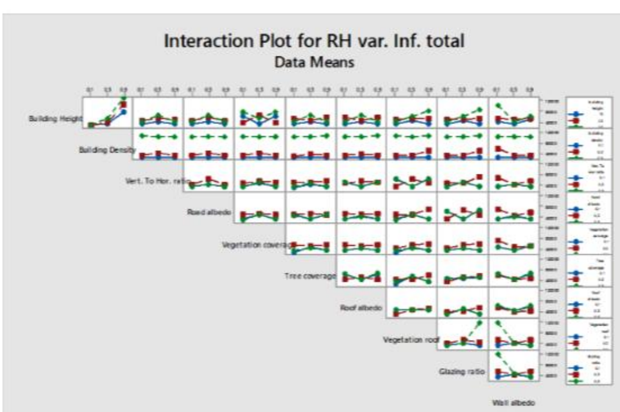
From Minitab, we generate interaction plots. These plots are made from Annex 2 : Minitab Data's and Annex 3: Results data.

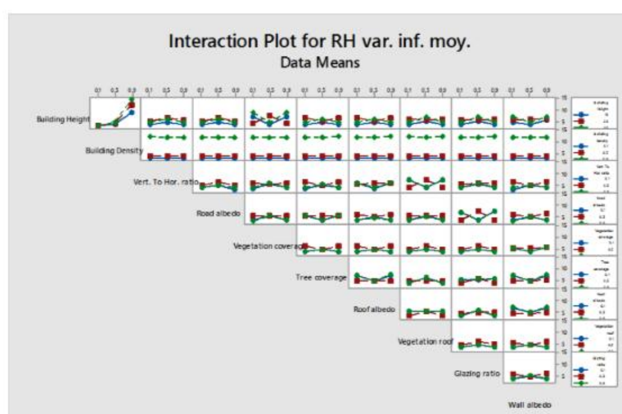


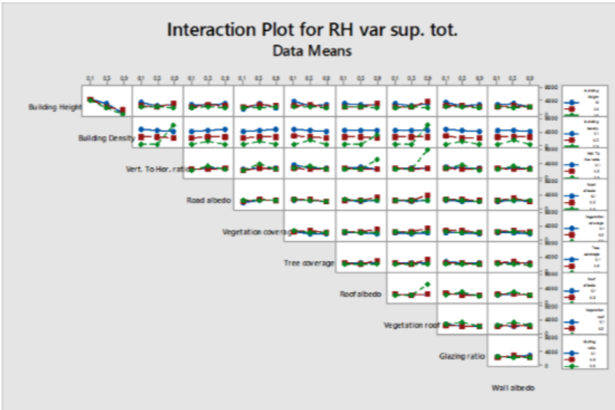


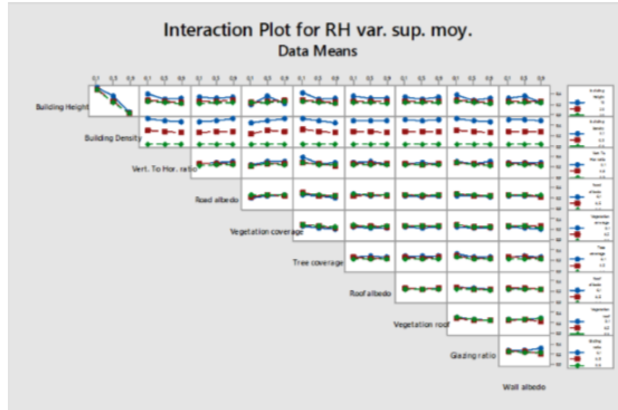


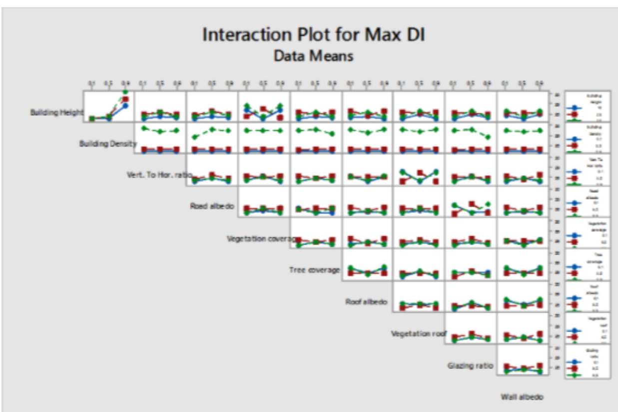


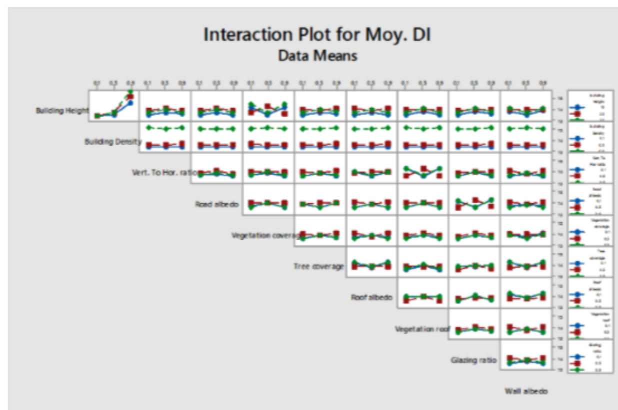


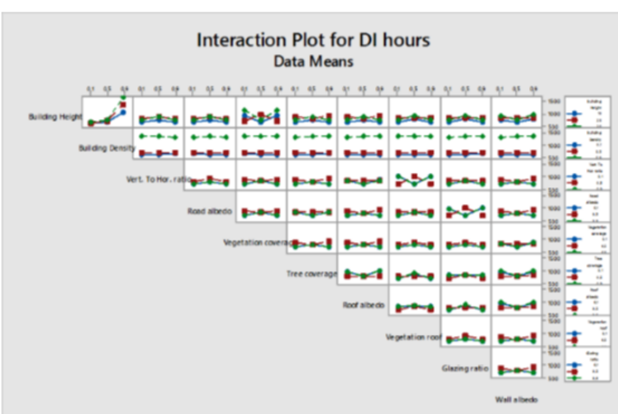



Interaction Plot for RH var sup. tot.
Data Means
Building Height
Building Density
Vert. To Hor. ratio
Road albedo
Vegetation coverage
Tree coverage
Roof albedo
Vegetation roof
Glazing ratio
Wall albedo


Interaction Plot for RH var. sup. moy.
Data Means
Building Height
Building Density
Vert. To Hor. ratio
Road albedo
Vegetation coverage
Tree coverage
Roof albedo
Vegetation roof
Glazing ratio
Wall albedo

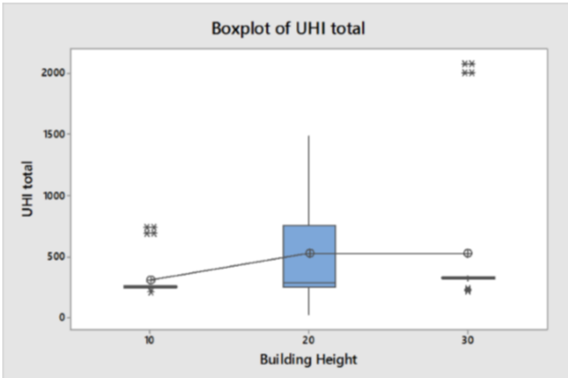

Interaction Plot for Max DI
Data Means
Building Height
Building Density
Vert. To Hor. ratio
Road albedo
Vegetation coverage
Tree coverage
Roof albedo
Vegetation roof
Glazing ratio
Wall albedo

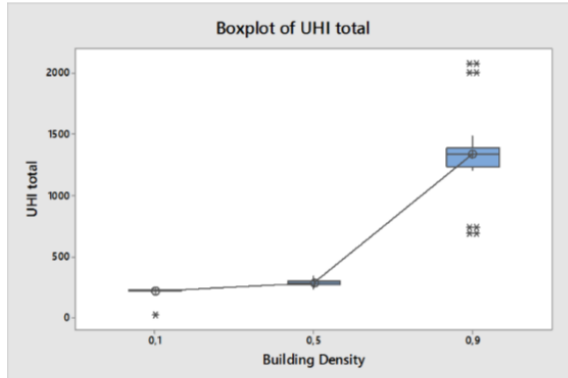

Interaction Plot for Moy. DI
Data Means
Building Height
Building Density
Vert. To Hor. ratio
Road albedo
Vegetation coverage
Tree coverage
Roof albedo
Vegetation roof
Glazing ratio
Wall albedo

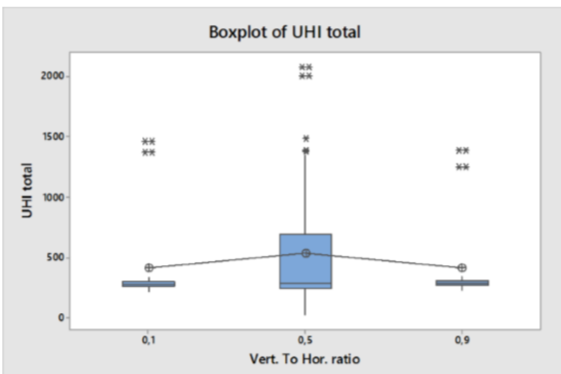

Interaction Plot for DI hours
Data Means
Building Height
Building Density
Vert. To Hor. ratio
Road albedo
Vegetation coverage
Tree coverage
Roof albedo
Vegetation roof
Glazing ratio
Wall albedo

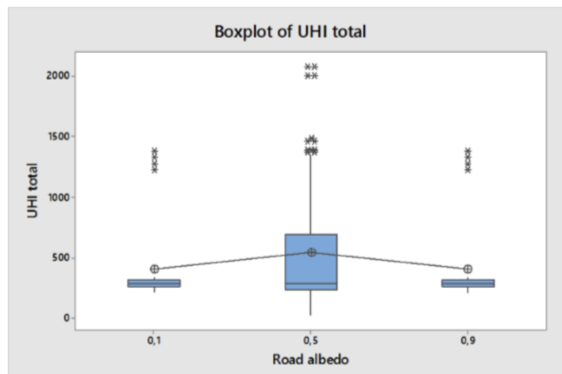
Annex 5: Box plots

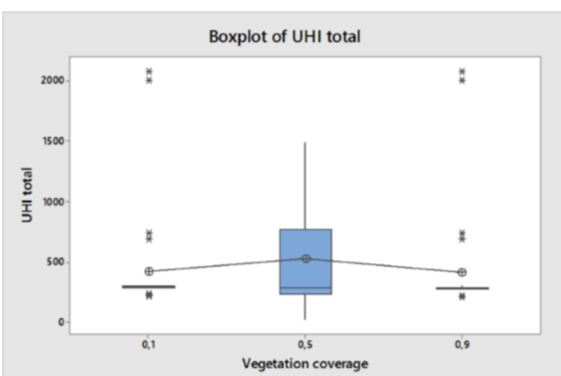
From Minitab, we generate box plots. These plots are made from Annex 2 : Minitab Data's and Annex 3: Results data.

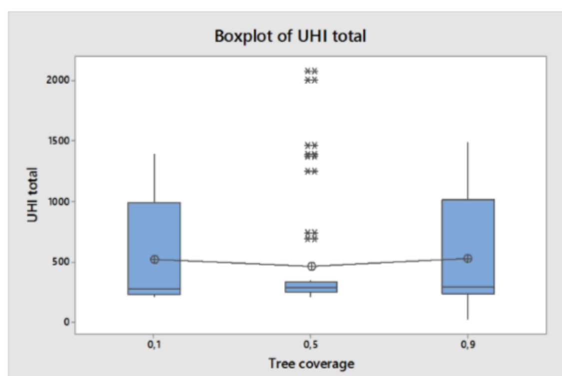


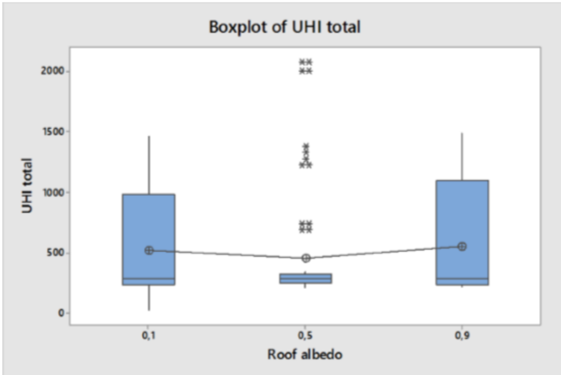


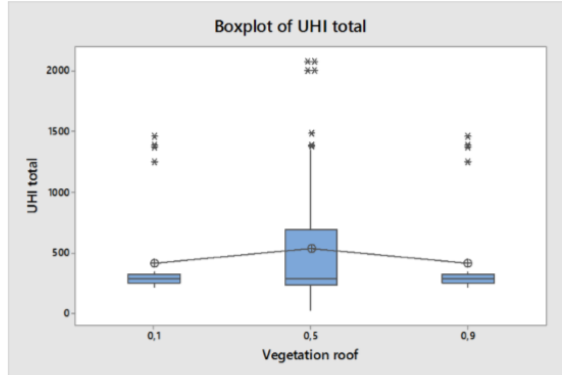


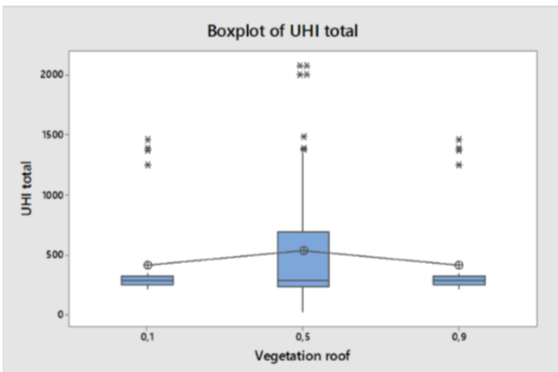


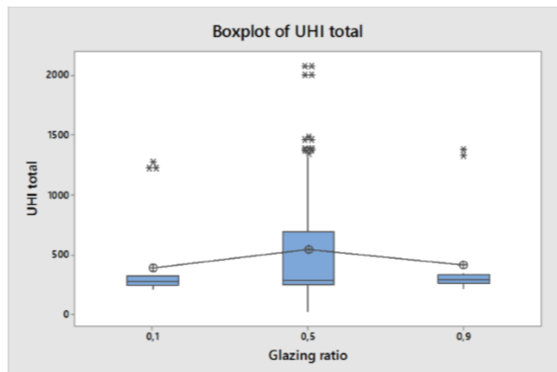


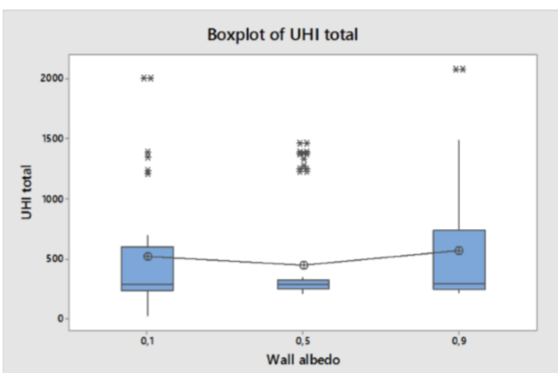



Boxplot of UHI total
UHI total
2000
1500
1000
500
0
0,1
0,5
0,9
Roof albedo


Boxplot of UHI total
UHI total
2000
1500
1000
500
0
0,1
0,5
0,9
Vegetation roof


Boxplot of UHI total
UHI total
2000
1500
1000
500
0
0,1
0,5
0,9
Vegetation roof


Boxplot of UHI total
UHI total
2000
1500
1000
500
0
0,1
0,5
0,9
Glazing ratio


Boxplot of UHI total
UHI total
2000
1500
1000
500
0
0,1
0,5
0,9
Wall albedo