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SOURCES AND MEANS OF ACTION TO REDUCE THE URBAN HEAT ISLAND EFFECT APPLIED TO SERVICE AND LOGISTICS BUILDINGS

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

SOURCES AND MEANS OF ACTION TO REDUCE THE URBAN HEAT ISLAND EFFECT APPLIED TO SERVICE AND LOGISTICS BUILDINGS

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico 2021/22 es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos.

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Autorizada la entrega del proyecto

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Fuentes y medios de actuación para reducir el efecto de las Islas De Calor Urbanas aplicado a los edificios de servicios y logística

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Entidad colaboradora: Sociedad PAYET

Resumen del proyecto

El objetivo principal de este proyecto es mostrar la influencia de las islas de calor urbanas mediante su cuantificación (Puntuación ICU). Este fenómeno se produce en áreas metropolitanas y tiene un impacto directo en el medio ambiente y en la salud y bienestar de sus ciudadanos [1]. Este estudio se realizará desde el punto de vista del mundo de la construcción y la rehabilitación de edificios.
Del mismo modo, se presentará un plan de acción para reducir las islas de calor urbanas mediante medidas que podrían ser tomadas en los proyectos.
Este proyecto ha sido posible gracias a mi posición como alumna de prácticas en la empresa PAYET durante 5 meses. Finalmente, para mostrar todos los conocimientos adquiridos durante este periodo, se presentarán algunos estudios sobre el comportamiento ambiental de diferentes proyectos de construcción y renovación que han sido realizados. Estos estudios energéticos se han realizado al mismo tiempo que el desarrollo de la declaración de investigación sobre las islas de calor urbanas.

Palabras clave: islas de calor urbanas, cuantificación, plan de acción.

1. Introducción

Las certificaciones o etiquetas medioambientales en el sector de la construcción están empezando a expandirse y a popularizarse desde que el cambio climático es un problema innegable, encontrándose presente en nuestro día a día.
La sociedad PAYET me ha permitido realizar durante un periodo de 5 meses un enunciado de investigación en el ámbito de la construcción sostenible. Dicho enunciado consiste en la investigación de la prevención de los efectos causados por las islas de calor urbanas.
PAYET es una sociedad joven de aproximadamente 15 empleados que se encarga de ayudar a las distintas empresas a transformar el sector de la construcción hacia un ámbito más sostenible [2]. Una de estas ayudas consiste en el acompañamiento en el proceso de obtención de unas etiquetas/certificaciones medioambientales (HQE BD, BREEAM, WELL…) a diferentes equipos de construccion. Dichas

certificaciones no son obligatorias, sin embargo, las empresas las consideran una buena herramienta para atraer inversores o clientes.

Para la obtención de dichas certificaciones, es necesario cumplir ciertas pautas marcadas por la certificación que normalmente tratan temas como el confort del usuario o el control de la consumición energética del edificio (de agua, electricidad…)

El enunciado de este trabajo de fin de grado surge de la necesidad de PAYET para adaptarse a la nueva actualización del reglamento HQE BD (acrónimo de “Alta calidad medioambiental Edificio Sostenible” en castellano), que incluye en su nueva versión una necesidad de valoración de las islas de calor urbanas.

2. Descripción de la propuesta

Las islas de calor urbanas se representan por la diferencia de temperatura entre un área metropolitana y sus alrededores. Hasta ahora, no se trata de un tema que haya sido estrictamente evaluado por el sector de la construcción sostenible y por tanto no hay ninguna herramienta estándar de cálculo y valoración oficial establecida por ninguna entidad. Como consecuencia, el objetivo de esta investigación consiste en crear una herramienta de cuantificación de las islas de calor urbanas a nivel de la parcela de una construcción/renovación que permita satisfacer los requisitos de la nueva versión de la certificación HQE BD. Los requisitos de esta regulación determinan que, para un proyecto que sea considerado aplicable para la obtención de los créditos, los efectos de las islas de calor urbanas deben verse reducidos un 10% con respecto a la situación parcelaria anterior al comienzo del proyecto.

Para cuantificar dicho efecto serán considerados aquellos factores posibles de evaluar en una escala horizontal “micro” y verticalmente desde la superficie hasta la capa de dosel. Todos ellos son causados por la acción humana, es decir, son modificables. Dichas variables son: la relación de aspecto, el factor de superficie del edificio, el factor de superficie permeable, la altura de los elementos voluminosos, el albedo, la emisividad y el calor antrópico. [3]

3. Resultados e interpretación

Para comprobar la eficacia del método de cuantificación creado a partir de la valoración de las variables mencionadas, se ha probado la herramienta de cálculo “Puntuación ICU” en 3 tipos de proyectos distintos: una construcción con finalidad logística nueva en un terreno vacío y con suelo vegetal (Corbas T3); una construcción de un hotel nuevo a partir de una estructura abandonada (MOB Hotel Bordeaux) y un proyecto de renovación de un edificio haussmaniano céntrico en la ciudad de París (1bis Foch).

Los resultados obtenidos para cada uno de los proyectos han sido coherentes con las particularidades de cada uno de ellos:

- El proyecto PRD Corbas T3 ha obtenido un resultado de porcentaje de mejora con respecto a su parcela inicial de -181%. Esto es un resultado con un valor absoluto muy grande y con signo negativo, lo que quiere decir que dicho edificio contribuirá fuertemente al empeoramiento de los efectos causados por las islas de calor urbanas de una manera muy considerable. Dicho resultado resulta ser coherente, puesto que al tratarse de un edificio nuevo construido sobre un terreno campestre es evidente que variables como la permeabilidad, la altura o la emisividad entre otros se verán empeorados. Si damos un paso hacia atrás, un nuevo edificio construido en un terreno vegetal retendrá siempre más calor en su parcela que si este mismo no existiese.
- El proyecto MOB Hotel Bordeaux ha obtenido una Puntuación ICU de 21%. Al ser este porcentaje positivo y superior a un 10%, este proyecto obtendría los créditos que corresponden al criterio de evaluación de las islas de calor urbanas, permitiéndole mejorar su evaluación de la certificación HQE BD. El resultado obtenido resulta coherente con las características presentadas por este proyecto de construcción nueva, puesto que al partir como base de construcción de una estructura inutilizada, variables como la altura o el porcentaje de superficie construida no se ven modificadas. Además, variables como la relación del aspecto, la permeabilidad y el albedo se han visto mejorados. Sin embargo, variables como el calor antrópico y la emisividad se han visto empeoradas, esto es debido al reforzamiento de las paredes verticales y la instalación de sistemas de aire acondicionado.
- Finalmente, el proyecto 1bis Foch ha obtenido un resultado de porcentaje de mejora con respecto a su parcela inicial de -1%. Esto quiere decir que su realización apenas ha influido al efecto de las islas de calor urbanas, más precisamente, ha causado un ligero empeoramiento de dicho efecto. Esto resulta de nuevo lógico, puesto que al tratarse de un proyecto de renovación la base y las paredes exteriores del mismo no se han visto modificadas y por tanto se intuía que el resultado de mejora seria próximo a 0. Variables como la permeabilidad se han visto mejoradas debido al ligero aumento de los espacios verdes: Sin embargo, variables como el calor antrópico, debido a la instalación de un sistema de aire acondicionado, se han visto perjudicadas. Al final, se ha establecido prácticamente un equilibro neutro con respecto a la provocación de un efecto de islas de calor urbanas.

4. Plan de acción

La certificación HQE BD también precisa la importancia de la elaboración de un plan de acción contra el efecto causado por las islas de calor urbanas: Este plan tiene como objetivo el poder ofrecer una alternativa de reducción de este efecto a los proyectos evaluados. Algunas de las estrategias de acción a seguir son: la utilización de materiales con un alto albedo (cool roofs), el incremento de los espacios verdes, el aumento de las superficies que contengan agua, la instalación de estructuras de sombra, la evaluación de los fluidos frigoríficos que son utilizados en los aires acondicionados, la instalación de sistemas de regulación de temperatura geotérmicos… [4]

5. Conclusiones

Finalmente, puede ser concluido que de entre los 3 proyectos evaluados solamente uno de ellos obtendría los créditos de la certificación HQE BD con respecto al tema de las islas de calor urbanas. El hecho de poder cuantificar este efecto nos ayuda a tener una base numérica y más visual sobre la cual justificar la aplicación de medidas de las acciones contra los efectos de las islas de calor urbanas.

Sin embargo, el objetivo final de esta evaluación no es la obtención de puntos si no la concienciación sobre este dañino efecto a todo el equipo del proyecto y la valoración de las distintas alternativas que permitirían reducirlo.

La obtención de una certificación o de una etiqueta medioambiental no debe verse como un fin último, sino como una justificación de que el proyecto ha sido examinado desde una perspectiva medioambiental. La constante presencia del proceso de consecución de estas etiquetas durante el avance del proyecto sirve de ayuda a la progresiva concienciación de resto del equipo de construcción. Como consecuencia, ciertas medidas suplementarias, que van más a allá de la certificación medioambiental, pueden llegar a ser consideradas e incluso aplicadas. De esta manera, se conseguiría reducir el cambio climático desde uno de los sectores más contaminantes del planeta.

6. Referencias

[1]Morgann Stanley, «Urban Heat Island», https://www.nationalgeographic.org/encyclopedia/urban-heat-island/, (accessed April 2022)

[2] Official Web Page, «Home», https://PAYET.fr/, (accessed May 2022)

[3] I. D. Stewart and T. R. Oke, 2012, Local Climate Zones For Urban Temperature Studies. (accessed July 2022).

[4] ADEME, Guide de Recommandation Pour Lutter Contre L’effet D’Ilot de Chaleur Urbain (accessed July 2022)

Sources and means of action to reduce the effect of Urban Heat Islands applied to service and logistics buildings.

Author: González Alonso, Ángela

Director: Houdayer, Justine

Collaborating entity: PAYET Society

Summary of the project

The main objective of this project is to show the influence of urban heat islands through their quantification (ICU score). This phenomenon occurs in metropolitan areas and has a direct impact on the environment and on the health and well-being of its citizens [1]. This study will be carried out from the point of view of the world of construction and building rehabilitation.

Likewise, an action plan will be presented to reduce urban heat islands through measures to be taken in construction and renovation projects.

This project has been possible thanks to my position as an internship student in the PAYET company for 5 months. Finally, to show all the knowledge acquired during this period, some studies on the environmental performance of different construction and renovation projects that have been carried out will be presented. These energy studies have been carried out at the same time as the development of the research statement on urban heat islands.

Keywords: urban heat islands, quantification, action plan.

1. Introduction

Environmental certifications or labels in the building sector are starting to expand and become popular since climate change is an undeniable problem, being present in our day to day life.

The PAYET company has allowed me to carry out during a period of 5 months a research statement in the field of sustainable construction. This statement consists in the research of the prevention of the effects caused by urban heat islands.

PAYET is a young company of about 15 employees that is in charge of helping different companies to transform the construction sector towards a more sustainable field [2]. One of these aids consists in accompanying them in the process of obtaining environmental labels/certifications (HQE BD, BREEAM, WELL...). These certifications are not mandatory, however, construction companies consider them as a good tool to attract investors or clients.
In order to obtain these certifications, it is necessary to comply with certain guidelines set by the certification, which usually deal with issues such as user comfort or control of the building's energy consumption (water, electricity, etc.).
The statement of this final degree work arises from the need for PAYET to adapt to the new update of the HQE BD regulation, which includes in its new version a need for assessment of urban heat islands.

2. Description of the proposal

Urban heat islands are represented by the temperature difference between a metropolitan area and its surroundings. So far, this is not an issue that has been strictly evaluated by the sustainable building sector and therefore there is no official standard calculation and valuation tool established by any entity. As a consequence, the objective of this research is to create a tool for quantifying urban heat islands at the plot level of a building/renovation to meet the requirements of the new version of the HQE BD certification (acronym for "High Environmental Quality Sustainable Building" in Spanish). The requirements of this regulation determine that, for a project to be considered applicable for obtaining credits, the effects of urban heat islands must be reduced by 10% with respect to the plot situation prior to the start of the project.
To quantify this effect, those factors that can be evaluated on a horizontal "micro" scale and vertically from the surface to the canopy layer will be considered. All of them are caused by human action, i.e., they are modifiable. Such variables are: aspect ratio, building surface factor, permeable surface factor, height of bulky elements, albedo, emissivity and anthropogenic heat. [3]

3. Results and interpretation

In order to test the effectiveness of the quantification method created from the assessment of the above mentioned variables, the calculation tool "UHI Score" has been tested on 3 different types of projects: a new logistic purpose building on a vacant lot with topsoil (PRD Corbas T3); a new hotel construction from an abandoned structure (MOB Hotel Bordeaux) and a renovation project of a central

Haussmannian building in the city of Paris (1bis Foch). The results obtained for each of the projects have been consistent with the particularities of each one of them:

- The PRD Corbas T3 project has obtained a result of percentage improvement with respect to its initial plot of -181%. This is a result with a very large absolute value and with a negative sign, which means that this building will contribute to the worsening of the effects caused by urban heat islands in a very considerable way. This result turns out to be coherent, since it is a new building constructed on a rural terrain, it is evident that variables such as permeability, height or emissivity, among others, will be worsened. If we take a step back, a new building built on a green field will always retain more heat in its plot than if it did not exist.
- The MOB Hotel Bordeaux project has obtained an ICU score of 21%. As this percentage is positive and higher than 10%, this project would obtain the credits corresponding to the urban heat island evaluation criterion, allowing it to improve its evaluation for HQE BD certification. The result obtained is consistent with the characteristics presented by this new construction project, since the construction of an unused structure as a basis for construction, variables such as height or percentage of built-up area are not modified: In addition, variables such as aspect ratio, permeability and albedo are improved. However, variables such as anthropic heat and emissivity have been worsened, this is due to the reinforcement of vertical walls and the installation of air conditioning systems.
- Finally, the 1bis Foch project has obtained a result of -1% improvement percentage with respect to its initial plot. This means that its implementation has hardly influenced the effect of urban heat islands, more precisely, it has caused a slight worsening of this effect. This is again logical, since being a renovation project, the base and exterior walls of the project have not been modified and therefore it was expected that the improvement result would be close to 0. Variables such as permeability have been improved due to the slight increase in green spaces: However, variables such as anthropic heat, due to the installation of an air conditioning system, have been harmed. In the end, practically a neutral balance has been established with respect to causing an urban heat island effect.

4. Action plan

The HQE BD certification also specifies the importance of the elaboration of an action plan against the urban heat island effect: this plan aims at offering an alternative to reduce this effect to the evaluated projects. Some of the action strategies to be followed are: the use of materials with a high albedo (cool roofs), the increase of green spaces, the increase of surfaces containing water, the installation of shade structures, the change to better cooling fluids that are used in air conditioners... [4]
.

5. Conclusions

Finally, it can be concluded that among the 3 evaluated projects only one of them would obtain the credits of the HQE BD certification with respect to the issue of urban heat islands. Being able to quantify this effect helps us to have a numerical and more visual basis on which to justify the implementation of measures of actions against the effects of urban heat islands.

However, the final objective of this evaluation is not to obtain points but to raise awareness of this harmful effect among the entire project team and to evaluate the various alternatives that would allow us to reduce it.

Obtaining a certification or an environmental label should not be seen as an ultimate goal, but as a justification that the project has been examined from an environmental perspective. The constant presence of the process of achieving these labels during the progress of the project helps to progressively raise the awareness of the rest of the construction team. As a consequence, certain supplementary measures, which go beyond environmental certification, can be considered and even applied. In this way, climate change could be reduced in one of the most polluting sectors on the planet.

6. References

[1] Morgann Stanley, «Urban Heat Island», https://www.nationalgeographic.org/encyclopedia/urban-heat-island/, (accessed April 2022)

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Sources and means of action to reduce the Urban Heat Island effect applied to service and logistics buildings

END-OF-DEGREE THESIS

VERSION |	7- End of the project
WRITTEN BY |	Ángela GONZÁLEZ ALONSO
DATE |	06.09.22
AT |	PARIS
DIRECTOR |	Justine HOUDAYER
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ABSTRACT

The main objective of this project is to show the influence and importance of **urban heat islands** through their quantification in order to reduce them. This phenomenon takes place in metropolitan areas and has a direct impact on the environment, as well as on the health and well-being of its citizens. This study is carried out from a **construction** and building **renovation** point of view, which is one of the main sectors involved in the creation of this phenomenon. In order to better visualize and account for this effect, a **quantification model** is presented: the **UHI Score**.

This tool will be of great help to the PAYET company, the enterprise where I have done my **internship** for my engineering degree. In the same way, an action plan to reduce the effect of urban heat islands is presented. Finally, to further show the knowledge acquired during this period, some studies that I have done on the **environmental performance** of building projects of the company are presented. These energy studies have been carried out simultaneously with the urban heat islands research.

This end-of-degree thesis will allow to link the main topic with its context, helping to understand the atmosphere in which I have been working and learning for 5 months.

Keywords: urban heat islands, construction, renovation, quantification model, UHI Score, internship, environmental performance.

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First, I would like to thank PAYET for giving me the opportunity of joining their company, integrating me into their team from the very beginning and, above all, giving me the possibility to continue developing my awareness and training on environmental issues.

Similarly, I would wholeheartedly want to thank my tutor Justine HOUDAYER for having given me the research statement that constitutes the topic of this end-of-degree thesis, as well as trusting me since the start and following up with my work. Her daily support in both the realization of this project and the other energy studies has helped me acquire confidence in my work and has made this learning experience one of the most enriching of my life.

I would also like to thank Louise CARDONA, for having advised me during the development and progress of the project, especially in the ecology part.

To my friend Emmie BROUSSEAU, for making me discover PAYET and for encouraging me to join their team. In THE same way to my friend Diego GONZALEZ, for helping me with the final lecture of the project and for giving me many important advices.

And finally, to my parents, for giving me the opportunity to come to France to study for two years, thus allowing me to discover another culture and way of life, as well as introducing me to, among others, the environmental issues in my daily thoughts.

UPDATE HISTORY

Version	7	End of the project	Date	04.09.2022
Version	6	Ending of the urban heat island action strategy plan and page setup	Date	24.08.2022
Version	5	Improvement of the tool and some tool test in different projects	Date	10.08.2022
Version	4	Drafting of the urban heat island action strategy plan	Date	09.08.2022
Version	3	Improvements in the method's format and first results	Date	20.07.2022
Version	2	Method's definition	Date	11.07.2022
Version	1	First correction and assessment by the director	Date	29.05.2022
Version	0	Creation of the document	Date	04.05.2022

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EVE®: Espace Vegetale Ecologique - Ecological Vegetable Space

HQE BD V4: Haute Qualité Environnementale Bâtiment Durable Version 4 - High Quality Environment Sustainable Building Version 4

BREEAM - Building Research Establishment's Environmental Assessment Method

CSTB: Centre Scientifique et Technique du Bâtiment - English Technical and Scientific Building Center

NF HQE BD: Norme Française Haute Qualité Environnementale Bâtiment Durable - French High Environmental Quality Standard for Sustainable Buildings

UHI: Urbain Heat Island

UHIC: Urban Heat Island Canopy

LCZ: Local Climate Zone

SVF: Sky View Factor

AR: Aspect Ratio

BSF: Building Surface Factor

ISF: Impervious Surface Factor

PSF: Pervious Surface Factor

IAU: Institut d'Aménagement et d'Urbanisme - Institute of Urban Planning and Development

CLHI: Canopy Layer Heat Island

SHI: Surface Heat Island

CCTP: Cahier des Clauses Techniques Particulières – Special Technical Specifications

DCE: Dossier de Consultation des Entreprises - File of Consultation of the Companies

OPR: Opérations Préalables à la Réception - Operations prior to reception

GWP: Global Warming Potential

PC: Permis de Construire – Construction Permission

FDES: Fiche de Déclaration Environnementale et Sanitaires. – EHDS: Environmental and Health Declaration Sheets

ACV: Analysis du Cycle de Vie - LCA: Life Cycle Analysis

STD: Simulation Thermique Dynamique – DTS: Dynamic Thermal energy simulation

1. INTRODUCTION

The world is starting to become more conscious about the environmental problem, and as a consequence, lots of measures are being put in place, such as the creation of **environmental certifications or labels**. We will explore these measures from a sector of industry that is being developed by leaps and bounds: **sustainable construction**.

1.1. Context of the project

As a student in double degree in France, in second year at the École Centrale de Nantes and in the last year of my degree at the Universidad Pontificia de Comillas, I have done an internship which has constituted the subject of this end-of-degree thesis.

The internship consisted of 21 weeks, from the beginning of April to the end of August, in a consulting company called PAYET, located in the 8th district of Paris. The title of the internship is: **Project management HQE in sustainable construction and urban planning.**

The opportunity of spending half of my engineering studies abroad (2 years), has allowed me to become more conscious about certain sensitive problems which affect us directly in our daily routine, such as the environmental issue. Currently, the planet's health is proving to be one of the main problems faced by humanity. This is logical, since the exponential decline in the environmental conditions endangers natural species, entire ecosystems and, ultimately, our wellbeing and health. We can directly perceive this global trend through the current temperature increases and more intense droughts.

As a result of my desire to be an active and dynamic person in order to influence and help the environment, I decided to embark on the option of Energy's Production and Management in the École Centrale de Nantes in the last year of my studies. In order to focus my professional career in the same field, I decided to start with an internship in an enterprise which works in the sustainable construction sector, which has a huge impact in carbon emissions.

During this internship I have developed a research statement assigned to me by the company. This was carried out concurrently with the other environmental performance studies previously mentioned. Nevertheless, the research statement will be the main topic of this document, giving the title to this final degree project: **"Sources and means of action to reduce the Urban Heat Island effect applied to service and logistics buildings".**

1.2. Presentation of the enterprise

The society **PAYET** was created at the end of 2020 from the separation of the historical activities of Dauchez PAYET, a company co-founded in 2003, which also involved management in the construction sector.

This company carries out different missions such as assisting, engineering and consulting different clients (situated in the tertiary and logistical sector) mainly focusing on the high ecological and environmental quality of the projects.

This enterprise takes action from their various offices located in the principal cities of France: Paris, Lyon and Bordeaux (its head office). It has actually 15 workers and has delivered 150 projects. By the end of September 2022, the company will be

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recruiting more employees, increasing its number to 15.

PAYET is divided into three areas of expertise supported by the eco-initiatives® brand: Sustainable Construction, Ecology & Landscape and Environmental Design, which are combined in order to accomplish their objectives on a national scale. [1]

1.2.1. Ecology & Landscape

This area of the company focuses on the study, management and evaluation of the project's **green spaces**[1], studying their ecology and assesing their landscape potential with the aim of promoting their biodiversity.

Some of the tasks related to this area are:

- → Regarding ecology engineering:
    - Carrying out diagnostics on the flora and fauna of the project: ecological studies.
    - Advising and accompanying the companies on the care and treatment of the different species during the construction period and the subsequent maintenance period.
    - Identifying and managing the appearance of invasive species during the construction period.
    - Improving the biodiversity of the green areas and raising the awareness of the entire construction team about it.
    - Obtaining the Biodivercity® certification.
- → Regarding the landscape:
    - Advising and accompanying clients in the distribution and layout of green areas appearing in the project.
    - Proposing different alternatives for rainwater management.
    - Obtaining EVE® [2] and EcoJardin certifications.

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1.2.2. Environmental Design

This area of the company collaborates actively with the other two teams and is in charge of evaluating the energy performance of the project, always taking care of the users' comfort and well-being.

- → The values of reusing and circular economy are especially important to this group, since one of its main activities is giving a second chance to objects that will no longer be used in the renovation projects.
- → Another activity related to this area is the optimization and proper usage of the space, for example, by creating an optimal bicycle local. This has also an environmental impact as it encourages workers to take the bicycle when going to work. An example of a PAYET's bicycle room design is as follows:

[1] Green space (or greenspace) is an area of vegetated land (grass, trees, shrubs, etc.) within an urban context, i.e. the countryside is generally not considered as a greenspace. [2]

[2] EVE is the acronym of "Espace Vegetale Ecologique", Ecological Vegetable Space in English.

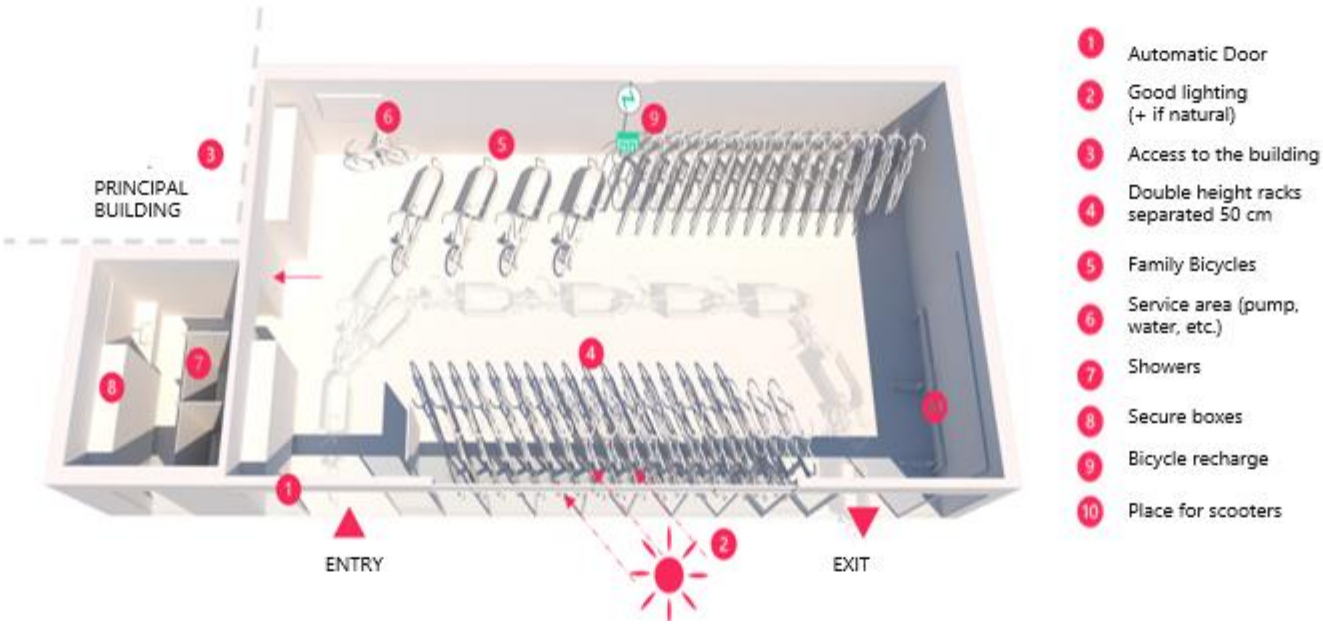


FIGURE 1 – GOOD PRACTICES FOR A BICYCLE ROOM (SOURCE : PAYET, ENGLISH ADAPTATION)

1.2.3. Sustainable Construction

Always in order to achieve a high environmental quality, PAYET offers a complete environmental expertise throughout the whole process of construction and renovation, from the project management to the studies. The final and most important objective is to concretize and develop a strategic and useful procedure for raising awareness in the environmental problem and helping reduce the negative impact on the health of the planet.

In order to develop these action plans, one of the necessary requirements is to rely on different environmental performance engineering building studies such as:

- → Life cycle analysis (study of the energy impact of building materials)
- → Dynamic thermal simulations
- → Light autonomy studies
- → Acoustic performance
- → Overall cost study

The objectives of this area can also be carried out within the framework of environmental certifications, which can also be of great use to attract investors. These environmental certifications will be explained in section 1.3.

My internship was integrated in this working area: **Sustainable Construction**, which has proved to be a helpful context for the development of this end-of-degree thesis as an engineer specialized in energy production and management.

1.3. Environmental certifications

A certification (or label) is a certificate issued based on a reference system related to different themes, e.g., ecology, health and comfort. Obtaining environmental certifications is the way to testify that the project has undergone a monitoring process about its environmental performance.

Environmental certifications are a very effective way of attracting investors, since obtaining them implies guarantees of **ecology, health and comfort**. It should be noted that obtaining an environmental certification does not mean that we must stop being critical with the project, furthermore, we should all try to go beyond it, achieving its best possible environmental performance within its capabilities.

Obtaining an environmental certification is a voluntary process (as opposed to a regulatory obligation), the decision of going for it is carried out by the project owner. Some reasons for wanting to have an environmental certification could be the following:

- → Project owner commitment: its commitment to an environmental approach may be linked to a group policy or to a specific objective for the project.
- → Sign of quality: commitments are subject to control by an independent authority.
- → Objective: to allow every construction group member (private individuals, builders, etc.) to target the result they want to achieve, to be guided to achieve it and to check the final performance.

1.3.1. Types of labels and certifications

There are three types of labels and certifications:

1.3.1.1. Certifications

Certifications (HQE, BREEAM, WELL...) are based on reference systems that rely on the work of associations or private bodies and are carried out by an official and independent organization.

The quality of the work is subject to an audit carried out by an independent third party, at least on documentary evidence, sometimes supplemented by a site visit.

1.3.1.2. State Labels

The labels supervised by the public authorities are based on regulatory texts.

They can be used to grant public aid and tax benefits. Most of the state labels concern energy performance and are built in anticipation of a change in regulations.

1.3.1.3. Private Labels

Private labels are generally based on a commitment (declaration, charter...) to respect some defined criteria. The control can sometimes be done by an independent organization. For example, we can mention Effinergie +, BEPOS Effinergie 2013, (or, private labels from other countries, such as Minergie or Passiv'haus).

The following image shows all the certifications and labels currently existing in the office construction sector **in France.**

FIGURE 2 – LABELS AND CERTIFICATIONS IN FRANCE (SOURCE: PAYET)

1.3.2. Environmental Certifications seen during the internship

Within the framework of this internship, the main certifications that have been dealt with have been:

- → HQE BD
- → BREEAM
- → WELL

1.3.2.1. HQE BD: Haute Qualité Environnementale Bâtiment Durable

In English: High Quality Environment Sustainable Building.

This is a certification which is mostly used in France. Its regulations are carried out thanks to a collaboration of the CSTB (Centre Scientifique et Technique du Bâtiment, in English, Technical and Scientific Building Center) and its subsidiary Certivéa.

The regulation is currently in its **fourth edition (4th version)**, which was launched in June 2022, during my internship period, and will come into force for projects registered in October.

The main commitments that serve as the basis for the regulations are:

- → Responsible management
- → Economic performance
- → Quality of life
- → Respect for the environment

Once the project has been evaluated it can be given one of several final grades: **Performing** < **Very Performing** < **Excellent** < **Exceptional**. The grades are computed and separately attributed to each sub-theme/theme/objective/commitment and they have been organized as follows:

Cadre de référence du bâtiment durable (AHQE-GBC) – Engagements	Objectifs	Thèmes du référentiel "HQE Bâtiment Durable - certifié par CERTIVEA" v4
QUALITE DE VIE	Des lieux de vie plus sûrs et qui favorisent la santé	Qualité de l'air intérieur
		Qualité de l'eau
		Ondes électromagnétiques
	Des espaces agréables à vivre, pratiques et confortables	Confort hygrothermique
		Confort acoustique
		Confort visuel
		Accessibilité
	Des services qui facilitent le bien-vivre ensemble	Transports
		Services
RESPECT DE L'ENVIRONNEMENT	Une utilisation raisonnée des énergies et des ressources naturelles	Energie
		Eau
	Une limitation des pollutions et la lutte contre le changement climatique	Déchets
		Carbone
		Adaptation au changement climatique
		ACV
	Une prise en compte de la nature et de la biodiversité	Biodiversité
PERFORMANCE ECONOMIQUE	Une optimisation des charges et des coûts	Maîtrise des coûts
	Une amélioration de la valeur patrimoniale, financière et d'usage	*(à définir)*
	Une contribution au dynamisme et au développement des territoires	Economie locale
MANAGEMENT RESPONSABLE	Une organisation adaptée aux objectifs de qualité, de performance et de dialogue	Contexte
		Engagement
		Planification
		Ressources et moyens
	Un pilotage pour un projet maîtrisé	Réalisation des activités opé. : Adaptabilité
		Réalisation des activités opé.: Chantier
		Réalisation des activités opé.: Commissionnement
		Réalisation des activités opé.: Gestion Durable
	Une évaluation garante de l'amélioration continue	Evaluation
		Amélioration

FIGURE 3 – ORGANISATIONS OF THE REGULATION HQE BD V4 (SOURCE: HQE BD)

FIGURE 4 – EVALUATION OF THE TECHNICAL COMMITEMENTS OF HQE BD V4 (SOURCE: HQE BD V4)

The process for obtaining this certification is represented in the following figure:

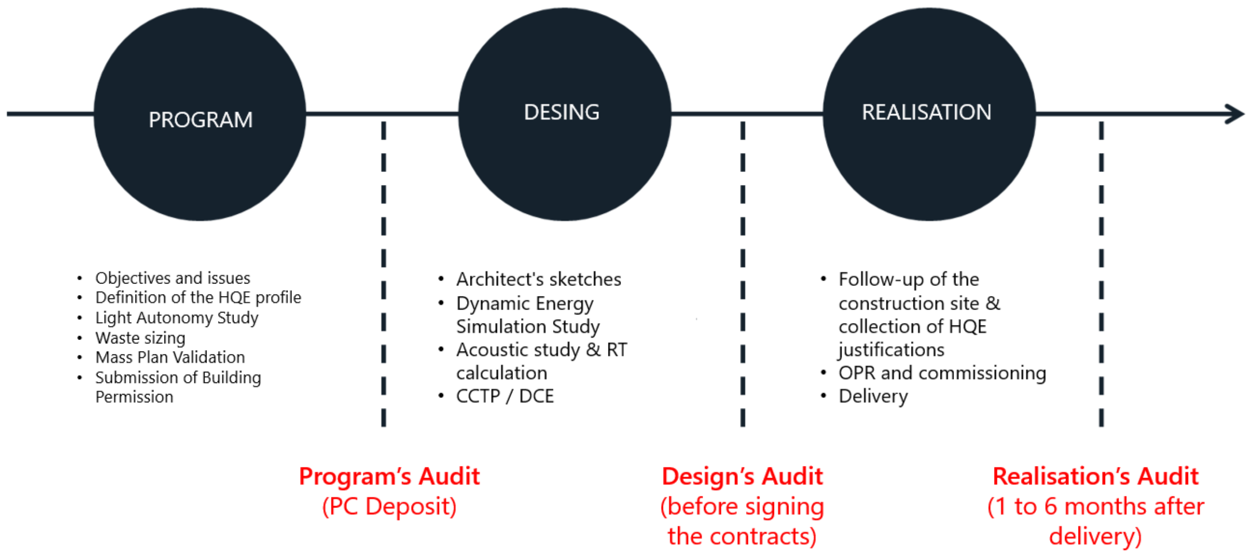


FIGURE 5 – HQE CERTIFICATION PROCESS (SOURCE: PAYET ENGLISH ADAPTATION)

One of the most characteristic properties of this regulation is monitoring a "low environmental impact worksite"(follow-up construction site) during the realization phase.

A "low environmental impact worksite" is defined as a worksite in which the field surroundings of the field are not affected in an abrupt way nor does the site have a disproportionate environmental impact.

Since my tutor is the director of several projects that are in the realization phase, I was fortunate enough to accompany her to different worksites, being able to check if the environmental impact standards established by the HQE BD regulation were being met (such as the waste sorting, or the implementation of safety standards).

FIGURE 6 – PHOTOS TAKEN IN WORKSITES (SOURCE: PAYET)

The HQE BD is the **main certification** that will be treated in this end-of-degree thesis.

1.3.2.2. BREEAM

The BREEAM certification, acronym of Building Research Establishment's Environmental Assessment Method, is an internationally better recognized certification, since it is used in more than 50 countries. It was created in the United Kingdom in 1990 and it is used in France since 2009. This regulation updates its version every 3 or 4 years.

It is based on 10 different topics, each with their own sub-topics:

Section	Assessment issues
Management	— Project brief and design — Life cycle cost and service life planning — Responsible construction practices — Commissioning and handover — Aftercare
Health and wellbeing	— Visual comfort — Indoor air quality — Safe containment in laboratories — Thermal comfort — Acoustic performance — Accessibility — Hazards — Private space — Water quality
Energy	— Reduction of energy use and carbon emissions — Energy monitoring — External lighting — Low carbon design — Energy efficient cold storage — Energy efficient transport systems — Energy efficient laboratory systems — Energy efficient equipment — Drying space — Flexible demand side response
Transport	— Public transport accessibility — Proximity to amenities — Alternative modes of transport — Maximum car parking capacity — Travel plan — Home office
Water	— Water consumption — Water monitoring — Water leak detection — Water efficient equipment
Materials	— Life cycle impacts — Hard landscaping and boundary protection — Responsible sourcing of materials — Insulation — Designing for durability and resilience — Material efficiency
Waste	— Construction waste management — Recycled aggregates — Operational waste — Speculative floor and ceiling finishes — Adaptation to climate change — Functional adaptability
Land use and ecology	— Site selection — Ecological value of site and protection of ecological features — Minimising impact on existing site ecology — Enhancing site ecology — Long term impact on biodiversity
Pollution	— Impact of refrigerants — NO_x emissions — Surface water run-off — Reduction of night time light pollution — Reduction of noise pollution
Innovation	— Innovation

FIGURE 7 – TOPICS AND SUBTOPICS OF BREEAM'S REGULATION (SOURCE: BREEAM CERTIFICATION)

Each topic is awarded with a number of credits. Depending on the number of credits obtained at the end of the project's evaluation, the final grade can be between one the following: **Pass**< **Good**< **Very Good**< **Excellent** <**Outstanding**.

The process for obtaining this certification is shown on the following diagram:

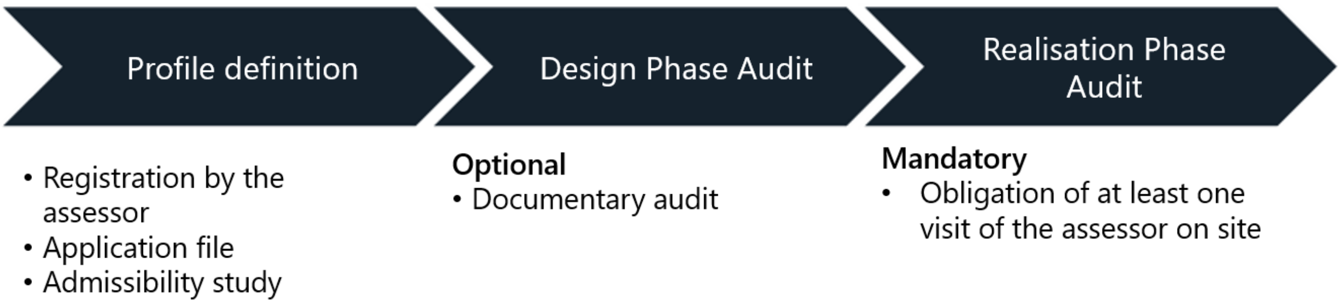


FIGURE 8 – BREEAM CERTIFICATION PROCESS (SOURCE: PAYET)

1.3.2.3. WELL

This certification is of American origin and is not very widespread in the French environmental certification world. It is currently in its second version, which explores 10 different concepts focused on the comfort, well-being and health of its users. Unlike the two previous regulations, WELL does not evaluate certain important issues such as energy or water consumption.

The final grade can be: **Bronze** < **Silver** < **Gold** < **Platinum**.

I was in contact with this regulation through a project in which I had to study the origins of different construction materials, evaluating them according to the environmental impact of their constituents.

1.4. Internship's Challenge

The title of the internship I have done is: **"Project management HQE in sustainable construction and urban planning"**. This title covers 3 main activities that have been carried out during the last 5 months:

- → Giving support to various eco-initiatives project managers currently working in different **energy studies.** The purpose of this studies is to achieve constructive environmental improvements in the projects. Some examples of energy studies carried out were: **Thermal Dynamic Simulations, Light Autonomy Studies or Life Cycle Analyses** on different logistical and tertiary projects with the help of **Pléiades and Elodie software**.

- → **Visiting different construction worksites** of projects in realization phase. This includes meetings with the project team members, such as architects and managers, as well as companies in charge of building demolition. After each visit, a "Site Report" (including the progress that has been made, current photos of the worksite and an analysis of the topics that had been discussed at the worksite meeting) was written. Some of the topics that are usually discussed are: the waste and recycling management, the protection of green spaces and actions to take to obtain the required certification. I was usually in charge of writing these documents.
- → Developing a **research statement** assigned to me at the beginning of the internship, which is the basis of this **end-of degree thesis statement**. This has been a guiding thread in my daily work. Its title is: *Sources and means of action to reduce the Urban Heat Island effect applied to service and logistics buildings*.

The core challenge of this internship has been achieving a balance between managing the wide range of tasks related to the different projects, while attending visits to the worksites and advancing on the research subject. Time management and prioritizing the tasks at hand were the determining factors in my success with this experience. Even though I allocated a considerable amount of time to the other activities, this project was the focus of my research statement. The presentation of the diverse energy studies that have been done will be presented on *Appendix A*.

1.5. Thesis statement

The statement of my research subject is: **Sources and means of action to reduce the urban heat island effect applied to service and logistics buildings.**

Urban Heat Islands (UHI) expose the temperature difference between metropolitan and suburban areas, and has negative consequences like the creation of smoggy climate and damaging the ecosystem, further endangering people's health [3].

I was entrusted with this subject of study because one of the principal environmental certifications PAYET works with, HQE BD, released in June 2022 a new version of its regulation (number 4), coinciding with my time in the company.

In this new version, the effect of the UHI has to be taken into account. Evaluating this effect is necessary in order to be able to certify projects registered from October onwards.

2. STATE OF ART

2.1. Definition of UHI

Urban heat islands (UHI) are represented by the **air temperature difference between an urban area and its rural surroundings**. [5]

City temperatures are generally higher than those in rural areas, with a usual difference of around 1 to 3 degrees for a city with 1 million inhabitants and up to a maximum delta of around 12°C. Consequently, they are a main cause of hazy climate and people's health degradation [3].

The main and primary interest in fighting against urban heat islands is to maximally reduce the health problems against humans and the planet. Epidemiological studies have revealed a stronger sanitary impact in the cities. The most common health problems that the UHI effect can cause are respiratory problems, increased allergies, loss of sleep quality, widespread distribution of certain diseases, invasion of species (such as the tiger mosquito, that carry pathogenic agencies and diseases), etc.

2.2. Evaluation's Objective

In order to set the basis for the UHI Score tool, the contents of the regulation HQE BD have to be taken into account.

The issue related to urban heat islands is addressed in section "*ACCL1.2.2-Réduction de l'effet d'îlot de chaleur*"[3].

2.2.1. HQE BD V4's requirements for the issue of UHI

Projects that will be affected by an assessment of this phenomenon are those having the following characteristics:

- → A vegetation rate at the plot of less than 30 %
- → An average ground reflection factor (albedo) of less than 0,35.

If the projects evaluated do not satisfy these characteristics, they will be considered as "not applicable" for the obtention of points and this theme will not be considered.

The following table, extracted from the referential [4], shows a summary of the points obtained in relation to the UHI theme:

[3] ACCL1.2.2-Reducing the effet of heat islands

ANSWER	POINTS
Not Applicable	N/A[4]
Not Achieved	0
Achieved	5

TABLE 1- POINT UHI (SOURCE: HQE BD ENGLISH ADAPTATION)

In order to obtain the 5 points, eligible projects will have to improve their "UHI Score" by at least **10%**.

However, it is difficult to determine this **"UHI Score"** because there is currently no freely available evaluation system. Each Engineering and Design Consulting Office is responsible for setting up a system to quantify and evaluate this effect.

A presentation of a **strategic action plan** for improving this "UHI Score" is also important. Some ideas are mentioned in the regulation HQE BD V4, such as:

- → Using materials with a high solar reflective capacity to reduce heat absorption and avoid excessive temperature increases on the plot surfaces and the building envelope (high albedo).
- → Increasing the vegetation of the surfaces (facade surroundings, plot, etc.).
- → Shading buildings and surface parking lots, etc. [4]

2.2.2. My research objective

In developing my research statement, my objective as an internship member of the company consisted of:

- → Establishing a first version from beginning to end of a tool that allows to quantify the effect of urban heat islands. It outputs a final score called **UHI Score**. *(Chapter 3 and 4)*
- → Creating supporting documents such as a user guide document (**tutorial**) for the tool so that it can be easily used in a systematic and efficient way.
- → Developing a **strategic action plan** against urban heat islands that was presented to the company in a Power Point format in order to have a clearer and more concise visualization. This document will be very useful to PAYET as it will allow them to offer different **alternative solutions** to this problem to the rest of the construction project team (architects, construction manager, etc.). The application of these alternative solutions can help fight the environmental issues, as well as obtain the environmental certification points related to urban heat islands in order to get, in the end, the desired HQE BD certification. *(Chapter 5).*

The reason why PAYET has given me this research subject is that this evaluation is necessary for the evaluation of company's projects.

2.3. UHI's History

According to what Stewart said in 2011, the first study of urban heat islands was carried out in the middle of the XIXth century, in 1833, by Luke Howard during a meteorological study in London. Later, in 1931, the scientist Sasakura recorded a difference between 1 and 2°C between the city center of Tokio and its surroundings.

[4] Not Applicable : the criteria will not be considered for the calculation of the final result.

It was not until more than 100 years later that the concept of Urban Heat Islands was born, created by Balchin and Pye during a micro-climatological study in 1947. In her thesis, Amelie Parmentier [5], states that the effect of urban heat islands has only become a widespread research topic in the last 50 years.

Some of the most representative and recent studies on this subject are:

- → Sundborg in 1951 (Oke, 1995). He was the first researcher to have established a statistical link between the urban heat islands size and the surface energy balance (radiation exchange in the narrow streets, including conduction of heat to the earth's surface and the release of heat from artificial combustion).
- → Einarsson and Lowe in 1955, laid out the foundations of the relationship between conductivity and thermal capacity of the soil and air related to this phenomenon.
- → Chandler in 1965 in London, pointed out the relationship between physical properties of urban surfaces (roughness, humidity, reflectivity and the presence of artificial heat sources) and the urban heat islands intensity.
- → I. D. Stewart and T.R. Oke, in 2012, in their study **Local Climate Zones for Urban Temperature Studies (LCZ)**, put together the foundations for a system of quantification and classification of the different types of urban heat islands according to their intensity. This source has been one of the main information bases for my study [6].

2.4. UHI Types

Urban Heat Islands are defined based on the following scales.

2.4.1. Vertical Scales

This scale is the one that divides the space below the "Boundary Layer", since it is in this area that the UHI effects are reproduced.

"The "Boundary Layer" is the interface zone represented by a relative movement between two fluids. It is a consequence of the difference in the fluids viscosity. The fluids next to the city are normally more viscous than the ones above the Boundary Layer". [7]

Depending on the vertical layer in which the Urban Heat Island effect is studied, a different type of UHI can be defined.

Four layers can be distinguished [5]:

- → <u>Underground Heat Island:</u> this is the UHI's effect evaluated by the temperature delta below the Earth's surface. This type of studies is currently not too advanced due to a lack of research on the topic.
- → <u>Surface Heat Island (SHI)</u>: which allows to observe that temperatures on certain city surfaces are higher than in many other surfaces.
- → <u>Canopy Layer Heat Island (CLHI)</u>: this study area includes a small range of the atmosphere, rising from the Earth's surface to the top of buildings and trees. This upper boundary is called Canopy Layer. The **Urban Canopy Layer** is very heterogeneous and turbulent because it is where human activity takes place.

- → <u>Boundary Layer Heat Island</u>: it is the variation of air temperature that can be found from the Canopy Layer to the Boundary Layer. In urban areas, it is defined by a dome of warm air located above the agglomeration. It mostly depends on wind speed.

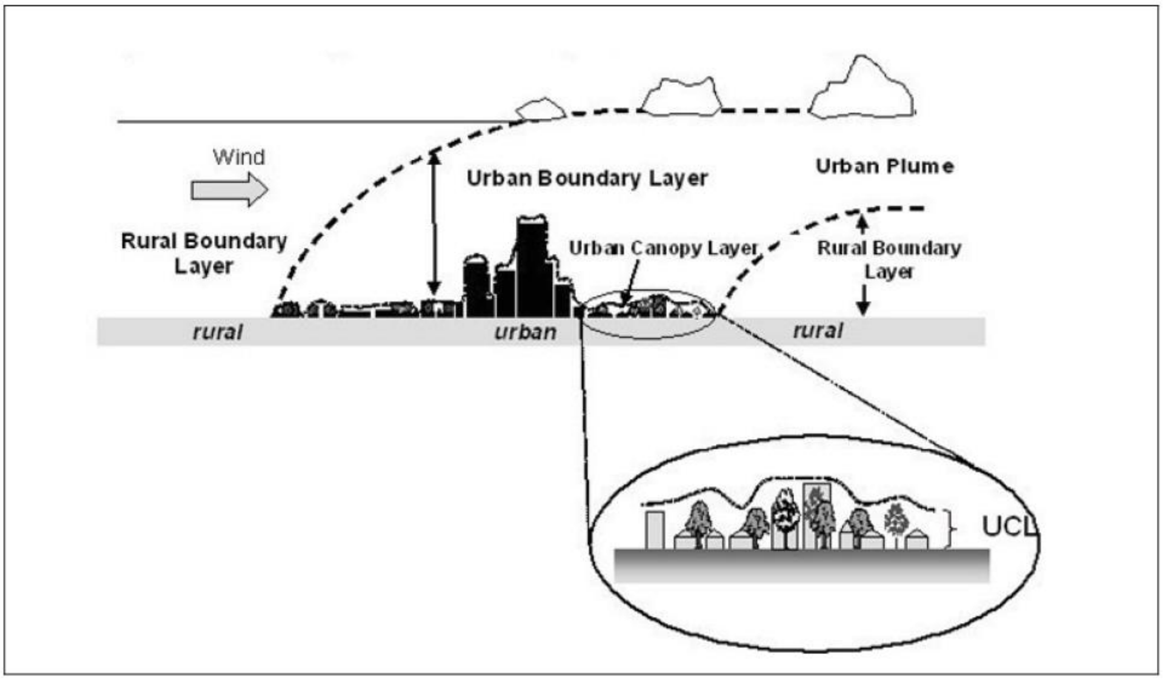


FIGURE 9 – MAIN COMPONENTS OF THE URBAN ATMOSPHERE (SOURCE: VOOGT AND AMELIE PARMENTIER (1987))

The type of UHI which is going to be studied in this project is the **Canopy Layer Heat Island** (CLHI) as it is the one involved in human activity and its consequences. From now on, **every reference for the UHI will be specifically addressing the CLHI**.

2.4.2. Horizontal scales

This type of scales allow us to define a characteristic role for each of the parameters that influence the creation of this phenomenon.

Three zones can be distinguished within the group of horizontal scales [8]:

- Meso-Scale (meso-climatic): It's the biggest one. The study can have a size ranging from 10 000 to 200 000 meters according to Leconte's these. It contains cities and their periphery. The parameters which have a huge influence in this type of zone are the vegetation and the anthropogenic heat.
- Local Scale: from 100 to 10 000 meters. It contains neighborhoods, parks or industrial wastelands. The parameters which have a more important role are the same as in the meso-scale, as well as considering the construction materials.
- Micro-scale: from 0,01 to 100 meters. The elements of the urban environment corresponding to this scale are the buildings, the parcs, the streets… Leconte affirms that the parameters which will have a bigger impact at this scale are the thermic properties of the material and the geometric form of the building.

In this project, following the requirements of the HQE BD V4, the horizontal scale studied has been the **micro-scale**.

2.5. Energy balance for the explanation of UHI

To better understand this effect, it is useful to have a physical notion about the creation of UHI on urban surfaces. Erell and al; in 2011 [9] established an equation defining the energy exchange at a local or meso-climatic scale.

Although it is not the case for the scale of this project, it is a formula that helps in understanding the development of this phenomenon in its globality.

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_s + \Delta Q_A$$

This picture represents the different energy flows:

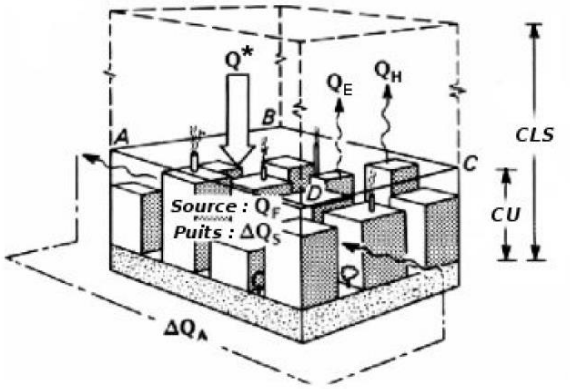


FIGURE 10 – GRAPHIQUE REPRESENTATION OF THE TERMS WHICH APPEAR IN THE FLOW ENERGY EQUATION (SOURCE: OKE, 1998 IN LECONTE'S THESIS [8])

The definition of each of the elements are the following:

- → Q^*: net radiative flow
- → Q_F: anthropogenic heat flow
- → Q_H: sensible heat flow
- → Q_E: latent heat flow
- → ΔQ_s: energy storage in urban materials
- → ΔQ_A: horizontal advection

2.6. Properties for the quantification of UHI

According to the guides of the HQE BD V4, the aim is to improve **the UHI Score** by **10%** of the existing **project's plot** and to elaborate a strategy to fight against it. This is the reason why the projects will be evaluated at the **micro-scale (plot level).**

Rizwan in 2008, made a classification of the variables which influence the creation of this phenomenon, classifying them into "controllable" and "un-controllable" as in the following figure:

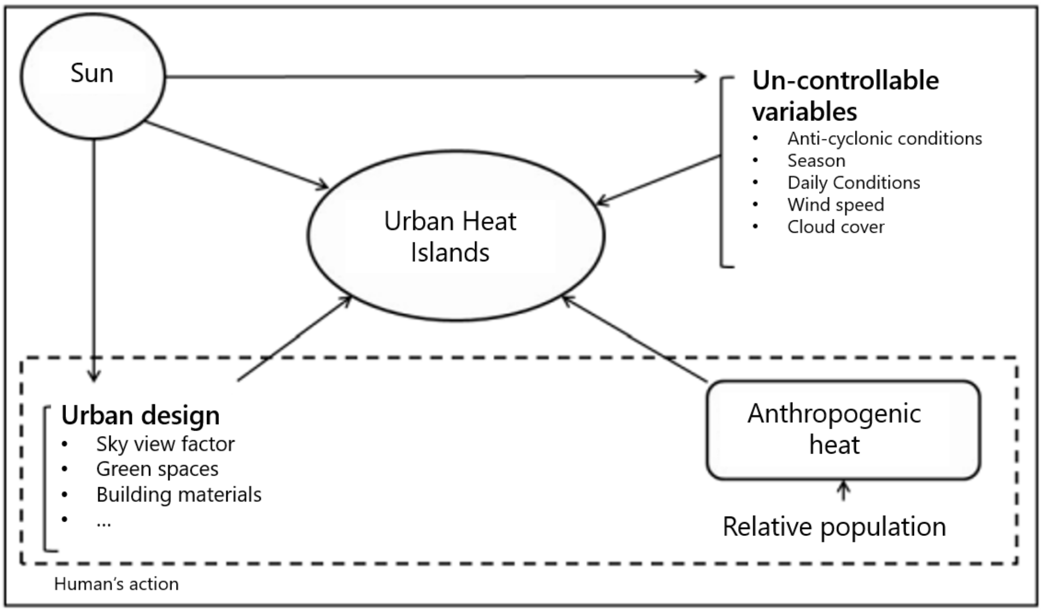


FIGURE 11 – SUMMARY OF THE CAUSES OF URBAN HEAT ISLANDS (SOURCE: GUIDE DE LUTTE CONTRE LES ICU, ADAPTATION OF RIZWAN'S VERSION IN 2008 [12], ENGLISH ADAPTATION)

2.6.1. Un-controllable variables

These are factors that are neither controllable, constant, nor permanent over time, and not entirely predictable. They are those that depend mainly on meteorological conditions. However, each one affects the UHI phenomenon in a different way.

According to Amelie Parmentier [5], the most influential factors are **wind speed and cloud clover**.

2.6.1.1. Wind Speed

An increase in wind speed implies a mixing of the elements suspended in the atmosphere. It is for this reason that the higher the wind speed, the lower the UHI intensity effect [11].

Some significant figures were established by Oké (1971) where he stated that the UHI disappeared for wind speeds greater than 11 m/s and was strongly influenced at a moderate time speed between 3 and 6 m/s. The following comparative table helps to better visualize this effect:

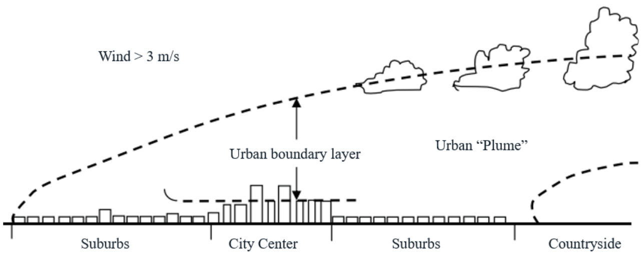
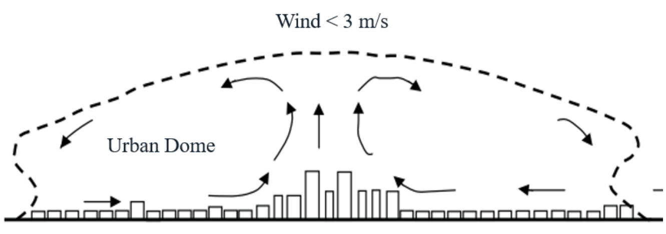
<table>
<tr><th>Wind > 3 m/s</th><th>Wind < 3 m/s</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Creation of an urban mix</td><td>Air stagnation</td></tr>
</table>

TABLE 2 – WIND ACTION IN AN URBAN ATMOSPHERE (SOURCE: OKE 1971)

2.6.1.2. Cloud Cover

This variable is responsible for slowing down the UHI since it acts as a shield to the passage of infrared rays and sunlight. Therefore, it reduces the concentration of heat [12].

2.6.1.3. Other Variables

It is worth noting the impact of being in a **daytime or night-time phase** of the day. During the diurnal period the temperature is higher and there is an absorption of this heat that will be emitted at night, when temperatures are lower, and cooling takes place.

For the rest of the meteorological variables, it is concluded that **rain or the absence of sunlight** diminishes the effect of the UHI.

All these limitations have a direct impact on the creation of the UHI. However, they will **not** be quantified or modelled for this study, since they have an impact on a much larger scale than that of a plot; as well as **not being modifiable** through the construction or renovation of a building.

2.6.2. Controllable variables

These variables are those that **can be modified** by human beings, and therefore it is on this type of variables that the UHI Score can be reduced.

In their study LCZs (Local Climate Zones), Oké and Stewart divided these types of variables into two groups:

- → **Geometric and surface** cover properties, which depend on urban morphology.
- → **Thermal, radiative, and metabolic** properties.

This study is going to be based on the classification of properties made in the method LCZ.

2.6.2.1. Geometric and surface cover properties

All the factors which are going to be explained are **unitless** except for the roughness variable (f).

a. <u>Sky View Factor</u>

The Sky View Factor is the ratio between the amount of sky surface that is visible from the surface level of a street or a square and the surface without obstacles between them. This factor is quantified by a number between 0 and 1.

The lower the number of obstructing obstacles, the closer the SVF factor is to 1, which means that more energy will be received from the ground. On the contrary, a coefficient closer to 0 means a larger shadow surface and therefore less energy received on the surface.

The following figure shows some examples of SVF quantification:

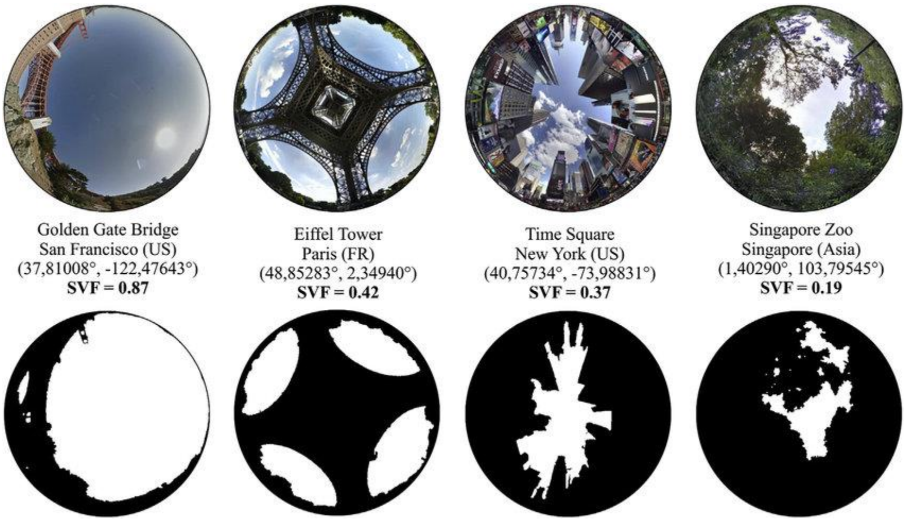


FIGURE 12 – EXAMPLE OF DIFFERENT SVP FACTORS (SOURCE: MIDDLE A. (2018))

b. Aspect Ratio

Also called building spacing, is represented by the equation:

$$AR = \frac{building's\ height}{width\ of\ street\ canyons}$$

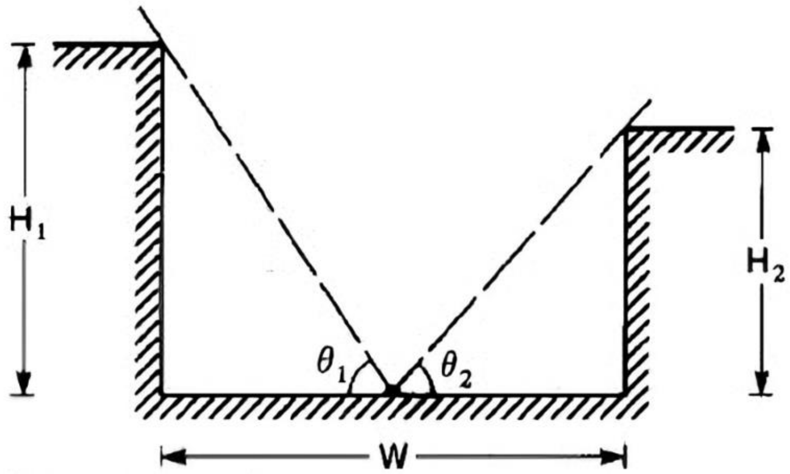


FIGURE 13 – GEOMETRY OF AN UNAYMMETRIC CANYON FLANKED BY BUILDINGS 1 AND 2 (SOURCE: OKE, T. R. "STREET DESIGN AND URBAN CANOPY LAYER" (1988))

"Depending on type of zone, it measures the height-to-width ratio of street canyons, building spacing or tree spacing. [6]."
The smaller the angles, the more ventilation there will be in the streets, though, the UHI effect is lower.

For an **urban and heterogeneous environment**, the formula has been adapted:

$$AR = 0{,}5 * \frac{\sum S_{green}}{S_{total} - \sum S_{building}}$$

c. Building Surface Fraction

The percentage between the built plan area and the total plan area.

d. Pervious and Impervious Surface Fraction

The objective of these variables is to evaluate the infiltration rate of rainwater in the plot.

→ The **Pervious Surface Factor (PSF)** is the absorption ratio that is calculated by dividing the surface area of the plot that has an infiltration capacity by the total surface area. It represents the maximum water flow that can be absorbed by a limited surface. Some examples of pervious surfaces could be: vegetation, water surfaces, gravel, turf...[13]

→ The **Impervious Surface Factor (ISF)** is the imperviousness ratio of the plot that is calculated by dividing the area of the plot with no infiltration capacity by the total area. Some examples of impervious surfaces could be: pavement, rocks, cement, asphalt, concrete, traditional stone, bricks...[13]

Both coefficients are complementary:

$$PSF + ISF = 1$$

This is a variable which is also treated in the HQE BD V4 regulation, more precisely in section "2.2A Gestion Des Eaux Pluviales - Fonction ''Infiltration'' - Taux D'absorption De La Parcelle (EAU 2.2.1)" [5][4].

e. Terrain roughness class

Oké and Stewart, in their LCZ method, quantify roughness from a generic table developed by A.G. Davenport in 2000 [16]. In this table, the roughness of a zone is determined from its **structural characteristics** and its characterizing parameter z_0. This parameter has a low value for morphologically rural and spacious areas and a high value for dense urban areas. The table in which these zones are characterized is as follows:

Davenport class	Roughness length, z_0 (m)	Landscape description
1. Sea	0.0002	Open water, snow-covered flat plain, featureless desert, tarmac, and concrete, with a free fetch of several kilometers.
2. Smooth	0.0005	Featureless landscape with no obstacles and little if any vegetation (e.g., marsh, snow-covered or fallow open country).
3. Open	0.03	Level country with low vegetation and isolated obstacles separated by 50 obstacle heights (e.g., grass, tundra, airport runway).
4. Roughly open	0.10	Low crops or plant covers; moderately open country with occasional obstacles (e.g., isolated trees, low buildings) separated by 20 obstacle heights.
5. Rough	0.25	High crops, or crops of varying height; scattered obstacles separated by 8 to 15 obstacle heights, depending on porosity (e.g., buildings, tree belts).
6. Very rough	0.5	Intensely cultivated landscape with large farms and forest clumps separated by 8 obstacle heights; bushland, orchards. Urban areas with low buildings interspaced by 3 to 7 building heights; no high trees.
7. Skimming	1.0	Landscape covered with large, similar-height obstacles, separated by 1 obstacle height (e.g., mature forests). Dense urban areas without significant building-height variation.
8. Chaotic	≥ 2	Landscape with irregularly distributed large obstacles (e.g., dense urban areas with mix of low and high-rise buildings, large forest with many clearings).

TABLE 3 – ROUGHNESS CLASSIFICATION (SOURCE: TABLE 5 OF LCZ RAPPORT ADAPTED OF DAVEPORT AND AL. 2000)

However, this method is effective at a meso-climatic scale, which are those territories extending horizontally between 10 000 to 200 000 meters. As this is not the scale case for this end-of-degree thesis, this method of roughness quantification is not considered.

In order to try to find another roughness quantification method adapted to our needs, another calculation method will be analysed, that of the: Institut d'Aménagement et d'Urbanisme, d'Île-de-France [6](IAU).

[5] 2.2A Stormwater Management - Infiltration Function - Parcel Absorption Rate (WATER 2.2.1)"
[6] Institute of Urban Planning and Development in English

It characterizes an urban surface from the vegetation and mineral roughness based on addition of the parameters in the following figure [17]:

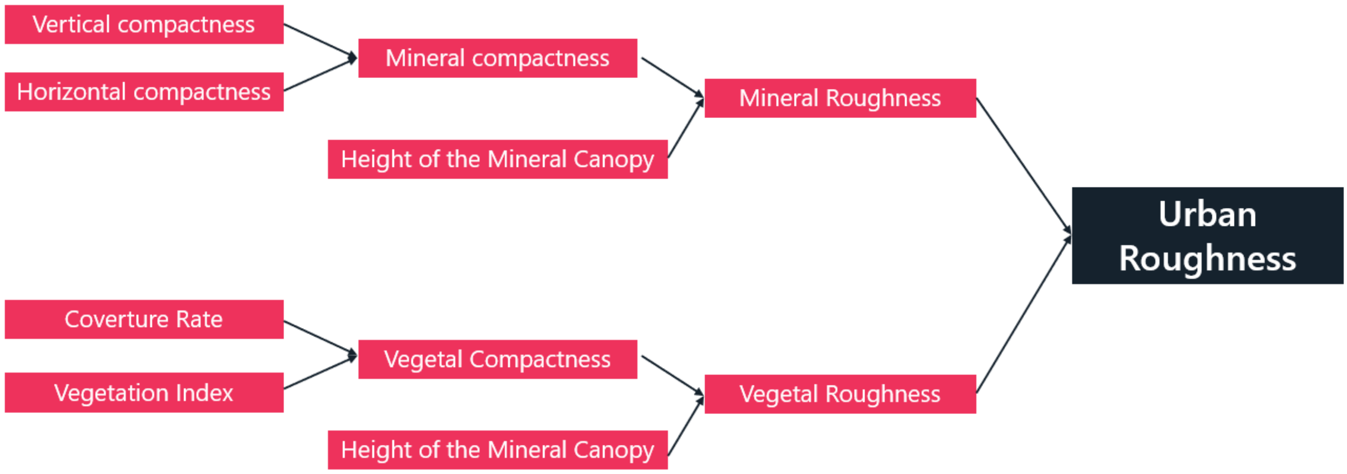


FIGURE 14 – ROUGHNESS CLASSIFICATION AND PARAMETERS (SOURCE: IAU ENGLISH ADAPTATION)

This method can be applied to a plot scale.

f. <u>Height of voluminous elements</u>

The geometric height average of the different voluminous elements in the plot, such as buildings and vegetation.

2.6.2.2. Thermal, radiative, and metabolic properties

At this point, the variables related to **energy exchange** will be explained. These are the variables related to the **type of construction materials** used in buildings and the **anthropogenic heat** produced by human activity.

In relation to construction materials, the parameters evaluated are:

a. <u>Albedo</u>

$$albedo = \frac{solar\ energy\ reflected\ by\ a\ surface}{total\ solar\ energy\ received}$$

The value of the albedo is situated between 0 and 1. An albedo equal to 1 means that the surface is of a light colour and reflects all the energy that it receives from the sun.

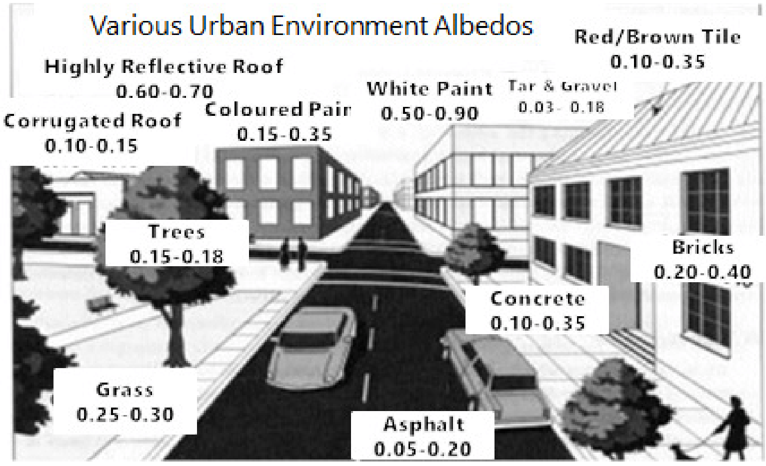


FIGURE 15 – ALBEDOS IN THE URBAN ENVIRONMENT (SOURCE: COLOMBERT)

These are the albedo values mentioned as guide in the regulation HQE BD V4.

b. Emissivity

Emissivity is a variable that measures how close is a body to being a blackbody. A blackbody is the most efficient body at emitting energy at a given temperature. That means that it is a property that depends only on how the body behaves thermally.

It is also a variable represented by the symbol ε, unitless and achieving values between 0 and 1. It is defined by the equation:

$$\varepsilon = \frac{M_e}{{M_e}^0}$$

Where:

- M_e: is the energy emitted by a surface at a specific temperature.
- ${M_e}^0$: is the energy emitted by the same surface at the same specific temperature if it were to act as a blackbody.

In order to apply this variable to our study on urban heat islands in the construction sector, it can be confirmed that: the higher the emissivity data of the building materials of the project site, the greater the effect of the urban heat islands will be, since more heat will be transmitted to the atmosphere.

This variable is named "admittance" in the LCZ method. Researchers such as Amelie Parmentier and François Leconte have also treated this parameter in the emissivity form, as his measure in the form of a coefficient between 0 and 1 allows for a better comprehension.

DIFFERENCES BETWEEN ALBEDO AND EMISSIVITY

Albedo and emissivity are **not** complementary values: $albedo + emissivity \neq 1$

Emissivity is a variable that can be analyzed without the need for the body surface to receive solar energy and depends on its thermal properties.

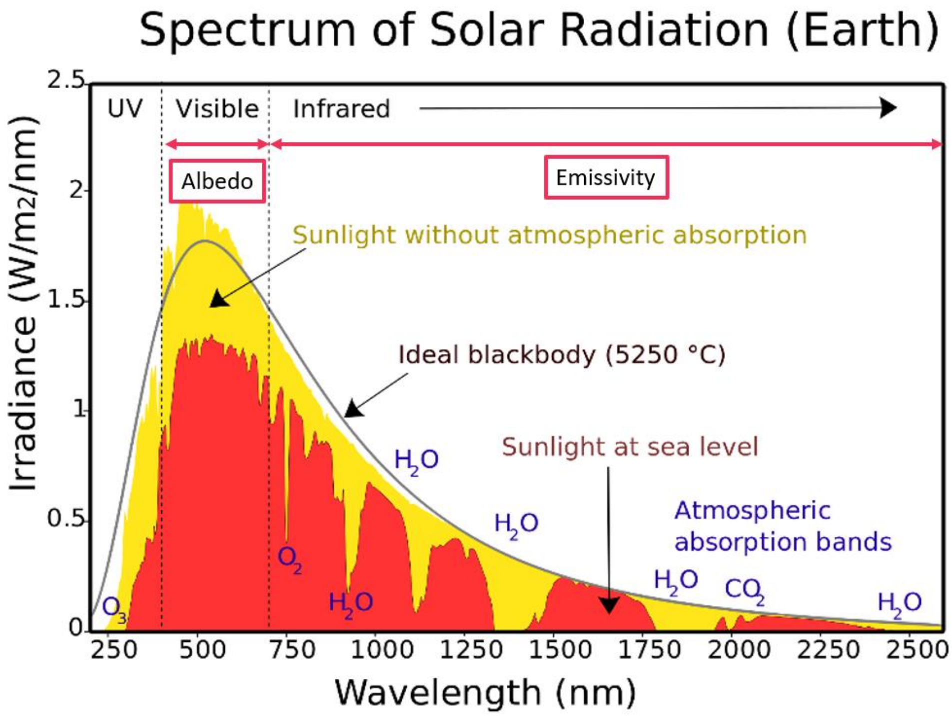


FIGURE 16 - SOLAR RADIATION RATE AT DIFFERENT WAVELENGTHS (SOURCE: RESEARCHGATE)

Figure 16 shows all the irradiance in the infrared spectrum that is evaluated in the emissivity variable but that cannot be evaluated in the albedo variable.

c. Anthropogenic Heat

Finally, we find the energy related to **human activity**. An increase in anthropogenic heat is produced by the usage of air conditioning or heating systems, pollutants suspended in the air (chemical products produced by factories, fuels from means of transport...) and natural heat caused by the metabolism of a person..

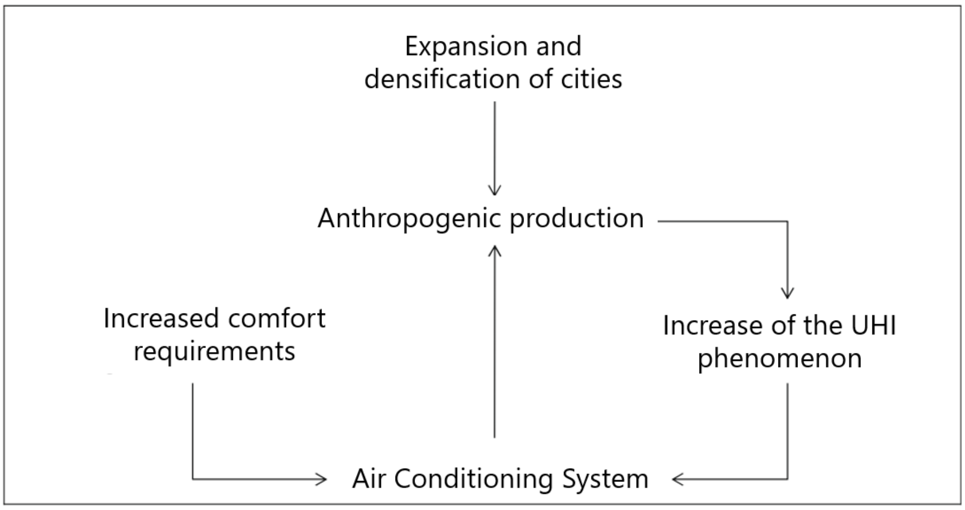


FIGURE 17 – LOOP OF ANTHROPOGENIC HEAT PRODUCTION AND UHI IN SUMMER (SOURCE: DEVELOPMENT ON A DECISION SUPPORT TOOL TO MITIGATE DE HEAT ISLAND PHENOMENON IN URBAN AREAS, AMELIE PARMENTIER, ENGLISH ADAPTATION)

Industry and the use of temperature control systems (air conditioner and heating) account for 48% of the total anthropogenic heat emissions. Transport accounts for 50% and the remaining 2% is made up of emissions from human metabolism and are therefore hardly significant [5].

→ **Air conditioning systems**

The physical description of the air cooling phenomenon produced by air conditioning systems is as follows:

> *"In order to lower the temperature of the air present in a room, a transfer of energy takes place in a heat exchanger between a cooling fluid and the hot air present in the room. Producing cold air inside the room and expelling hot air to the outside."*

The expulsion of hot air promotes the increase of the UHI effect.

This repercussion is more evident at night than during the day, since at night the temperatures decrease and the air conditioners continue to expel hot air.

The thesis carried out by C. de Munck in 2013 for the CLIM Project [2][18] quantifies the temperature increase caused by air conditioners in the department of "Ile de France". The following photo shows the temperature difference between night and day caused by air conditioning systems.

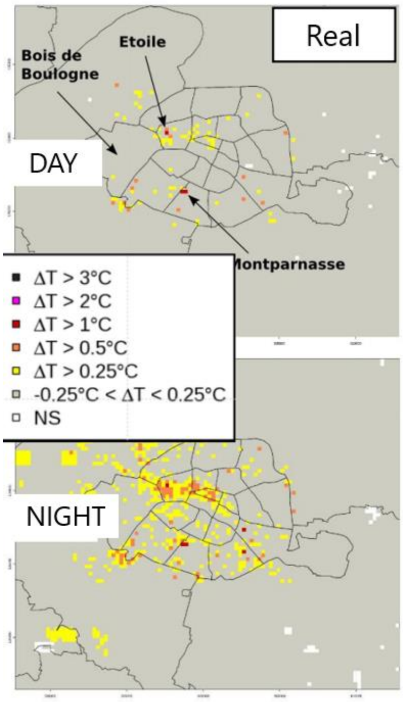


FIGURE 18 – TEMPERATURE'S VARIATION CAUSED BY AIR CONDITIONING (SOURCE: MUNCK (2013))

According to his study, in the current scenario in Ile de France, air conditioning systems increase the ambient air temperature in the urban core by 0,5°C. It also estimates that in 2030 the temperature would increase by 2°C due to the increase in demand of air conditioning systems and the increase of the globe's temperature.

In his these, C. de Munck divides the air conditioning systems into 2 different groups:

- → Dry Air Conditioners: they reject hot air
- → Wet Air conditioners: they reject the hot they produce by water's vapor

The expulsion of water vapor helps to reduce the effect caused by dry air conditioners.

In total, it conducts a study of 4 air conditioning scenarios:

- → DRY-ACx2: If dry air conditioners are multiplied by 2. (2030)
- → DRY-AC: If all the air conditioners were dry.
- → REAL-AC: Coexistence of dry and wet air conditioners. The actual existing case.
- → NO-AC: Without air conditioning.

The results of his thesis analysis are represented in the following picture:

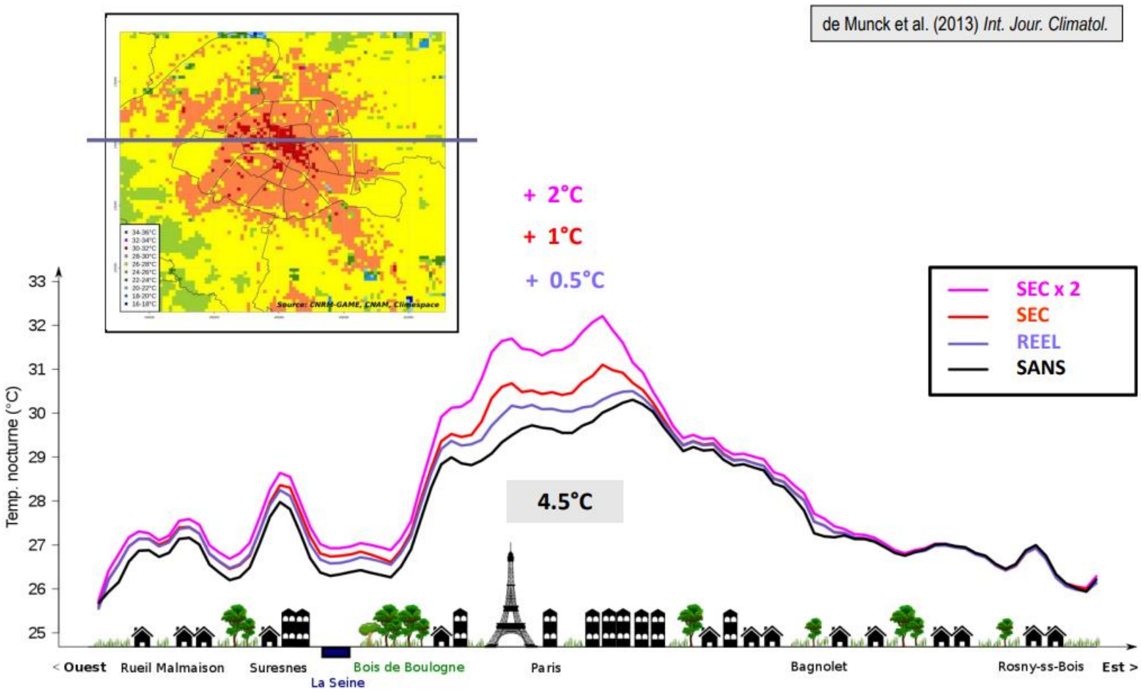


FIGURE 19 – INCREASES IN NIGHTTIME TEMPERATURES CAUSED BY AIR CONDITIONING (SOURCE: MUNK (2013))

3. METHODOLOGY'S DESCRIPTION

As explained above, this research has been performed at the **plot scale** of the construction/renovation project. This is because the requirements of the new HQE BD V4 version demand that the **UHI Score has to be improved by 10%** when comparing the plot before and after the assessment.

Our method consists of individually analyzing all the relevant controllable variables that can be accounted for.

For the analysis of each of the variables, an **Excel** document was created in which all the calculation procedures for each of the variables that will be explained below are dutifully performed.

It was also necessary to use a tool to calculate a specific surface of a plan (for example, to calculate the area of the green surfaces of a plot for calculating the vegetation ratio). For this purpose, the **PDF XChange Viewer** software has been used. This program allow us to outline a surface on a plan giving its resulting area data:

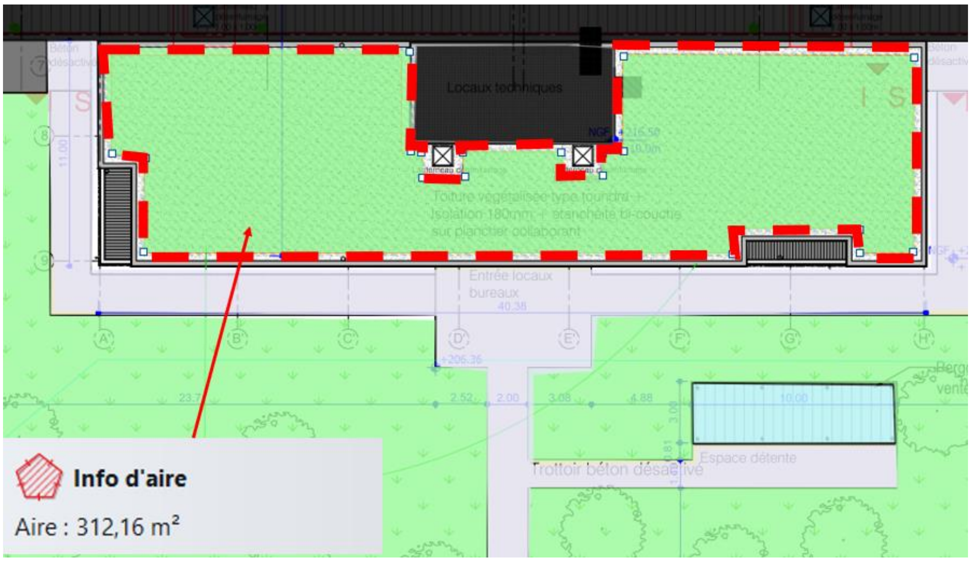


FIGURE 20 - SURFACE OF A GREEN ROOF (SOURCE: PDF XCHANGE VIEWER & PAYET)

At the end, the percentage of improvement before and after the realization of project was computed for each variable. Then, they were summed, and a final result was obtained.

A practical example of the method will be done in Chapter 4, to better clarify this process.

It is important to consider that the evaluation of this score was done by evaluating the different variables **during the day**. On the contrary, during the night, variables like the albedo cannot be evaluated.

3.1. Geometric and surface properties

3.1.1. Surface View Factor

It is very difficult to quantify this factor. The programs which can calculate this ratio (like for example QGIS) are not adapted for calculating it in a plot scale.

3.1.2. Aspect Ratio

If the project is located in an urban environment, the aspect ratio will be calculated through the following formula:

$$AR = 0{,}5 * \frac{\sum S_{green}}{S_{total} - \sum S_{building}}$$

If the project is not located in an urban area, the AR will be calculated by the traditional formula:

$$AR = \frac{building's\ height}{width\ of\ street\ canyons}$$

Generally, we will obtain a very small result when calculating the AR in a rural area, since the denominator of the formula (width of street canyons) usually has a large value.

3.1.3. Building Surface Factor

This factor is calculated by the ratio between the building surface and the total surface:-

$$BSF = \frac{S_{building}}{S_{total}}$$

3.1.4. Pervious and Impervious Surface Factor

The HQE BD V4 regulation proposes a calculation method for these factors. Since the UHI Score is intended to be validated by Certivéa for the HQE benchmark, the bases of the method proposed by HQE will be taken into account in order to get as close as possible to a pertinent value.

As we have seen in *Chapter 2*, both factors are complementary, therefore, the value of both variables will be represented by a single factor: the **absorption factor** (or pervious factor).

The calculation method consists of the following [14]:

1. To obtain the absorption factor, it is first necessary to calculate the Impervious Surface Factor:

$$ISF = \frac{Impervious\ surface}{S_{total}}$$

This coefficient is calculated from a weighted average of the sum of the different "unit surfaces", **each "unit surface" have the same permeable characteristics**. Each one of them is then multiplied by their respective waterproofing coefficient.

$$ISF = \frac{I_1 * S_1 + I_2 * S_2 + \cdots + I_n * S_n}{S_{total}}$$

The HQE BD reference proposes a series of standard values of imperviousness coefficients for different soil types. The UHI Score method will take the values in this table as a reference:

	Absorption coefficient of the project surfaces		
	Type of surface	**Elemental imperviousness coefficient**	**Elemental absorption coefficient**
Green spaces	Wooded green spaces	0,1	**0,9**
	Grassed green spaces	0,2	**0,8**
	Green spaces on slab	0,4	**0,6**
Roads	Porous concrete, stabilized or wide jointed paving surfaces	0,6	**0,4**
	Pavements with permeable reservoir structure on sandy soil	0,4	**0,6**
	Pavements with permeable reservoir structure on silty soil	0,7	**0,3**
	Vegetated parking lot	0,7	**0,3**
	Impermeable surfaces (paths, roads, parking lots)	1	**0**
Roofing	Intensive green roof	0,4	**0,6**
	Semi-intensive green roof	0,6	**0,4**
	Extensive green roof	0,7	**0,3**
	Impermeable roof	1	**0**

TABLE 4 – VALUES FROM THE ENCYCLOPEDIA OF URBAN HYDROLOGY (SOURCE: HQE BD V4 & B. CHOCAT, LAVOISIER, TEC & DOC ENGLISH ADAPTATION)

- → HQE clarifies that, if one of the surfaces present in the project is not within the standard data of this table, it will be necessary to attribute a permeability coefficient that is consistent and based on bibliographic data.
- → If rainwater infiltration is not allowed for the plot, the variable will not be applicable.

Finally, the absorption factor is calculated from:

$$PSF = \frac{average\ mean\ (pervious\ surface, elemental\ absorption\ coefficient)}{Total\ plot\ surface} = 1 - ISF$$

HQE benchmark evaluates plots according to their absorption coefficient in the following way:

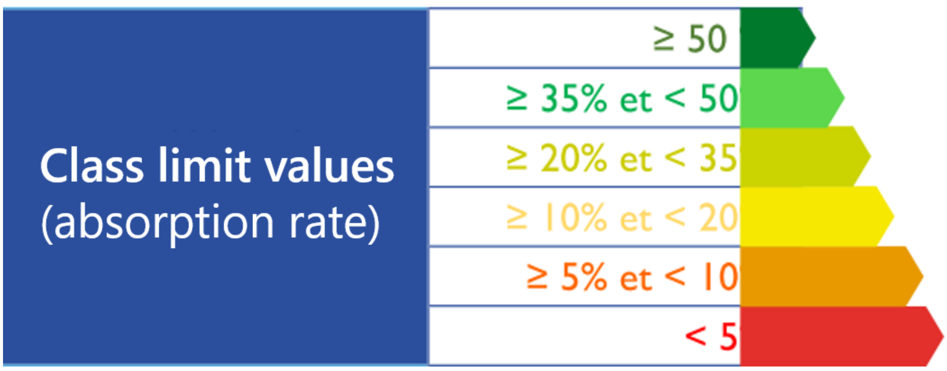


FIGURE 21 – INFILTRATION FUNCTION PARKING & PLOT ABSORPTION RATE (SOURCE: HQE BD V4 ENGLISH ADAPTATION)

3.1.5. Terrain roughness class

As we have seen in section 2.6.2.1.e, and according to *Figure 14*, , most of the parameters that are to be considered for the evaluation of these criteria (such as: building height, vegetation ratio, building surface, etc.) **will have already been evaluated** in this IHU Score methodology. Therefore, these parameters **will not be considered.**

3.1.6. Height of voluminous elements

The procedure for assessing these criteria will consist of measuring the building's average height and the vegetation on the plot. Regarding to vegetation measurements, there is no need to be very precise or concisely, since as stated in the V4 regulation: "It is not necessary to model the vegetation finely in the study".

Therefore, we will proceed as follows:

- → If it is a green area where several trees have been planted, a standard measurement for these trees of 3,5 meters will be considered. The surface affected by this tree would have a radius of 3,5 meters surrounding his trunk. These standard measures are approximations, if the size of the trees is indicated in the plan it is this last one which would have to be considered.
- → If it is a green area where there are not many trees, the height of the vegetation will not be taken into account as it will be considered as grass of negligible height when compared to the building height.

For example, for a project with the following characteristics:

- → 500 m² of plot
- → 350 m² of building surface. The height of the construction is 10m.
- → 20 trees

The result will be:

$$average\ height = \frac{350 * 10 + 20 * 3.5^2 * \pi}{500} = 8{,}5\ m$$

3.2. Thermal, radiative, and metabolic properties

3.2.1. Albedo

The calculation of this parameter was carried out only on the horizontal surfaces of the project (i.e., only on the roofs and on the floor), because if a building does not absorb but instead reflects the energy rays on a vertical wall, this energy will be absorbed or reflected again by the impact surface. Therefore, these rays will remain in the urban environment and the UHI effect will not be reduced. In addition, horizontal surfaces receive more direct solar rays than vertical surfaces.

Besides, according to the HQE BD V4 regulation, this coefficient is called "ground reflection coefficient" so technically, it can only be calculated for horizontal surfaces.

This hypothesis can be better visualized on the following figure:

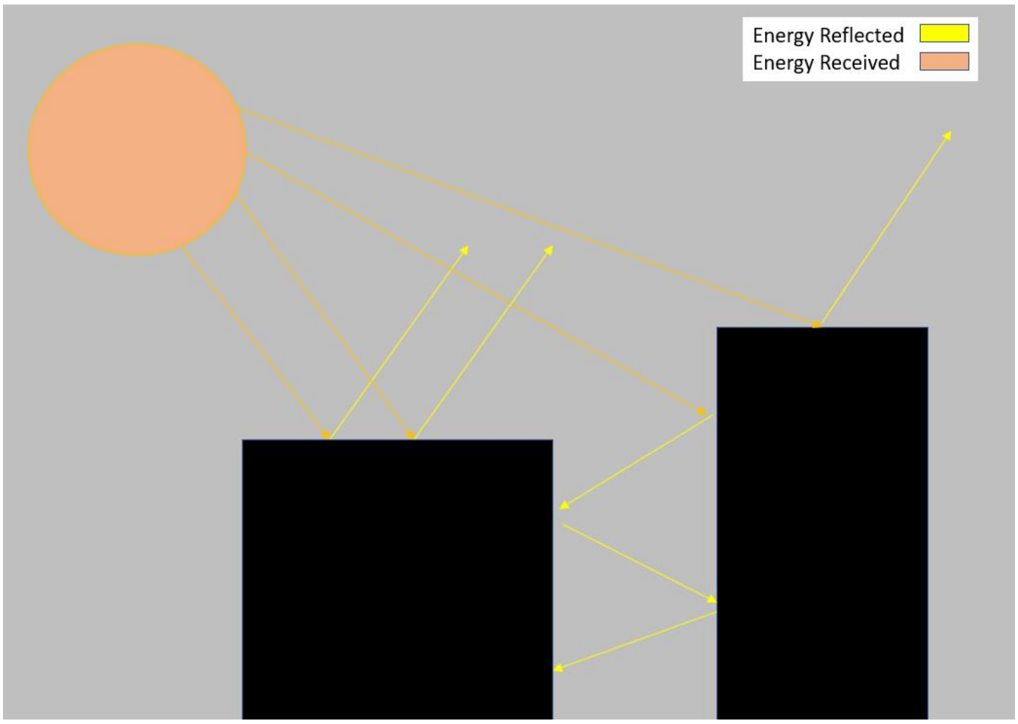


FIGURE 22 – ENERGY RECEIVED AND REFLECTED ON HORIZONTAL AND VERTICAL SURFACES (SOURCE: PAYET)

In addition, a **first evaluation** of the albedo of the surface is necessary to establish if the project if eligible for the obtention of credits or not. As a reminder, this factor must be **less than 0,35**.

3.2.2. Emissivity

This variable considers the thermal absorption properties of the building's material. Due to energy absorption being carried out by every building's surface, **both horizontal and vertical surfaces** have to be taken into account.

METHOD OF CALCULATION OF ALBEDO AND EMISSIVITY VARIABLES

For the analysis of these parameters, the calculation was carried out taking advantage of the fact that the study is evaluated at a small scale. The building materials which are used in a particular construction are easily identifiable, and that is why a **database** with the values of the albedo and the emissivity of the most common materials used in construction can be done. *(Appendix B*)

For the final calculation of the parameters, a **weighted average** between "unit surfaces" and their corresponding emissivity and albedo coefficients has to be done.

$$albedo = \frac{Alb_1 * S_1 + Alb_2 * S_2 + \cdots + Alb_n * S_n}{S_{total}}$$

(See section 3.1.4 as it is the same procedure as for the permeability and impermeability factors.)

3.2.3. Anthropogenic heat

There are some anthropogenic emissions which cannot be evaluated in a plot scale. Urban traffic, for example, will not take place on the plot and has therefore not be considered.

On the other hand, the projects that PAYET carries out are not factories (that emit a lot of polluting substances). As pollutant substances in this sector represent 50% of the total emissions produced by anthropogenic heat, this proportion has been left out of the calculation.

The only parameters that can still be evaluated are the use of air conditioning systems and the emission of heat from human presence. This last parameter, as it has been seen, accounts for only 2% of total emissions and has therefore not be considered either, as it is negligible.

The last and only source of anthropogenic heat that remains to be evaluated is that of **air conditioning systems**. To quantify for this effect, the following procedure has been followed, with differences depending on the situation of the project:

3.2.3.1. Air Conditioning Quantification in Renovation Projects WITH previous air conditioning systems

This process will consist of a ratio between the power dedicated to the air conditioning systems before and after the renovation of the building.

→ Power after renovation.
The data corresponding to the power installed can be founded in the "Bilan Thermique" [7] which is calculated by the Fluid Department in the form of W/m².
Subsequently, this data has to be multiplied by the surface that will be air-conditioned. This step is necessary, as most renovation projects tend to air-condition a larger surface area than that which was previously air-conditioned.
In this way, a final result will be obtained in unit of power (W).

→ Power before renovation
Normally this data is not readily available.

- In case this data is not available, a value of W/m² will be chosen depending on the description of the "before renovation" building between:

Type of building	Low Consummation Building	Building respecting the RT2012	Older than 10 years not renovated	Under 10 years old
Consummation (W/m²)	65	75	125	100

TABLE 5 – POWER TO USE DEPENDING ON YOUR AIR CONDITIONING SYSTEM (SOURCE: ENGIE)

Once the most appropriate data has been selected, we proceed to multiply it by the climatized surface, in order to have a value for total power (W).

- In case that it is possible to obtain both the data corresponding to the installed power and the previous air-conditioning surface, the process for obtaining the total power will be exactly the same as in the previous section.

In the end, both powers will be compared, and the final result will be obtained by means of the following formula:

[7] Thermal balance

$$\% \, Power \, Variation = 1 - \frac{Power \, after \, renovation}{Power \, before \, renovation}$$

3.2.3.2. Air Conditioning Quantification in Renovation Projects WITHOUT previous air conditioning systems or New Constructions

If the previous building:

- → Didn't have any air conditioning system but the future building will have it
- → Is a new construction which has installed and air conditioning system

A **standard penalization percentage** will be applied, this one will be of **-30%.**

This value of -30% has been chosen because it is a consistent value based on the UHI Score calculation of other projects that had an air conditioning system before de renovation. In this type of projects, the percentage penalty was around -10%. The fact of installing a new operational air conditioning system will have a penalty of 3 times the usual renovating value.

In general terms for these criteria, it is coherent with the fact of having a negative percentage. Air conditioning systems are being recently installed in new buildings as it improves our comfort. On the contrary, this causes an increase on the UHI effect.

4. APPLICATION OF THE METHOD

In order to demonstrate that the calculation tool is effective for any type of project (construction or renovation), the UHI Score will be calculated on three different types of projects:

- → Two new construction projects:
  - o New construction on the countryside at Lyon: CORBAS T3
  - o One starting from an unusable building structure: Hotel MOB Bordeaux.
- → A renovation project in the center of Paris: 1bis Foch

4.1. Corbas T3

In contrast to the two other projects, which were office projects, this one is a logistic platform.

4.1.1. Determination of the eligibility of the project and surface division.

The project will be built on an area where nothing has ever been built before:

FIGURE 23 – FUTURE PROJECT'S BUILDING PLACE (SOURCE: GOOGLE MAPS)

The horizontal and vertical division of the future building are as follows:

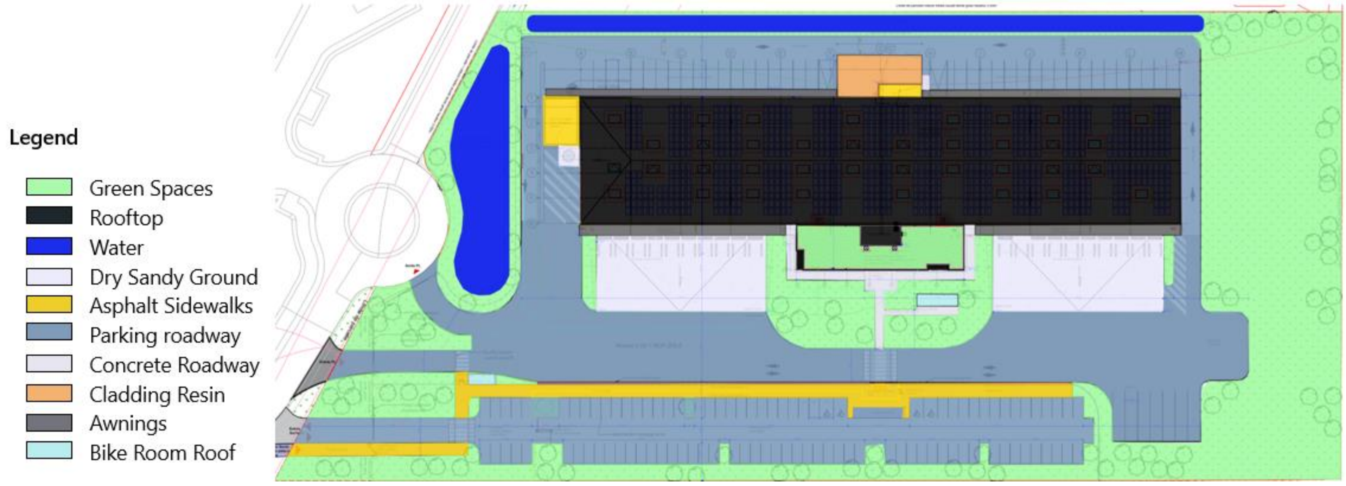


FIGURE 24 – HORIZONTAL SURFACE DIVISION OF THE PROJECT (SOURCE: PAYET)

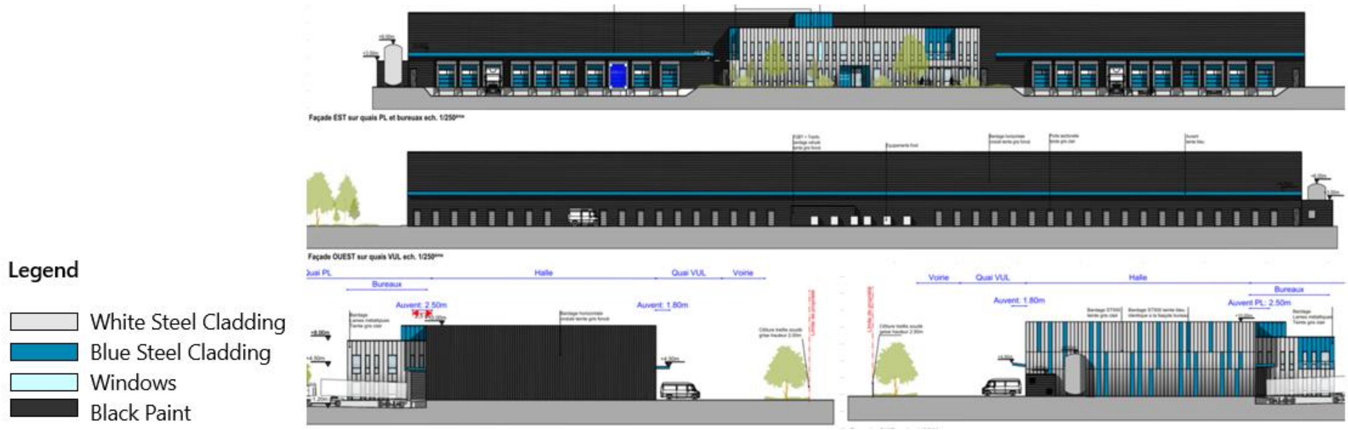


FIGURE 25 - VERTICAL SURFACE DIVISION OF THE PROJECT (SOURCE: PAYET)

Although the vegetation rate obtained has been of 30% and so the project is **not applicable** for obtaining the UHI points, the UHI Score has been calculated anyways in order to prove the effectiveness of the tool in a logistical project.

4.1.2. Determination of the UHI Score

VARIABLE	% OF IMPROVEMENT
Aspect Ratio	18,3
Albedo	0,7
Emissivity	-4
Building Surface Factor	-17,6
Absorption Ratio	-48,3
Height of voluminous elements	-100
Anthropogenic Heat	-30
TOTAL	-181,0

TABLE 6- FINAL UHI SCORE (SOURCE: PAYET)

The details of the calculations will be specified in the *Appendix C,* in order to show in more detail what the calculation tool consists of.

4.1.3. Conclusions for CORBAS T3

The result for this project is -181%. This is a very high absolute value, however, it is consistent since it is a new construction on a site on which there was previously nothing. This has meant a maximum penalty on anthropogenic heat and height variables.

Obtaining points for this HQE BD criterion would be impossible for this project.

4.2. 1bis Foch

This project consists of a renovation of a Parisian, central and Haussmann building that is used as an office building.

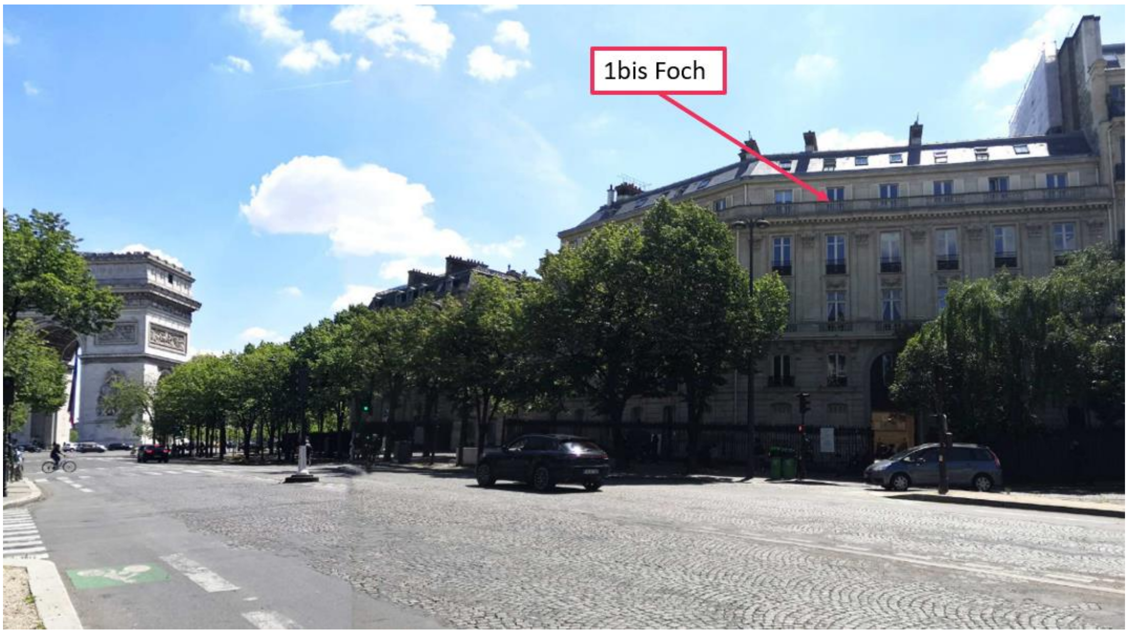


FIGURE 26 – 1BIS FOCH RENOVATION PROJECT (SOURCE: PAYET)

4.2.1. Determination of the eligibility of the project and surface division.

First of all, it will be examined whether the project is eligible for the credits given by HQE BD V4 *(Table 1)*.

As a reminder, for a project to be eligible for these points, it must fulfil the following criteria:

- → The vegetation rate of the plot is less than 30%.
- → The albedo of the plot in the horizontal surfaces is less than 0,35.

From a mass plan, thanks to the PDF-XChange Viewer software, the vegetation rate and the albedo can be calculated. The surfaces that have been considered for the calculation of these properties have been:

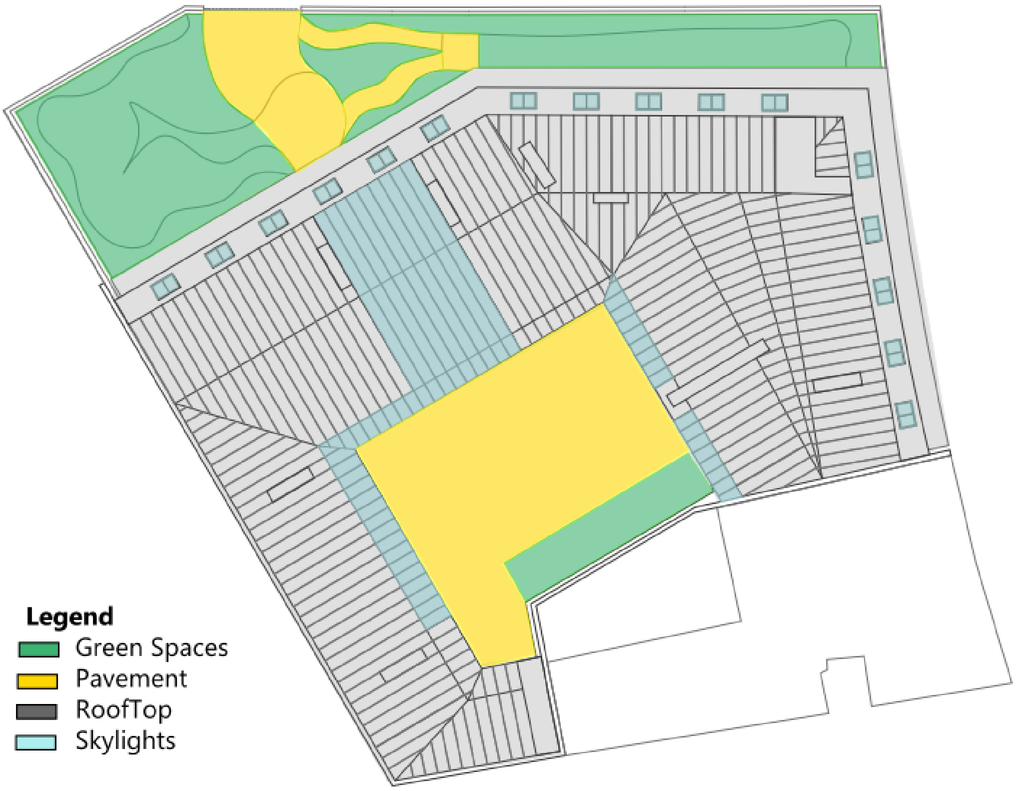


FIGURE 27 – IDENTIFICATION OF THE DIFFERENT HORIZONTAL SURFACES OF 1BIS FOCH PROJECT (SOURCE: PAYET)

Vegetation's rate Calculation

GREEN SPACES (m^2)	TOTAL SURFACE (m^2)	VEGETATION RATE
164,25	1029,19	16%

TABLE 7 - VEGETATION'S RATE CALCULATION (SOURCE: PAYET)

The vegetation rate is less than 30%. The project is **eligible** according to this criterion.

Albedo

MATERIAL IDENTIFIER	TYPOLOGY	ALBEDO	MATERIAL'S SURFACE/TOTAL SURFACE (%)	ALBEDO* MATERIAL'S SURFACE/TOTAL SURFACE
Green Spaces	Grass	0,21	16	0,033
Pavement	Average Pavement	0,25	18	0,055
Skylights	Glass	0,1	3	0,003
Rooftop	Non-metallic coated zinc	0,1	63	0,063
		TOTAL	**100**	**0,155**

TABLE 8 - ALBEDO'S CALCULATION (SOURCE: PAYET)

The albedo is less than 0,35

Conclusion

The project is **eligible** for the obtention of these credits.

In order to calculate the rest of variables which will determine the UHI Score of this project, we have to consider the different materials which constitute the horizontal and vertical surfaces of the project **before and after** the renovation takes place.

Horizontal surfaces have been divided as follows:

FIGURE 28 – HORIZONTAL SURFACE DIVISION BEFORE RENOVATION (SOURCE: PAYET)

The horizontal surface division after the renovation is represented in *Figure 27*.

Regarding vertical surfaces, the only surface which changes are the windows situated in the last floor of the building:

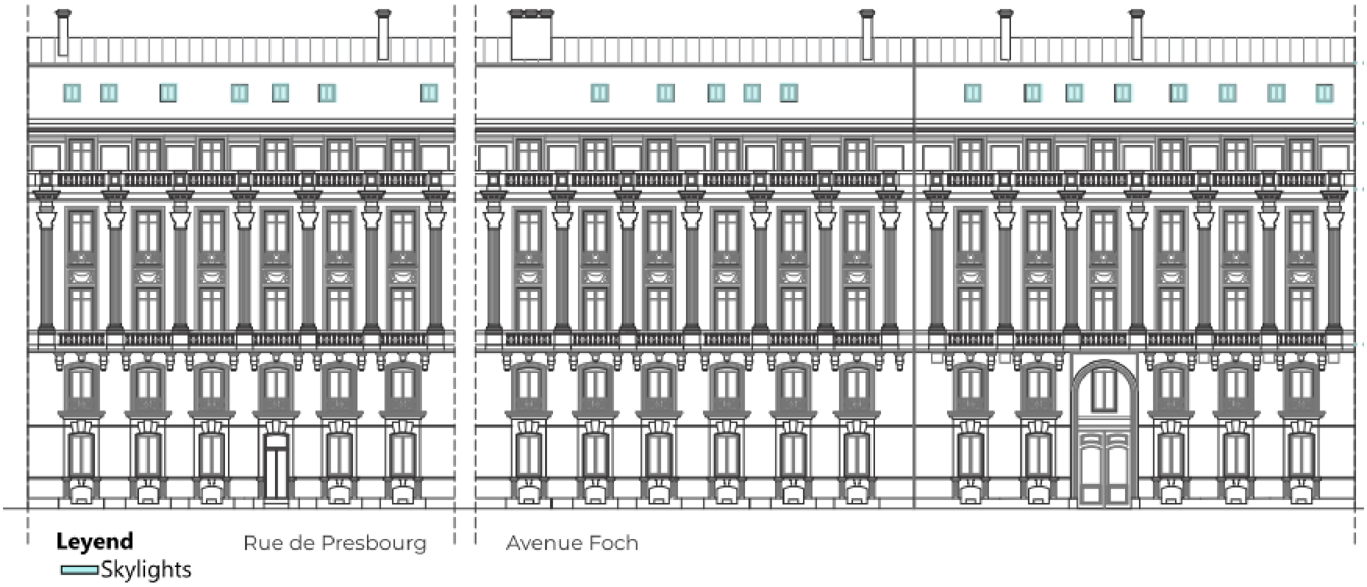


FIGURE 29 – VERTICAL SURFACE DIVISION BEFORE RENOVATION (SOURCE: PAYET)

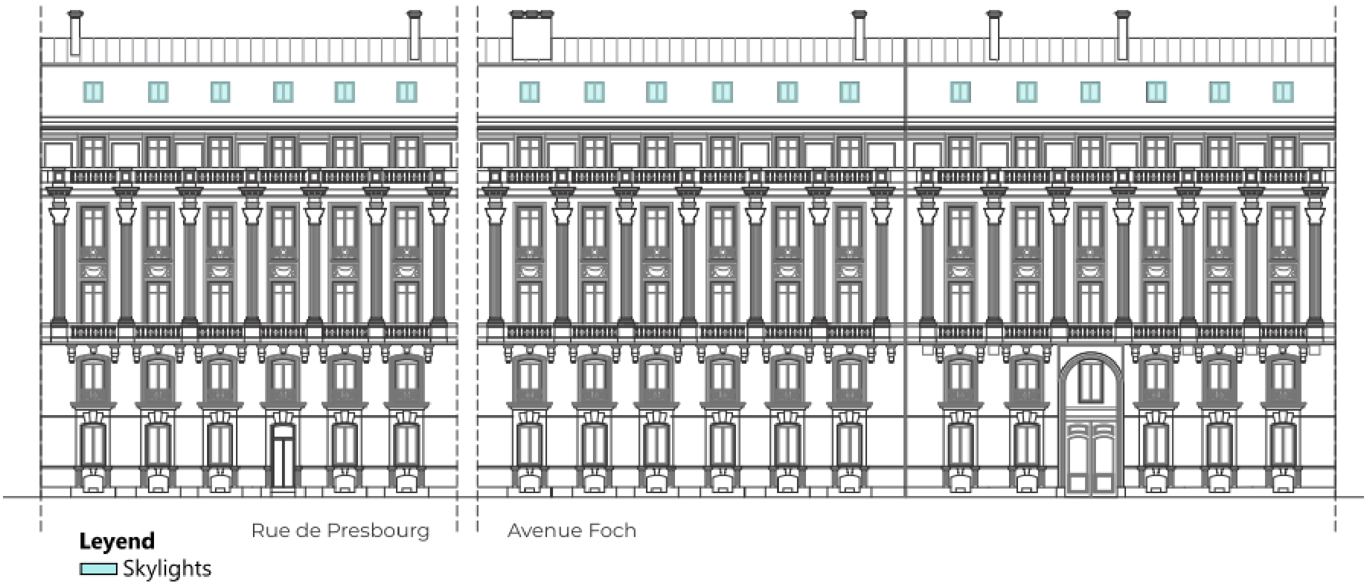


FIGURE 30 - VERTICAL SURFACE DIVISION AFTER RENOVATION (SOURCE: PAYET)

4.2.2. Determination of the UHI Score

The evaluation of each criterion has been done as explained in *Chapter 3*, and all calculations have been carried out using the database (for collecting the data of emissivity, albedo and pervious factor) and the Excel program.

As this is a renovation project, in order to calculate the improvement percentage for anthropogenic heat we have to select the climatized surface of the building before and after the renovation. After the renovation, the surface that will be climatized is bigger than the existing climatized surface before the renovation.

For the value corresponding to the factor before the renovation, the power data chosen has been of 125 W/m² and for after the renovation, a value of 75 W/m² has been chosen.

The final results, given in percentage of improvement between before and after the renovation are as follows:

VARIABLE	% OF IMPROVEMENT[8]
Aspect Ratio	6,07
Albedo	2,03
Emissivity	-1,65
Building Surface Factor	0
Absorption Ratio	2,73
Height of voluminous elements	0
Anthropogenic Heat	-9,93
TOTAL	-0,73

TABLE 9 -FINAL UHI SCORE (SOURCE: PAYET)

4.2.3. Conclusions

The final score obtained is -0,73 %, which means that, despite being an eligible project for the obtation of the points, this will not be possible since -0.73<10%.

This result is logical, since this renovation project does not modify in a huge way the FALTA INFO. It is logical for the final score to be close to 0, since there is no change in the external appearance of the building.

In addition, this building will have a new air conditioning system for all rooms, which is a penalty, since previously the air conditioning system was only available in some of the offices. This penalty is mostly neutralized by a small increase green spaces and the substitution of the rooftop zinc material with glass.

[8] Between the project and the existing building.

4.3. Hotel MOB Bordeaux

This is a new construction project which is going to take place in the suburbs of Bordeaux. .

4.3.1. Determination of the eligibility of the project and surface division.

The surface of the existent construction project is as follows:

FIGURE 31 – HORIZONTAL SURFACE BEFORE CONSTRUCTION (SOURCE: GOOGLE MAPS)

The material constituting the horizontal surface of the old structure will have a typology of: Galvanized Steel Very Dirty.

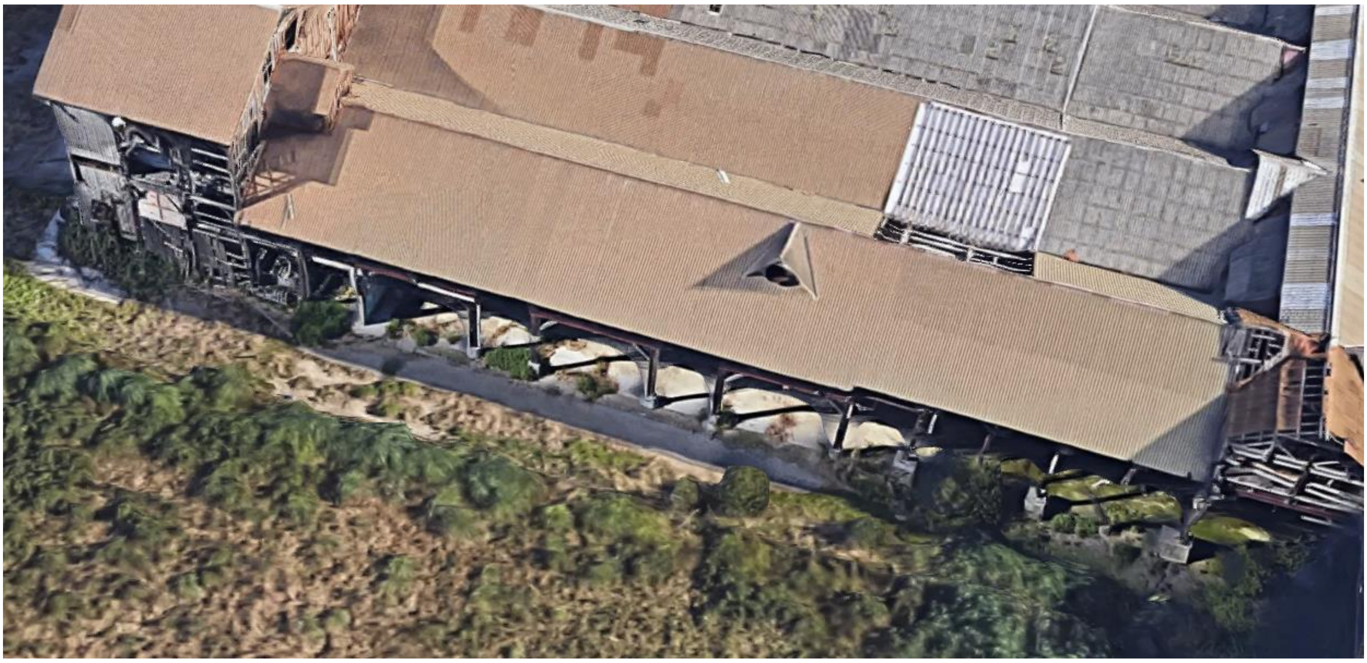


FIGURE 32 - VERTICAL SURFACE BEFORE CONSTRUCTION (SOURCE: GOOGLE MAPS)

As it can be seen in the *Figure 32*, the previous building vertical surfaces are almost inexistent, as so, it will be considered as such for our calculation.

The new project's surface division is as follows:

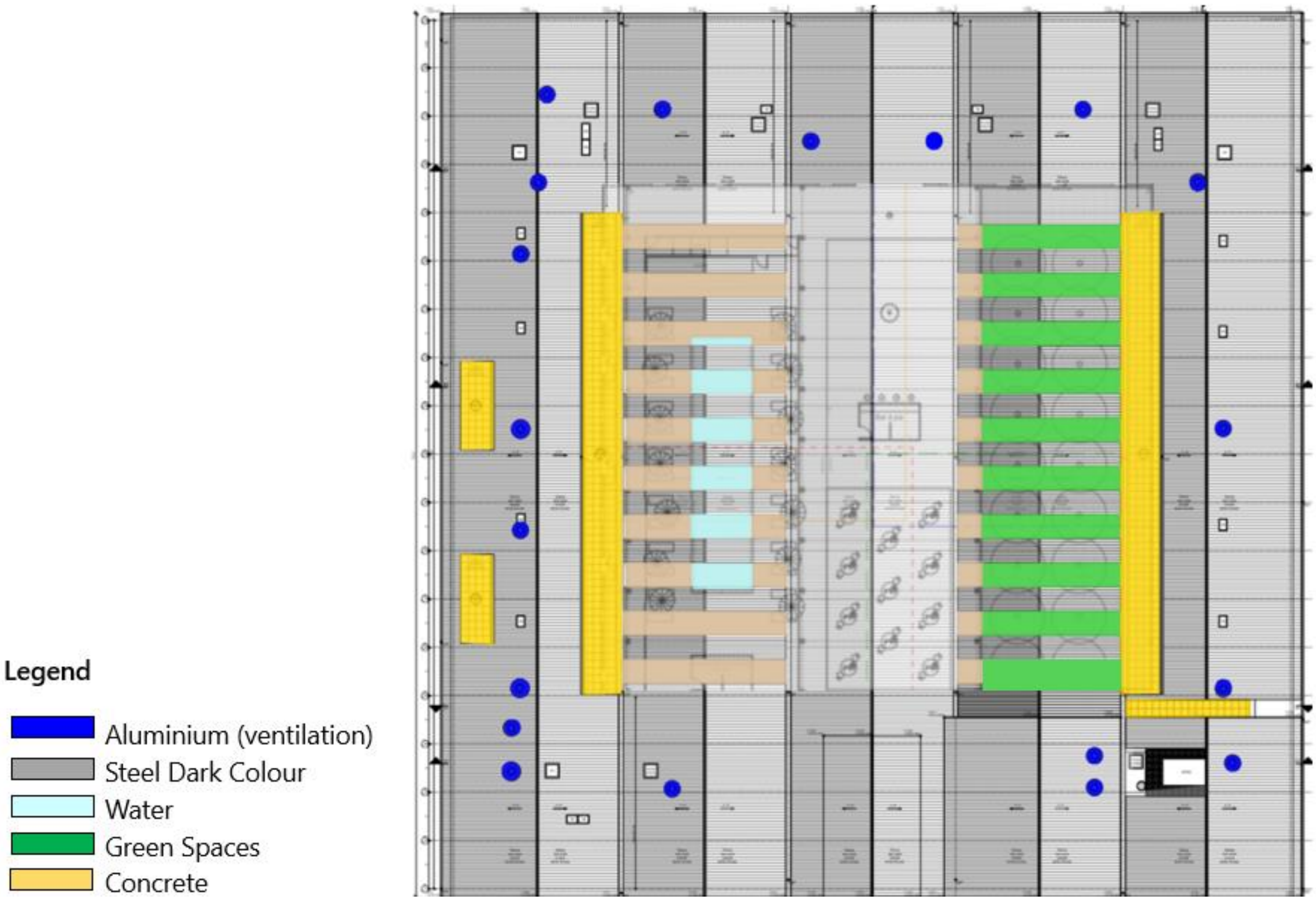


FIGURE 33 - HORIZONTAL SURFACE PROJECT'S DIVISION (SOURCE: PAYET)

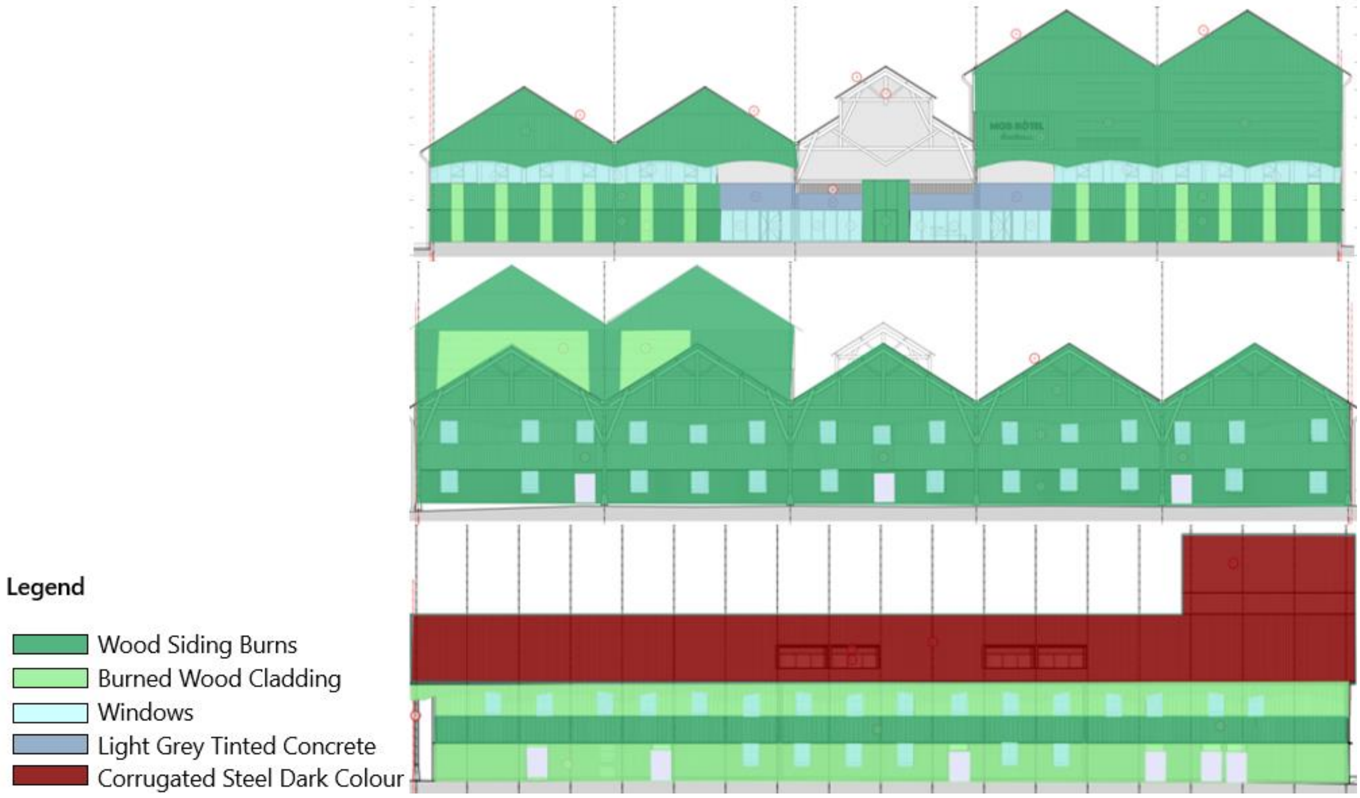


FIGURE 34 - VERTICAL SURFACE PROJECT'S DIVISION (SOURCE: PAYET)

With a result for the vegetation rate of 26% et an albedo of 0,34 it can be confirmed that the project is **eligible** for the UHI points.

4.3.2. Determination of the UHI Score

The results that have been reached are:

VARIABLE	% OF IMPROVEMENT[9]
Aspect Ratio	9,7
Albedo	26,7
Emissivity	8,7
Building Surface Factor	0
Absorption Ratio	5,5
Height of voluminous elements	0
Anthropogenic Heat	-30
TOTAL	20,6

TABLE 10 - FINAL UHI SCORE (SOURCE: PAYET)

[9] Between the previous and future project

4.3.3. Conclusions for Hotel MOB Bordeaux

The final result for this project is 20,6%. This result is consistent because, although it is a new construction and the maximum penalties for the anthropogenic heat variable (-30%) have been applied, due to having an existing structure, values such as floor area and height of voluminous elements remain unchanged and therefore do not penalize the final score.

The value of emissivity for vertical surfaces is negative as they have been considered non-existent for the previous structure. Nevertheless, it has been compensated by the value of emissivity of horizontal surfaces, reaching a final value of 8,7%.

Other variables such as the albedo or the absorption ratio are improved since some green areas and a swimming pool have been installed. As a consequence, the improvement percentage will be positive.

As the final improvement percentage is **bigger than 10**, this project would obtain the 5 points corresponding to this criterion in HQE BD V4

4.4. Method's Weaknesses

4.4.1. Equality of the importance of variables

This study has considered that the all the different variables affect the result of the UHI Score in the same way, however this cannot be possible.

For example, a 20% improvement in the emissivity parameter does not improve the creation of the UHI effect as much as a 20% improvement in the variable of permeability (absorption factor). However, in the UHI Score calculation tool they have been accounted for in the same way.

The lack of studies on the quantification of the importance of variables has prevented their inclusion in this study.

4.4.2. Measurement of vegetation height

Section 3.1.6 explains how tree heights will be counted. After consultation with PAYET's Department of Ecology and Landscape, a standard and meaningful measure for trees has been stablished (3,5 meters).

However, this measurement is very indicative, since the height of the trees and the surface that they occupy as seen from the sky varies according to the age of the tree, the time of the year, etc. Therefore, the standard measure that has been taken it is neither an exact nor a precise methodology.

However, if we do not rely on what HQE BD V4 says: "It is not necessary to model the vegetation finely in the study" we can consider this weakness as "not very significant"

4.4.3. The application of a standard penalization percentage

For the anthropogenic heat variable, it has been considered that, in the case of a project without a previous air conditioning system, a standard penalty of -30% will be applied. As this is a standard penalty, the individual characteristics of each project are not taken into account, and therefore, this is not a very accurate method as it potentially generates an error in the final result.

5. STRATEGIC ACTION PLAN

An evaluation of the UHI Score is of little use if it is not accompanied by a strategic action plan that helps to improve the result obtained. The fact of having this effect quantified allows us to have a numerical justification which confirms that changes can be applied with the objective of reducing the effects of UHI.

The HQE BD V4 reference cites: "In addition, it is important to present a strategy for improving this Score UHI".

PAYET will propose a strategic action plan adapted to each project to contribute to the reduction of this phenomenon, harmful for the environment and the health and well-being of its users.

5.1. Use of materials with high solar reflectivity

The materials with strong solar reflectivity are those with a high value of albedo. As it has been seen in *Chapter 2*, the materials that help developing the effect of the UHI are those with a dark coating or covering, because their capacity to reflect the sun's rays is smaller.

For example, according to the albedo and emissivity database used to calculate the UHI Score, white paint has an albedo of 0,82 while black paint has an albedo of 0,06, which makes a difference of a 76% of the value of the variable.

Typically, buildings found in coastal areas, or in countries where there is a constant and a high sunny presence tend to have a light coating color.

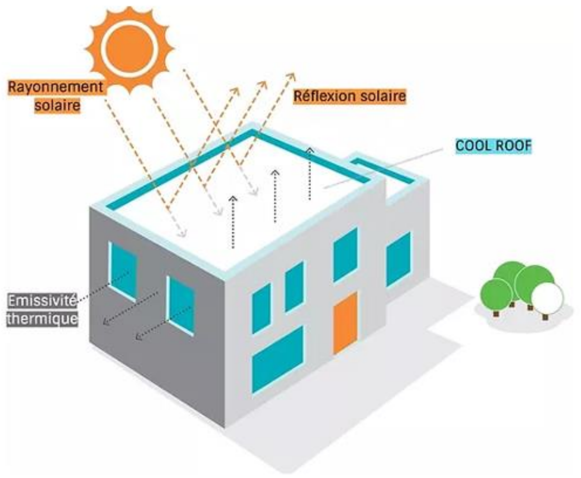


FIGURE 35 – COOL ROOFS (SOURCE: MTX-COOLROOF.COM)

Actually there is an American technique which gives instructions to adapt the roofs of buildings in order to achieve an energy gain, its name is **Cool Roof.** [15]

5.1.1.1. Cool Roofs

The objective is to install a high albedo material or coating on the surface of the roof.

The positive consequences of this technique are: reducing the temperature inside the building (this temperature can decrease up to 10°C), reducing the consumption of air conditioning, avoiding overheating of electrical equipment usually located on the roofs of buildings and prolonging their life span, reducing the electricity bill, **and helping to reduce the UHI effect**.

The most important feature for the installation of a cool roof is to choose a clear coating paint of the material (white for example). Within our albedo database (*Appendix B*) alternatives for the construction materials with a higher albedo than the standard ones, can be found:

MATERIAL	STANDARD ALBEDO	VARIANT	ALBEDO OF THE VARIANT
Cement Tile	0,2	Red Clay Hand-Molded Tile	0,4
Colored Paint	0,15-0,35	White Paint	0,82
New Galvanized Steel	0,36	White Clean Galvanized Steel	0,78
Ordinary Red Brick	0,34	White Varnished Brick	0,74
Slate	0,1	Slate Greenish gray	0,37

TABLE 11 – COMPARATION OF DIFFERENT MATERIAL VARIANTS (SOURCE: PAYET)

We confirm on the table above that the variants with a white/clear coating reduce the albedo value.

5.1.1.2. Variable applied to 1bis Foch

To better visualize the improvement of the UHI Score, this solution is going to be applied to the project 1bis Foch.

If we substitute the horizontal surface materials as follows:

MATERIAL	STANDARD ALBEDO	VARIANT	ALBEDO OF THE VARIANT	Δ
Pavement	0,25	Sandy White Ground	0,55	0,3
Zinc Rooftop	0,10	White painted rooftop	0,80	0,7

TABLE 12 – VARIANTS FOR HORIZONTAL SURFACES (SOURCE: PAYET)

The substitution of the material that constitutes the floor pavement by a light and sandy material allows to improve the UHI Score by 5%.

The substitution of the material that constitutes the actual roof by a white painted material allows to improve the UHI Score by 34%.

As a consequence the application of these two alternatives would allow the project to obtain the points related to the UHI by the regulation HQE BD V4 in its entirety, adding up to a total improvement percentage of the project of 39%.

5.2. Renewal of urban geometry

The purpose of implementing alternative construction techniques to reduce the UHI effect is to get as close as possible to **natural environments**. This can be possible by permeable or vegetated surfaces, which can reflect the sun's rays without transforming them into heat [10].

In this UHI Score methodology, parameters such as the albedo, the absorption factor, or the emissivity will be improved with the implementation of one of the following three different solution types:

5.2.1. Green Solutions

It consists of the installation of green spaces either on roofs, walls or floors of the different plots. According to Fenner and Pigeon in 2006, the nighttime temperature decreases by 0,3°C with a 10% of increase in green surfaces [10].

There are different types of performance variations in relation to these solutions which depend on the following factors:

- → Type of planting support: ground, walls, roof.
  - As seen in the previous solution, roofs are those urban surfaces that receive solar radiation first. In addition, due to their horizontality, they are the ones that heat up more intensely. During a sunny day with 26 °C in the shade, a roof can reach temperatures of 80 °C if it’s dark, 45 of it’s a “cool roof” and 29 °C if it is covered by vegetation[10]. It is therefore evident that the vegetation measure is more effective than the "cool roof" according to standard measures, however, the installation costs are higher.

PAYET has carried out several projects of re-vegetation of roofs for example a project located at 34 Boulevard de Courcelles in the XVIIth Boulevard of Paris:

FIGURE 36 – EXAMPLE OF A GREEN ROOF FROM A PAYET'S PROJECT (SOURCE: PAYET)

There are different variables when constructing a green rooftop:

- → Height of the vegetation
  - o It is necessary to find the balance for this parameter. It is not necessary to have a very high height because on a large scale it can block the wind and therefore prevent the air circulation. On the other hand, a certain height is recommended because it will allow more permeability of the surface and more cooling of the plot.
- → Type d'essence pour des arbres: platane, érable, liquidambar, etc.;
- → Size of the green space considered: square, parcs…
  - o The more surface the more good influence on the effect of the UHI.
- → Use of watering systems
  - o A good watering system to meet the needs of plants is important to maintain a good performance.

FIGURE 37 – DIFFERENT TYPES OF GREEN ROOFS (SOURCE: ADEME RAFRAICHISSEMENT URBAIN)

5.2.1.1. Variable applied to Corbas T3

Corbas T3 is a project in which there is a large area dedicated to parking areas and roads (8500 m²).

To quantify the importance of the existence of green surfaces, the surface of the project built in asphalt will be replaced by a grassy parking area as in the following photo:

FIGURE 38 – GRASSY PARKING (SOURCE: GOOGLE PHOTOS)

The substitution of this surface varies the result of the albedo and emissivity variables as follows:

	ALBEDO	EMISSIVITY	TAUX D'ABSORPTION
Asphalted parking	0,09	0,93	0
Herbaceous parking	0,16	0,76	0,3
Δ	0,07	-0,17	0,3

These changes would improve the UHI Score by almost a **20%**. Increasing it from -181% to -161%.

5.2.2. Blue Solutions

Blue Solutions are all those that include the use of water to cool the environment.

- Ponds, water bodies, rivers
  - They are large bodies of water. It is important to find a balance with respect to their volume and their stagnation. Small bodies of stagnant water may accumulate the heat that they emit to their surroundings during the night, warming the environment instead of cooling it down.
  - Even if the water itself is impermeable, its absorption factor will be considered as maximum since in this case it helps to neutralize the UHI effect.
- Water uses within urban infrastructures
  - Dampening of pavements: this method consists of spraying water on streets and asphalts during very hot periods. Temperature reduction can reach up to one degree by using 2.2-3 mm of water over 2550 hectares [10].
  - Foggers, fountains: Urban water emission devices reduce temperatures by 2 to 7°C [10]. In addition, the installation of drinking water fountains helps considerably to keep citizens hydrated.

FIGURE 39 - WATER EMISSION DEVICES INSTALLED IN PARIS (SOURCE: ADEME RAFRAICHISSEMENT)

5.2.2.1. Variant for MOB Hotel Bordeaux

MOB Hotel Bordeaux has a semi-covered swimming pool in its interior courtyard. An increase in the surface area of the pool could modify variables such as the albedo, the emissivity and the absorption factor.

If we were to multiply the surface of the pool by two and subtract that surface from the surface of the interior patio built in concrete, the final UHI Score would be modified as follows:

% of IMPROVEMENT	ALBEDO	EMISSIVITY	ABSORPTION FACTOR
Before	26,74	8,67	5,46
After	26,63	8,64	5,94
Δ	-0,11	0,03	0,48

TABLE 13 - RESULTS FOR A CHANGE IN THE SWIMING POOL SURFACE (SOURCE: PAYET)

The albedo shows a deterioration compared to the previous situation. This is due to the fact that the albedo of the water is worse for the UHI Score than concrete. The absorption percentage is improved since the water absorption ratio is considered equal to 1 and therefore unbeatable.

Its impact on the final UHI Score is not very high despite having doubled the surface of the pool, **which is a major renovation for a small improvement.**

5.2.3. Grey Solutions

These are modifications to urban constructions that make possible to reduce the urban temperature.

- → Installation of shade structures.
  - They block the passage of the sun's rays and direct incidence on horizontal urban surfaces. Some examples of this type of urban installations are:

FIGURE 40 - SHADE STRUCTURES (SOURCE: ADEME RAFRAICHISSEMENT URBAIN)

- For example, according to a study conducted in Poland [19], a car exposed to the sun has a temperature of 76,1°C while the ambient temperature in the shade is 26 °C. Covering parking lots or roads with shade structures would help to reduce the ambient temperature by reducing the temperature of heat-emitting sources such as cars and road surfaces.

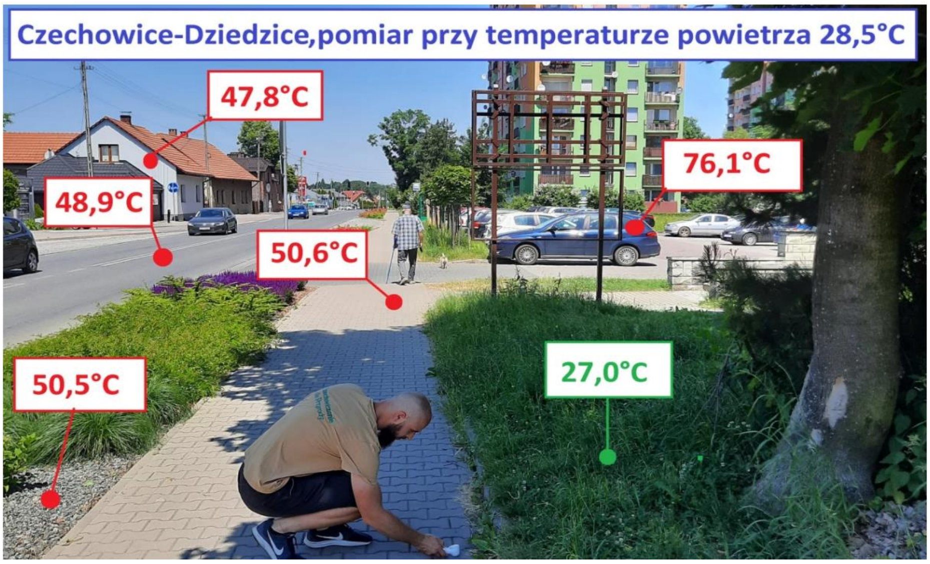


FIGURE 41 – TEMPERATURE MEASUREMENTS ON DIFFERENT SURFACES IN THE POLISH MUNICIPALITY OF CZECH DZIEDZIZICE (SOURCE: BAREFOOTS.COM)°

→ The use of water-retaining materials.

- They are particularly useful in rainy and humid regions. Their installation can allow a drop in air temperature of up to 1 °C [10] as their pervious factor will be increased.

FIGURE 42 – DIFFERENT EXAMPLES OF WATER RETENTION (SOURCE: ADEME RAFRAICHISSEMENT URBAIN)

5.2.4. Soft solutions

These are solutions that can be applied in the day-to-day life of citizens. They are practical solutions with short-term effects.

- → Opening of parks and green areas during the night.
- → Action plans in extreme hot situations.

5.3. Optimization of energy consumption in buildings

This section refers to the process of decreasing the heat produced by the variable "Anthropogenic Heat". As we have seen in section 2.6.2.2.c, the anthropogenic heat that increases the UHI effect can be reduced by retrofitting air conditioning systems.

5.3.1. Coupling the cooling network

This is an operational network that works in Paris since 1991 and its owner is *Fraîcheur de Paris*[10], and it is one of the most important cooling systems in the world. [20].

Its operation consists in producing chilled water using the water of the Seine as a cooling element. Its refrigeration plant is located on the banks of the Seine. The chilled water is distributed to its customers through a piping system that extends in the city:

[10] Freshness of Paris

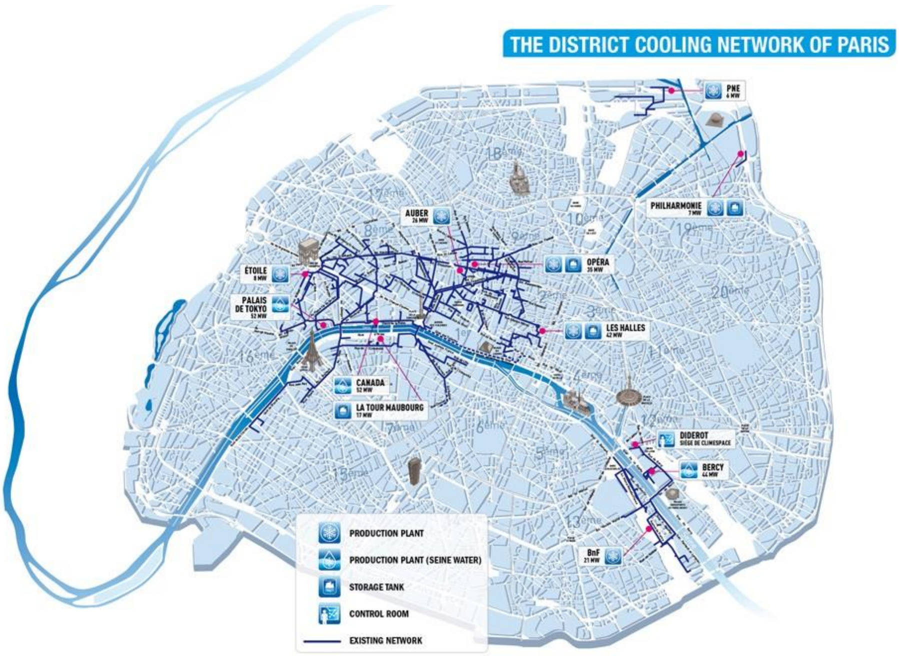


FIGURE 43 – DISTRIBUTION STRUCTURE (SOURCE: PARIS ACTION CLIMAT)

Once the customers have made use of this resource, the water, now full of calories (hot), is returned to the cooling plant and cooled again. This is a closed-loop system that does not directly emit dry heat to the outside [20]. Nevertheless, this network is currently very little developed, since its distribution system and it is not available for every citizen in Paris. Nevertheless, it could be an interesting alternative for projects with a possibility of coupling Paris (PAYET currently has a large number of them).

5.3.2. Changing the refrigerant fluid

Another way to assess the impact of air conditioning systems is to evaluate the refrigerant fluid by which they operate.

The **GWP factor** (acronym of Global Warming Potential) indicates how much heat a greenhouse gas absorbs compared to how many carbon dioxide (CO2) absorbs. The GWP of CO2 is equal to 1.

The cooling fluids that run air conditioning systems have an associated GWP, an evaluation of this factor is interesting when choosing the fluid since the values of this factor can vary from 1 to 2500 and so, their impact on the atmosphere can be very different when there is a leak. Some examples of different fluids with their respective GWP are shown in the following table:

	GWP
R410A	2088
R134A	1430
R32	675
R450A	601
R454 B	466
R1234ZE	6
R744 (CO2)	1
R717 (NH3)	0

TABLE 14 - DIFFERENTS FLUIDES FRIGORIGENES AVEC SON DIFFERENT GWP (SOURCE: PAYET)

Nevertheless, there are other parameters such as flammability and persistence in the atmosphere that are equally crucial in the choice of a coolant. However, these details are **unattainable** at the scale of this project.

5.3.3. Using geothermal systems

The principle of operation of these systems consists of [21]:

- → The hot air inside the building is expelled from the building.
- → A quantity of outside air is absorbed and introduced into a subway duct system.
- → During this circulation the air is cooled due to the temperature difference between the subsoil and the air.
- → The cooled air is sent into the building

These systems are called Provence Wells.

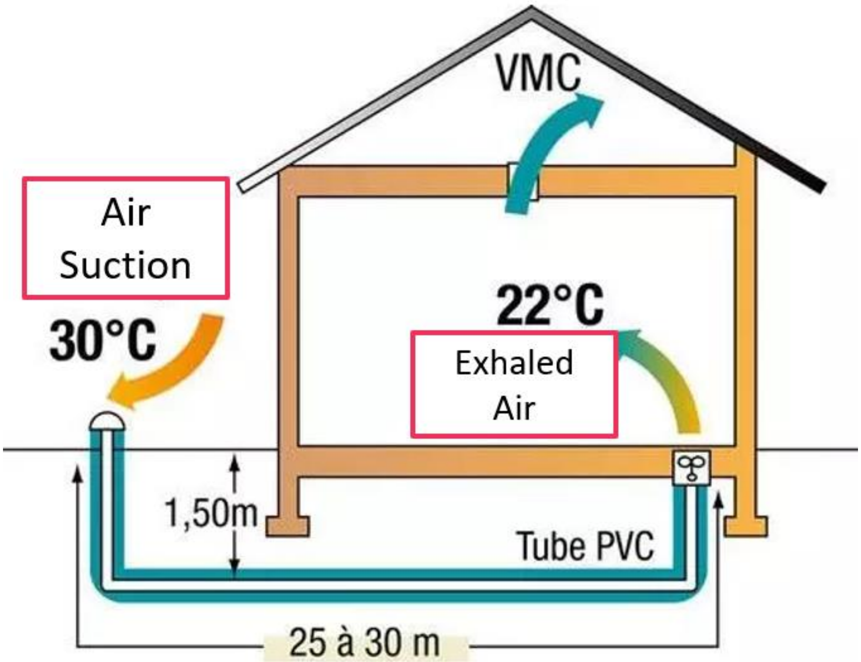


FIGURE 44 - PERFORMANCE OF A GEOTHERMAL COOLING SYSTEM (SOURCE: DECO.FR)

They can also act inversely, heating instead of cooling the indoor air. This can be useful in cold periods, and they are called Canadian Wells.

UHI SCORE IMPROVEMENT

It is evident that the application of all the improvement approaches that have been exposed would imply an improvement in the UHI Score. However, some of them cannot be quantified by the parameters that have been exposed above.

It is for this reason that an indicative table is shown below with some compensation values for each variable that could be added to the final UHI Score. It should be noted that this table **is only indicative** and it doesn't have a precise scientific basis.

VARIABLE	% OF IMPROVEMENT
Shade structures	10
Coupling the cooling network	15
Changing the refrigerant fluid	5
Using geothermal systems	15

TABLE 15 - % OF IMPROVEMENT ACCORDING TO THE MEASURE APPLIED (SOURCE: PAYET)

6. CONCLUSIONS

Finally, it can be concluded that among the 3 evaluated projects only one of them would obtain the credits of the HQE BD certification for the issue of urban heat islands. Being able to quantify this effect helps us to have a numerical and more visual basis on which to justify the implementation of measures of actions against the effects of urban heat islands.

However, the final objective of this evaluation is not to obtain points but to raise awareness of this harmful effect among the entire project team and to evaluate the various alternatives that would allow us to reduce it.

Obtaining a certification or an environmental label should not be seen as an ultimate goal, but as a justification that confirms the project has been examined from an environmental perspective. The constant presence of the process of achieving these labels during the progress of the project helps to raise awareness in a progressively way of the rest of the construction team. As a consequence, certain supplementary measures, which go beyond environmental certification, can be considered and even applied.

In a personal vision, the completion of this end-of-degree thesis, in addition to the wide range of different tasks in which I have been able to participate at PAYET, has taught me to develop both my technical skills and my personal skills (such as time management, my daily organization, etc.).

At the same time, I have been able to discover the sustainable construction sector, an area of industry in which I had not worked in depth during my studies.

In addition, the fact of developing a topic such as urban heat islands, has allowed me to become aware of an environmental problem that we are all confronted with every day. However, before this study I didn't have a great notion of its existence and I hope that this investigation will give others the opportunity to learn about this effect in the same way as me.

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APPENDIX A

Much of the time during the internship has been used for the realization of environmental performance studies. It should be noted that these studies have extracts which have been literally substracted from projects done by myself in the company.

This appendix will briefly explain and exemplify some of the studies which have been carried out:

Life cycle analysis

Two life cycle analyses have been done, both have been carried out in different kind of projects: the first one has been carried out in a renovation project of an office building and the second one has been carried out in a new construction project of a logistics building.

Definition of a Life cycle analysis

"Life cycle assessment is the most advanced tool for the global and multi-criteria evaluation of environmental impacts. It is a standardized method for measuring the quantifiable effects of products or services on the environment.

Life Cycle Assessment (LCA) identifies and quantifies the physical flows of materials and energy associated with human activities throughout the life of a product. It evaluates the potential impacts and then interprets the results obtained according to its initial objectives." [22]

Methodology's description

Based on the ELODIE v3 software developed by the CSTB for the realization of the study, the main contributor which has been considered for this study is: Construction products and equipment.

The contributor " Construction products and equipment." allows to enter data related to materials and construction products used for the construction and/or renovation of buildings as well as technical equipment installed at the end of the works.

It allows to take into account the 4 mandatory phases defined in the EN 15804 standard regulation:

- → The **construction product phase**, including the extraction and transport of raw materials to the factory, as well as the manufacturing process
- → The **construction phase**, including freight and site
- → The **use phase**, which includes maintenance and replacement of components, energy consumption and water consumption
- → The **end-of-life phase**, which concerns the demolition or deconstruction of the structure, the transport of materials and their treatment in a specialized subsidiary.

This contributor uses **the Environmental and Health Declaration Sheets (EHDS)** of construction products, which can be exploited from the **INIES** national database (www.inies.fr).

The EHDS describe the environmental impact of products according to 15 environmental indicators:

- → Primary Energy Consumption [kWhep]
- → Renewable Energy Consumption [kWhep]

- → Non-Renewable Energy Consumption [kWhep]
- → Resource Depletion [t eq. Sb]
- → Total Water Consumption [m3]
- → Hazardous Waste [kg]
- → Non-Hazardous Waste [kg]
- → Inert Waste [kg]
- → Radioactive Waste [kg]
- → Climatic Change [kg eq. CO2]
- → Atmospheric Acidification [kg eq. CO2]
- → Air Pollution [m3]
- → Water Pollution [m3]
- → Photochemical Ozone Formation [t eq. ethylene]
- → Ozone Layer Destruction [kg CFC11]

In order to have a better organization of all the materials to be evaluated, they have been divided into the following batches with its corresponding number:

1. Streets and various networks
2. Foundations and infrastructure
3. Superstructure – Masonry
4. Roofing - Waterproofing - Carpentry - Zinc work
5. Partitioning - Doubling - Suspended ceilings - Interior joinery
6. Facades and external joinery
7. Floor, wall and ceiling coverings - Screed - Paintings - Decorative products

Exemplification: TISHMAN LEGEND Project

TISHMAN LEGEND is an office building renovation project.

First of all, all the quantities of products used and their equivalent in the INIES database have been collected. For this purpose, they have been organized in the table below:

2			FONDATIONS ET INFRASTRUCTURES		valeur	unité	Valeur calculée		
	Lot CCTP	Réf DPGF	CCTP Demolition Gros Œuvre						
Demolition Gros Œuvre		Poutres	Nouvelles poutres béton	Foundations (including excavation)	74,33	m^3	74,33	m^3	Béton arm
			Renforts de poteaux	Foundations (including excavation)	2,49	m^3	2,49	m^3	Béton arm
			Renforts de poutres	Foundations (including excavation)	11,03	m^3	11,03	m^3	Béton arm
			Contre-poteaux	Foundations (including excavation)	6,48	m^3	6,48	m^3	Béton arm
		Voiles	Nouveaux voiles	Foundations (including excavation)	217,94	m^3	217,94	m^3	BÉTON C2
			Renforts de voiles	Foundations (including excavation)	110,94	m^3	110,94	m^3	BÉTON C2
			Contre-voiles	Foundations (including excavation)	67,60	m^3	67,60	m^3	BÉTON C2
		Dalles	Renforts de dalles	Basements/retaining walls (including excavation)	36,70	m^3	36,70	m^3	Béton arm
			Nouvelles dalles	Basements/retaining walls (including excavation)	280,68	m^3	280,68	m^3	Béton arm
			Dalles mixtes	Basements/retaining walls (including excavation)	0,82	m^3	0,82	m^3	Béton arm
			Massifs micropieux	Foundations (including excavation)	4,33	m^3	4,33	m^3	Micropieu
			Création maçonneries	Foundations (including excavation)	80,04	m^3	80,04	m^3	Bloc de m.
3			SUPERSTRUCTURE MACONNERIE		valeur	unité	Valeur calculée		
	Lot CCTP	Réf DPGF	lot n°04 Charpente béton/ lotn°5 Murs coupe feu						
Demolition Gros Œuvre		Ecran acoustique	Supports béton écran acoustique	Foundations (including excavation)	317,00	ml	317,00	ml	Béton arm
			Longrines	Foundations (including excavation)	1,82	m^3	1,82	m^3	Béton arm
			Nouveaux supports pour équipements existants	Foundations (including excavation)	1202,50	m^3	1202,50	m^3	Béton arm
			Volées d'escalier	Stairs and ramps	9,00	U	36,00	ml	Escalier dr
			Corbeaux filants	Structural frame (vertical)	1,34	m^3	1,34	m^3	
			Peinture intumescente	External walls (envelope, structure and finishes)	1468,16	m^3	1468,16	m^3	Peinture ir
			Isolant déppose repose	External walls (envelope, structure and finishes)	6042,40	m^3	6042,40	m^3	Système c

FIGURE 45 – EXTRACT FROM THE PROJECT MATERIALS SYNTHESIS TABLE (SOURCE: PAYET)

The results obtained using the ELODIE V3 software have been presented as follows in the final document sent to the customer:

CONSTRUCTION PRODUCTS AND EQUIPMENT CONTRIBUTOR

The following table lists the contribution to environmental impact of the renovation for the **life of the building (50 years)**:

Indicators	Construction product phase	Construction phase	Use phase	End-of-life phase	**Total life cycle**
Global warming (kg CO2 eq.)	3.38e+6	7.64e+5	3.42e+6	5.25e+5	**8.11e+6**
Ozone depletion (kg CFC-11 eq.)	4.56e+0	1.06e-1	1.14e+1	2.89e-2	**1.61e+1**
Soil and water acidification (kg SO2 eq.)	2.28e+4	4.92e+3	1.69e+4	1.48e+4	**6.01e+4**
Eutrophication (kg (PO4)3- eq.)	6.33e+3	6.10e+2	1.26e+4	6.77e+2	**2.02e+4**
Photochemical ozone formation (kg C2H4 eq.)	2.50e+3	8.11e+5	5.45e+5	8.01e+2	**1.36e+6**
Abiotic resource depletion - elements (kg Sb eq.)	2.18e+2	2.60e+1	3.72e+2	1.30e+0	**6.17e+2**
Abiotic resource depletion - fossil fuels (MJ)	4.94e+7	9.99e+6	5.02e+7	2.61e+6	**1.12e+8**
Air pollution (m^3 of air)	6.14e+8	1.49e+8	1.40e+9	1.16e+8	**2.32e+9**
Water pollution (m^3 of water)	1.13e+8	8.33e+6	3.88e+8	6.79e+6	**5.17e+8**
Renewable primary energy resource use (MJ)	1.38e+7	9.64e+5	9.04e+6	2.06e+4	**2.40e+7**
Non-renewable primary energy resource use (MJ)	8.12e+6	6.27e+5	1.33e+7	1.06e+4	**2.21e+7**
Total primary energy resource use (MJ)	7.34e+7	1.19e+7	6.92e+7	2.88e+6	**1.60e+8**
Secondary Material Use (kg)	1.97e+5	1.95e+5	3.74e+4	-8.87e+2	**4.28e+5**
Secondary renewable fuel use (MJ)	7.67e+5	2.20e+4	2.46e+4	0.00e+0	**8.48e+5**
Non-renewable secondary fuel use (MJ)	1.10e+6	3.26e+4	4.05e+1	0.00e+0	**1.14e+6**
Net freshwater use (m^3)	1.23e+5	6.10e+3	1.37e+5	1.01e+3	**2.69e+5**
Hazardous waste disposed (kg)	6.08e+5	6.91e+4	1.55e+6	2.63e+4	**2.26e+6**
Non-hazardous waste disposed (kg)	1.57e+6	7.79e+5	2.20e+6	4.91e+6	**1.16e+7**
Components for reuse (kg)	4.39e+1	2.18e+2	4.80e+1	0.00e+0	**3.10e+2**
Materials for recycling (kg)	4.44e+4	1.49e+5	5.33e+4	8.90e+6	**9.15e+6**
Materials for energy recovery (kg)	6.65e+2	2.80e+2	2.15e+3	5.39e+2	**3.64e+3**
Energy supplied externally (MJ)	2.00e+3	4.66e+3	3.62e+4	2.19e+5	**2.62e+5**

CARBON FOOTPRINT

The graph below shows the distribution of the carbon footprint (kg CO_2 equivalent / m^2 / year) according to the different lots.

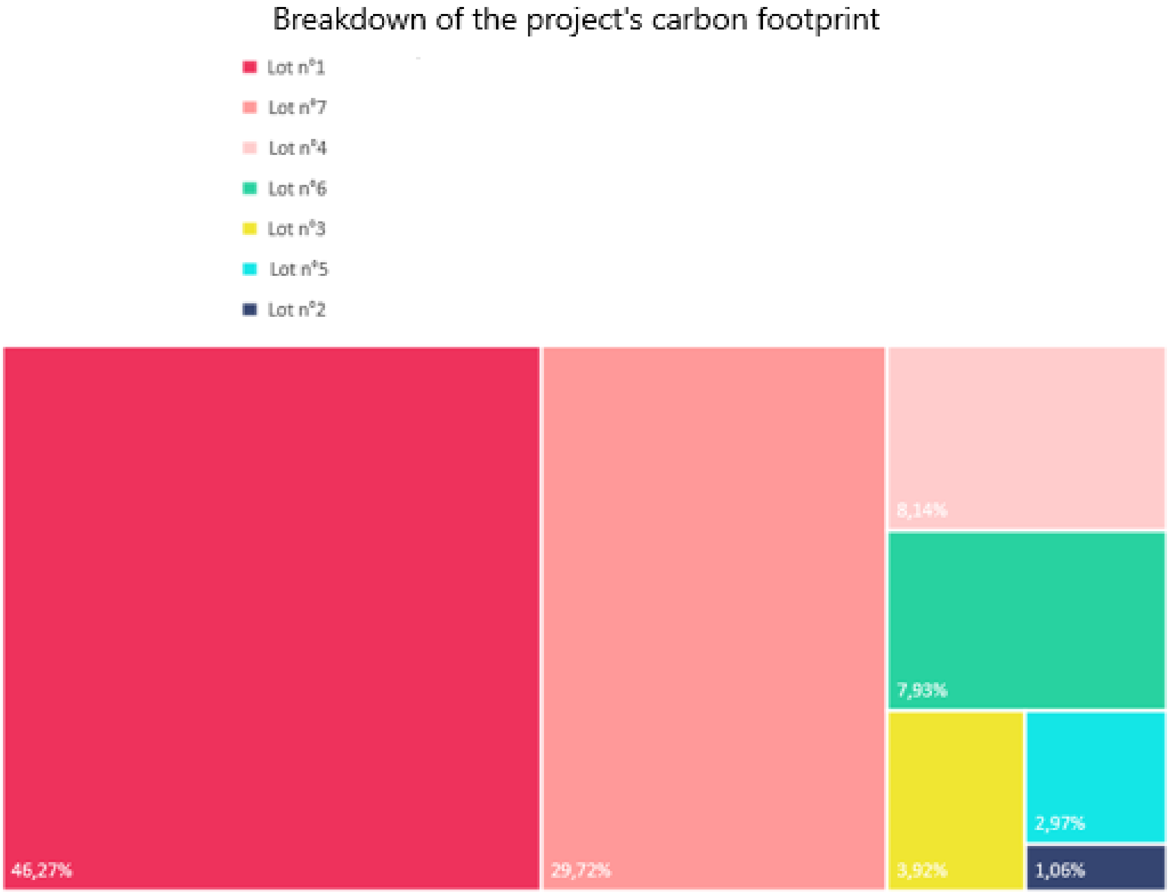

FIGURE 46 – CARBON FOOTPRINT OF TISHMAN LEGEND PROJECT

CONCLUSION

As this is a renovation project, these results make sense since the most polluting lots are:

- → Lot n°1 - Streets and various networks- since all the gardens and the exterior parts of the building will be renovated. There is a huge surface of green areas on this project.
- → Lot n°7 - Floor, wall and ceiling coverings - Screed - Paintings - Decorative products - since the carpets and painting of the interior of the project buildings will be changed.

LCA studies allow to validate the criteria for obtaining a certification. Nevertheless, they also give the possibility to better understand which lots are the most emitting on a given project, to compare projects between them and to choose the best option when two variants of different used products are possible.

Dynamic Thermal Simulations

One only DTS has been done during my internship, this is the one of a new construction project of a logistics building which searched to validate the **comfort credits** for the BREEAM certification.

The evaluation process of the DTS is evaluated by PAYET as follows:

Definition of a Dynamic Thermal Simulation and methodology's description

The dynamic thermal simulation or DTS is a thermal study that allows to model the thermal behavior of a building over a year thanks to a calculation made according to an hourly step. The software used in this study is: **PLEIADES software (v 5.21.3.0) developed by IZUBA Energies.**

To describe this behavior, the DTS software relies on the following data:

- → The geographical position of the site
- → Its architectural concept
- → The distant or close masks of its environment
- → The thermal characteristics of its walls and glazing
- → The internal heat sources related to its theoretical use

In addition, and contrary to the static thermal calculation of RT type, this software also allows to take into account the following elements:

- → The local meteorology of the building site
- → The inertia of the building
- → Passive solar gain

A DTS can be used to achieve one or more of the following objectives:

- → Optimize the architectural concept of a building (optimization of insulation thicknesses, sizing of solar protection, choice of the constructive system, minimization of the thermal need of a building…)
- → Choose the optimal orientation of a project
- → Evaluate the risks of summer overheating in a specific area of a building
- → Evaluate the energy needs of a building
- → Recommend operating set point temperatures to minimize future energy consumption…

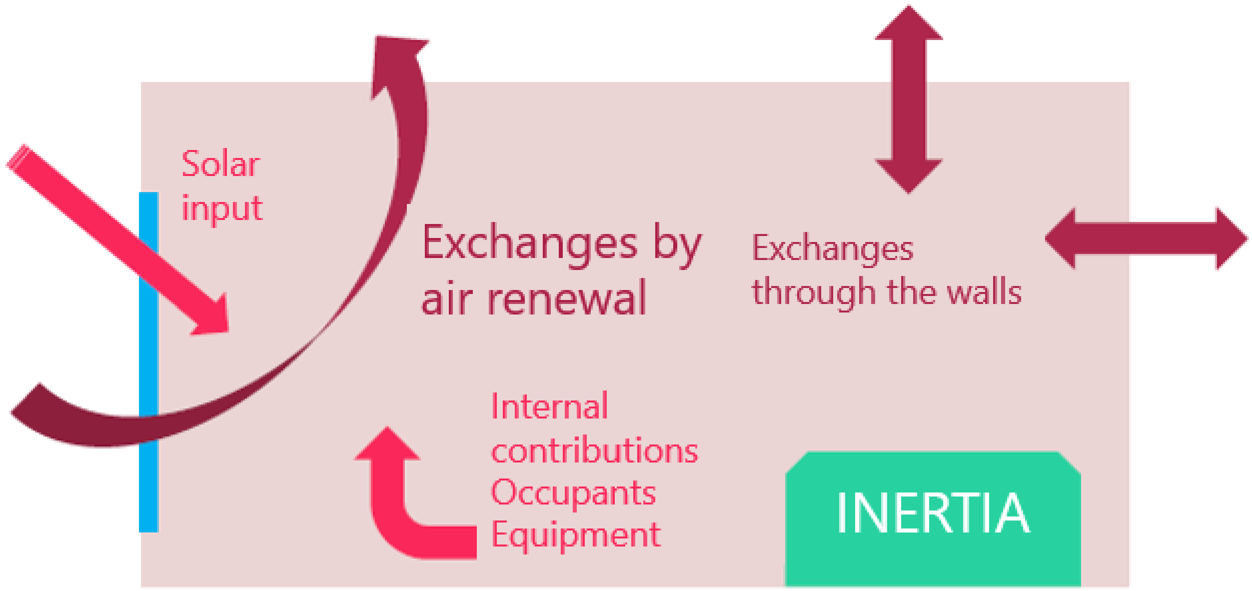

FIGURE 47 – MODELLING OF THE THERMAL EQUILIBRIUM OF A ROOM (SOURCE: PAYET ENGLISH ADAPTATION)

The input data necessary for the realization of a DTS are:

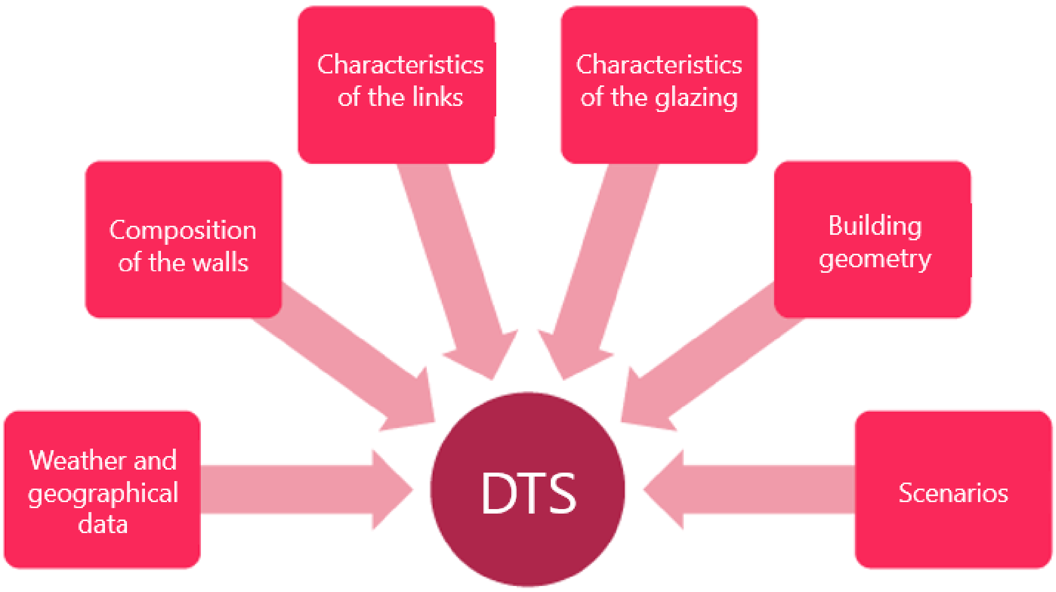

FIGURE 48 – THE INPUT DATA OF A DTS (SOURCE: PAYET ENGLISH ADAPTATION)

From these data, the software simulates the thermal behavior of a building according to a division chosen by the engineer who carries out the study. Depending on the software, this breakdown can be done at several levels. The main division is made at the level of thermal zones, generally a thermal zone being associated with a room.

The calculations make it possible to obtain results concerning the global behavior of the building but also for each thermal zone which makes it possible to evaluate the conditions of comfort in any point of a building.

The thermal behavior of the simulated object can be defined thanks to many parameters that constitute the result of the calculation:

→ Heating requirement
→ Air conditioning requirement

- → Comfort indices
- → Max overheating
- → Discomfort rate
- → Amplification of Text
- → Sankey diagram (graphic modeling of needs and losses)
- → Evolution of temperatures according to several time scale
- → Histogram of temperatures reached as a function of time…

DEFINITION OF COMFORT

An environment can be considered as comfortable from a thermal point of view when the body is in dynamic equilibrium with this environment.

Indeed, the human body permanently exchanges energy with its environment by using all the existing thermal transfer modes (conduction/convection/radiation).

A sensation of cold or heat will translate into a disruption of the thermal balance between the body and its environment.

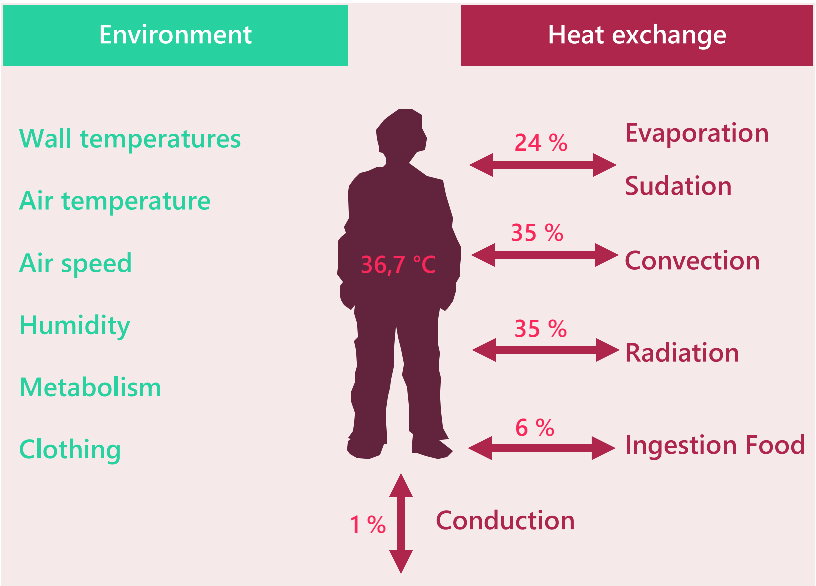

FIGURE 49 – ILLUSTRATIONS OF THERMAL EXCHANGES BETWEEN THE HUMAN BODY AND ITS ENVIRONMENT (SOURCE: ENERGIEPLUS-LESITE.BE)

The main parameters that come into play in the heat exchange between the body and its environment are:

- → The temperature of the walls
- → The temperature of the air
- → The air speed
- → Humidity
- → The metabolism
- → Clothing.

The thermal comfort of a room depends on several parameters that must be taken into account in the design of any new building.

Exemplification: CORBAS T4 Project

This is a new construction project of a logistics building which search the obtention of BREEAM credits related to the user's comfort. The following steps need to be made in order to reach to results:

Weather Data

The project is situated in Lyon. The weather files used to model the thermal behavior of the building are from the METEONORM pack. The meteorological data correspond to the measurements made by the Lyon-Bron station.

NAME	Lyon – Bron – Moyen fichier LyonBronMoyen.try	ALTITUDE	200 m
LENGTH	4° 57' 0"E	LATITUDE	45° 43' 1"N
TEMPERATURES	**MINIMAL**	**MAXIMUM**	**AVERAGE**
	-6.80°C	35.40°C	13.06°C

Modélisation 3D of the building

An extract of the modeling of the building made in the PLEIADES software:

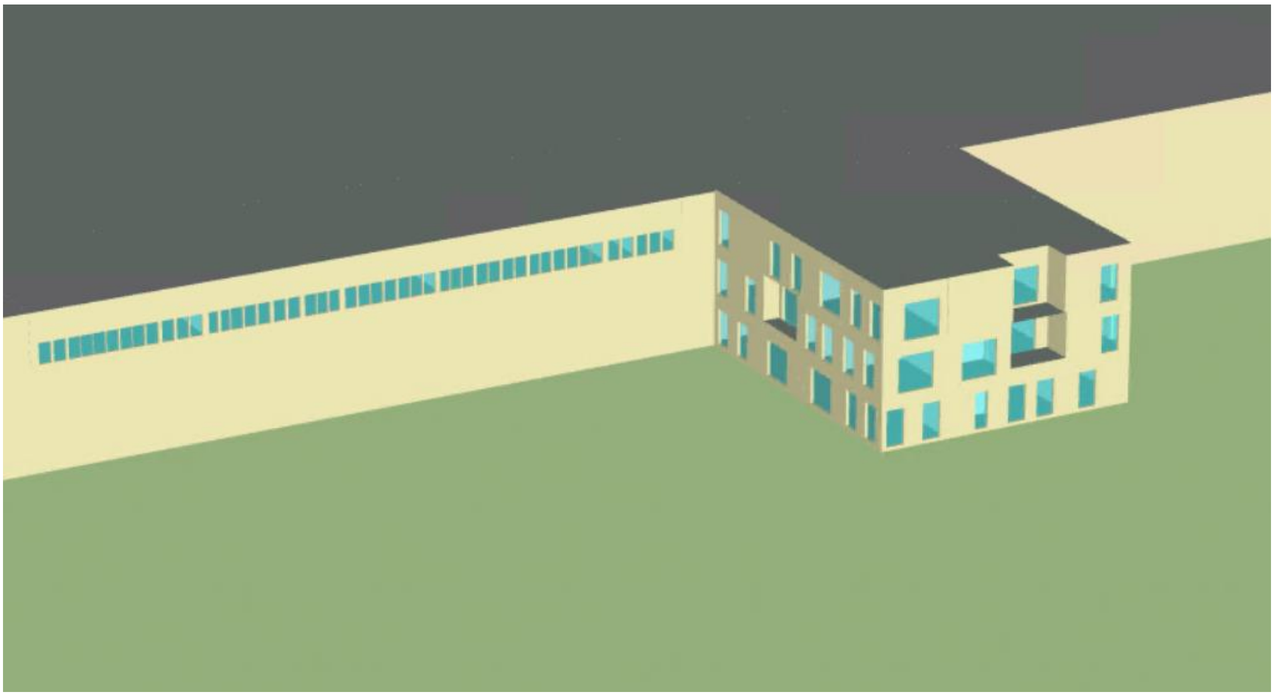

FIGURE 50 - 3D MODELLING SOUTH EAST VIEW ON THE OFFICE BLOCK (SOURCE: PAYET ENGLISH ADAPTATION)

Project Zoning

The study covers all premises with other than transient occupancy. The areas studied are the following:

- Office / Open Space areas
- Meeting room area
- Relaxation rooms
- Dining room Plot
- Meal Room Driver's Area
- Break room

Each of these areas has been assigned conditions of temperature, ventilation, occupancy, air filtration, etc. that correspond to the requirements of BREEAM certification for each of the rooms extracted.

Results and conclusions

The table below shows the percentage of occupied time during which the criteria and scenarios assigned are met in all cases.

Thermal zones	Heating season Category Valid	Cooling season Category Valid
Break Room	98.3% of the time	100% of the time
Driver's Lunch Room	95.2% of the time	100% of the time
Relaxation Rooms	100% of the time	81% of the time
Plot Meal Room	100% of the time	97.2% of the time
Meeting Room	98.1% of the time	100% of the time
Offices	100% of the time	99.9% of the time

As we can see from this table, the percentage of comfort of the users in these rooms is relatively high, exceeding 95% in all cases except for the cooling station of the relaxation rooms, which may be due to an anomaly in the construction of the project.

DTS studies are useful in the design phase to identify anomalies in the project and bring relevant solutions from a comfort and energy consumption point of view (better insulation, reduction of thermal bridges, addition of solar protections, …), as in this case for the relaxation rooms. These considerations are very important and can thus allow the actors of a project to really get involved in an approach towards neutrality by tackling the energy consumption of the building which represents an important part of the emissions.

Light autonomy study

Definition

The light autonomy study quantifies the percentage of occupied hours per year where the minimum lighting level is reached only by natural light. This study is carried out using a 3D model of the building and its environment. The software that will be used is: **PLEIADES (v 5.22.1.0) created by IZUBA Energies**. (the same as for the DTS) Depending on the results obtained, variants can be studied, including the following parameters:

- → Percentage of glazed surface
- → Geometry of openings
- → Luminous transmission of the glazing
- → Coefficients of light reflection of the interior linings.

Within the framework of the HQE BD certification, the study participates in the evaluation of the "Visual Comfort" theme.

The indicator of luminous autonomy is defined as the percentage of occupied hours per year during which a minimum level of illumination is maintained solely by natural light.

$$A_{E_{min}} = \frac{h_e > E_{min}}{H_{occ}} \%$$

- → E_min : The minimum threshold illuminance expressed in lux
- → A_(E_min): The luminous autonomy for a threshold illumination Emin (lux)
- → h_e>E_min : Number of occupied hours during which natural light alone produces an illuminance higher than the threshold value Emin.
- → H_occ : Total number of occupied hours during the year

As for the DST, only non-passenger spaces will be studied, i.e. spaces used for more than 30 minutes in a row during the same day.

The Homogeneous Blocks (HB) define a set of spaces with other than transient occupation with similar properties regarding visual comfort. The **parameters considered** for the definition of spaces in Homogeneous Blocks are the following:

- → Surface covering (floor, walls, ceiling)
- → Artificial lighting equipment
- → Solar protection
- → Orientation towards the sun
- → Height in the building
- → Proportion of glazed surfaces
- → Type of glazing in the joinery

The occupancy scenario is defined according to the type of building and its future use. An occupancy scenario is also defined according to the characteristics of each homogeneous block.

The software calculates the luminous autonomy thanks to the hour by hour simulations of the illuminations in a building according to the external climatic conditions. The calculation is dynamic, taking into account meteorological variations and the geographical position.

Exemplification: INTECHMER CHERBOURG Project

The project is a new construction of a future high school located on Boulevard de Collignon on the commune of Tourlaville (50110). The steps that have been followed for the realization of the project have been:

MODELLING OF THE PROJECT

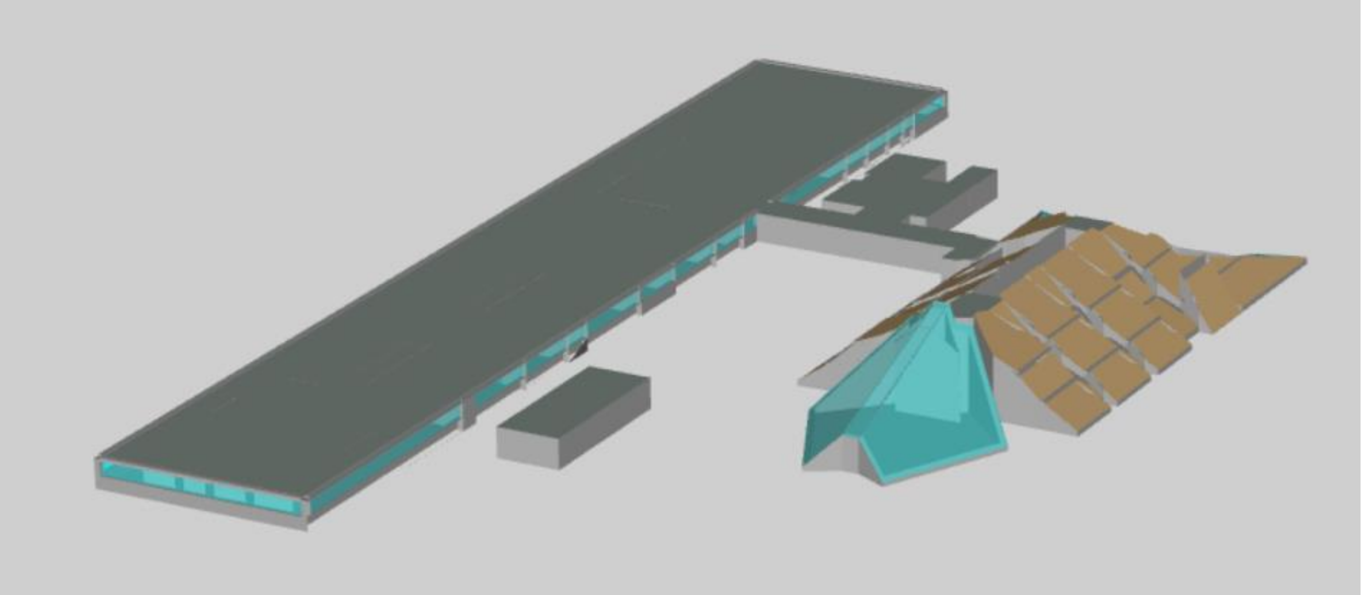

FIGURE 51 - 3D VISUALIZATION OF THE MODEL (SOURCE: PAYET)

DEFINITION OF THE CHARACTERISTICS OF THE INTERIOR FLOORINGS

The coefficients of reflection were taken by default according to the HQE BD of Certivéa

COVERING	LIGHT REFLECTION COEFFICIENT
Wall	0,5
Floor	0,2
Ceiling	0,7

DEFINITION OF THE CHARACTERISTICS OF THE JOINERY

The characteristics of the exterior joinery are taken from the technical data sheet TGU 66.2 SERALIT BL20 points (16) 4 (16) 4 ECLAZ ONE.

NAME	LOCATION	TLg
TRIPLE GLAZING	Exterior facade of new building	0,485

For the rest of the glazing, the characteristics are not yet defined. The following assumptions have been made in this study.

NAME	LOCATION	TLg
POLYCARBONATE	Roof of the experimental greenhouse	0,416

GLASS	North facade of the ROUGERIE building	0,65
INTERIOR WORKING	New building	0,65

DEFINITION OF OCCUPATION SCENARIOS

The occupancy of the spaces over a day is defined as follows:

SPACE	OCCUPANCY SCENARIO FOR THE DAY
Library / Practical room	8h – 20h30
Stay	8h - 18h

OCCUPANCY SCENARIO FOR THE DAY

The required lighting level for each space is as follows:

SPACE	ILLUMINATION LEVEL (LUX)
Laboratory / Practical room / Experimental greenhouse	500
Office / Classroom / Teacher's area / Break room / Cafeteria	300

DISTRIBUTION OF HOMOGENEOUS BLOCKS

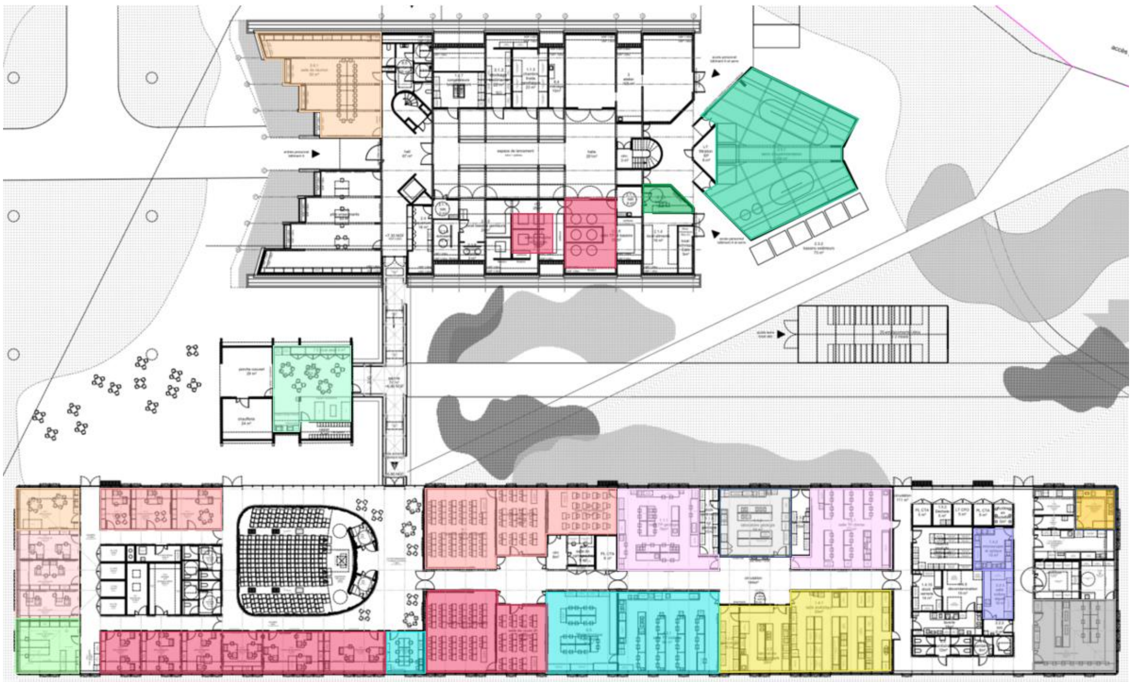

FIGURE 52 – DISTRIBUTION OF HOMOGENEOUS BLOCKS (SOURCE: PAYET)

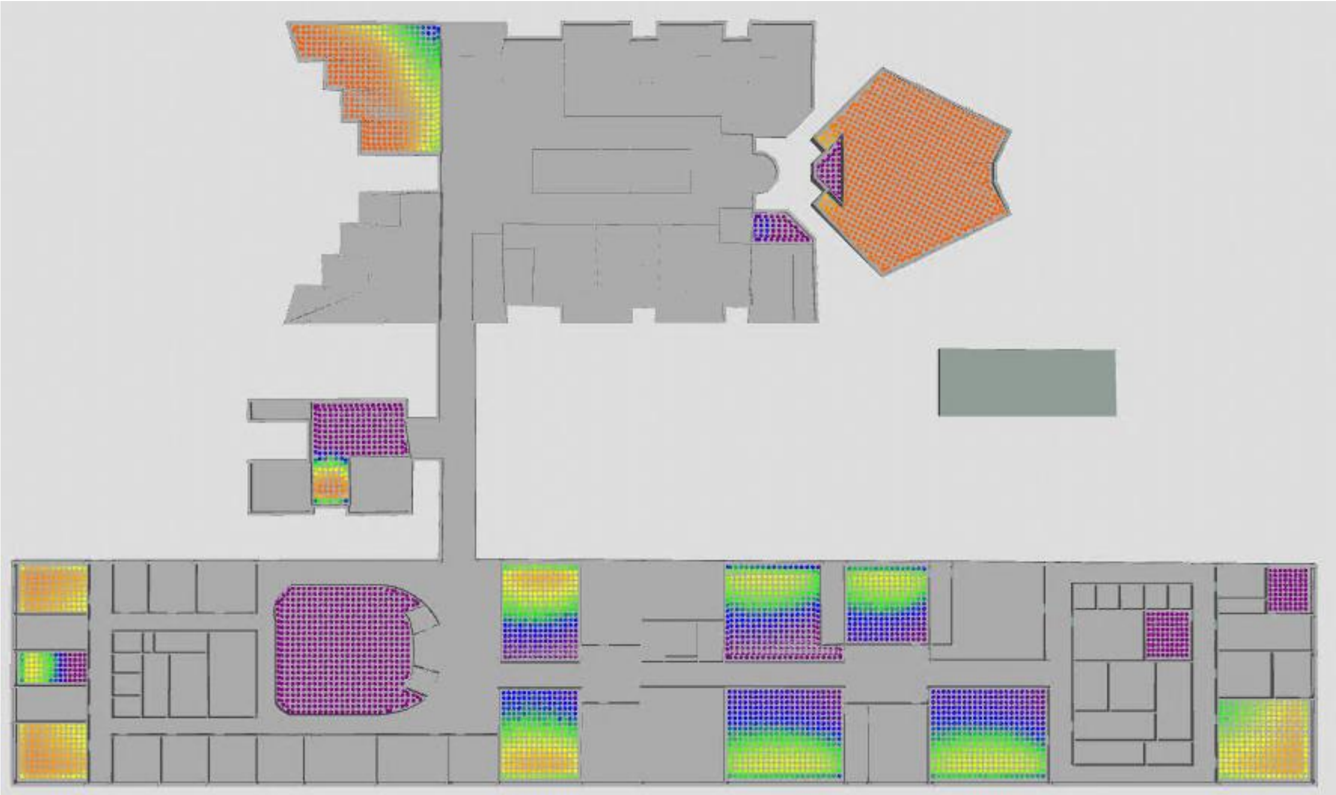

FIGURE 53 – AUTONOMY LIGHT RESULTS (SOURCE: PLEIADES)

The rooms studied shaded with lighter colors (such as orange or green) are those that have a greater light autonomy and therefore do not need artificial light to have a comfortable vision during a long stay.

The studies of light autonomy during the design phase may allow some adjustments in the visual comfort or the change of the model of the interior coverings or windows.

APPENDIX B

Database for the albedo and the emissivity.

	Albedo	Emissivity
Green Spaces		
Grass	0,21	0,75
High and dry grass	0,12	0,94
Agricultural fields	0,22	0,94
Forests	0,18	0,98
Trees	0,28	0,98
Grassed areas	0,17	0,94
Lawn	0,28	0,75
Water	0,06	0,95
Snow	0,87	0,95
Fresh powdery snow	0,87	0,95
Icy, granular snow	0,69	0,95
Soil	0,23	0,94
Alphalte / Tar	0,07	0,95
Moist clay	0,13	0,91
Moist clay (40% pore)	0,13	1,00
Dry Clay	0,13	0,91
Dry Clay (40% pore)	0,13	0,98
Bitumen and gravel	0,11	0,595
Cement	0,23	0,54
New asphalt pavement	0,09	0,93
Aged asphalt pavement	0,38	0,93
Medium Pavement	0,25	0,595
Sandy White strewn	0,55	0,76
Sandy Wet	0,09	0,76
Sandy Wet/Saturated (40% pore)	0,55	0,76
Dry sandy	0,18	0,76
Dry sandy (40% pore)	0,55	0,76
Building materials		
Concrete	0,20	0,91
Dense concrete	0,23	0,91
Rough concrete	0,20	0,94
Wood	0,40	0,93
Wood	0,40	0,93
Varnished wood	0,40	0,93
Brick	0,30	0,93
Blue Brick	0,11	0,93
Extruded or Spun Red Brick	0,48	0,93
Purple Marbled Brick	0,23	0,93
Ordinary Red Brick	0,34	0,93
Light Red Ordinary Brick	0,45	0,93
White Varnished Brick	0,74	0,93
Ivory to Cream Varnished Brick	0,65	0,93
Reddish Granite	0,45	0,97
Beige Brick	0,46	0,87
Light Grey Stone	0,38	0,87
Red Stone	0,27	0,87
White Marble	0,56	0,95
Dark Marble	0,34	0,95
Stone	0,28	0,93
White Gypsum	0,93	0,90
Glass	0,10	0,83
Wood: panelling, light finish	0,40	0,87
Wood: planed	0,40	0,90

	Albedo	Emissivity
Metals		
Polished aluminum	0,85	0,05
Anodized aluminum	0,85	0,77
Abraded aluminum	0,85	0,89
White Enamelled Steel	0,55	0,26
Green Enamelled Steel	0,24	0,26
Dark Red Enamelled Steel	0,19	0,26
Blue Enamelled Steel	0,20	0,26
Galvanized Steel New	0,36	0,23
Galvanized Steel Very Dirty / Old	0,08	0,88
White Galvanized Steel	0,78	0,23
Polished Copper	0,82	0,04
Tarnished Copper	0,36	0,03
Aged Lead Sheet	0,21	0,43
Roofing		
Slate	0,10	0,85
Silver Grey Slate	0,21	0,85
Blue Grey Slate	0,33	0,85
Dark Grey Slate Coarse	0,20	0,85
Slate Dark gray smooth	0,11	0,85
Slate Greenish grey coarse	0,37	0,85
Waterproofing in bituminous sheets Brown	0,33	0,91
Waterproofing in bituminous sheets Green	0,34	0,91
Tar and gravel	0,13	0,28
Tile	0,23	0,97
Clay tile	0,23	0,91
Cement tile without brown	0,15	0,97
Cement tile without dye	0,35	0,97
Cement Tile without Black	0,09	0,97
Clay Roof Tile Dark Purple	0,39	0,97
Red Clay Roof Tile	0,36	0,97
Hand Moulded Clay Roof Tile Brown - Red	0,31	0,97
Hand Moulded Clay Tile Red	0,40	0,97
Zinc coated non-metallic	0,13	0,75
Paints		
Colored	0,25	0,94
Aluminum	0,46	0,45
White	0,82	0,77
Dark blue	0,09	0,94
Brown	0,21	0,94
Grey	0,25	0,94
Yellow	0,67	0,33
Black	0,06	0,89
Orange	0,59	0,94
Dark Red	0,43	0,94
Bright Red	0,56	0,94
Bright Green	0,21	0,70
Light Green	0,50	0,70
Dark Green	0,12	0,70
Urban Area	0,19	0,91
Medium Urban	0,15	0,95

The values have been found on the following resources according to their color (bibliography):

LECONTE Tableau 1.3 Valeurs d'albedo et de emissivité pour differents matériaux urbains et naturels, (OKE 1987). LECONTE; A ECHELLE MESOCLIMATIQUE
These PARMENTIER Tableau 1.2 Valeurs d'émissivité pour des surfaces rencontrées en milieu urbain Tiré de Uherek (2005)
These PARMENTIER Tableau 1.1 Albédo des surfaces urbaines Tiré de Aida et Goreh (1982)
These PARMENTIER Etude Allemande (Peck, Taylor et Conway, 1999) page 16
Valeurs utilisées par l'ADEME: Les albédos de la ville Source: Colombert, 2008, Ilot de chaleur urbain: définition et conséquences (notre-planete.info) (accesed July 2022)
Aging albedo model for asphalt pavement surfaces - ScienceDirect (accesed July 2022)
Tableau émissivités en thermographie - La Librairie Thermographique (thethermograpiclibrary.org) (accesed July 2022)
Norme eclairage: NF EN 12464-1 2021 page 13 (accesed July 2022)
ADEME IDF 786-guide-lutte-icu Annexe 1
Infrared Emissivity Table (thermoworks.com) (accesed July 2022)
https://www.foxof.com/emissivite-rayonnement/ (accesed July 2022)
https://www.sodielec-berger.fr/files/39/emissivite-materiaux.pdf (accesed July 2022)

APPENDIX C

The calculation of the UHI Score on the excel file of the project Corbas T3 was carried out in the following way:

1. Filling of the area table

Surfaces			
	PROJET	EXISTING	
General			
Plot	25152,93	25152,93	m²
Building - built area	4432,84	0	m²
Horizontal surfaces			
Green	7600,53	0	m²
Roof	4224,37	0	m²
Water	1306,74	0	m²
Soil Sand Dry	0	25152,93	m²
Asphalt sidewalks	805,87	0	m²
Parking + light roadways	8531,71	0	m²
Concrete roadway	1751,82	0	m²
Lanterns	226	0	m²
Resin Metal cladding	172,93	0	m²
Awnings	488,84	0	m²
Pergola Bicycle room	44,12	0	m²
TOTAL	25152,93	25152,93	m²
Vertical Surfaces			
East facade			
White Enameled Steel	190,73	0	m²
Blue Enameled Steel	239,1	0	m²
Windows	88,04	0	m²
Black paint	937,03	0	m²
WEST Facade			
White Enameled Steel	107,45	0	m²
Blue Enameled Steel	68,58	0	m²
Windows	0	0	m²
Black paint	1270,27	0	m²
NORTH Facade			
White Enameled Steel	65,93	0	m²
Blue Enameled Steel	7,69	0	m²
Windows	17,92	0	m²
Black paint	306,54	0	m²
South facade			
White Enameled Steel	308,8	0	m²
Blue Enameled Steel	57,35	0	m²
Windows	19,46	0	m²
Black paint	11,13	0	m²
TOTAL			
White Enameled Steel	672,91	0	m²
Blue Enameled Steel	372,72	0	m²
Windows	125,42	0	m²
Black Paint	2524,97	0	m²

2. Determination of the legibility of the project by the calculation of the vegetation rate and the albedo

Vegetation Rate	30,22%	NO ELIGIBLE

Albedo	Material identifier	Typology	Surface P	Surface E	PROJET	EXISTING
		Horizontal Surfaces			0,186077075	0,18
0,18	Dry sandy soil	Dry sandy	0	25152,93		
0,21	Green Surfaces	Grass	7600,53	0		
0,36	Roof	New Galvanized Steel	4224,37	0		
0,06	Water	Water	1306,74	0		
0,105	Asphalt sidewalks	Bitumen and gravel	805,87	0		
0,09	Parking + light roadways	New asphalt pavement	8531,71	0		
0,2	Concrete roadway	Concrete	1751,82	0		
0	Skylights	Glass	226	0		
0,85	Resin Cladding meta	Polished Aluminum	172,93	0		
0,2	Awnings	Blue enamelled steel	488,84	0		
0,85	Pergola bicycle room	Polished Aluminum	44,12	0		
		TOTAL	25152,93	25152,93		

3. Determination of the rest of the parameters

a. Aspect Ratio

Aspect Ratio	Urban	Rural	PROJECT	EXISTING
	$AR = 0{,}5 * \frac{\sum S_{green}}{S_{total} - \sum S_{building}}$	$AR = \frac{building's\ height}{width\ of\ street\ canyons}$	0,183409676	0

b. Building Surface Factor

Building Surface Factor	Surface P	Surface E	PROJECT	EXISTING
	4432,84	0	0,176235532	0

c. Pervious and impervious factor: absorption ratio

Absorption Ratio / Pervious SF	Material identifier	Typology	Surface P	Surface E	PROJECT	EXISTING	
		Horizontal Surfaces					
0,8	Dry sandy soil	Grassed green spaces	0	25152,93	0,317	0,8	-48,3%
0,8	Green Surfaces	Grassed green spaces	7600,53	0			
0	Roof	Impermeable roofing	3912,21	0			
1	Water		1306,74	0			
0,6	Asphalt sidewalks	Pavements with permeable reservoir structure on sandy soil	805,87	0			
0	Parking + light roadways	Waterproofed surfaces (paths, roads, parking lots)	8531,71	0			
0	Concrete roadway	Waterproofed surfaces (paths, roads, parking lots)	1751,82	0			
0	Skylights	Impermeable roofing	226	0			
0	Resin Cladding meta	Waterproof roof	172,93	0			
0	Awnings	Waterproof roof	488,84	0			
0	Pergola Local vélos	Impermeable roof	44,12	0			
0,3	Vertes Toiture	Extensive green roof	312,16	0			
		TOTAL	25152,93	25152,93			

d. Height of voluminous elements

Height of roughness elements	Height P	Height E		Surface P	Surface E	PROJECT	EXISTING	
Building	10		0	25152,93		10	0	-100,0%
Vegetation	0		0					
		TOTAL		25152,93	0			

e. Emissivity

Emissivity	Material identifier	Typology	Surface P	Surface E	PROJECT	EXISTING	
		Horizontal Surfaces			0,726	0,76	3,4%
0,76	Dry sandy soil	Dry sandy	0	25152,93			
0,75	Green Surfaces	Grass	7600,53	0			
0,23	Roof	New Galvanized Steel	4224,37	0			
0,945	Water	Water	1306,74	0			
0,595	Asphalt sidewalks	Bitumen and gravel	805,87	0			
0,93	Parking + light roadways	New asphalt pavement	8531,71	0			
0,91	Concrete roadway	Concrete	1751,82	0			
0,93	Skylights	Verre	226	0			
0,048	Resin Cladding meta	Polished Aluminum	172,93	0			
0,26	Awnings	Blue enamelled steel	488,84	0			
0,048	Pergola bicycle room	Polished Aluminum	44,12	0			
		TOTAL	25152,93	25152,93			
		Vertical Surfaces					
0,26	White Enameled Steel	White Enameled Steel	672,91	0	0,074	0	-7,4%
0,26	Blue Enameled Steel	Blue Enameled Steel	372,72	0			
0	Glass	Glass	125,42	0			
0	Black paint	Black paint	2524,97	0			
		TOTAL	3696,02	0			

f. Anthropogenic Heat

Anthropogenic Heat		W/m²		Climatized Surfaces		W for use		
PROJECT	EXISTING			Surface P	Surface E	PROJECT	EXISTING	
XXXX			0	XXXX	0	#¡VALOR!	0	-30,0%

Finally, for each of the parameters, the percentages of the existing and the project are subtracted. Finally, the resulting percentages are added together and the total is the UHI Score. The results for each of the parameters are given in paragraph 4.1.2.

APPENDIX D: ALIGNMENT WITH SUSTAINABLE DEVELOPMENT

The 17 SDGs[11] are a list of goals that have been established with the aim of leaving no country behind in terms of poverty, climate development, the fight for gender equality or the design of the cities we live in. These goals were established in 2015 and approved within the "2030 Agenda for Sustainable Development" by the ONU[12]. The construction sector, as we have already seen, is one of the most polluting sectors of the planet and at the same time forms part of its design. That is why within the list of SDGs we have been able to find several that have a certain alignment with the topic addressed in this thesis:

SDG-07: "Affordable and clean energy"

SDG-07: "Affordable and clean energy" is part of the background of this study, since companies like Payet would not exist if the world were not moving towards a world where sustainable energy was the future. As target 7.b states "By 2030, expand infrastructure and improve technology to provide modern and sustainable energy services for all in developing countries, in particular the least developed countries, small island developing States and landlocked developing countries, consistent with their respective support programmes". [1]

SDG-09: "Industry, innovation and infrastructure"

SDG-09: "Industry, innovation and infrastructure" is directly related to this work, as it shows how infrastructure still has a long way to go in terms of sustainable development. It also shows how there is a very large development gap in this sector between rich and poor countries. As can be found in one of the target's "Highlights": "For many African countries, especially in lower-income countries, infrastructure constraints affect business productivity by about 40%". The importance of this study can also be seen in several of its targets. The first, 9.4, states: "By 2030, upgrade infrastructure and retrofit industries to make them sustainable, using resources more efficiently and promoting the adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities". 9.a "Facilitate the development of sustainable and resilient infrastructure in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States" and generally in target 9.1: "Develop reliable, sustainable, resilient and quality infrastructure [...]" and 9.2 "Promote inclusive and sustainable industrialisation [...]". [2]

SDG-11: "Sustainable cities and communities"

Furthermore, sustainable construction plays an important role in SDG-11: "Sustainable cities and communities". This goal emphasises the fact that a large part of the population lives or will live in a large city. As a consequence, it will be necessary to adapt to this new distribution, e.g. by studying the UHI. This is directly reflected in one of the targets of the goal: "By 2030, increase inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlements planning and management in all countries", target 11.3. [3]

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[11] acronym for Sustainable Development Goals

[12] acronym for Organisation des Nations Unies - Organización de Naciones Unidas

SDG-13: "Climate action".

All of the above-mentioned goals and this thesis in general are based on SDG-13: "Climate action". Because changes are urgently needed if we want to maintain an optimal quality of life. It is a fact that the climate is changing by leaps and bounds, with the highest temperature values in history in the decade 2010-2019. Target 13.2: "Integrate climate change measures into national policies, strategies and plans. [4]

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