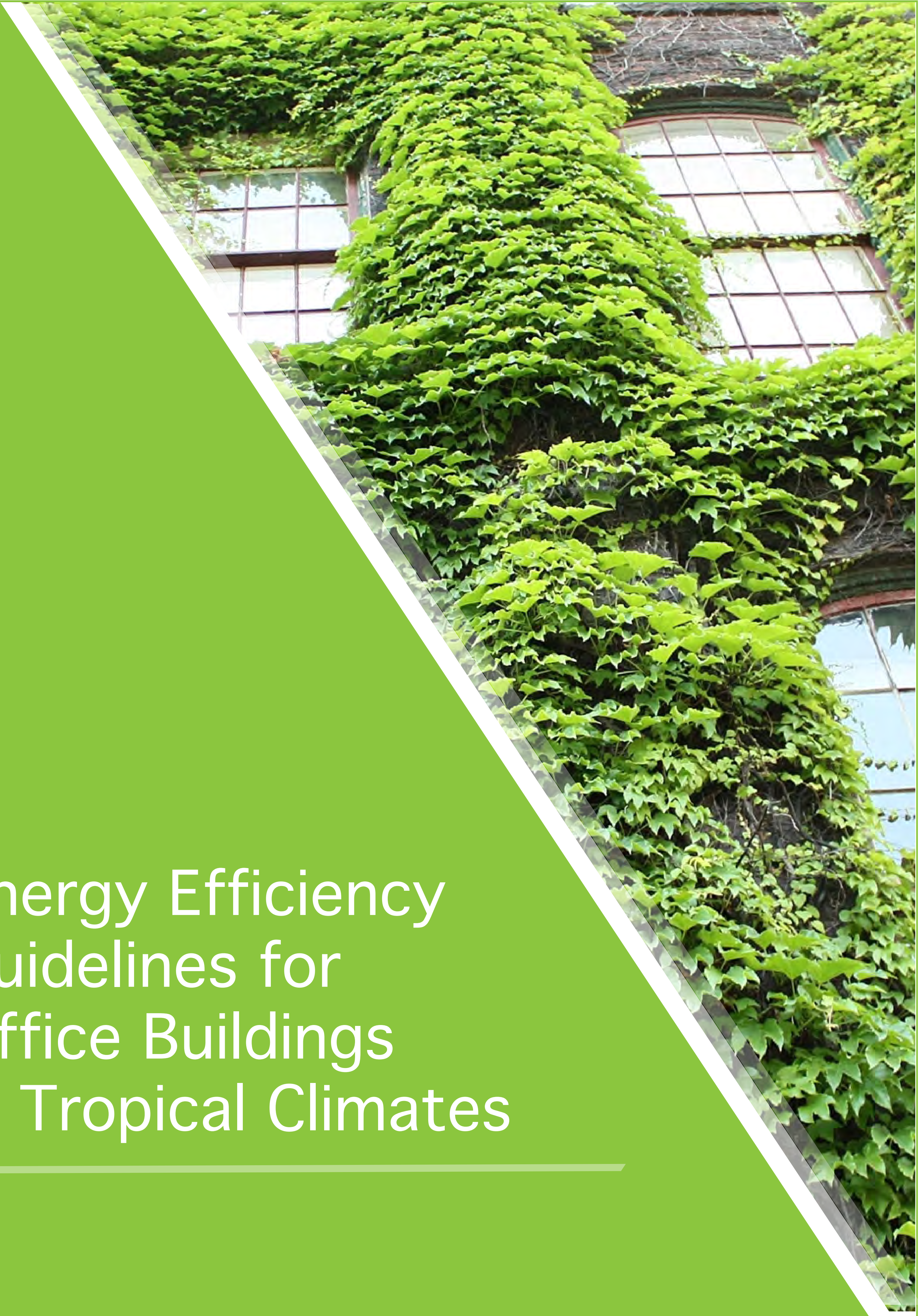

Energy Efficiency Guidelines for Office Buildings in Tropical Climates

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Disclaimer

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Acronyms

Ach	Ventilation “air changes per hour”
AHU	Air handling unit
BD	Baseline Design
COP	Coefficient of Performance
CRI	Color Rendering Index
EE	Energy Efficiency
EED	Energy Efficient Design
EPP	Energy Payback Period
FBC-EC	Florida Building Code - Energy Conservation 2010
HR	Heat Recovery
HW	Hot water
IECC	International Energy Conservation Code 2012
LC	Lighting Control
LCC	Life Cycle Cost
LED	Light Emitting Diode
m2	Square meters
MJ	Mega Joules
OAS	Organization of American States
PV	Photovoltaic
sqm	Square meters
FF	Form Factor
WW	Window-to-wall ratio

Energy Efficiency Guidelines for Office and Public Buildings in Tropical Climates

1. Background

In March 2011 a dialogue was convened on energy efficiency standards and labeling schemes among representatives from CARICOM Regional Organisation for Standards and Quality (CROSQ), the Bureau of Standards of ten Caribbean islands, Energy Programme of the CARICOM Secretariat, the Eastern Caribbean Supreme Court (ECSC) financed by the Caribbean Development Bank, the Government of Germany through its initiative Caribbean Renewable Energy Development Programme (CREDP/GIZ), Organization of the Eastern Caribbean States through the Sustainable Energy Technical Assistance Project (OECS/SETA) and the Organization of American States through the Caribbean Sustainable Energy Program (OAS-CSEP). The dialogue allowed synchronization of efforts to achieve regional cooperation in the establishment of regional energy efficiency standards. One of the recommendations raised was the need to establish concrete energy consumption thresholds that can be used in standards in the building sector throughout the Caribbean..

One of the first accorded steps was the development of the present Design Guidebook (DGB) for energy efficient office buildings that will support designers in tropical climates. The DGB shall consider as baseline all the previous efforts made in the Region and international best practices relevant to the Caribbean.

The DGB shall assist building designers in selecting the right design approach, suitable materials, equipment and building technologies to minimize the buildings' energy consumption, and if possible the building costs. The recommendations made in the DGB have been made based on dynamic simulations of the energy consumption.

It is expected that the DGB will be adopted in the future to be an integral part of the Caribbean Building Standards as it might be able to fast-track the Caribbean Application Documents (CADs) for the International Energy Conservation Code (IECC).

The DGB is thus presented as a guidebook for new constructions. Several important criteria for energy efficient and sustainable buildings are out of the scope of the guide, for instance, site selection, considerations to recycle and rehabilitate and retrofit existing buildings, minimum use of new resources etc. Buildings use energy, not only to operate but also as they incorporate materials with embedded energy. An energy efficient building should also take into consideration the use of local materials with embedded low energy and good life cycle performance.

2. Objective

The objectives of this Design Guidebook (DGB) for energy efficient office and public buildings in tropical climates will (a) assist on decision making for building designers, and (b) serve as the baseline to reach a comprehensive design manual for this buildings in tropical climates that consider energy efficiency measures and include the incorporation of renewable energy conversion technologies in the design to minimize energy consumption and building lifecycle cost.

Assuming a developer requires that a building project achieves compliance with a certain energy efficiency target, the building designers (i.e architects and engineers as well as builders) will then be required to study local conditions and priorities, balance short-term needs and long-term savings, and address environmental issues, in order to reach the stated target. The building concept may have to be modeled in computer simulation programs in order to estimate the energy use and demand associated with a specific measure compared to the overall energy consumption and peak load, and to determine the overall impact on target energy budget (kWh/m^2/yr) and power density (W/m^2), thereby confirming its compliance with the given target values.

The Design Guide Book (DGB) will provide the designer with advice on how to reach these stated energy efficiency targets, without the need to perform elaborate energy simulations of the designed building. The DGB contain an example of design modifications that have already been simulated to lower the building's energy consumption. This example and the corresponding figures will assist building designers to (a) select appropriate measures applicable to their building; and (b) help them to quantify, even if roughly, the impact of the efficient energy design measures without doing their own simulation.

Beyond explaining the concept of energy efficient building design as a holistic approach, the DGB also show examples of individual implemented measures that are suitable for the given climate, and their effects on the building's energy balance.

Some Case Studies are presented to complete the guide with examples of good practice that illustrate the application of energy efficiency measures analyzed throughout the guide.

The design of the buildings will be guided by Lifecycle Cost Analysis (LCCA). The target is to minimize the Life Cycle Cost (LCC) reducing the buildings' operation and maintenance costs through optimizing the buildings' energy loads through the use of efficient architecture design and introducing energy efficient systems and appropriate renewable energy technologies.

A. Introduction: climate, building codes

1. Climate

The design guide focuses on several countries of the Organization of Eastern Caribbean States (OECS) (Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St Lucia and St. Vincent and the Grenadines) and The Bahamas. The climate being one of the boundary conditions that determines the energy performance of a building and considering the limitations of the study, a preliminary comparison among climate data is performed to decide whether using a single climate for the study would be right or not.

1.1 Climate Report

The broad geographic scope, as shown by the diverse latitudes, of the analysis to be provided by this Design Guidebook (Antigua and Barbuda, The Bahamas, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines) suggests selecting a reduced representative number of climates to develop the energy simulations and design assessments.

City/station	Latitude (º N	City/station	Latitude (º N)
St John – Antigua & Barbuda	17,12	Kingstown – St Vincent and Grenadines	13,15
Nassau – Bahamas	25,03	Nassau Station (Bahamas)	25,03
Roseau – Dominica	15,30	Base Terre Station (Guadeloupe)	16,00
St George – Grenada	12,03	Le Raizet Station (Guadeloupe)	16,27
Castries – St Lucia	13,98	Fort de France Station (Martinique)	14,60
Baseterre – St Kitts and Nevis	17,30	Charlotte Amalie Station (Virgin Islands)	18,35

The criterion was to select the climate files, representing the climates of a majority of locations in the region, in order to cover the broad scope of the project without exceeding in simulation effort.

Climate data of the region

Available information

The climate data needed to perform energy simulations has to be detailed as much as hourly. The availability of such detailed climate data is not straightforward, as such information is not always provided by national meteorological agencies and seldom in a straightforward way. A solution to this is to use mathematical software such as Meteonorm.

Meteonorm climate files are based on data from existing meteorological stations (often from stations belonging to the World Meteorological Organisation WMO network of automatic stations). This software computes hourly data, useful for the energy analysis of buildings, from the data gathered by such stations, which is found in a less detailed time scale.

Data for the locations in the table has been found for five islands: Nassau – Bahamas, Basse Terre – Guadeloupe, Le Raizet – Guadeloupe, Fort de France – Martinique and Charlotte Amalie - Virgin Islands.

Besides, the following map shows the location of the climatic data found (represented by coloured pins) and the islands targeted by the project (represented by the colored circular shapes).

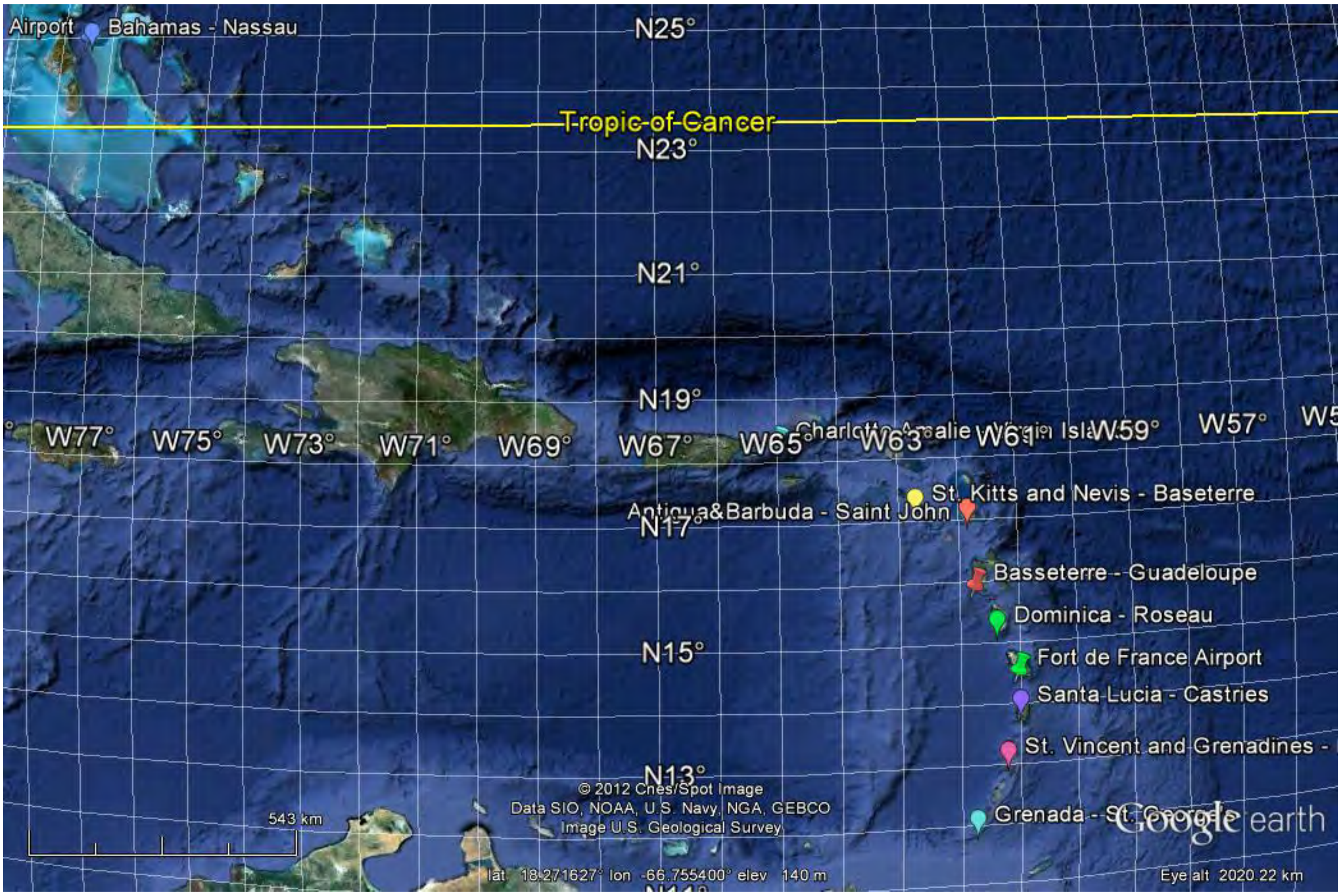


Figure 1- Geographical distribution of WMO stations considered and the targeted islands, within the Caribbean region (Edited with Google Earth)

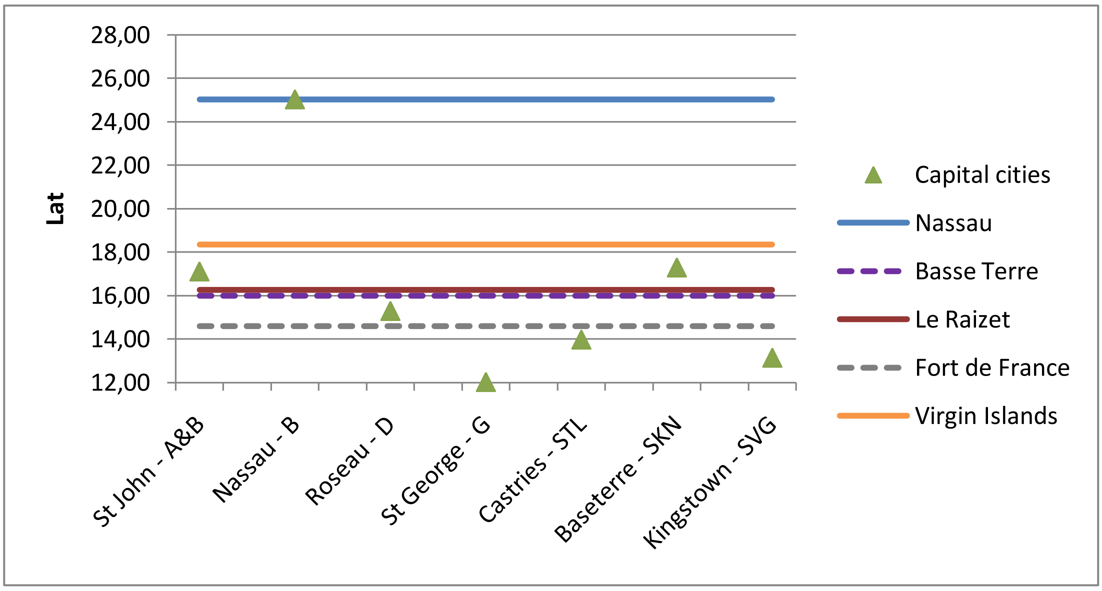


Figure 2- Comparison of latitude of the Capital cities (St John – Antigua and Barbuda, Nassau – -The Bahamas, Roseau – Dominica, St George – Grenada, Castries – St. Lucia, Baseterre – St. Kitts and Nevies, Kingstown – St Vincent and Grenadines and the weather st

Solar radiation.

The incident radiation in the region considered is mainly dependent on the latitude.

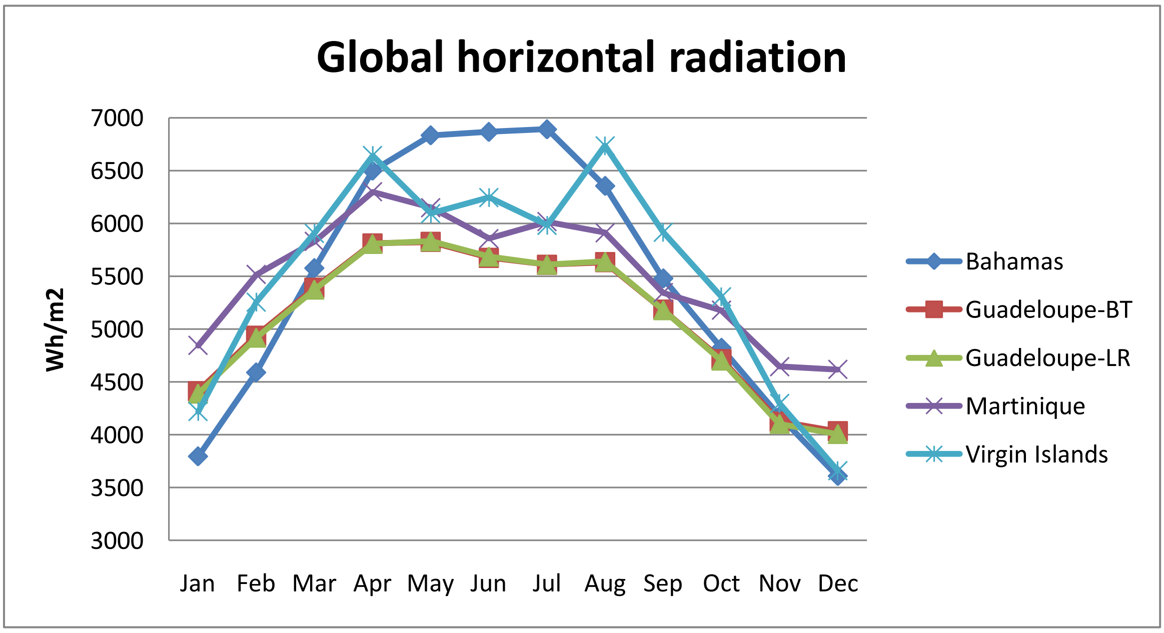


Figure 3- Incident global radiation on a horizontal surface

The next figure represents the share of direct vs. diffuse radiation, as a yearly average, for the different stations. The direct radiation is here considered as the direct radiation received by a surface following the sun's movement.

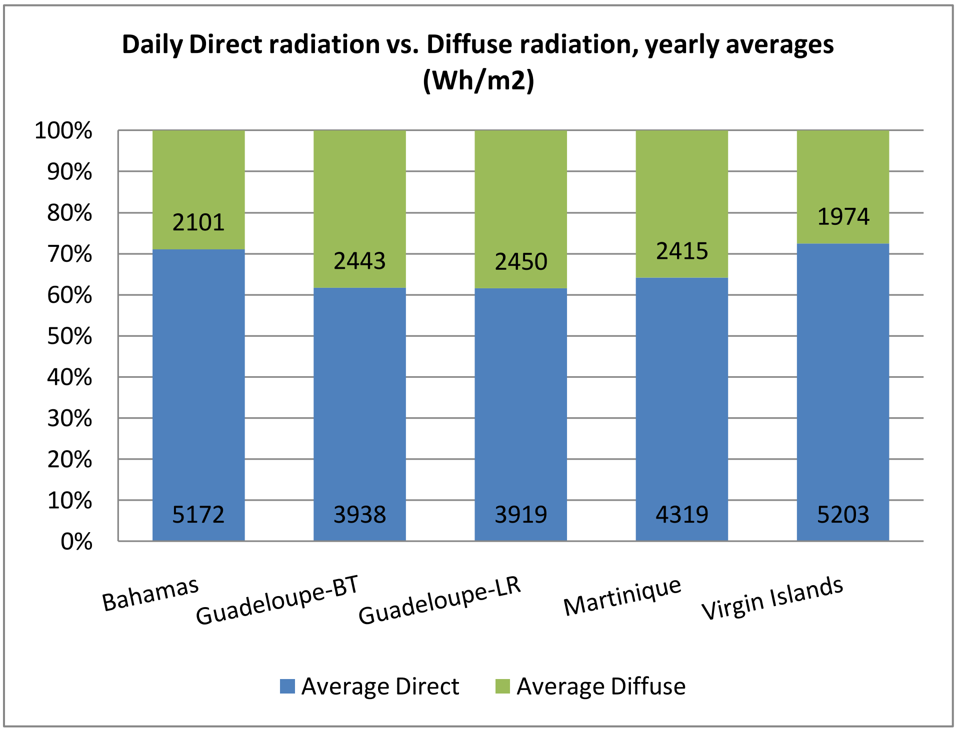


Table 1- Direct vs. diffuse radiation share, for sun-tracking surface, daily average

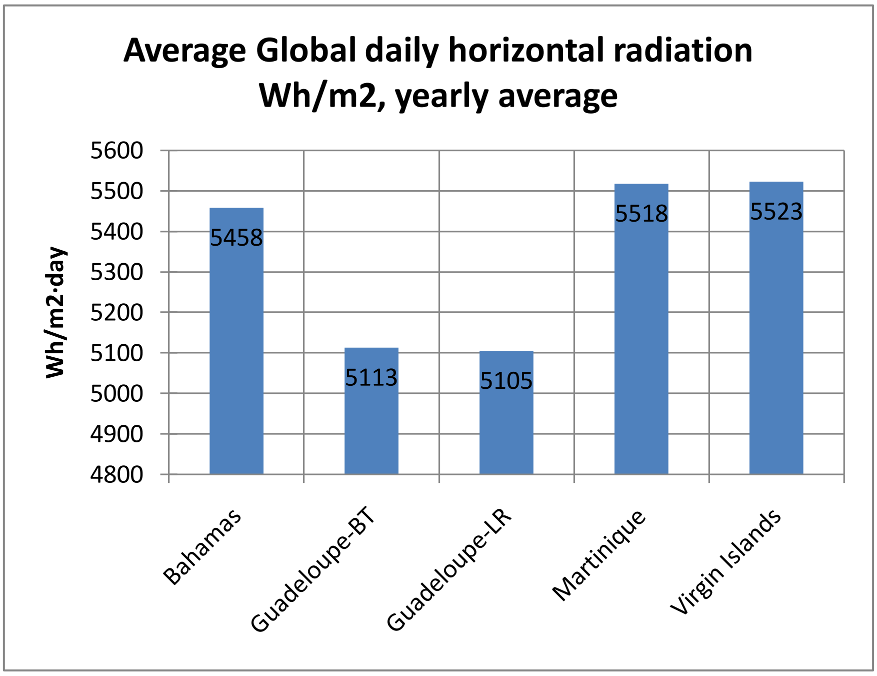


Table 2- Global horizontal radiation, daily average

If direct radiation for a horizontal surface is computed as the difference between the global radiation for a horizontal surface and the diffuse radiation, the following combined graph is obtained, showing the share received by such horizontal surface:

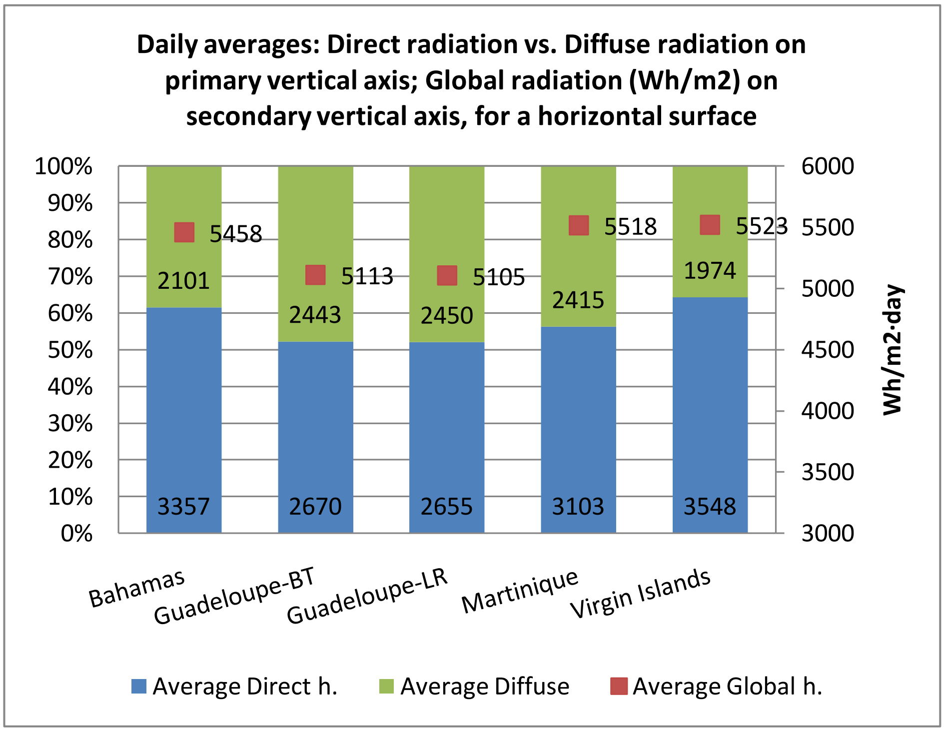


Table 3- Horizontal surface, daily average values: direct vs. diffuse share on primary vertical axis; average global radiation on secondary vertical axis

Temperatures and humidity

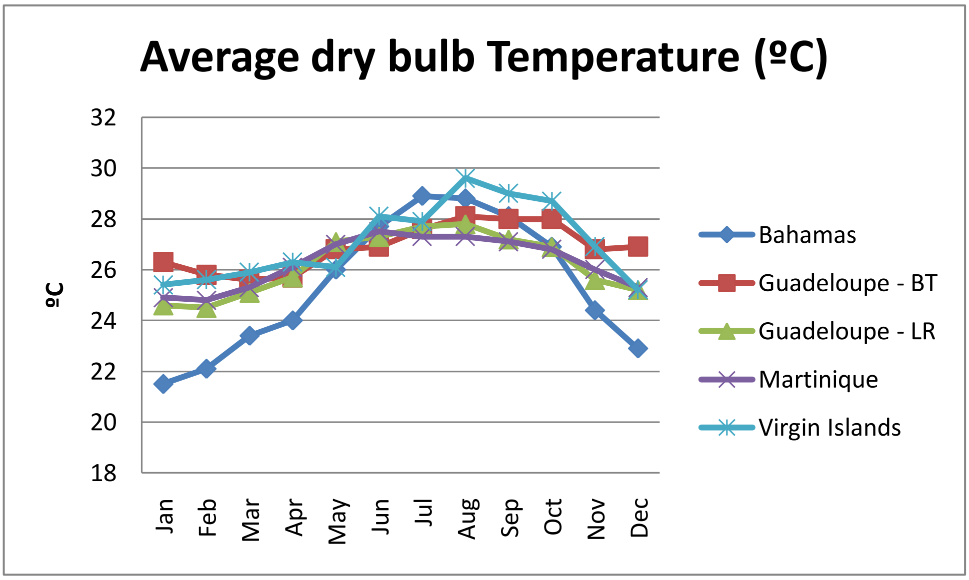


Figure 4- Average temperatures for several locations

Only the temperatures in Nassau differ from the rest, which follow a very similar pattern throughout the year and are restricted to an approximately 2ºC band. The temperature in Nassau drops more than the rest of the stations during winter but is similar to the rest in summer.

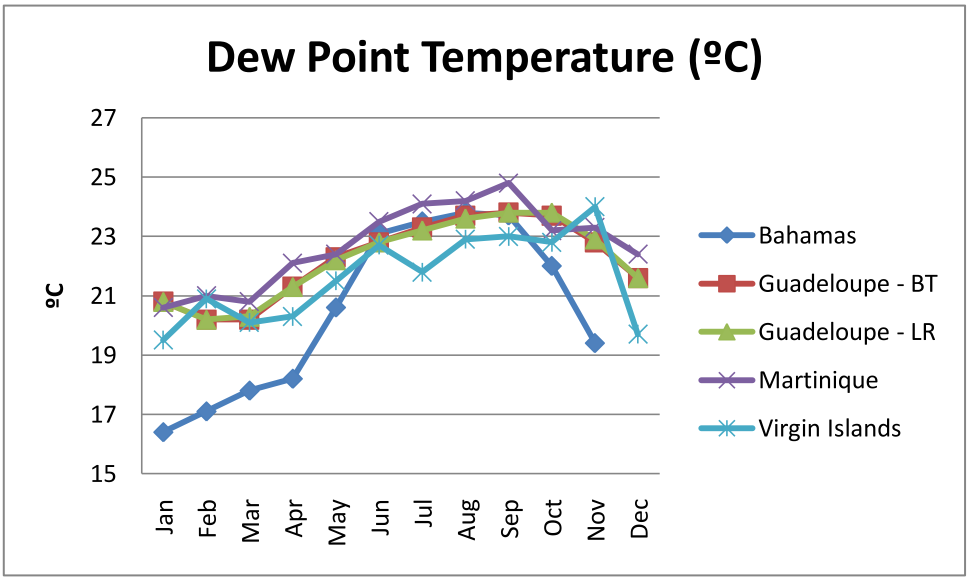
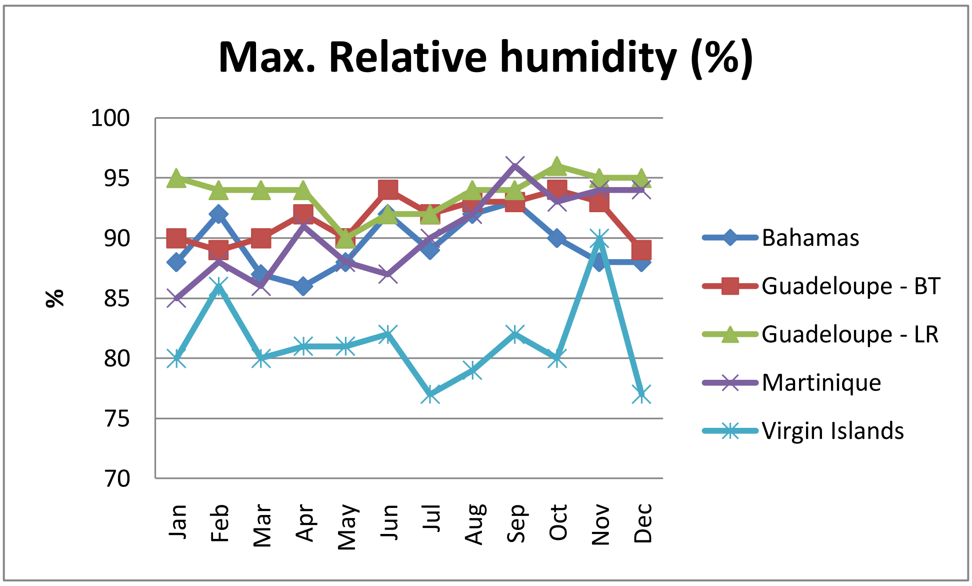


Figure 5- Dew point temperature for several locations

Regarding the dew point temperatures, they are also lower in winter for Nassau, the rest follow a very similar trend throughout the year with slightly hotter temperatures in the wet season than in the dry season.



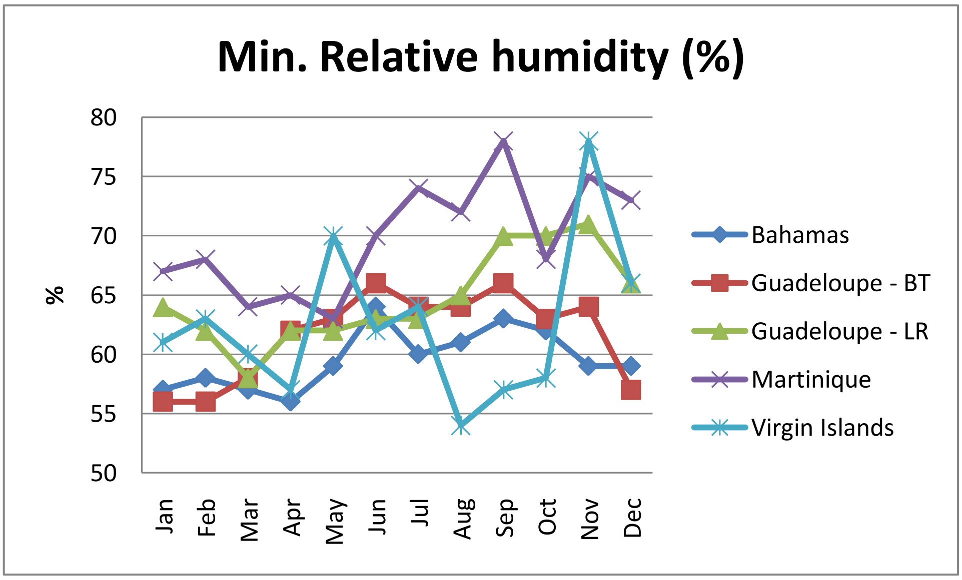


Figure 6. Average monthly relative humidity (%), maximum and minimum; variation throughout the year, for the different stations

The average monthly maximum humidity is high for all the stations throughout the year, without any significant dependence on wet or dry season, it lays approximately between 95% and 80%. The average monthly minimum relative humidity is also high, the lowest value being close to 55%.

This means that the relative humidity values for all locations are very high throughout the year.

Degree-days, degree-hours

In all the locations studied the heating degree-days (indicator of the heating needs) of a certain location are insignificant or zero, meaning that, along the year, there will be no heating needs to be met.

Instead, the degree-hours for cooling are important all around the region.

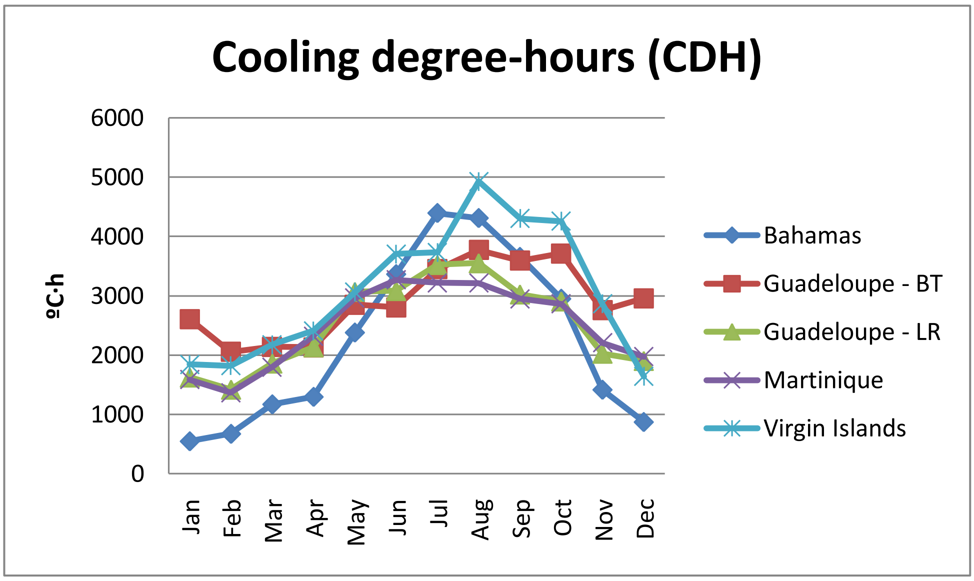


Figure 7- Cooling degree hours, different locations

All stations show similar needs for cooling, actually even the coldest season shows non-zero cooling needs, which peak in July-September at between 4000- 5000 degree-hours. The data for Bahamas show a lower cooling demand in winter months, a direct impact of the lower temperatures shown above.

Guadeloupe stations are the closest to the mean value of total cooling degree-days.

Wind

The wind resource does affect the building design as it can offer possibilities of natural ventilation, reduced energy consumption and even renewable energy (electricity) production.

The following graphs and tables compare wind speed and direction found in the data at the different stations. Other than average wind speed, an important characteristic of the wind resource is the distribution of such wind speed and the direction it blows from.

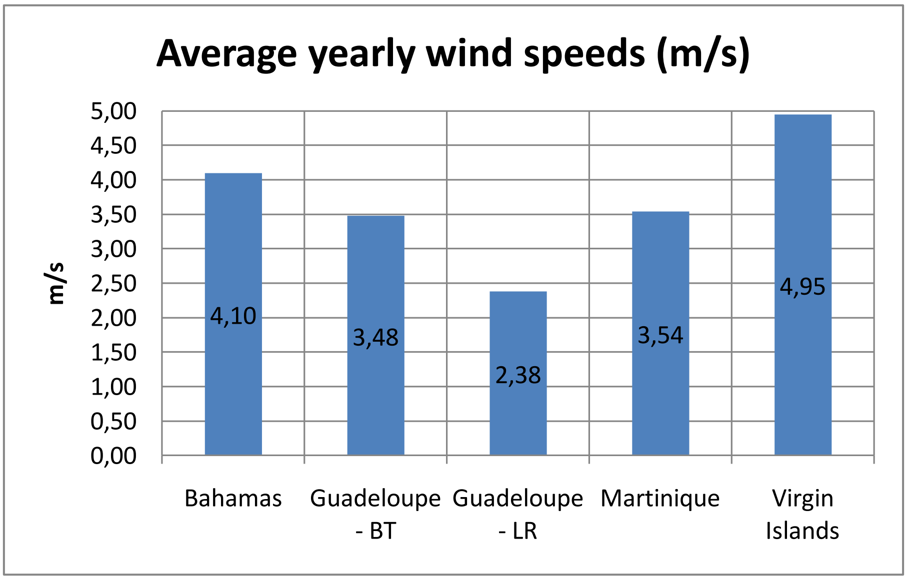


Table 4- Yearly average wind speed at the different stations.

As the figure above shows, differences are significant. This can be due, as said before, to location-specific features (orography etc.). The data shown here can be as much as double, for the station at the Virgin Islands, than the station in Guadeloupe.

Rain

The impact on energy simulation of rainfall data is very limited and particular to only green roof analysis, which, if applied, will be done with the local data. A representative profile of monthly rainfall with a dry and a wet period is shown at the following graphic.

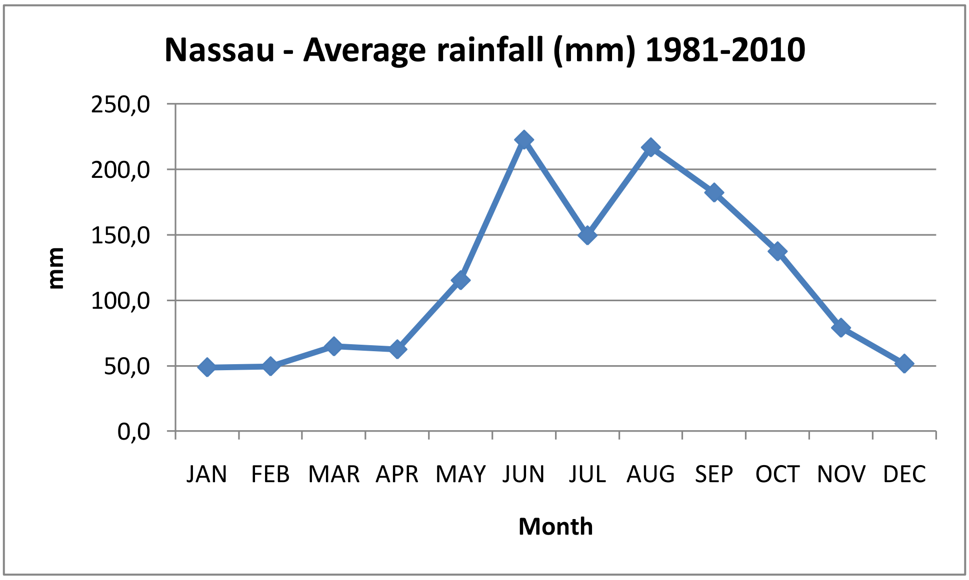


Table 5- Average monthly rainfall in Nassau 1981-2010. *Department of Meteorology – The Bahamas*

Conclusion

Considering all of the above results, the climate data file from Guadeloupe has been selected to develop the energy simulations of the buildings.

2. Technical review of codes

2.1 Introduction

The review of building codes has been developed in order to feed information to the designs of the Baseline and the Energy Efficiency measures to be simulated. A summary of relevant building codes and labels is explained.

2.2 Technical review of codes

An initial literature review of current existing building codes and other labels related to energy efficiency has been developed, namely limited to those belonging to countries with Tropical climates or those relevant to the countries studied (e.g. USA codes). The selection has been made by the consultant team.

The following paragraphs describe the main features of the codes whose characteristics can be included in the Baseline Design of the Design Guidebook.

General Requirements and Indoor Design Conditions

The structure of the analyzed codes (Florida Building Code 2010, Energy Conservation – FBC-EC) includes different requirements and considerations for the different climatic zones. Generally speaking the region of the present project will fall into the climate Zone 1A (Hot and Humid Climate). However, the design team of each particular project can verify through the specific project local climatic data and calculation of CDD50°F (Cooling Degree Days 50°F) if the project would fall into the climate Zone 2A (Warm and Humid Climate). As defined in the referenced codes and standard if the there are more that 9000 CDD50°F the project is to be considered as Zone 1. If the CDD50°F falls between 6300 and 9000 (which may be the case for some high altitude areas) the project would be considered to be in Zone 2.

The designation A is for humidity and would apply for all locations in the Caribbean region (for the same temperature range a distinction between humid-A and dry-B climates is made). It is important to mention that the analyzed energy conservation codes require that the interior design condition for heating and cooling load calculation shall be performed for a minimum of 24°C (75°F) for cooling. That is, it will not be allowed to set cooling threshold temperatures lower than 24 ºC.

As far as USA regions are concerned, only Miami and the very southern part of Florida fall in the Zone 1A.

Envelope Energy Efficiency Considerations as it related to the analyzed energy conservation codes and standards

Special consideration has been placed on the review and the analysis of the envelope characteristics that are adopted in the FBC-EC, that states particular amendments and requirements; these requirements would be adaptable and more appropriate for the climate condition of the project region.

There are two different approaches to demonstrate or determine compliance with the energy conservation codes: Prescriptive and Total Building Performance.

For the region subject of the present project it would be recommended to use the Total Building Performance method which is a more comprehensive method and allows tradeoffs between different envelope components and building system efficiency, making it more adaptable approach for the particularities of each individual site and project conditions. However, using the performance based method requires using hourly simulation software that simulated the proposed building design and characteristics and compares energy consumption using the Energy Cost Method and simulation for Standard Reference Design.

The Standard Reference Design characteristics shall be established according to Appendix B of FBC-EC that refers to section 11 of ASHRAE 90.1 The tables collected in Annex VI have been extracted from the document, to establish the prescriptive requirements and the characteristics of the Standard Reference Design used as comparison in the total building performance method.

Review of other codes/standards considered, RESET from Costa Rica, Casa Azul from Brazil, Green Building Index from Malaysia.

3. Considerations for hurricane and other weather phenomena

3.1 Introduction

Recent Development of Analyzed Codes: In the mid 1990s, three formerly competing code agencies in US, ICBO, SBCCI and BOCA, joined to form the International Code Council (ICC). Their mission was to take the recommendations of the NEHRP agencies and develop a national model construction code. The codes they developed are known as the International Building Codes with the following editions IBC- 2000, IBC-2003, IBC-2006, IBC-2009 and IBC-2012. To date, every state in US has now adopted one of the versions of the IBC Code. Most states in US have adopted the code at the state level and there is a recent initiative of the CDB-CROSQ (Caribbean Development Bank - CARICOM Regional Organization for Standards and Quality) to develop New Caribbean Building Standards that will be adopting by reference selected ICC (International Code Council) standard.

3.2 Design Consideration for Mechanical Systems

There are two main aspects and design consideration that will have to be incorporated in the building systems and equipment design. The design and integration of the mechanical systems at system level in the building design and its integrity as far are withstanding weather events. The second consideration shall be the specification of the equipment that has the necessary certification and testing. Equipment manufacturers of the specified equipment need to guarantee the “on line” performance through independent testing and analysis as outlined in section 1708 of the IBC .

Similarly the FBC Mechanical requires that mechanical equipment exposed to wind shall be designed to resist the wind pressures and the equipment shall be adequately attached to the building structure to prevent equipment overturning causing damaging on the roof and compromising the roof integrity or parts of the equipment flying away and becoming a projectile.

B. Methodology

The Energy Efficient Design is developed based on design principles that are presented in this chapter and on the results delivered by a Parametric Study that is performed using energy simulation software to quantify the impact of such design strategies in the given climate.

The following figure illustrates the steps followed:

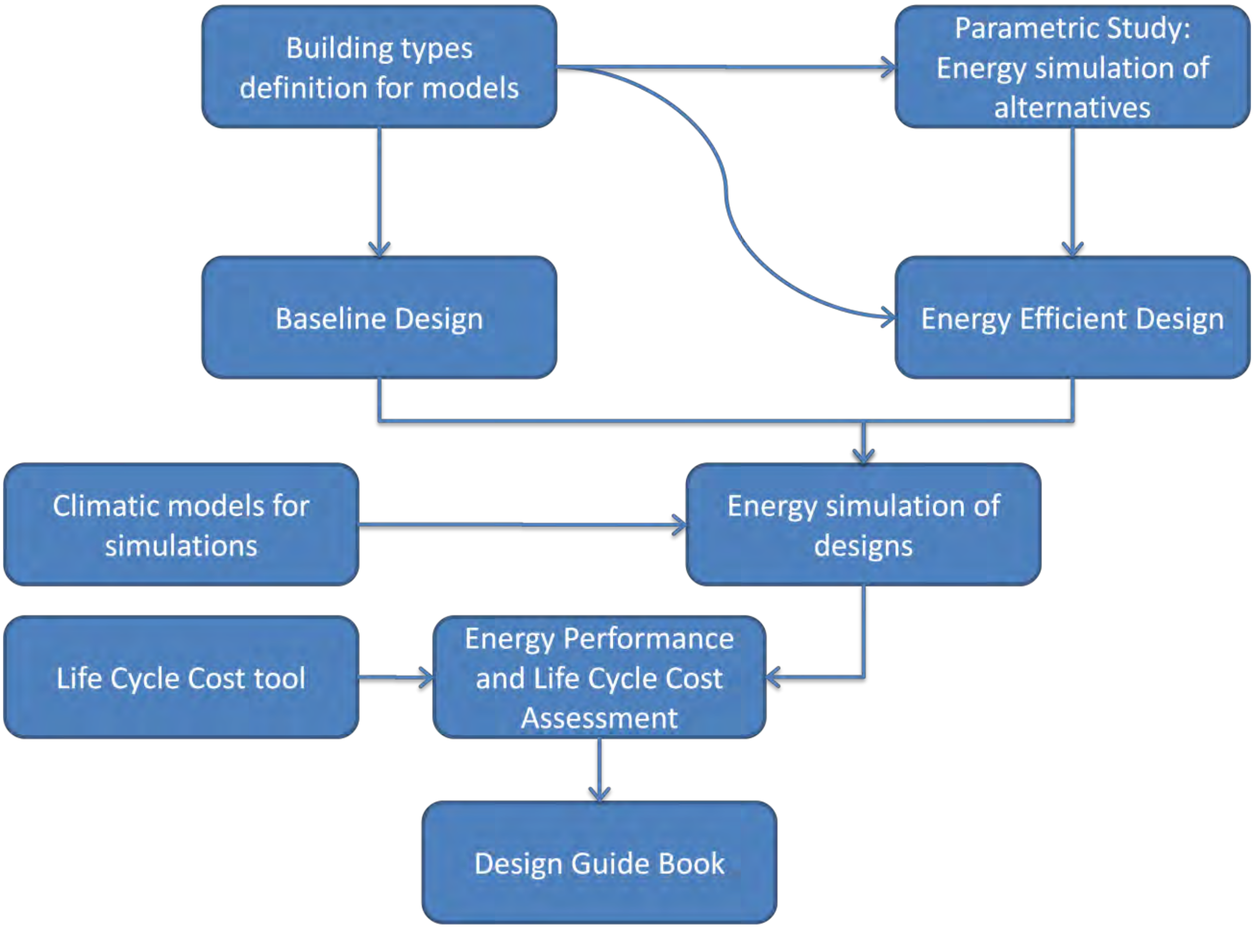


Figure 8. Methodology for work

1. Energy Efficient Design Strategies

Strategies to deliver energy efficient buildings are presented within three areas: architecture or passive strategies, related to the building design itself; mechanical and other building installation and energy service distribution considerations; generation of energy (namely electricity) using renewable resources.

1.1 Architecture/Passive

The following energy efficient strategies are to be determined at design step, when decisions are inexpensive to take and strongly impact energy performance. The decisions taken at this level of the project commit the life-cycle building costs to a great extent.

Building site and orientation

Description

It is recommended to select the location of a new building in a site with existing infrastructure (access to drinking water service, sewage and wastewater treatment, access to the electricity grid, solid waste collection, etc.), a site accessible by public transport and clean mobility paths, such as bicycle paths or pedestrian paths, etc. This greatly reduces the environmental and energy impact of the building and the ecological footprint of its operation.

The orientation of a new building is essentially conditioned by the existing urban layout and municipal planning rules. However, it is important to consider other conditions, related to the solar shading, daylight availability, sun access, prevailing winds, etc., determined by the building orientation that will greatly influence the energy performance of the building.

Rationale

Thus, the orientation of the building should consider both the protection from the sun and the access to daylight as well as the incidence of the prevailing winds on the main façades.

Application

Regarding daylighting, priority should be given to the northern façade, which receives a uniform natural light and low direct sunlight. The other façades must be adapted to limit the incidence of direct and excessive sunlight that would heat up the air inside the building.

The prevailing wind direction should be considered in order to both, ventilate the façades and to facilitate natural ventilation of built spaces.

It is recommended to sufficiently separate buildings to facilitate penetration of breezes.

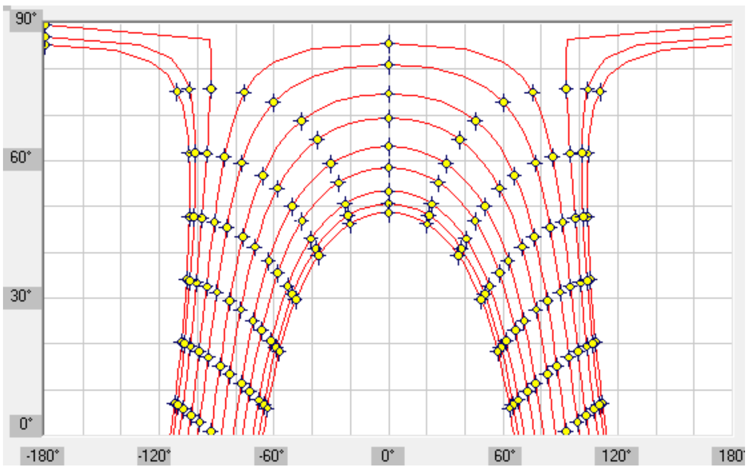


Figure 9- Façades are designed in a different way according to their orientation (left); depending on the latitude the sun path changes is different and thus the incidence on facades and roofs varies. For an average latitude in the Caribbean, the central months of the year represent a considerable incidence on the North façade, as shown by the orthographic projection (right)

Cross ventilation

Description

Installing practicable and adjustable windows will allow for adequate ventilation rates without creating uncomfortable drafts. Thus, an air flow will be established from the opening at the façade at higher wind pressure to another opening at a lower pressure.

Rationale

Temperatures in the tropical region are high, combined with high relative humidity and these climatic conditions produce thermal stress which fatigues workers and hinders job and cognitive performance. A gentle air breeze on the skin dries it and cools it, and creates an increased feeling of comfort.

Application

The façades more or less perpendicular to the wind direction are subject to overpressure. It is recommended to create narrow building volumes, arranged more or less perpendicular to the prevailing wind direction. Cross ventilation will exist between this and the opposite façade, considering that there is always a certain depression, due to the turbulence leeward.

The façades more or less parallel to the prevailing wind direction will experience a depression as the wind speed increases due to the presence of buildings, causing a suction effect.

The width of the building should allow cross ventilation between opposite façades.

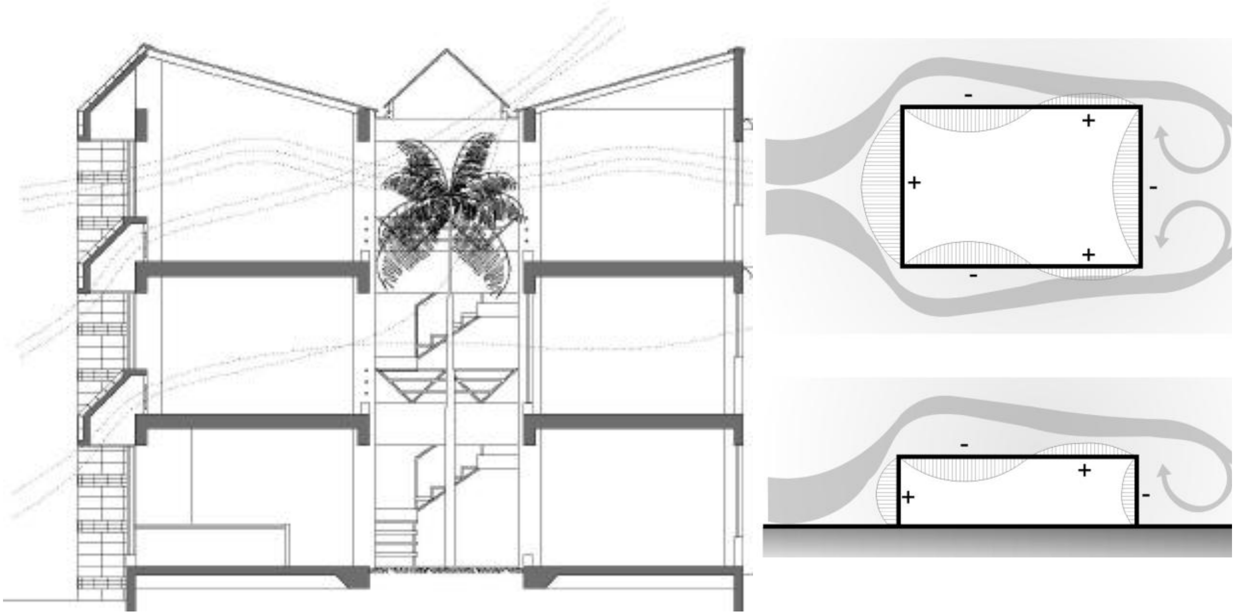


Figure 10- Buildings with opposed facades and connected spaces may have air flows that provide improved thermal comfort during certain periods of the day or year (left); the wind creates overpressure or suction zones that facilitate the circulation of air through the building

As regards the internal layout of the building, in the case of the spaces located perpendicular to the prevailing wind, the partition walls should be parallel to it. The average porosity[1] of the walls perpendicular to the wind should be greater than 20% of the surface.

It is also recommended to use architectural / building façade elements to provoke changes in wind direction, acceleration and wind input to interior spaces.

The building design must ensure that the ceiling height is enough to facilitate the evacuation of heated air. The distance between windows on opposite walls must be appropriate to achieve effective cross winds, and the proportion and size of openings is also important.

To maximize air flows, the inlet and outlet should not be in a straight line. To optimize the ventilation, it is recommended that the inlet, upwind openings are located in a non symmetrical arrangement and at the bottom part of the wall or at users' height. The output, downwind openings should be at the top of the walls.

In the case of absence of natural breezes, there are options of chimneys that enhance natural ventilation flows. Thus it is recommended to develop air-flow acceleration systems on the roof.

Sources of air pollutants are a threat to the healthiness of naturally ventilated spaces. Therefore, spaces that generate such air pollutants should be at a lower pressure than the other areas. This applies to internal areas such as restrooms, smoking areas and printing areas.

Solar shading

Description

The best solution to reduce passive heat gain from solar radiation is to provide shading to façades and roofs.

Rationale

In order to achieve the shading of these outer surfaces screens may be provided or a second skin, overlying these external surfaces; trees or plants placed outdoors are also a strategy to provide shade.

The screens should be ventilated to reduce the pressure in hurricane events. Attachment to structural elements must be adequate to withstand the extreme weather conditions found in the region.

[1] Ratio between total openings surface and total façade or wall surface

Figure 11- Some constructive elements can be designed to provide solar protection on roofs and façades, protection from the rain and creation of transition spaces (left); protection devices may be fixed or mobile and adapted to the different conditions depending on the orientation

Application

It is recommend using special software to design elements that create shade during the months of highest temperatures, determining solar incidence angles for the site (latitude). Vertical or horizontal louvers as shading elements are recommended for East and West façades of the building. North and South façades should have horizontal eaves or overhangs.

Transition Spaces

Description

It is recommended to incorporate transitional spaces ("buffer spaces") between the inside and outside of the building.

Rationale

The intermediate spaces between the inside and outside protect the walls and the inner space from climatic conditions, generating a shaded space with an air-flow and therefore a cooling effect.

These spaces allow the user to adjust the temperature and light differential between outside and inside.

Figure 12- Transition spaces protect the air-conditioned zones and reduce the cooling demand, offer natural lighting and provide space for vegetation

Options

Among the options to provide such transition spaces are: atriums, circulation spaces such as corridors and stairways and other, such as terraces, balconies. In general, these spaces are protected from the rain, but have no walls.

Use of vegetation

Description

It regards the use of vegetation in the design of the building, either outside the building or inside.

Rationale

Having vegetation is possible and beneficial in the courtyards, to decrease the heat gain. Besides, plants are capable of removing chemical vapors.

In the site where the building is located, the vegetation preserves the soil's draining capacity, provides shade and reduces heat island effect and is an opportunity to enhance the conservation and preservation of species in areas of high biodiversity.

Figure 13-Use of vegetation around buildings reduces the incidence of solar radiation on enclosures, reduces external air temperature and improves the comfort at workspaces

Options

It is possible to include courtyards, gardens, green roofs and green walls or other elements with easy plant growth, low maintenance and resistant to pests.

It is recommended to use native species and avoid using invasive species.

However, plants increase humidity generation and thus, should only be present in naturally ventilated spaces. Plants should never be grown in airtight, air-conditioned, mechanically dehumidified spaces or in those in permanent shade.

Roof Design

Description

Reduce the solar incidence on the roof.

Rationale

The roof design, in addition to protection against rain, should consider the heat transfer from this surface towards the inside of the building, as this is the one building surface receiving the highest solar incidence. Shading strategies, thermal insulation and green roofs are three suggested strategies.

Options

The "cool roof" effect can be achieved with strategies such as:

Ventilated roof: It is recommended to leave a gap between the outer skin of the cover and the internal ceiling, allowing cross ventilation. This strategy can also be used in spaces between the top floor and the ceiling. As a precaution, protection should be provided against insects, nesting of birds and bats.

Low absorption/ low heat capacity materials: Bright colored materials should be used.

Lightweight, discontinuous materials may not be the best option (such as asphalt tiles), given the risk of high speed winds and storms.

Large heights of ceilings: In order to keep the heat gained through the roof away from the users, given the fact that hot air rises, the use of high ceilings is recommended; thus the warm air mass will be kept far from the occupants.

Double roof for shade: When using double roof strategies the most external one, usually lighter, provides shade to the one below, serving as a sunscreen.

Green roof: The vegetation on roofs keeps the inner surface cool and increases the biodiversity of the project. However, it is a strategy where special care should be taken given continuous high humidity in the tropical climate; perfect waterproofing is essential and also the correct disposal of the drained water.

Daylight

Description

The aim of this strategy is to allow indirect natural light to enter the building and lit the working areas.

Justification

This reduces the electricity demand for artificial lighting that would otherwise provide the necessary lighting in order to perform jobs.

Besides, natural light is beneficial for people who work indoors and improves their performance.

Figure 14-Window-to-wall ratio, the depth of spaces and the use of transparent indoor openings are design criteria that improve daylighing

Options

The shape, orientation and openings surface of the building will condition its daylighting availability.

The distribution of natural lighting is determined by the maximum depths between opposing façades and the openings found between them, which should be at least partially transparent.

Indirect light through windows should be prioritized and minimization of the entry through skylights on the roof.

Another strategy is to incorporate elements that filter or reflect direct sunlight such as screens or light shelves that favor the distribution of diffuse or reflected light into the rooms.

In spaces with reduced access to natural lighting (underground, without windows or far from the building perimeter) it is possible to provide sunlight using light tubes.

Window Design

Description

Windows provide an entrance for natural lighting, ventilation and allow to have views to the environment surrounding the building, which is a desirable thing for most office jobs.

Justification

The ratio between opaque walls and transparent openings is a critical variable to energy performance; besides, the area of such openings must be selected so that they provide natural ventilation without compromising excessive solar heat load.

Windows must be designed together with other strategies described here, in order to allow exterior views for the majority of users.

Options

The position, size and material of the windows should be decided depending on the location and for all façade orientations. Windows must be practicable in an appropriate proportion to ventilate the building.

In office spaces, accessibility of users to operate the practicable windows is necessary. In other common areas, with public access, etc.., this should be controlled by the building manager, or opt for a centralized control system (with a higher cost and with high maintenance requirements in tropical and humid coastal climates).

The most important strategy to prevent heat input through the windows is that glazed openings remain in the shade, with a solar protection, to reduce or eliminate direct sunlight and the greenhouse effect in the building, throughout the year.

If glazing is unavoidably exposed to the sun, it is recommended to use double glazing with air gap, non-conducting frames or thermal bridge breaking frames and reduce its size.

In common office areas the partitions will be such that the view to the outside is not obstructed.

Material thermal transmittance

Description

The thermal transmittance of the façades and windows should be the appropriate depending on the orientation and the maximum temperature difference between ambient air and comfort conditions, in the local climate.

Justification

The materials of the enclosures in such warm, humid tropical climates should have low thermal capacity and short transmission time. That is, thermal inertia should be low, in order not to retain heat given the fact that night temperatures are high.

Options

The use of lightweight materials and composite structures (with lower thermal mass or ventilated) since they store less heat.

The walls should be light, with bright colors finishes and permeable in areas without mechanical air-conditioning. It is preferable to keep them in the shade. If exposed to direct sunlight, it is recommended to include insulation materials.

A further consideration would be to use industrialized solutions, which may be lightweight, flexible, modular, removable, allowing the optimization of a clean and air-tight assembly.

Rain protection

Description

The three main aspects of protection from the rain are:

Roof

Roofs with large overhangs are recommended, with an appropriate slope for efficient evacuation of water and intermediate overhangs over windows and doors.

Floors

It is recommended to waterproof the ground floor, to prevent capillary filtration; lifted floor structures and baseboards reduce moisture penetration in the spaces.

Façade Finishes

Façade finishes must be resistant to continued humidity conditions, such as sealants in materials and at several layers of antifungal paint.

Rationale

One of the most significant aggressions on buildings in the tropics is the continuous moisture in the ambient, soil and heavy rains.

To enhance the life of cladding materials and minimize leakage, it is recommended to adequately protect façades and windows against rain infiltration.

Options

For the evacuation of rainwater, free fall combined with floor drains can be applied, and properly sized rain gutters and downspouts with an auxiliary downspout to reduce blocking risks. Slopes should be greater than 20% and large continuous roofs should be avoided due to increased flow rate.

As for soil and drains, speed reduction elements and retention ponds should be applied, if necessary, and also avoid the use of impervious outdoor surfaces.

Mechanical HVAC

Description

Cooling of the closed working spaces and forced ventilation should be applied depending on environmental conditions of the outside air (humidity, outside temperature) and comfort temperature in the occupied spaces.

In areas without air conditioning, a café, for example, it is preferable to use ceiling fans, in the absence of natural airflow. In this case, energy efficient fans should be selected.

During office hours the occupied spaces must be kept within the “comfort zone”, which is not always possible in a climate with high temperature and humidity, adding to this, the heat gains from the activity and equipments. In these cases, the use of an active cooling system should be considered.

The HVAC control system could close the windows and other elements that are active for natural ventilation and it could meet the cooling or mechanical dehumidification needs when the temperature exceeds 26 º C and 80% humidity.

If necessary, the installed air based, HVAC equipment, should have a high performance rating and it should be free of gases that are harmful to the ozone layer. Besides all, there should be a constant renewal of air in spaces with a high occupancy density.

Artificial lighting

Definition

Artificial lighting design must be complementary to the availability of natural lighting. Its characteristics must be determined for each activity. The selection of energy-efficient lighting must be prioritized.

Justification

The adequate design of artificial lighting and the selection of efficient equipment render energy savings over the life of the building.

Options

Lighting design should target a luminance of 250-500 lumen/m2 for workstations. Given the use of computer screens at the workstations, a low general luminance is recommended, complemented with desktop lighting, closer to the work surface.

User-control of the artificial lighting must be enhanced using switches, "dimmer" or other control devices. Motion sensors and timers must be used in spaces where the frequency of use is low and short stay spaces (circulation and restrooms), also in basements for parking.

Daylighting sensors should regulate the intensity of the artificial lighting.

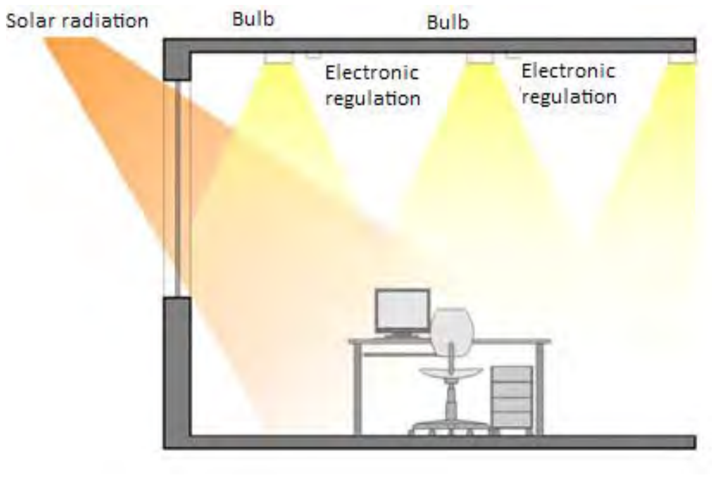


Figure 15- An illustration of how natural lighting should be complemented by artificial lighting with regulation of artificial lighting luminance (left); LED fixtures that look like fluorescent tubes reduce the electrical consumption and the heat load (right)

1.2 Mechanical, electrical and plumbing

Improvements in the efficiency of the cooling system

The following strategies are addressed to provide cooling in a more efficient way: distribution of cooling only to those spaces that require it, disconnection of the distribution out of office hours, moving small volumes of air (just the air renovation volume), decrease of the airflow values, improvement of the comfort due to cold surfaces (and not just cool air), altogether improving the efficiency compared to conventional solutions.

Cooling through radiating panels integrated in false ceiling

Radiant cooling achieves comfort conditions by reducing the radiant temperature of the internal surfaces of the occupied spaces. A relatively low radiant temperature improves the comfort even if the air temperature is slightly warm. The reasons to suggest a radiant cooling system instead of a conventional cool air distribution system are:

- Decrease the volume of air to be conditioned and transported
- Decrease the air velocity, drafts and noise related to the distribution of conditioned air.
- Decrease the relative humidity of the renovation air and that of the ambient air in a more effective way
- Increase the temperature of the conditioned air and that of the room air without compromising comfort
- The possibility of zoning the radiant temperature to relatively small spaces
- The comfort felt with a radiant system is very high even at temperatures outside the normal range, given the fact that the operative temperature, that is, the average between the room air temperature and the radiant temperature of the surfaces, is positively impacted by the temperatures closest to that comfort operative temperature.
- This system has a lower energy consumption compared to other systems, given the fact that the cooled water can be delivered at 15-17 ºC instead of 7-9ºC for all-air systems;

this is thanks to the big radiant exchange surface used. The energy is saved at cooling equipment and cool distribution level.

- The radiant panels take very little usable space and are practically invisible.
- The response is fast so it can be turned on little before the activity in the building begins and can be turned off once finished, thus reducing the energy consumption.

Figure 16-The use of radiant panels on ceilings provides an energy efficient cooling without moving air

Zoned cooling distribution

Office buildings tend to have clearly distributed and separated spaces (meeting rooms, offices, printer rooms etc.), as well as open spaces, with uniformly distributed workstations. The cooling demands vary depending on the orientation of the closest façade, the density of electronic equipments etc., as well as the requirements of the users. That is the reason why the cooling distribution system must allow for a zoning of all closed spaces. In spaces without separating walls, the possibility to regulate the intensity of cooling should exist, focused on small working spaces.

Ventilation with cooled air and dehumidifier

The aim with mechanical ventilation is to keep the healthy conditions of the ambient air in a building that will be very air-tight, in order to avoid the non-controlled entry of humidity and heat. Also in order to ensure a hygienic comfort, in terms of CO2 and other contaminants generated by the activity within the building.

HVAC units will be installed to allow the input of fresh, external, filtered, conditioned and de-humidified air into the building.

The air will be distributed through ducts delivering it to all closed and conditioned rooms.

A similar network of ducts will be responsible for extracting the rejection air with slightly lower volume rates, in order to compensate the air losses and create a slight overpressure in the rooms to avoid the non-controlled infiltration of outside air.

Zone dampers - temperature, CO2 detectors or manually controlled

The spaces without any activity or with a varying activity throughout the day, the air flow should be regulated using manually activated dampers, or automatically with a motion or CO2 concentration sensor. Thus, the total air flow can be regulated and the energy used for this purpose saved.

Internal air dehumidifiers

Besides the conditioned air supply with humidity control, the activity itself generates humidity that must be controlled in order to keep the relative humidity of the ambient air below 60% and, in any case, below the dew point for the setpoint temperature, if radiant elements are used.

Electrical de-humidifiers will be used as needed in order to limit the increase of the relative humidity even when the number of occupants increases.

Extraction air heat recovery to cool the renovation fresh air

In order to keep healthy conditions of rooms with high occupancy densities and with relatively air-tight buildings it is important to renovate the air in the rooms several times per hour. The extraction of conditioned air is one of the big energy losses in an air-conditioned building. That is why the use of heat recovery units is suggested in order to cool the input, fresh (but warm) air.

The strategies to develop such heat recovery are the following two:

- Heat recovery: equipment composed of two fans, air filters and a plate heat exchanger for air, with counterflow, through which the internal, extracted air and the external, fresh air move. In the plate heat exchanger, the external warmer air, transfers heat with the extraction cooler air, thus cooling the fresh air taken into the building for air renovations.

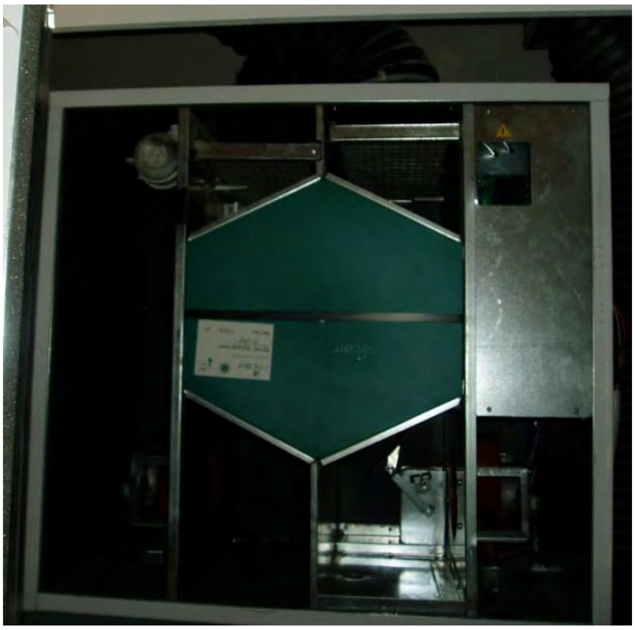


Figure 17- Heat recovery units (heat/cold) reduce the external, fresh and warm renovation air temperature for ventilation

- Heat pump: the cooling air-water equipment can use the extracted air flow as a heat sink. Since the extracted air is cooler than the fresh, external air, the efficiency of the heat pump will increase, delivering an energy saving equivalent to that of the heat recovery unit.

1.3 Renewable Energy Generation

Among the energy services that renewable energy sources can provide in the case of an office building project, the following can be highlighted:

Energy Service	Opportunities
Electricity	Photovoltaics, micro-wind[2]
Hot water	Solar Thermal
HVAC	Geothermal energy

Photovoltaics

The integration of a photovoltaic (PV) generator into an energy efficient building is probably the most effective way, in terms of investment, to generate renewable energy locally. The improvements that such installation can deliver are:

- Electricity production
- Shading the roof
- Allow ventilation of roof
- Harvesting clean rainwater

The following criteria were taken into account for the specific design of the EE Designs (EED):

- Sizing the installation depending upon available space and the electricity demand of the building
- Connection to the electricity distribution grid compatible with most common regulation
- Protection against extreme climatic conditions common in the region

Proposal of Photovoltaic system

The photovoltaic (PV) system is composed of the generator (PV modules and supporting structure), the electrical protections and the inverters.

The proposal is to install the photovoltaic system on the roof. Other arrangements are discarded, such as façades (vertical position for PV is very inefficient in Caribbean latitudes and installed on overhangs does not maximize the available space and has concerns regarding extreme climate events) or installations on the ground (not considered for this study, which is only focused on building-integrated solutions).

The roof is the surface with the highest and most regular incident solar radiation throughout the year. The challenge in this case is designing a PV installation meeting all of the above requirements.

Thus, the solution adopted for both small and medium models consists of a 2 m high support structure for the PV modules, to allow access of maintenance staff, over the flat roof. The PV system would be divided into two parts longitudinally with a 5º tilt to the center of the roof. A 2 m high perimeter wall above the flat roof is suggested in order to protect the whole installation from extreme winds.

[2] Micro-wind has not been considered due to the uncertainty created by extreme climatic events

Figure 18- The photovoltaic modules installed on roofs have a high electricity production in Caribbean latitudes (versus PV on facades), besides, they reduce the thermal load from the ambient to the building if adequately ventilated

Electrical layout

The inverters and the electrical protections of the DC and the AC three-phase circuits would be installed on the roof. The connection of the output line would be such that:

- The photovoltaic output will be connected downstream of the low voltage connection of the building.
- During the day hours with the sun shining, the generated electricity will be used within the buildings and, in case the electricity demand is lower than the generation, the surplus solar electricity will be exported and sold to the grid.
- The generated solar electricity will be measured using electricity meters and the exported surplus electricity will be read by the utility meter, which will have to be a reversible or an electronic multi-reading meter. Thus, the exported electricity value will be substracted from the bought electricity value.

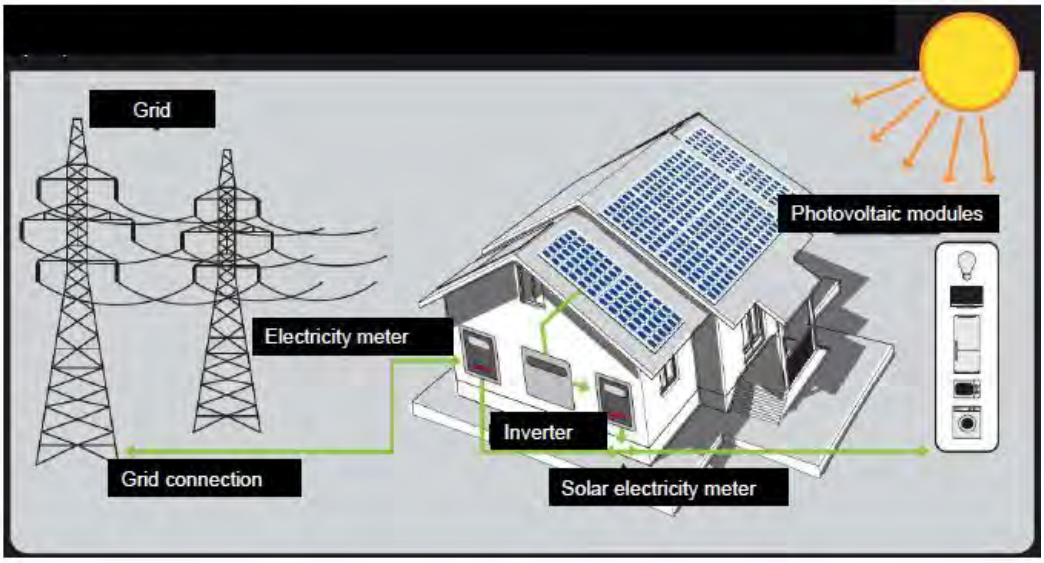


Figure 19-The simplest and most useful connection scheme for a photovoltaic system is in self-consumption mode with net-metering. The PV connects directly to the inner electricity grid of the building

Electricity production

A specific software (PVSyst) has been used to simulate the yearly PV electricity production. For the simulation, the weather data from Guadeloupe will be used.

The estimation of generated electricity is calculated following the equation:

$$Ep = \frac{G_{dm}(\alpha\beta) \cdot P_{mp} \cdot PR}{G_{CEM}}$$

Where:

- Ep: Electricity produced
- Gdm(α,ß): average daily radiation, for each month (kWh/m2-day)
- Pmp: Peak power of generator (W)
- PR: Performance Ratio
- GCEM: Standard conditions radiation 1 kW/m2

The Performance Ratio is an indicator of the efficiency of the installation and is calculated by the software considering:

- Losses in the received radiation due to dirt, shadows etc.
- Losses due to temperature
- Losses in wiring and connections
- Losses due to non-optimal tracking of maximum power point (MPP)
- Losses due to inverter efficiency

Solar Thermal

. It is generally true that office buildings (administrative, private office, etc.) do not have hot water demands. However, this may not be true for mixed use office buildings, such as those including dressing rooms for their staff or having medical services that require hot water, or cafeterias and kitchens with a restaurant for staff. In such cases there should be a centralized system to meet such hot water demand as efficiently as possible.

The two alternatives would be:

- Reuse of the HVAC system rejected heat (valid solution only if the cooling demand is regular all year round).
- Solar thermal collectors (This would be the most adequate technology for hot water production)

Other systems based on electricity and Joule effect or fossil fuels should be discarded

Figure 20- Service, commercial buildings (such as hotels, hospitals (right), sports centers (left) etc.) and residential buildings centralized solar thermal installations are the most effective solution to provide hot water all year round

Geothermal HVAC

The use of geothermal energy is based on low depth, low temperature energy. Ground source heat pumps are used to provide cooling, by using the underground or underground water as a heat sink, for the heat extracted from the building. This system is only valid when the heat sink temperature is relatively stable and is able to dissipate the heat input. This is the case with the ground temperature, more stable and lower than the air temperature during the hottest days.

In the case of zones with relatively hot and dry soil, the constant supply of heat to the ground might provoke a temperature increase of the ground and thus the improved performance compared to the air heat pumps would be cancelled.

Figure 21-The ground source heat pump, preferably with water (groundwater, seawater etc.) can be placed inside the building and there is no need for cooling towers or external air heat exchangers

Thus, the sites for geothermal energy use for cooling would have to be specifically assessed for their adequacy to meet the above requirements. However, the advantages are many:

- The efficiency of the system could be two times higher than those condensing with the air (COP approx. 5 is possible, for cooling)
- The heat pump is installed within the building and does not affect the aesthetics of the building and is safe from vandalism or extreme climate events.

- Heat pumps are silent (there are no fans)
- There is no need for a cooling tower
- There is no rejected hot air
- Does not contribute to heat island effect.

The improvement in efficiency remains practically independent from meteorological conditions since the temperature of the heat sink, that is, the underground, remains practically constant throughout the year.

C. Results - Energy Efficient Design

The following chapters describe the design process of the Energy Efficient design, including the evaluation of the impact on energy demand of several design strategies.

Study of the cost analysis of the following results is described later.

1. Parametric Study

This part of the study aims at assessing the impact that several architecture parameters have in the energy performance of office buildings, for this given climate. The energy performance of the buildings is given in terms of energy demand for lighting and energy demand for cooling. In the following tables and graphs, although otherwise stated, the energy demand is given as the sum of the demand for lighting and the demand for cooling (the last independent of the cooling generator performance). In the next chapter about the Energy Efficient design, the total electricity demand is calculated assuming a HVAC performance (COP) of 2,5.

Basically, this part assesses the specific weight of these different design aspects, in order to better judge which the best and most viable strategies are. The following parameters have been evaluated independently:

- Shape of the building
- Insulation and thermal mass
- Glazing type and amount of glazing
- Building Orientation
- Solar protection – window glazing elements
- Contact between building and ground
- Night natural ventilation
- Heat recovery device in ventilation system

After these parameters have been analyzed independently, a building model combining the design alternatives that provide for the best results is suggested.

1.1 Input data of the Parametric Study

The energy simulation of the above design criteria of the parametric study have been carried out with the same building use, occupancy and internal heat gain data as the baseline reference buildings, as explained in previous chapter. This is done in order to have a reference and comparison example and in order to be able to assess where, within the infinite scope of design options and energy performances, the baseline designs lay.

1.2 Building parameters

Geometry

The study is developed upon six prismatic models with different shapes, ranging from an extended, single floored building, up to a 16 storey tower. The geometric features of each of the six alternatives are shown on Table 6, including compactness indexes and form factor. In order to keep built surface and volumes constant throughout the different models, all are compositions based on different set ups of sixteen 12mx12m base and 3m high blocks, as shown in the figure.

	Useful surface m^2	External surface m^2	Built volume m^3	Shape factor	Compactness
Extended 1floor	2.304,0	5.184,0	6.912,0	**0,75**	**1,33**
Extended 2floor	2.304,0	3.168,0	6.912,0	**0,46**	**2,18**
Long Bar	2.304,0	2.592,0	6.912,0	**0,38**	**2,67**
Tower	2.304,0	2.592,0	6.912,0	**0,38**	**2,67**
Short Bar	2.304,0	2.304,0	6.912,0	**0,33**	**3,00**
Compact	2.304,0	2.304,0	6.912,0	**0,33**	**3,00**
Shape factor = S_{ext} / Vol; Compactness = Vol / S_{ext} External surfaces include walls, roof and floors					

Table 6- Geometry of the different building shapes considered

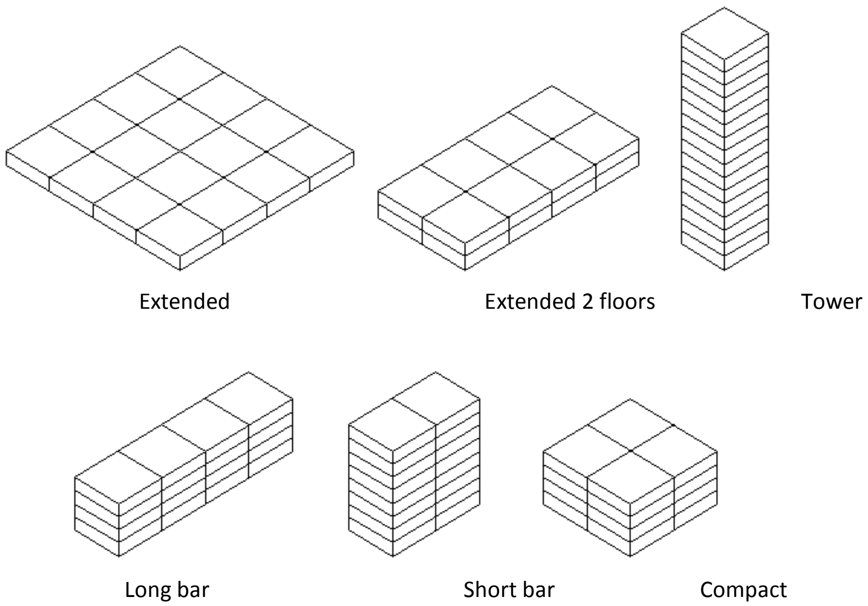


Figure 22- Modular composition of the 6 different shapes studied; Extended 1 floor, Extended 2 floors, Tower, Long Bar, Short Bar, Compact (top to bottom, left to right)

In all models, the floor is divided into 5 thermal zones: four along the perimeter (one for each orientation) and a central zone. The separation is made using partition walls that allow for air exchange between zones. The walls that separate the central zones from the others are set at 4 m from the external walls. This was a decision made in order to assess with higher accuracy the day lighting potential –so only perimeter zones are simulated with regards to the day lighting availability.

All these different shapes were used for the simulation concerning the building shape. For the simulations concerning the rest of the parameters studied, the “short bar” shape was used.

Figure 23- Inner distribution of different shapes, with the perimeter and central zones; Extended 1 floor, Extended 2 floors, Long Bar, Tower, Short Bar, Compact (top to bottom, left to right)

Opaque enclosures

In order to estimate the impact on the energy performance that different insulation and thermal mass levels have, 9 different opaque enclosures were built. The general features are shown in the following figure.

		Encl01	Encl02	Encl03	Encl04	Encl05	Encl06	Encl07	Encl08	Encl09
		A010-M025	A025-M025	A050-M025	A075-M025	A100-M025	A025-M050	A025-M075	A025-M100	A025-M125
Walls	ID	M01	M02	M03	M04	M05	M06	M07	M08	M09
	U Value	2,059	1,162	0,673	0,474	0,366	1,141	1,121	1,102	1,083
	Heat C.	49,50	55,11	55,37	56,58	56,58	93,50	121,00	148,50	220,00
Roof	ID	C01	C02	C03	C04	C05	C06	C07	C08	C09
	U Value	2,195	1,204	0,687	0,481	0,370	1,182	1,160	1,140	1,120
	Heat C.	49,50	55,11	55,37	56,58	56,58	93,50	121,00	148,50	220,00
External floor	ID	SE01	SE02	SE03	SE04	SE05	SE06	SE07	SE08	SE09
	U Value	1,708	1,041	0,631	0,452	0,353	1,024	1,008	0,993	0,977
	Heat C.	49,5	55,1	55,4	56,6	56,6	93,5	121,0	148,5	220,0

Table 7- Transmittance U (W/m2-K) and Heat capacity (kJ/m2-K) of enclosures analyzed

All enclosures of these 9 construction types were built up using three material layers:

1. External: Cladding material

2. Intermediate: Insulation material (properties similar to expanded polystyrene)

3. Internal: Material with thermal mass (properties similar to conventional concrete)

The different levels of insulation and thermal mass were determined allocating different widths to these three layers. Thus, for instance, A010-M025 stands for a 1 cm wide insulation layer and a 2.5 cm wide thermal mass layer. A025-M075 stands for 2.5 cm and 7.5 cm for the insulation and thermal mass layers, respectively.

All these 9 options were simulated only within the "insulation and thermal mass" chapter of the Parametric Study. All other simulations used generally 2.5 cm wide layers both for insulation and thermal mass (represented as A025-M025).

Glazing

As a part of the Parametric Study, for the topic concerning the Type of glazing and amount of glazing, six glazing types were studied (in the other analyses double, clear glazing was considered):

1. Single pane glazing, clear.
2. Double glazing, clear.
3. Double glazing with low emissive layer (LoE).

4. Double glazing with absorptive external pane.
5. Double glazing with reflective coating.
6. Double glazing with spectrally selective layer.

The aim of this part of the study was to assess these options and determine the extent to which they can affect the energy consumption in the building.

Internal gains

The internal gains (occupancy, electricity using equipment and lighting) data has been simplified in this parametric study, using the same parameters for all zones. The following tables show the values used when a different data than the baseline design simulation has been used.

The electricity demand for artificial lighting depends on the amount of daylight available, in the perimeter zones of the floors (not in central zones), as there is a daylighting control sensor that dims the artificial light as necessary to keep the illuminance values in the levels required for office activity.

Zone	Density (pers/m^2)	Met.rate. (W/pers)	Met. Factor	Gain (W/m^2)	Schedule
Generic area	0,110	120	0,90	11,9	Occupancy

Table 8- Input data - Occupancy - Parametric Study

Zone	Gain (W/m^2)	Concept
Generic area	**12,0**	Office equipment

Table 9- Input data - Equipment gains - Parametric Study

Zone	Min. Ilumin. (lux)	Ilum. Energ. (W/m^2-100lux)	Gain (W/m^2)
Generic zone	500	4,00	20,00

Table 10- Input data - Lighting

Occupancy and lighting schedule (time – % value) - January 01 to December 31					
Weekdays		**Saturday**		**Sunday and holidays**	
00:00 - 08:00 =	0,00	00:00 - 08:00 =	0,00	00:00 - 24:00 =	0,00
08:00 - 09:00 =	0,25	08:00 - 09:00 =	0,25		
09:00 - 14:00 =	1,00	09:00 - 13:00 =	1,00		
14:00 - 16:00 =	0,25	13:00 - 24:00 =	0,00		
16:00 - 19:00 =	1,00				
19:00 - 20:00 =	0,25				
20:00 - 24:00 =	0,00				
Equipment schedule (time - % value) - January 01 to December 31					
Weekdays		**Saturday**		**Sunday and holidays**	
00:00 - 08:00 =	0,05	00:00 - 08:00 =	0,05	00:00 - 24:00 =	0,05
08:00 - 09:00 =	0,25	08:00 - 09:00 =	0,25		
09:00 - 14:00 =	1,00	09:00 - 13:00 =	1,00		
14:00 - 16:00 =	0,25	13:00 - 24:00 =	0,05		
16:00 - 19:00 =	1,00				
19:00 - 20:00 =	0,25				

20:00 - 24:00 =	0,05

Table 11- Schedules for Occupancy and Lighting and Equipment

1.3 Results and analysis

Shape of building

As explained in the paragraphs about the geometry, all 6 different building shapes studied were composed of 16 12mx12mx3m blocks, so that the total floor surface and inner volume are kept constant but the external surface and the level of compactness vary as shown in the following table. This table also shows the total glazed surface, which is considered to be a 30% of the external wall surface. The Global glazing ratio is the ratio between the glazed surface and the total external surface (not only walls). The results suggest that this last parameter does play an important role in defining the energy performance of the buildings.

	Usfeul surface m^2	**External surface** m^2	**Built volume** m^3	**Form factor**	**Compactness**	**Glazed surface** m^2	**% Global glazing ratio** %
Extended 1floor	2.304,0	5.184,0	6.912,0	**0,75**	**1,33**	230,4	4,4%
Extended 2floor	2.304,0	3.168,0	6.912,0	**0,46**	**2,18**	345,6	10,9%
Long Bar	2.304,0	2.592,0	6.912,0	**0,38**	**2,67**	576,0	22,2%
Tower	2.304,0	2.592,0	6.912,0	**0,38**	**2,67**	921,6	35,6%
Short Bar	2.304,0	2.304,0	6.912,0	**0,33**	**3,00**	691,2	30,0%
Compact	2.304,0	2.304,0	6.912,0	**0,33**	**3,00**	460,8	20,0%

Form factor = S_{ext} / Vol; Compactness = Vol / S_{ext}
External surfaces include walls, roof and floors
A 30% of the external walls is glazed, continuously

Table 12- Form factors and compactness

For simulations, enclosure A025-M050 (from Table 7) (2.5 cm insulation and 5.0 cm thermal mass material). The orientation was South for the main facades (or one of the facades, when square shape).

Layer	Material	Width (m)	Thermal Conductivity (W/m-K)	Specif. heat (J/Kg-K)	Density (Kg/m3)
1 (Ext)	External Material	0,0100	0,200	1500,00	1200
2	Insulation	0,0250	0,040	1400,00	15
3 (Int)	Thermal mass	0,0500	1,600	1000,00	2200
1,141	W/m2-K thermal transmission coefficient (U)				

Table 13- Thermal properties of the A025-M050 enclosure

The following tables and graphs show the results obtained, for both compactness and global glazing ratio. Energy consumption is more directly related to the % Global glazing ratio (the more % Global glazing[3], the higher demand) than the Compactness (which renders more irregular results).

[3] Global glazing refers to the whole building envelope, including roof and basement

Shape	Compactness	Lighting kWh/m2	Cooling kWh/m2	Total kWh/m2	Improvement
Ext. 1P 1.33	1,33	41,6	342,1	383,7	16,6%
Ext. 2P 2.18	2,18	36,1	341,5	377,6	17,9%
Long B. 2.67	2,67	24,9	363,9	388,8	15,5%
Tower 2.67	2,67	19,6	440,2	459,9	Ref.
Short B. 3.00	3,00	23,2	386,6	409,8	10,9%
Comp. 3.00	3,00	31,8	358,0	389,8	15,2%

Table 14- Comparison of 6 building shapes' energy performance, sorted, Compactness

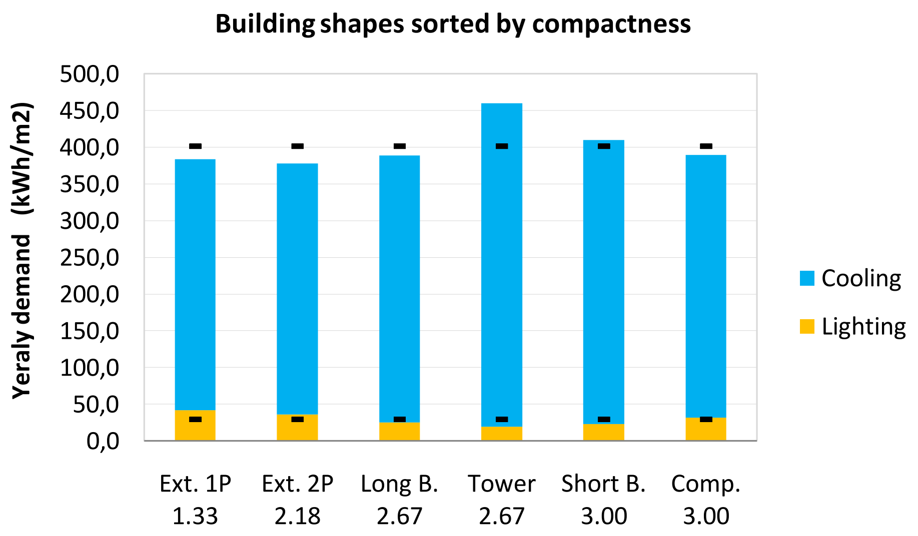


Figure 24- Yearly energy demand - Building shapes sorted by compactness

Shape	% Gl. Glazed	Lighting	Cooling	Total	Improvement
Ext. 1P 4.4%	4	41,6	342,1	383,7	16,6%
Ext. 2P 10.9%	10,9	36,1	341,5	377,6	17,9%
Comp. 20.0%	20	31,8	358,0	389,8	15,2%
Long B. 22.2%	22	24,9	363,9	388,8	15,5%
Short B. 30.0%	30	23,2	386,6	409,8	10,9%
Tower 35.6%	35,6	19,6	440,2	459,9	Ref.

Table 15- Comparison of 6 building shapes' energy performance, sorted by % Global glazing ratio

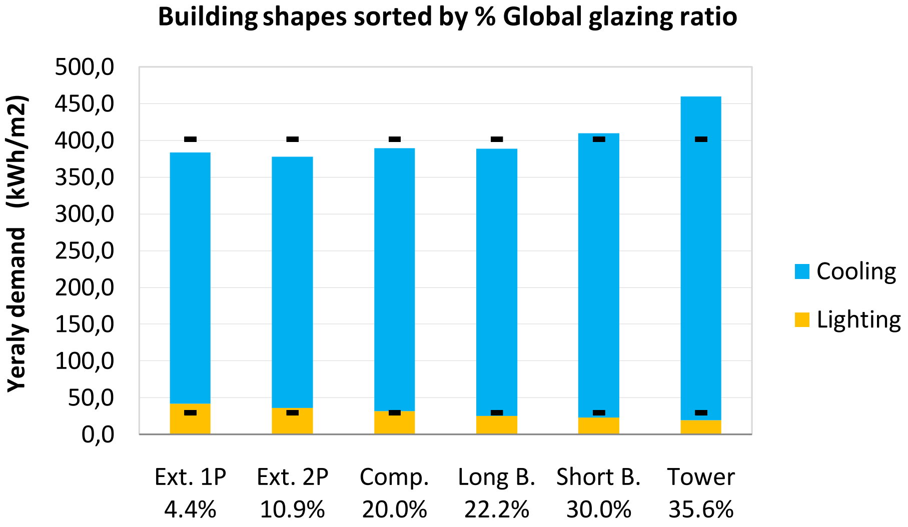


Figure 25- Yearly energy demand - Building shapes sorted by % Global glazing ratio

Insulation and thermal mass

Different combinations of insulation and thermal mass material are simulated here (their thermal properties can be found in Annex III). The insulating material is similar to expanded polystyrene (always placed on the external side of the structural wall) and a material with a thermal mass similar to concrete (always placed in the inner side of the insulation). The overall transmittance values are the result of combining different widths of each material (varying at 2.5 cm intervals).

The shape of the building was kept constant as a Short Bar shape, with the largest facade South-oriented and 40% of the surface glazed with double, clear glazing, uniformly distributed on all facades.

The following tables and graphs show the results obtained. Given the climate considered, the parameter referred to insulation and thermal mass does not prove to be determinant in the energy performance.

Enclosure	Lighting	Cooling	Total	Improvement
A001 M025	23,2	390,8	414,0	Ref.
A025 M025	23,2	384,0	407,2	1,6%
A050 M025	23,2	380,8	404,0	2,4%
A075 M025	23,2	379,6	402,8	2,7%
A100 M025	23,2	379,0	402,2	2,8%

Table 16- 5 different levels of insulation, layers ranging from 1 cm to 10.0 cm

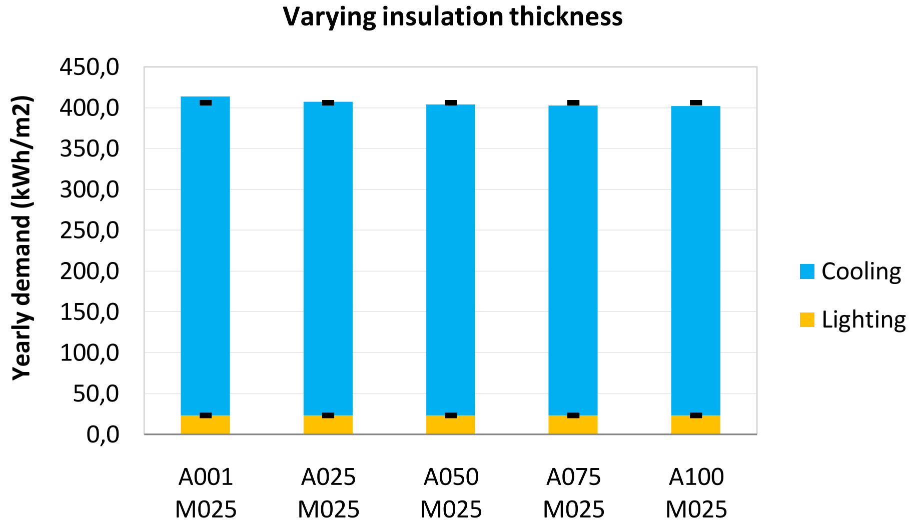


Figure 26- Yearly energy demand for 5 different levels of insulation, layers ranging from 1.0 cm to 10.0 cm

Enclosure	Lighting	Cooling	Total	Improvement
A025 M025	23,2	384,0	407,2	Ref.
A025 M050	23,2	386,6	409,8	-0,6%
A025 M075	23,2	387,4	410,6	-0,8%
A025 M100	23,2	388,0	411,2	-1,0%
A025 M125	23,2	388,4	411,6	-1,1%

Table 17- 5 different levels of thermal mass, layers ranging from 2.5 cm to 12.5 cm

Figure 27 shows the total electricity demand and the improvement from one to another, that is, e.g: going from A001-M025 to A025-M025 improves total electricity demand 1,5% (HVAC COP 2,5). Thus, the improvement decreases as the width of the insulation layer is increased.

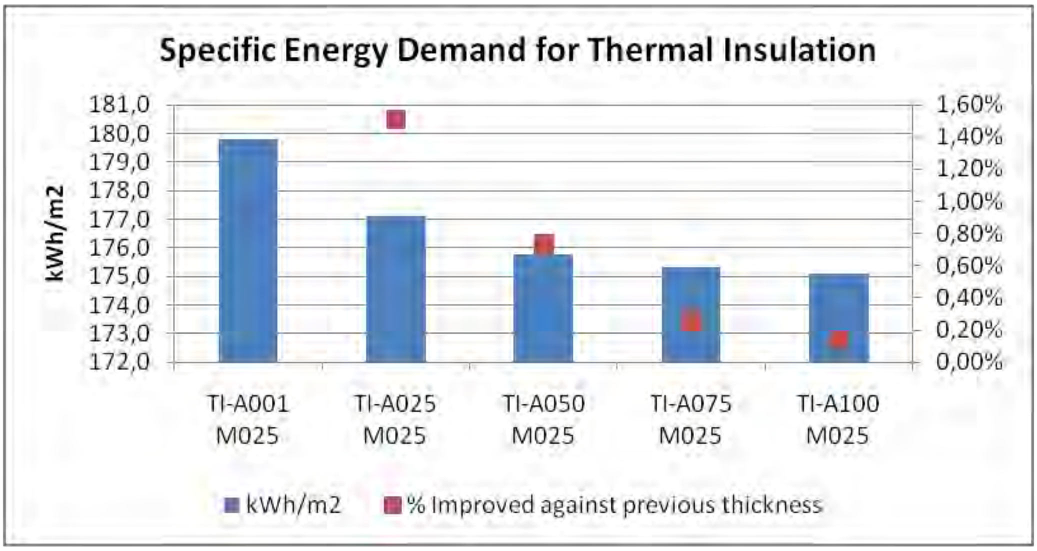


Figure 27- Specific Energy Demand for Thermal Insulation;

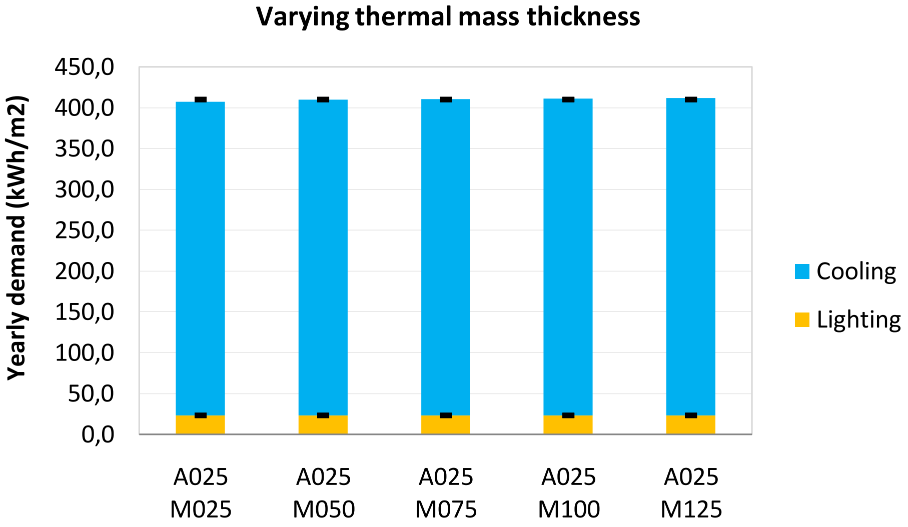


Figure 28- Yearly energy demand for 5 different levels of thermal mass, layers ranging from 2.5 cm to 12.5 cm

Glazing type and amount of glazing

This part of the analysis studies two factors: the proportion of glazing on the walls and the impact of different common types of glazing. For the first case, the Short Bar shape was used, with the largest façade south oriented, varying the proportion of glazing with increments of 20%.

For the second case, the Short Bar shape was used, keeping a constant glazing proportion at 40% of the wall but different types of glazing: Single pane clear glazing; Double clear glazing; Double glazing with low emissive layer (LoE); Double glazing with absorptive external pane; Double glazing with reflective coating and Double glazing with spectrally selective layer. Detailed thermal characteristics of these glazing types can be found in Annex III.

The results obtained are shown in the following tables and graphs. They suggest that the proportion of glazing is a determining factor for the energy performance of the building in this climate, especially due to the impact of solar radiation.

Regarding the impact of different types of glazing, the spectrally selective and the reflectant glazing can decrease energy demand for cooling. However, the degree of impact is lower than the proportion of glazing; thus, this latter should be prioritized when designing efficient buildings.

Glazing to wall wall ratio	Lighting	Cooling	Total	Improvement
80%	22,8	504,7	527,6	Ref.
60%	23,0	446,6	469,7	11,0%
40%	23,2	384,0	407,2	22,8%
20%	23,9	309,6	333,5	36,8%

Table 18- Comparison among 4 different glazing ratios (glazing to wall), from 20% to 80%

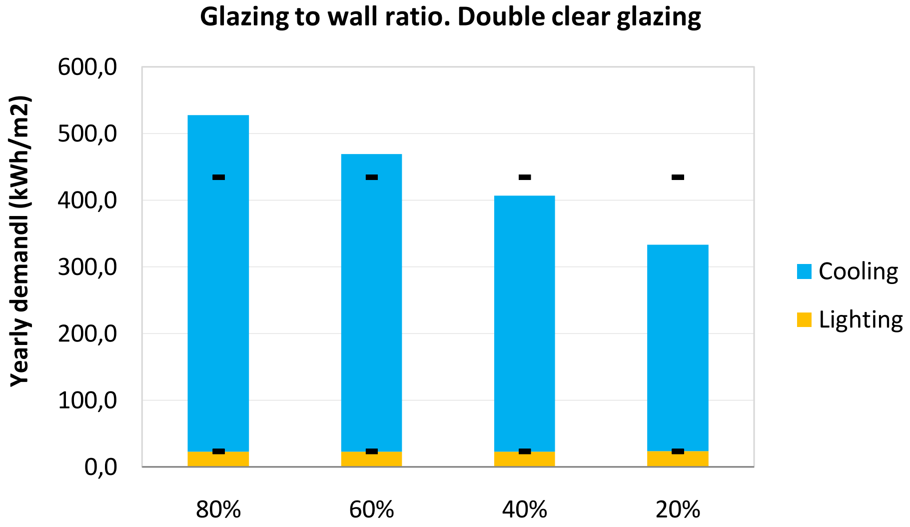


Figure 29- Yearly energy demand of different Glazing to wall ratio values

Glazing type	Lighting	Cooling	Total	Improvement
Clear Single	23,1	402,3	425,4	Ref.
Clear Double	23,2	384,0	407,2	4,3%
Low Emissivity	23,3	362,7	385,9	5,2%
Absorptive	23,8	350,5	374,3	8,1%
Reflection	24,5	338,2	362,7	10,9%
Spec. Selective	23,3	337,1	360,4	11,5%

Table 19- Comparison of different glazing types

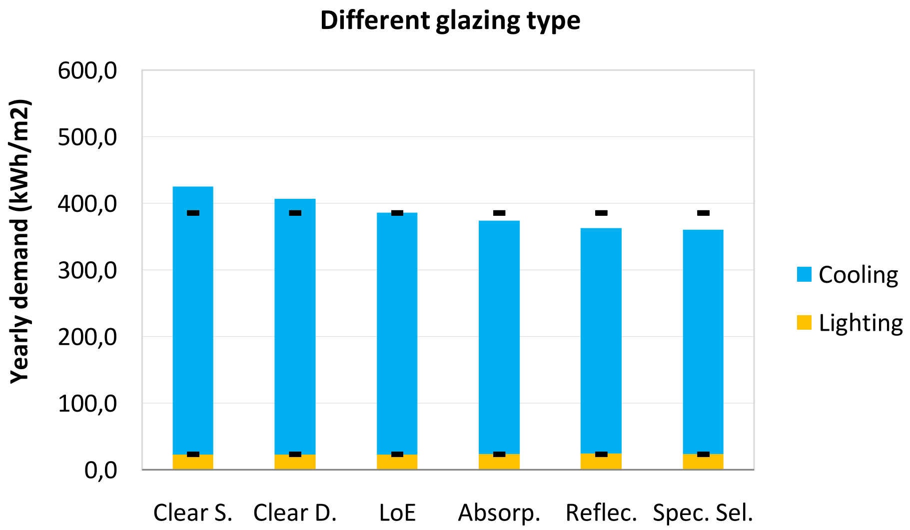


Figure 30- Yearly energy consumption of different glazing types

Building orientation

The Short Bar shape was used for this simulation, with 8 different orientations (results show only 4, due to symmetry the building and thus, of the results).

Another factor considered as variable was the distribution of glazing on large and small facades but keeping a constant global glazing ratio.

- 40% on large and small facades
- 50% on large facades and 20% on small facades
- 60% on large facades and 0% on small facades

According to these results, apparently orientation does not play an important role as it might have been expected (although it does become an important factor as glazing on Eastern and Western walls is increased). However, orientation, together with glazing distribution is a key factor of design to attain an effective solar protection of windows: choosing incorrect orientations would require more complex and more expensive solar protection or glazing. The following images illustrate the orientation alternatives for the Short Bar building.

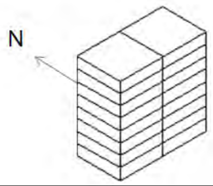
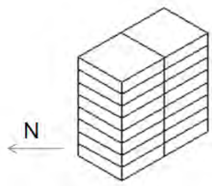
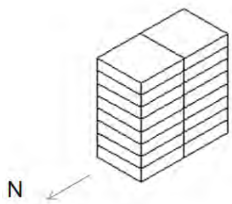
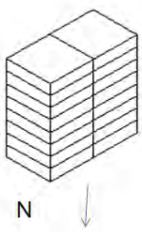
Orientation of the large façades	Figure (arrow point to North)
South - North	
Southwest - Northeast	
West - East	
Northwest – Southeast	

Table 20- Orientations of the Short Bar building to assess impact of orientation on energy demand

Orientation	Lighting	Cooling	Total	Improvement
S-N	23,2	384,0	407,2	Ref.
SW-NE	23,2	395,5	418,7	-2,8%
W-E	23,3	402,1	425,4	-4,5%
NW-SE	23,3	396,4	419,6	-3,0%

Table 21- Orientation of the largest facades of a Long Bar shaped building, 40% glazing on large and small facades

Orientation	Lighting	Cooling	Total	Improvement
S-N	23,3	377,1	400,4	Ref.
SW-NE	23,3	394,2	417,5	-4,3%
W-E	23,4	407,7	431,1	-7,6%
NW-SE	23,4	395,6	419,0	-4,6%

Table 22- 50% glazing on large facades, 20% glazing on small facades

Orientation	Lighting	Cooling	Total	Improvement
S-N	27,0	381,2	408,2	Ref.
SW-NE	26,1	403,9	430,0	-7,4%
W-E	25,6	424,1	449,7	-12,3%
NW-SE	26,1	405,7	431,8	-7,8%

Table 23- 60% glazing on large facades 0% glazing on small facades

Figure 31- Yearly energy demand - uniform glazing distribution 40%

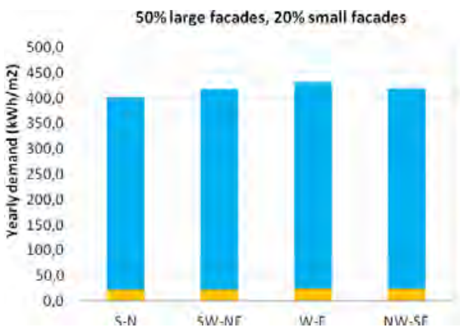


Figure 32- Yearly demand for 50% glazing on large facades and 20% glazing on small facades

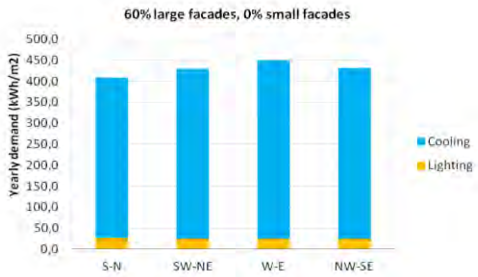


Figure 33- Yearly energy demand for 60% glazing on large facades, 0% on small facades

Solar protection – window glazing elements

Again, the Short Bar shape was used, with a single orientation (South) and a 40% of the walls glazed, uniformly distributed. Three conclusions are drawn from such orientation-glazing composition:

South-oriented glazing: incident solar radiation is high during the first and the last months of the year. It is relatively easy to adequately protect glazing with eaves/overhangs, although another very efficient option would be lateral protections at short distance. Another good alternative would be using external louvers.

North-oriented glazing: incident solar radiation is moderate during the central months of the year but is easier to protect than the south-oriented glazing. Generally, intermediate size eaves are enough, although an increased protection would require for lateral protection (also with intermediate size) louvers or jalousies would, in general, not be necessary.

East and West oriented glazing: incident solar radiation is high all year long, in the morning hours for East and afternoon for West. When sun angles are low it is difficult to protect with eaves and lateral protections so louvers or jalousies, screens or mobile sunscreens are required.

The simulation uses two levels of solar protection (approx. 60% and approx. 95%), using the respective devices.

a) Solar protection - average shading coefficient[4] close to 60%

East and West: windows were protected with a 10 cm wide external louvers, separated 20 cm and 45º angle, as shown in the image.

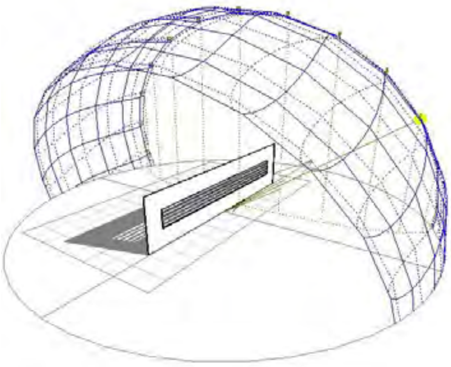


Figure 34- External louvers on East and West facades, protection approx. 60%

Month	Avg.SC	Max.SC	Min.SC
January	72.4%	100.0%	40.0%
February	70.1%	100.0%	36.0%
March	73.5%	100.0%	39.0%
April	70.7%	100.0%	36.0%
May	72.2%	100.0%	40.0%
June	73.2%	100.0%	40.0%
July	72.4%	100.0%	36.0%
August	71.2%	100.0%	36.0%
September	70.2%	100.0%	36.0%
October	70.0%	100.0%	36.0%
November	70.2%	100.0%	36.0%
December	71.1%	100.0%	36.0%
Winter	71.2%	100.0%	37.3%
Summer	72.6%	100.0%	38.7%
Annual	71.4%	100.0%	37.2%

Table 24- Shading coefficients - External louvers on East and West facades, approx. 60% protection

[4] Shading coefficient: fraction of solar heat gain that **does not pass** through a transparent solar aperture compared to the amount of solar radiation incident upon it

North: a 25 cm eave, no lateral protection, as shown in the image:

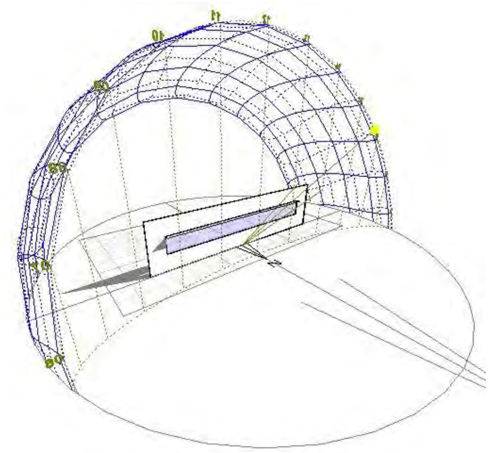


Figure 35- Eave protection on North facade, approx. 60% protection

Month	Avg.SC	Max.SC	Min.SC
January	[Behind]	–	–
February	[Behind]	–	–
March	38.0%	57.0%	19.0%
April	69.6%	100.0%	2.0%
May	72.3%	100.0%	1.0%
June	65.5%	100.0%	1.0%
July	73.5%	100.0%	2.0%
August	61.8%	98.0%	2.0%
September	[Behind]	–	–
October	[Behind]	–	–
November	[Behind]	–	–
December	[Behind]	–	–
Winter	0.0%	0.0%	100.0%
Summer	70.4%	100.0%	1.3%
Annual	31.7%	46.2%	52.2%

Table 25- Shading coefficient - Eave protection on North facade, approx. 60% protection

South: a 60 cm wide eave, no lateral protection, as shown in the image:

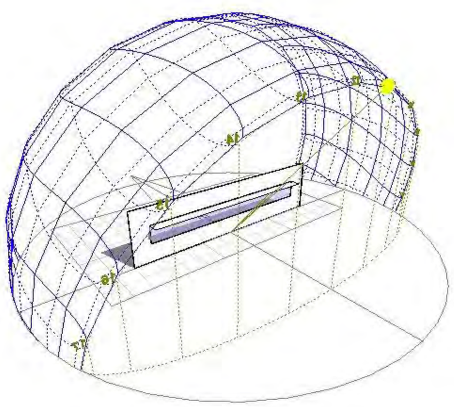


Figure 36- Eave protection on South facade, approx. 60% protection

Month	Avg.SC	Max.SC	Min.SC
January	63.2%	88.0%	5.0%
February	79.6%	100.0%	12.0%
March	94.7%	100.0%	63.0%
April	99.1%	100.0%	97.0%
May	[Behind]	–	–
June	[Behind]	–	–
July	[Behind]	–	–
August	99.7%	100.0%	97.0%
September	88.5%	100.0%	22.0%
October	77.1%	100.0%	12.0%
November	56.5%	80.0%	5.0%
December	48.9%	79.0%	5.0%
Winter	63.9%	89.0%	7.3%
Summer	0.0%	0.0%	100.0%
Annual	58.9%	70.6%	51.5%

Table 26- Shading coefficient - Eave protection on South facade, approx. 60% protection

b) Solar protection – average shading coefficient close to 95%

East and West: windows were protected with a 10 cm wide external louvers, separated 10 cm and 45º angle, as shown in the image.

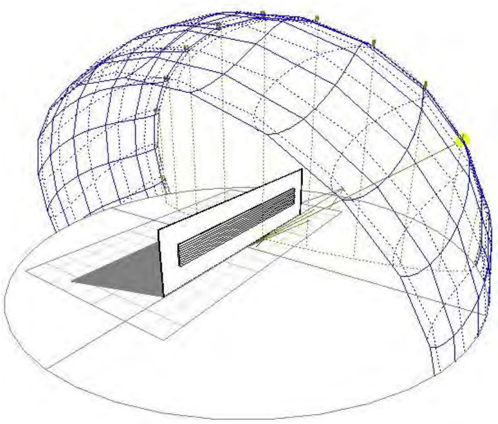


Figure 37- External louvers on East and West facades, protection approx. 95%

Month	Avg.SC	Max.SC	Min.SC
January	96.8%	100.0%	81.0%
February	95.7%	100.0%	73.0%
March	97.1%	100.0%	80.0%
April	96.1%	100.0%	73.0%
May	97.4%	100.0%	81.0%
June	96.6%	100.0%	81.0%
July	96.5%	100.0%	73.0%
August	95.3%	100.0%	73.0%
September	95.5%	100.0%	73.0%
October	94.9%	100.0%	73.0%
November	96.3%	100.0%	73.0%
December	95.2%	100.0%	73.0%
Winter	95.9%	100.0%	75.7%
Summer	96.9%	100.0%	78.3%
Annual	96.1%	100.0%	75.6%

Table 27- Shading coefficient - External louvers on East and West facades, protection approx. 95%

North: a 25 cm eave, a 25 cm lateral protection at every 1.20 m, as shown in the image:

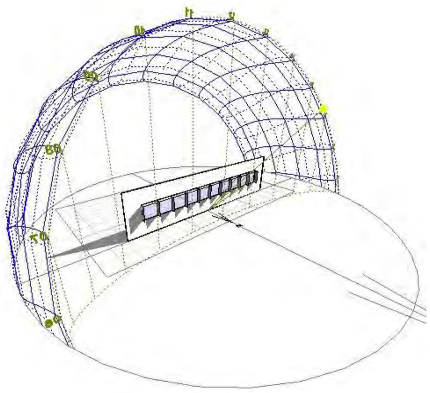


Figure 38- Eave and lateral protection on North facade, approx. 95% protection

Month	Avg.SC	Max.SC	Min.SC
January	[Behind]	--	--
February	[Behind]	--	--
March	100.0%	100.0%	100.0%
April	100.0%	100.0%	100.0%
May	92.0%	100.0%	45.0%
June	87.6%	100.0%	45.0%
July	95.1%	100.0%	73.0%
August	100.0%	100.0%	100.0%
September	[Behind]	--	--
October	[Behind]	--	--
November	[Behind]	--	--
December	[Behind]	--	--
Winter	0.0%	0.0%	100.0%
Summer	91.6%	100.0%	54.3%
Annual	47.9%	50.0%	88.6%

Table 28- Shading coefficient - Eave and lateral protection on North facade, approx. 95% protection

South: a 60 cm wide eave, a 60 cm lateral protection at every 1.20 m, as shown in the image:

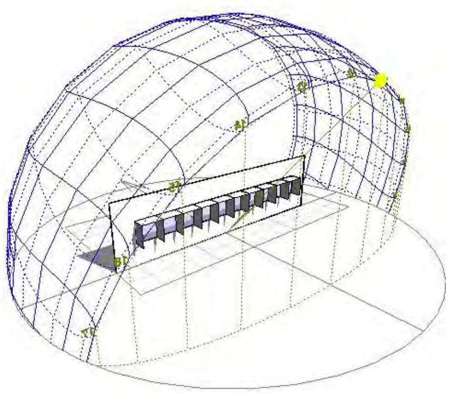


Figure 39 - Eave and lateral protection on South facade, approx. 95% protection

Month	Avg.SC	Max.SC	Min.SC
January	93.8%	100.0%	80.0%
February	100.0%	100.0%	100.0%
March	100.0%	100.0%	100.0%
April	99.1%	100.0%	97.0%
May	[Behind]	--	--
June	[Behind]	--	--
July	[Behind]	--	--
August	100.0%	100.0%	100.0%
September	100.0%	100.0%	100.0%
October	100.0%	100.0%	100.0%
November	90.5%	100.0%	79.0%
December	86.8%	100.0%	72.0%
Winter	93.5%	100.0%	84.0%
Summer	0.0%	0.0%	100.0%
Annual	72.5%	75.0%	94.0%

Table 29- Shading coefficient - Eave and lateral protection on South facade, approx. 95% protection

The table summarizes the solar protection devices:

	Average shading coefficient								
	60%				95%				
Orientation	Device	Width	Separation	Angle	Device	Width	Separation	Angle	
East and West	Louver	10 cm	20 cm	45º	Louver	10 cm	10 cm	45º	
Orientation	Device	Width	Lateral device	Lateral size	Device	Width	Lateral device	Lateral size	Lateral device separation
North	Eave	25 cm	No	-	Eave	25 cm	Yes	20 cm	1.20 m
South	Eave	60 cm	No	-	Eave	60 cm	Yes	60 cm	1.20 m

Three scenarios were considered for the simulations: no solar protection devices, 60% shading coefficient devices and 95% shading coefficient devices.

The results are shown in the following table and graph. They suggest that solar protection devices can decrease the energy consumption of a building, especially when designed to achieve high shading coefficients.

Shading coefficient	Lighting	Cooling	Total	Improvement
CS = 0%	23,2	384,0	407,2	Ref.
CS = 60%	24,0	333,1	357,1	12,3%
CS = 95%	25,0	304,4	329,4	19,1%

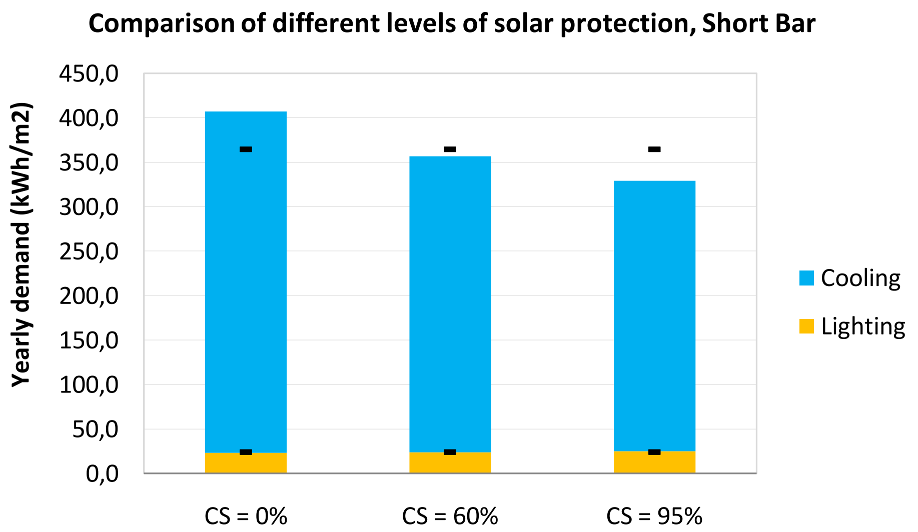
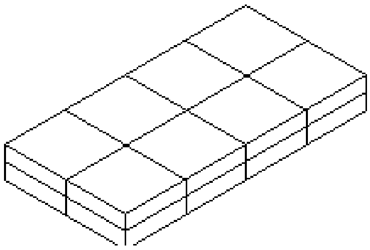


Figure 40- Yearly energy demand - different levels of solar protection, for a Short Bar shaped building

Roof

Different roof compositions/solutions were studied, using the Extended 2 floor model (since it has considerable roof surface), oriented South and a 40% double clear glazing uniformly distributed. The roof composition varies and the rest of the enclosures use A025-M050. 6 alternatives were simulated:



1. Roof, no insulation: All the enclosures except for the roof are modeled according to A025-M0505 (2.5 cm insulation, 5.0 cm thermal mass). The roof only has the thermal mass layer.
2. Roof with insulation: All enclosures are A025-M025 (2.5 cm insulation, 2.5 cm thermal mass).
3. Roof, no insulation, shaded. Enclosures as in “1”, but a shading surface is considered, 100% opaque, 2m far from the roof and overhangs extending 2m beyond façade perimeter.
4. Roof, no insulation, ventilated attic. Enclosures as in “1”, but a ventilated attic on top of the roof. The roof of such attic is metallic, with a rate of renovation of 10 ach.
5. Roof with insulation, shaded. As in “3”, but with an insulated roof.
6. Roof with insulation, ventilated attic. As in “4” but the roof is insulated.

Results show that when the roof surface holds a significant share of the building envelope (in this case 36,4%), adequate values of insulation may offer slight energy savings. However, as the following table and graph show the shaded and ventilated options render better results. The simulation has given the best solution with the shaded, non-insulated roof. This is because heat dissipation occurs through the roof; in such solution, it is important to minimize the potential radiative heat exchange between the shading element and the roof.

	Lighting	Cooling	Total	Improvement
No insulation	36,1	378,5	414,6	Ref.
A025 M025 in roof	36,1	341,5	377,6	8,9%
No ins. + shade	36,1	304,5	340,6	17,8%
No ins. + ventilated	36,0	321,5	357,5	13,8%
Ins. + shade	36,1	311,5	347,6	16,2%
Ins. + ventilated	36,0	317,8	353,8	14,7%

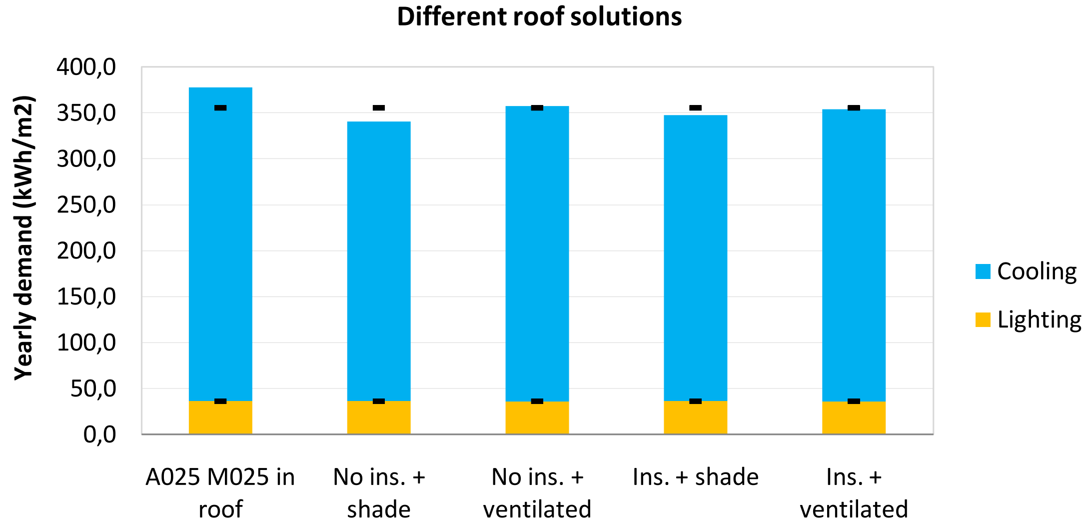


Figure 41- Yearly energy demand - different roof solutions, for an Extended, 2 floor building

Contact between building and ground

5 alternatives were simulated for the contact between the building (occupied zones) and the ground:

- No contact with ground (pilotis).
- Contact with ground, no insulation on ground floor.
- Contact with ground, 2.5 cm insulation on ground floor.
- Contact, with underground floor, no insulation on floor.
- Contact, with underground floor, 2.5 cm insulation on floor.

The results show that the ground contact without insulation renders the best results in terms of reduced energy demand for cooling. The conclusion that can be drawn is that ground contact is not a significant design parameter in this climate.

Option	Lighting	Cooling	Total	Improvement
No contact	31,8	357,5	389,3	Ref.
Cont. + No insl.	31,8	332,5	364,2	6,4%
Cont. + Insl.	31,8	352,0	383,8	1,4%
Ugr. + No insl.	31,8	348,1	379,8	2,4%
Ugr. + Insl.	31,8	356,5	388,3	0,3%

Table 30- Comparison between different building-ground contact options

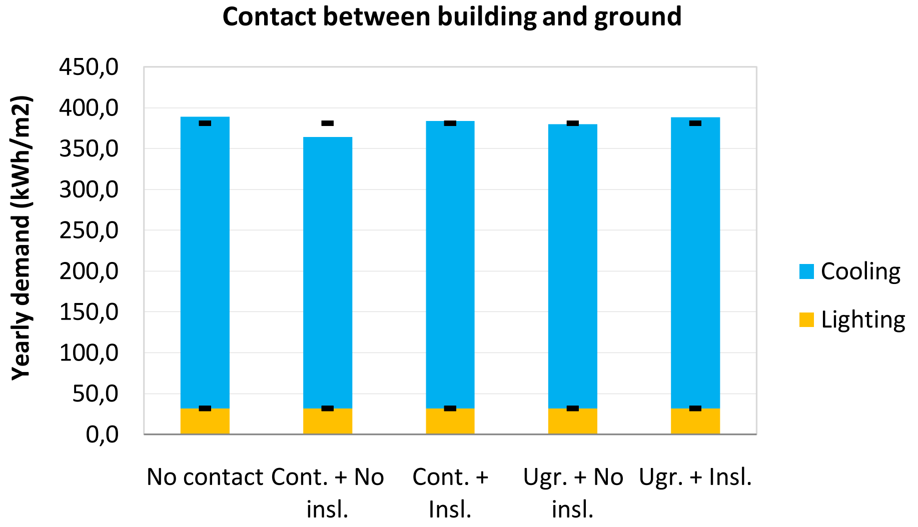


Figure 42- Yearly energy demand - different contact options building - underground

Night natural ventilation

The impact of using night natural ventilation was evaluated in order to reduce the day cooling demand. Four scenarios were simulated

- 3 air changes per hour, low thermal mass (2.5 cm wide)
- 9 air changes per hour, low thermal mass (2.5 cm)
- 3 air changes per hour, higher thermal mass (7.5 cm)
- 9 air changes per hour, higher thermal mass (7.5 cm)

Short Bar shape was again used here, with a uniformely distributed 40% glazing. The results how that the impact is energy demand reduction is low although the improvement is more remarkable than the use of higher thermal mass. Besides, designs of openings and humidity input due to external air should be additionally considered.

Option	Lighting	Cooling	Total	Improvement
No vent	23,2	384,0	407,2	Ref.
3 ach M025	23,2	368,9	392,1	3,7%
9 ach M025	23,2	360,5	383,7	5,8%
3 ach M075	23,2	369,4	392,6	3,6%
9 ach M075	23,2	357,6	380,8	6,5%

Table 31- 5 different options for night natural ventilation

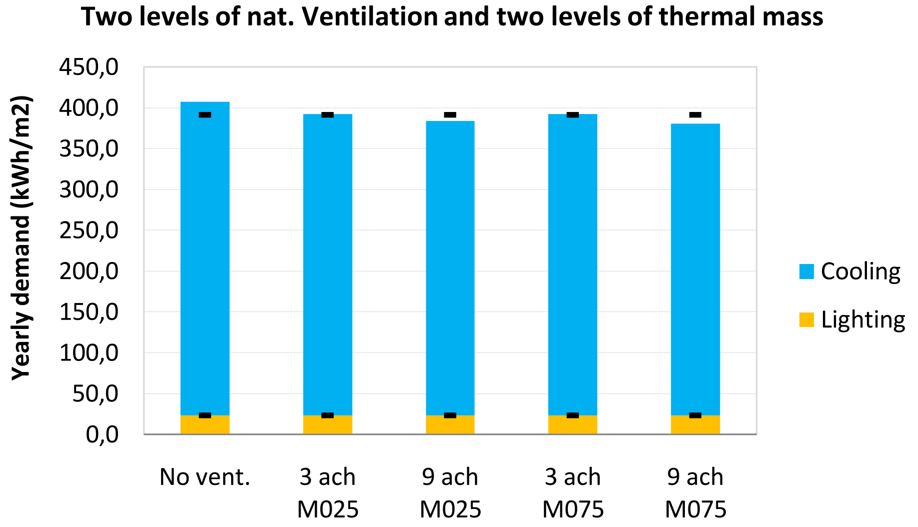


Figure 43- Yearly energy demand - air changes per hour (ach) and different thermal mass values

Heat recovery device

A similar model was used to simulate the thermal recovery of renovation air as part of the HVAC system, considering both sensible heat recovery and enthalpic heat recovery (includes the exchange of heat with the condensation of the water vapour in the air).

Results suggest that enthalpic heat recovery renders good energy demand reduction results in the given climate.

Option	Lighting	Cooling	Total	Improvement
No HR device	23,2	384,0	407,2	Ref.
Sensible HR	23,2	367,5	390,7	4,1%
Latent HR	23,2	305,7	328,9	19,2%

Table 32- Different options for heat recovery of exhaust ventilation air

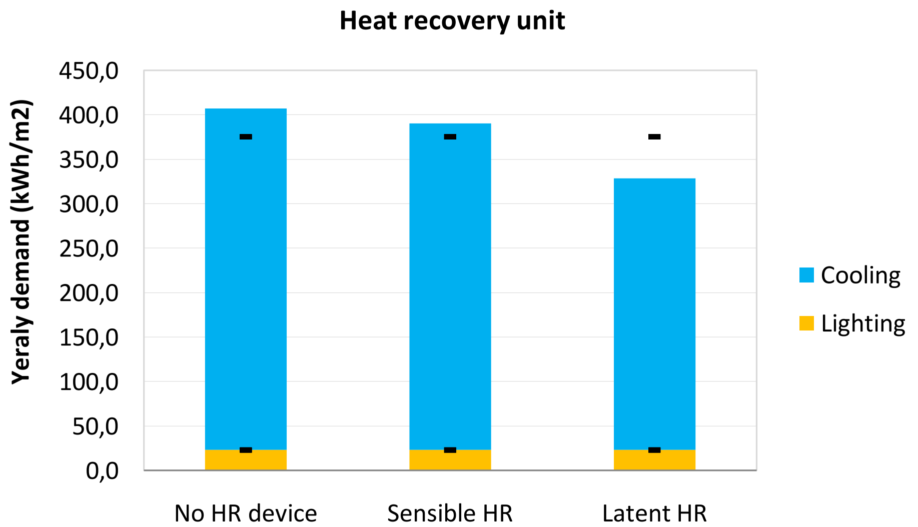


Figure 44- Yearly energy demand for different heat recovery options

1.4 Optimized model

The parametric study results can be analyzed individually, in order to infer which design strategies should be applied, in the given climate, in order to deliver an energy efficient office building design.

The project team will work towards producing an energy efficient building design using some of the features described herein.

A preliminary optimized building model was designed by putting together several of the design strategies that rendered the best results. Its features are the following:

Long Bar shape: this shape performs better than the average although not the best. However, when considering the other design strategies, such as solar protection (which has shown to be the most important parameter, with the right orientation), it allows for better results (e.g., has different façade sizes that will be oriented correctly).

Large facades north and south-oriented: The parametric analysis has shown that when glazing is placed mainly on north and south facades, this orientation is the optimal one and renders energy savings. Besides, as explained on the previous point, this glazing distribution allows for optimal solar protection.

40% glazing on large facades, 20% on small facades: This strategy strengthens the strategies for reduction of solar gains through glazing, besides facilitates solar protection solutions.

Solar protection with shading coefficient close to 95%: Together with the heat recovery strategy as described in the parametric study, this strategy renders the best results. The devices used are the ones explained before.

Heat recovery unit: a heat recovery unit is applied in the optimal building.

Besides the mentioned strategies, considered as the most significant and most viable at a first optimization step, other features used were:

- Opaque enclosures with 2.5 cm insulation and thermal mass layers.
- Double, bright color glazing.
- Occupancy and internal gain data were kept equal to the ones used throughout the parametric simulations.

The results of this optimal building are compared against the results of the alternatives that scored best in each of the parametric study chapters. These are:

- **Shape of building**: Extended, 2 floors
- **Orientation and distribution:** south-north orientation with 60% glazing on large facades and 0% on small facades.
- **Solar protection**: shading coefficient close to 95%.
- **Heat Recovery**: Sensible and latent heat recovery.

Option	Lighting	Cooling	Total	Improvement
Long Bar	36,1	341,5	377,6	7,5%
Orient. Distr.	27,0	381,2	408,2	Ref.
Solar Prot.	25,0	304,4	329,4	19,3%
Heat recov.	23,2	305,7	328,9	19,4%
Opt.	26,5	213,3	239,9	41,2%

Table 33- Comparison of Optimized model against other alternatives

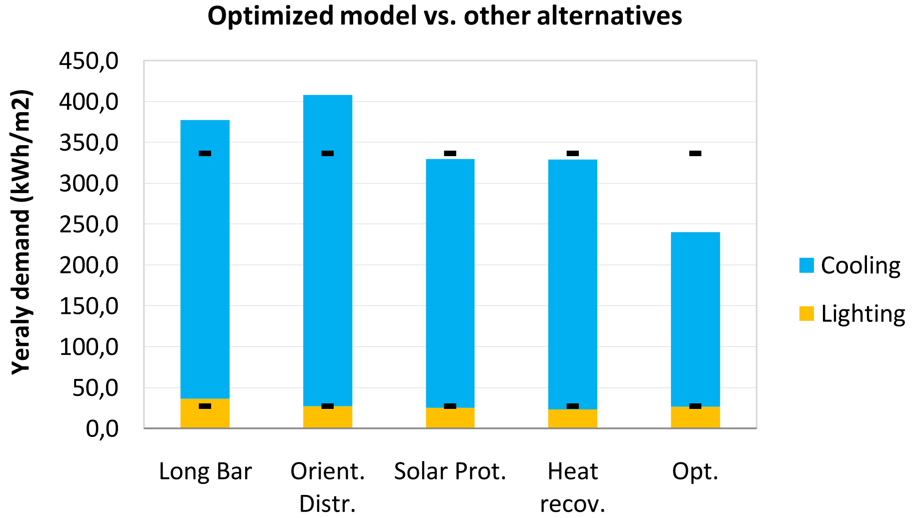


Figure 45- Yearly energy demand of Optimized model against other alternatives from the parametric study

2. Energy Efficient Design

2.1 Buildings Shape

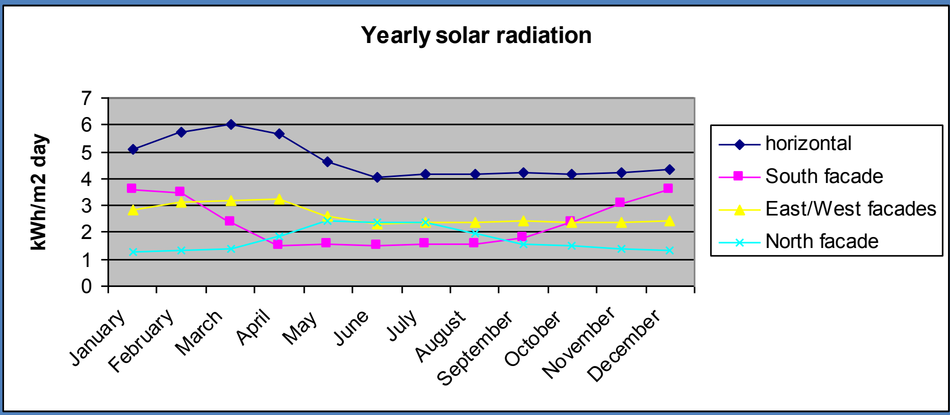
A "Bar" shape has been selected, 14 m wide, in order to provide daylighting to all workstations. In order to guarantee this for the medium building, it is composed of two modules, whereas the small one has one single module. Both models will have three floors above ground and an underground floor for parking purposes mainly.

2.2 Orientation

The orientation of the building will be South/North for the long facades. However, it has been rotated 20º SW in order to allow dominant Eastern winds to have a slightly higher incidence on one of the long facades to improve natural ventilation without compromising the optimal orientation advantages.

Orientation

- **The orientation of the building will be mainly South/North for the long façades.**
- **The East and West facades receive the second highest solar load after the roof, with a lower incidence angle**
- **This low incidence angle makes a good shading strategy that is compatible with views and daylighting availability more difficult**
- **North and South facades are very easy to shade**



2.3 Thermal insulation

An equivalent 2.5 cm expanded polystyrene insulation has been opted for the facades. No insulation is installed in the underground slab neither the first floor. The roof is not insulated since it is shaded and ventilated.

2.4 Windows

The window to wall ratio is 20% for all orientations. The double glazed windows will have a metallic frame with thermal bridge break and an air gap between the two panes.

2.5 Thermal mass

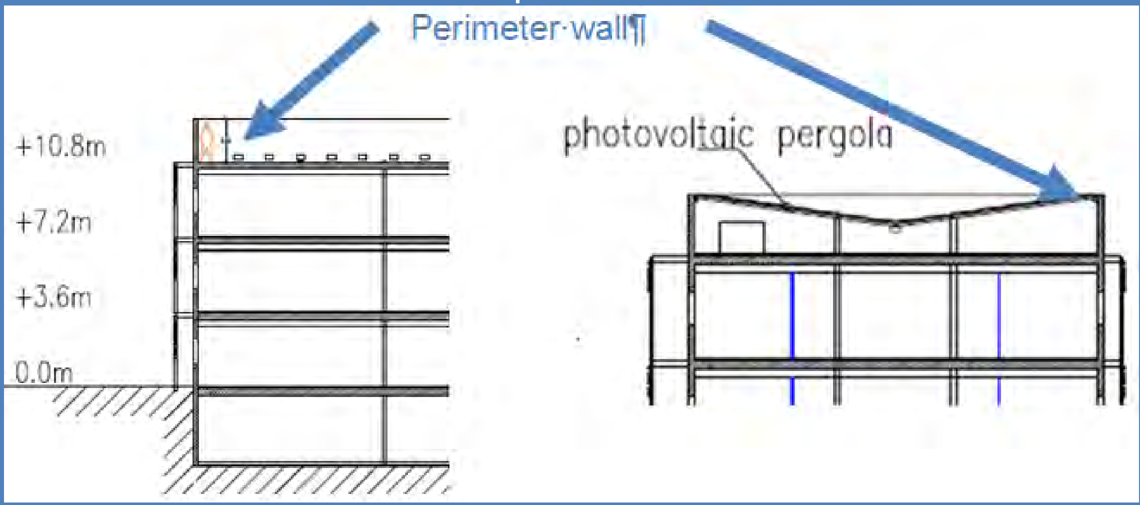
A low thermal mass construction is preferable. The simulations have been performed with a 2.5 cm wide layer equivalent to concrete.

2.6 Roof

A photovoltaic pergola serves as solar protection for a great part of the roof, preventing direct solar incidence on it and also a good ventilation. Some space in the roof will be used to install the HVAC equipment. In such area the roof floor would be floating and ventilated.

Resilience against extreme climatic events

- **Structural resistance: the design must meet the local standards and regulations;**
- **Façade finishes: will have to be certified for use in zones with high hurricane risk**
- **The insulation layer could be installed on the inner part of the wall**
- **Windows will have to be hurricane rated with tempered glass**
- **The PV pergola will be protected from wind and flying objects by a perimeter wall exceeding the roof height.**
- **The external HVAC units will have protections around**



2.7 Solar Protection

Besides the mentioned solar protection with solar modules, all facades will have solar protection for the windows. Different strategies will be used for East/West, South and North facades.

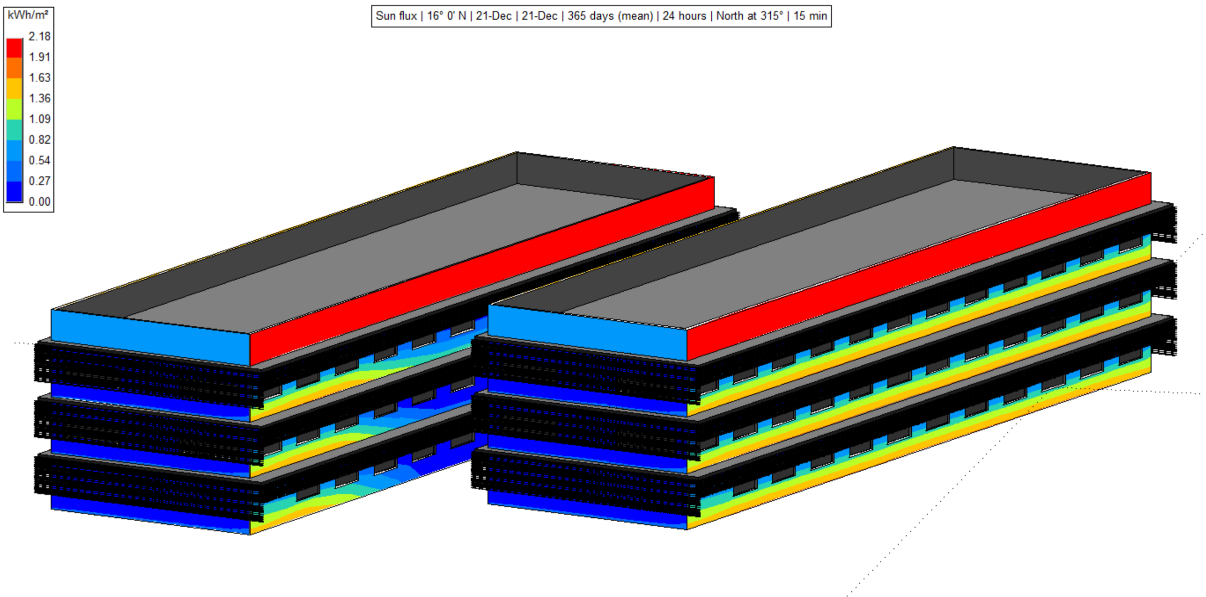


Figure 46- Perspective of solar incidence (view from West)

- East/West: the proposed solar protection partially covers the façade with a three-dimensional vertical and horizontal louver protection. The separation is 10 cm vertically and 50 cm horizontally. Mobile solutions have been discarded for this external part. Besides, this solar protection does not eliminate the view to the exterior environment from the workplaces. It is also recommended to complement the external protection with an internal protection (white, orientable louver blind)

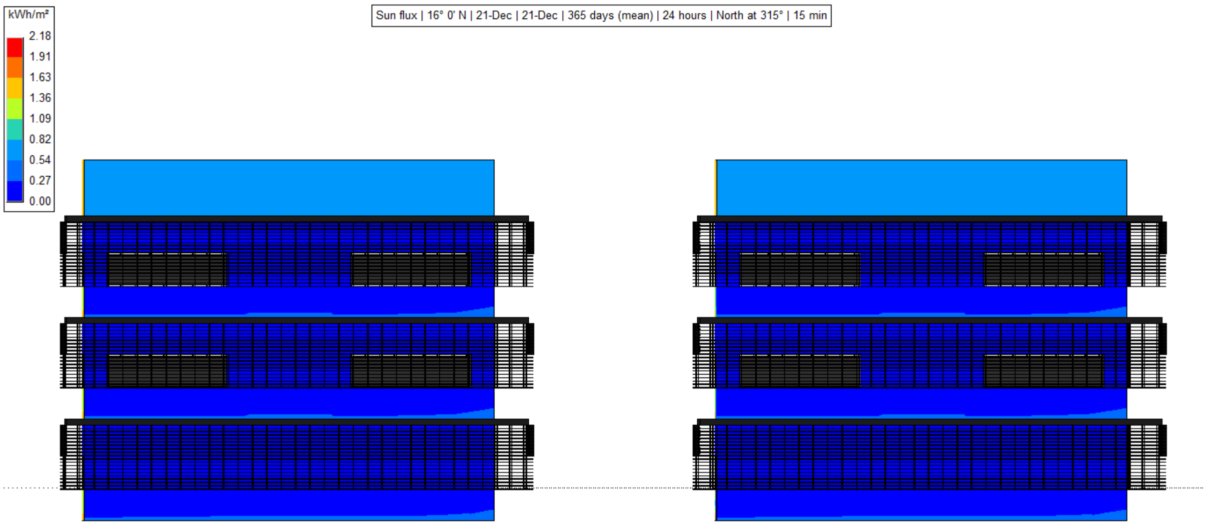


Figure 47- East facade. Simulation of solar incidence

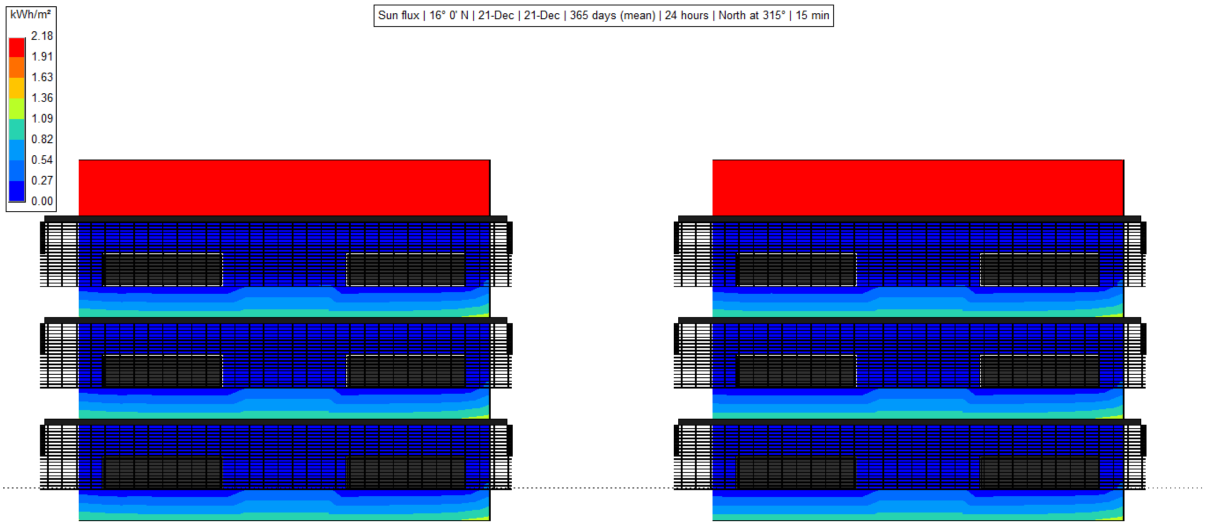


Figure 48- West facade. Simulation of solar incidence

- South: A 1.2 m totally opaque overhang as a continuation of the floor is considered. Besides, this overhang can serve as an emergency exit corridor towards the external staircase.
- A vertical protection element with horizontal louvers will be used in order to enhance the solar protection function.

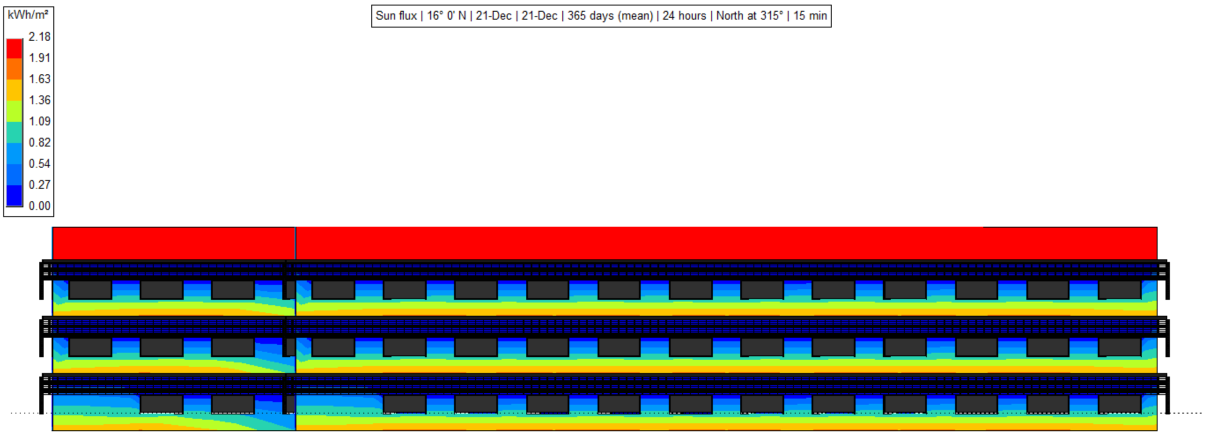


Figure 49- South facade. Simulation of solar incidence

- North: A 1.2 m totally opaque overhang as a continuation of the floor is considered. This overhang would be used only for maintenance.

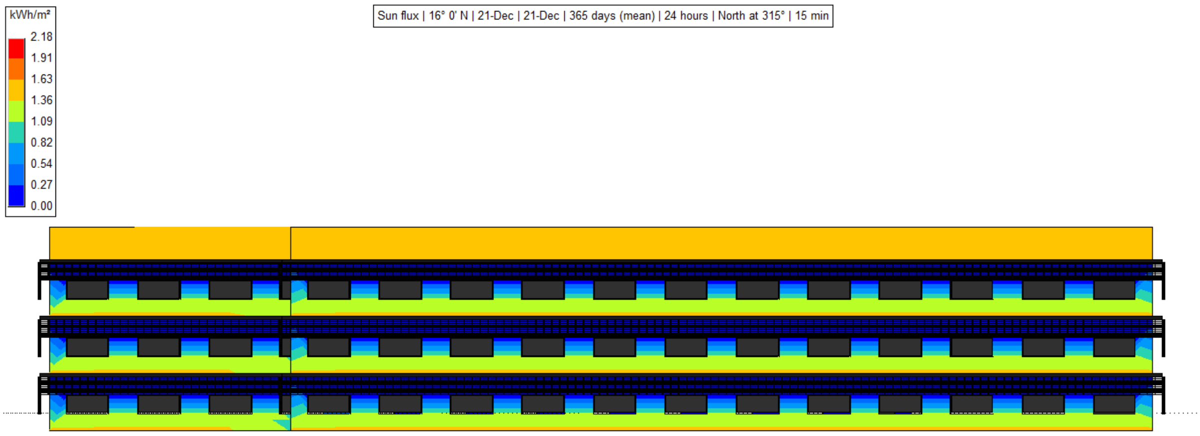


Figure 50- North facade. Simulation of solar incidence

2.8 Efficient lighting

The great majority of office buildings use fluorescent lighting and ferromagnetic ballasts and incandescent light bulbs, especially halogen lighting, for interior lighting. In this case, the installed power for artificial lighting is around 20 W/m2 for workstations (excluding parking areas or non air-conditioned areas). New office buildings or retrofitted office buildings normally improve lighting fixtures by using fluorescent tubes with electronic ballasts and halogen lamp. The reduced installed power may, in these cases, decrease to 16 W/m2.

For the EED a completely different proposal is made: it uses LED lighting for all uses and all zones. Although LED use in areas with a long time of use pays off rapidly and thus currently its used is limited to such conditions, given the evolution in performance and cost reduction, high lifetime and lack of maintenance, probably its use in new buildings will be widespread soon.

Daylight

The specific design of the EED enhances the contribution of natural lighting compared to the BD, especially by reducing the depth of the zones (distance from windows). However, due to climatic reasons, direct incidence of sunlight has been radically reduced by:

- Reducing window-to-wall ratio from 40% (BD) to 20% (EED).
- A different solar protection solution for every orientation.
- No skylights; all daylight enters through facades.

These measures contribute to only allow indirect or diffuse light to enter the building.

The availability of natural light within the building has been simulated in different zones of a standard floor plan, applying the mentioned direct light incidence limiting factors and also making a difference between closed and open spaces.

The simulation is made for the second floor of the southern block of the medium sized building. Only indirect radiation is considered and it is performed for a clear sky day at 10.30 a.m., it considers a 90% transparency in windows and internal divisions. The results are shown in Figure 51:

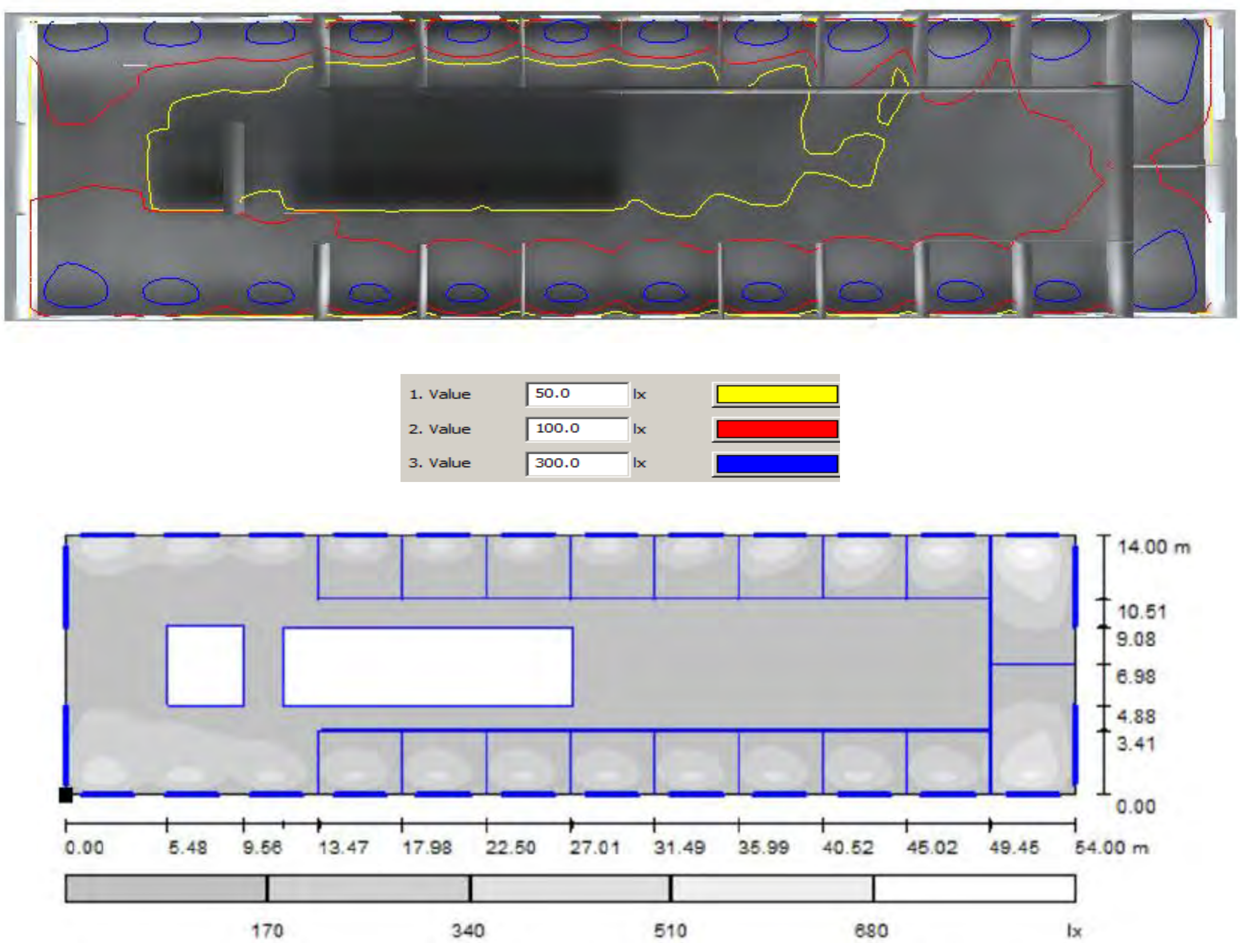


Figure 51. Daylighting simulation results for illuminance on a 80 cm high plan over the floorplan, for a clear sky day at 10.30 a.m.

The conclusions from these simulations are:

- The intensity of daylight is between 170 and 340 lux in the perimeter and less than 170 lux in the center of the floor plan.
- The illuminance between perimeter zones and the center varies between 100 and 200 %.
- Circulation areas and staircases have access to daylight.

Another positive aspect of the EED is that all workstations have visual access to the exterior environment, improving visual comfort and conditions for work.

LED lighting

For such reason, all zones in the building have been supplied with LED lighting, essentially using 40W and 45W panel-like fixtures. Their characteristics are summarized in the following table:

Power	40	45	W
Size	60 x 60 x 1	120 x 20 x 1	cm
Luminous flux	3,590	4,010	lm
Luminous efficiency	89.8	89.1	lm/W
Power Factor	0.9	0.9	kVAhr/kWh
Color Temp.	6,000	6,000	K
CRI	85	85	
Lifetime	50,000	50,000	h

Table 34. Characteristics of the LED lights used for the simulation

Simulations of illumination values over the workstations has been performed using Dialux software, using the second floor block of the southern medium size EED building (analogous results can be drawn for the small building block).

The illuminance values recommended by international standards are achieved (500 lux in workstations and meeting rooms, 300 lux in circulation, WC, archives and similar) with the LED panel distribution proposal.

The lighting fixtures considered were the following, LED rectangular and square shaped:

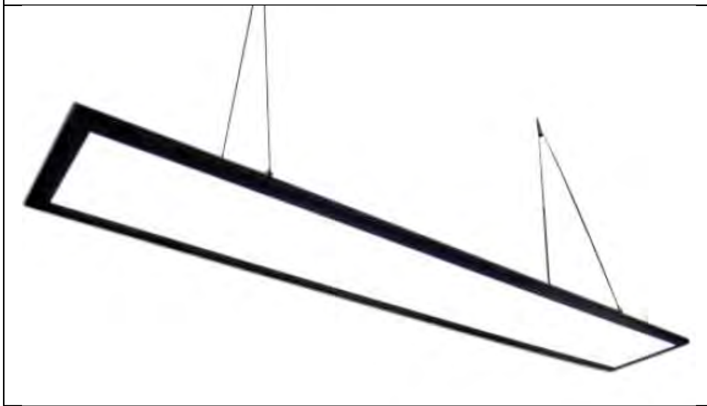
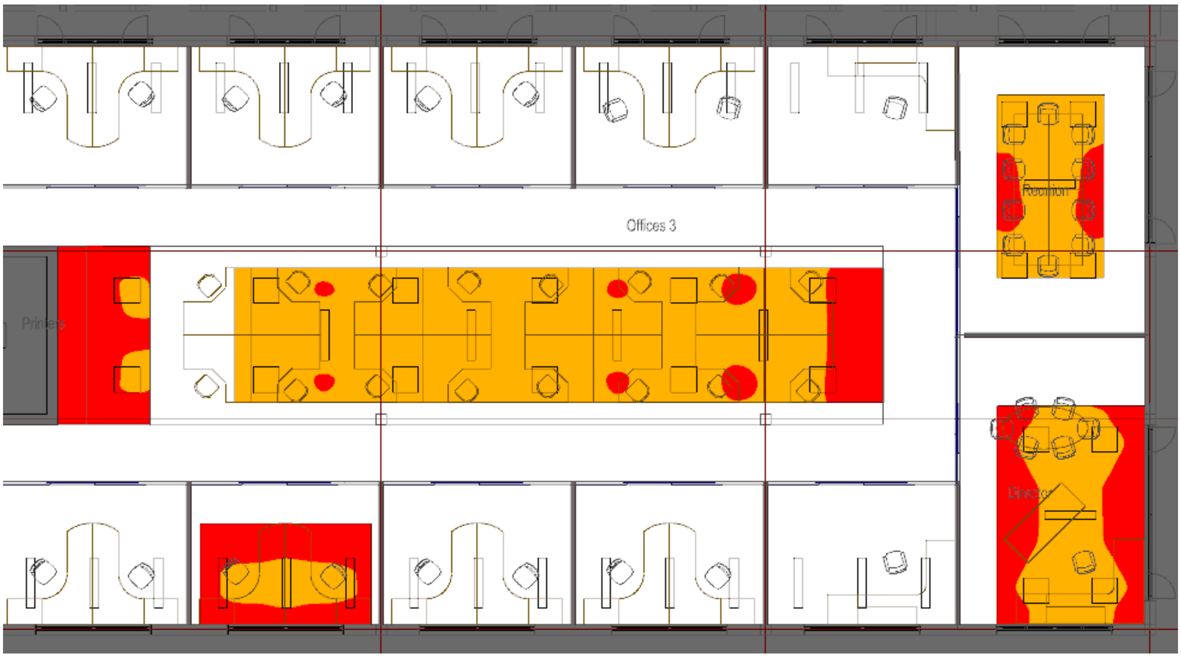
79 x DIALux DALLE LED 1200x200 45W BN D	35 x DIALux DALLE LED 40W BN 600x600
	

Table 35. LED luminaries used for the simulation

The proposed distribution of lighting fixtures is the result of considering the distribution such that the required illuminance values and homogeneity are met over a plane at a height of 80 cm over the floor (working plane). The lighting fixtures are installed hung from the ceiling, at a height of 2,3 m. The total luminous flux is thus 252,845 lm and the total electrical load 5,025 W.

The following picture shows the simulation results over the workstations, meeting room and director' room: the shaded colored areas represent different levels of illuminance according to the legend. As shown in the figure, 500 lux values are met in a homogeneous way throughout the working areas, as said before, considering a working plane at 80 cm over the ground (the white areas are analogous to the workstation with the same lighting fixture distribution, low left).



Color	Value
(red)	300.00 lx
(orange)	500.00 lx
(yellow)	750.00 lx

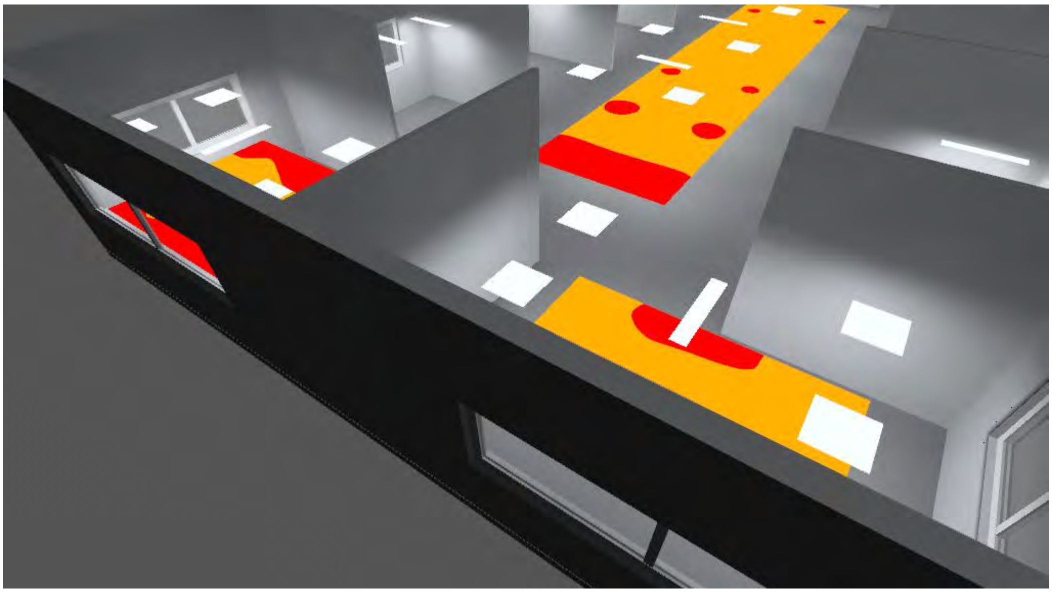


Figure 52. Simulation results for LED lighting on the 80 cm high plane, illuminance legend and 3D model

Fluorescent lighting

An analogous study has been performed using the following fluorescent lighting fixtures in order to compare the installed power reduction and the improved lighting comfort conditions provided by the LED alternative.

67 x LAMP 6,504,000 MODULAR V.BR T8 4X18W	23 x LAMP 6,542,810 MODULAR TECH 2X14/24W
	

Figure 53. Fluorescent lighting fixtures considered for comparison

In this case, the distribution of lighting fixtures has also been done in order to meet, with a reasonable number of elements, the illuminance requirements explained above. The fixtures are installed at a height of 2.3 m over the floor level. The results are presented in an analogous image of the LED case.

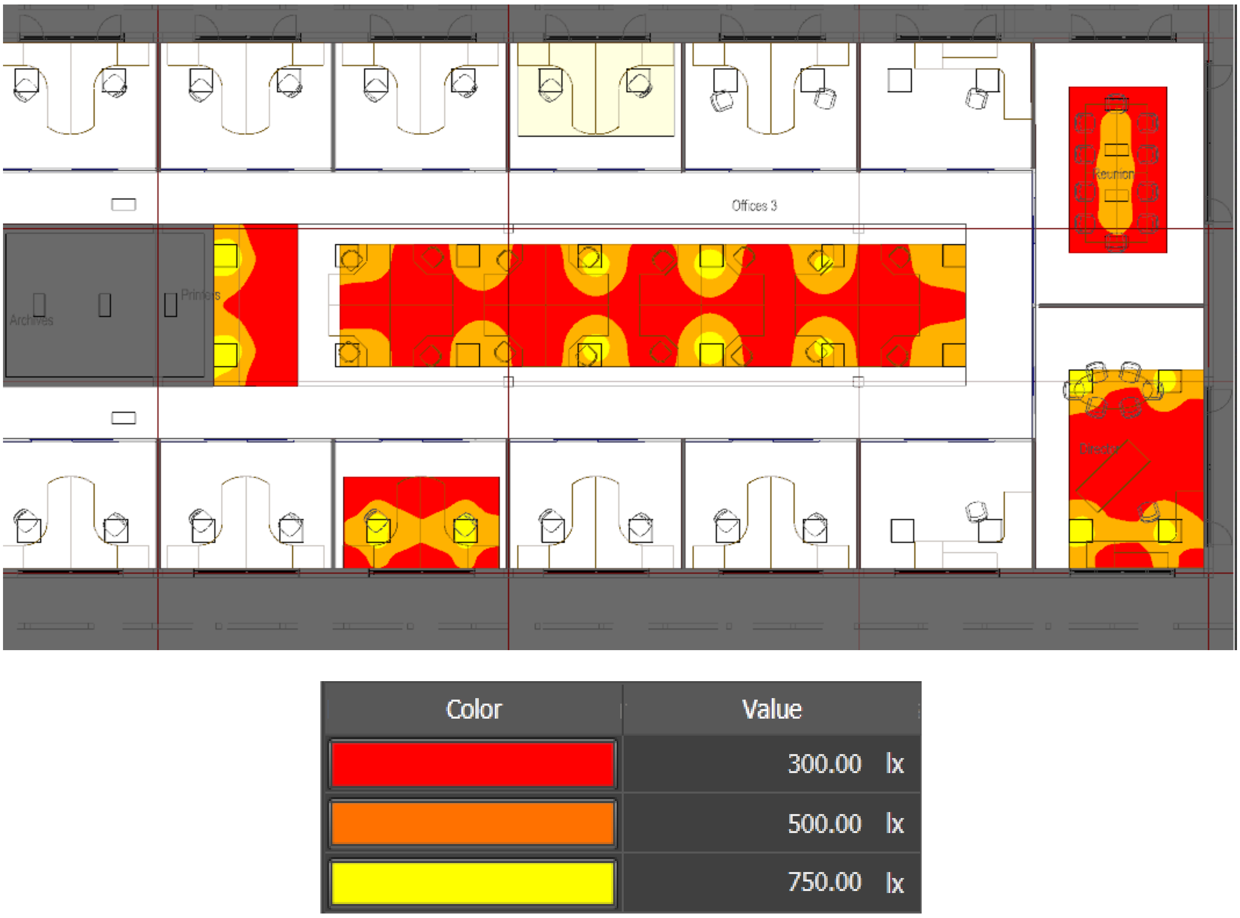


Figure 54. Simulation results for fluorescent lighting on the 80 cm high plane

The results show that the fluorescent fixtures have a higher illuminance right below the fixtures' installation location and that the distribution is less homogeneous. Besides, the decay of the illuminance is stronger and more reduced portions of the space are equally lit.

What is more, the total luminous flux is 403,600 lm, the total Load being 12,728 W; that is, by more than doubling the installed power for lighting, the illuminance result obtained is worse.

Lighting Control

The EED energy performance simulation models have included daylight control devices in order to dim artificial light according to daylight brightness. The system dims artificial lights during the lighter moments of the day, supplying the required illuminance according to the values explained above that depend upon the activity performed.

Besides, motion control devices should be applied to short-time residence areas such as WC, archive, warehouse etc.

To sum up, efficient lighting in the EED enhances energy efficiency in two important aspects:

1- Reduces in 65% the installed power of lighting devices, compared to the common practice in baseline office buildings.
2- Reduces thermal gains related to the electricity use of lighting fixtures, a 17 %.

Efficient lighting

- **Daylighting control will be used to regulate artificial lighting depending on available daylight.**
- **No skylights; all daylight enters through facades**
- **No workstations further than 7 m from windows**
- **Internal partitions mostly transparent**
- **A 100% LED lighting is selected, with a target illuminance of 500 lux in workplaces, approx. 300 lux in corridors, service areas etc. and approx. 100 lux in the parking.**
- **Around 180 lumens/W**
- **Around 4 W/m2**

2.9 Mechanical Systems

Cooling and ventilation systems have been modeled within the energy performance simulations. The cooling system chosen has been a conventional air-water one, cooled with water (cooling tower). The different design strategies applied have rendered different energy consumption results.

Regarding the distribution system, two have been considered: fan coils or AHU and radiant cooling panels. The first alternative is the most common and practically the only one used in the Caribbean region; besides, as far as the consultants are concerned, there are no experiences with radiant cooling panels in these countries. However, the consultants have considered interesting to suggest the second option as a solution for an energy efficient office building

The comparison of performance between radiant cooling panels and conventional systems, in this case, cooling distribution with fan-coils, has been studied[5] for an office building in tropical climate, specifically for Panama City in Panama, also using Design Builder and Energy Plus.

The results of such study show that the difference in electrical energy demand (for the whole system: cooling device, heat dissipation, recirculation of fluids, terminal unit) is 21% lower if radiant cooling panels or chilled beams are used, compared with the fan-coil system.

The main reasons behind such improvement are:

- Increase of COP of the cooling system given the fact that the process and distribution temperature of cold water is 15ºC instead of 7ºC in the case of fan-coils.
- The volume of air to be mechanically blown is significantly lower, since it is limited to the renovation air volume needed to keep healthy conditions.
- The room air temperature can be higher since the comfort temperature felt by the users has a strong component of the radiant temperature supplied by the radiant cooling system.

[5] "*Simulación de Sistema HVAC del Complejo Regional de las Naciones Unidas en Panamá con un Modelo desarrollado en EnergyPlus con Vigas Frías y Bomba de Calor Geotérmica*", URV, September 2011

2.10 Renewable Energies

The renewable energies considered are PV for electricity generation and solar thermal for hot water.

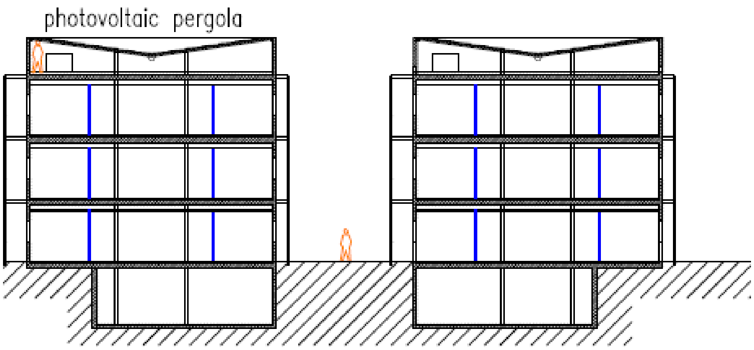
Photovoltaics

The integration of a photovoltaic generator into an energy efficient building is probably the most interesting solution to generate renewable energy locally. The improvements that such installation can deliver are:

- Generates electricity, the final energy most used in office buildings, in general, and almost the only one in the Caribbean.
- The electricity generation is simultaneous in time with a big share of the daily working hours of office buildings, thus on-site use is enhanced.
- The integration of the PV generator is made at the roof, thus using an existing built surface that commonly in other buildings has no added value.
- The PV pergola provides shading to the roof, this being the very external surface of the building with the highest incident solar radiation throughout the year. Besides, it creates a ventilated space.
- This PV pergola installed on the flat roof replaces the ventilated roof of the BD.
- The suggested tilted design allows for rainwater harvesting that can be stored and used to meet part of the non-drinking water needs of the building.

Thus, the optimization of the yearly electricity generation has not been the only criteria to design the PV generator. The above mentioned factors have also been considered, as well as the resistance against extreme climatic conditions.

Besides, the PV system does not cover the whole roof, a small zone is reserved for the external cooling system devices and the solar hot water system.



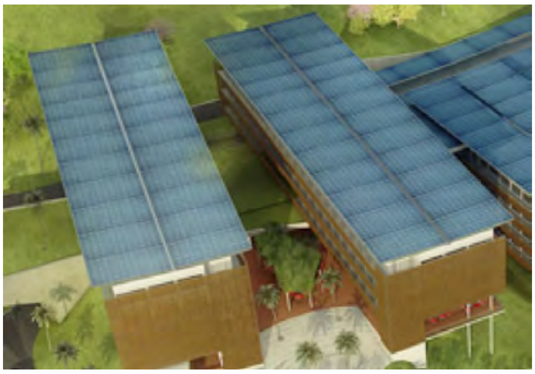


Figure 55- The EE Design incorporates a PV roof protected from extreme winds (top-left). In locations were extreme climatic events are weaker or non-existing, the PV itself can be a solar protection for the façade (top-right, bottom)

Adopted solution and electricity generation estimation:

The photovoltaic (PV) system is composed of the generator (PV modules and supporting structure), the electrical protections and the inverters.

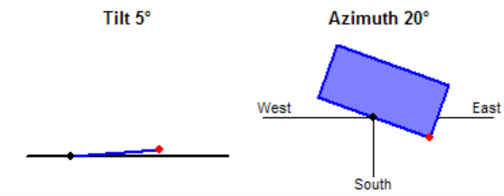
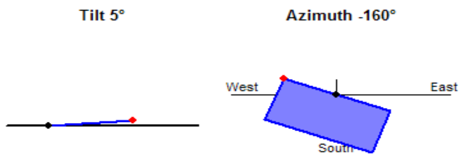
Thus, the solution adopted for both small and medium models consists of a 2 m high support structure for the PV modules, to allow access of maintenance staff, over the flat roof. The PV system would be divided into two parts longitudinally with a 5º tilt to the center of the roof. A 2 m high perimeter wall above the flat roof is suggested in order to protect the whole installation from extreme winds.

Each building has two tilted generators: one is slightly oriented NE (20º), the other 20º SW (-160º). Obviously, the annual generation of these two generators is different, given the fact that the incident radiation is also different due to the orientation and tilt.

The following table summarizes the characteristics and estimated generation, using PVSyst software and the climatic data from Le Raizet, Guadeloupe, very similar to the climatic data used for the Design Builder simulations:

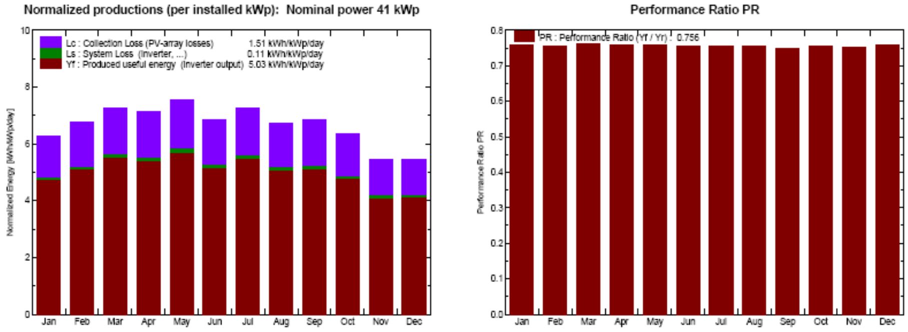
	PV power	**Number of PV modules**	**PV module**	**Estimated PV generation**	**PV rating**
	kWp	-	Wp	MWh/year	kWh/kWp
SW modules	41	165	250	75.8	1,837
NE modules	41	165	250	72.9	1,766
Small EE building	82	330	250	148.7	1,801.5
Medium EE building	164	660	250	297.4	1,801.5

Table 36- Features of the designed PV installations and an estimated electricity generation

Modules facing SW	Modules facing NE
	

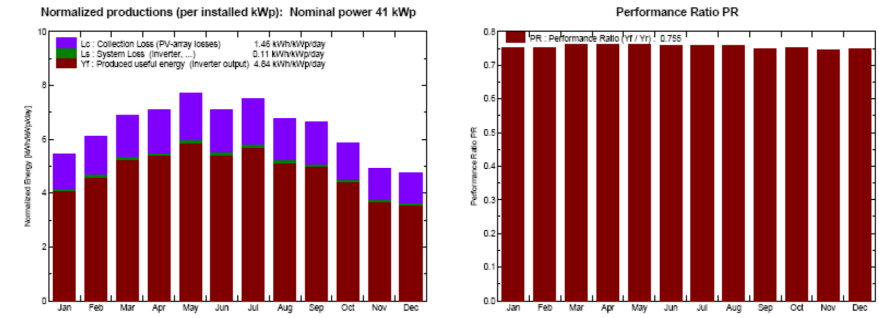
Main simulation results
System Production

Produced Energy **75.8 MWh/year** Specific 1837 kWh/kWp/year
Performance Ratio PR 75.6 %



Main simulation results
System Production

Produced Energy **72.9 MWh/year** Specific 1766 kWh/kWp/year
Performance Ratio PR 75.5 %



On top, left, modules facing SW: The image on the right shows that the longest bars on the left figure are quite constant throughout the year, this is due to the incident radiation on the modules oriented SW. The purple portion stands for the losses due to collection loss (namely temperature, orientation, optical, etc.). To the right, the “Performance Ratio” between the maximum possible output and the actual output, per month (average annual 75,6%)

Below, modules facing NE. The incident irradiation is less regular throught the year. The average Performance Ratio is 75,5%.

Table 37- PV orientation and tilt and electricity generation estimation for both sub-systems

The loss diagram over the whole year illustrates the impacts that several non-ideality conditions:

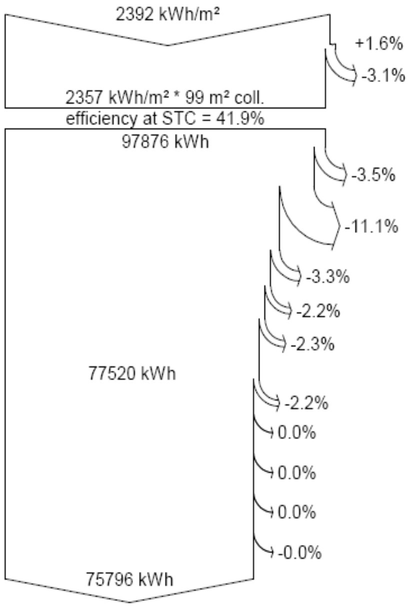
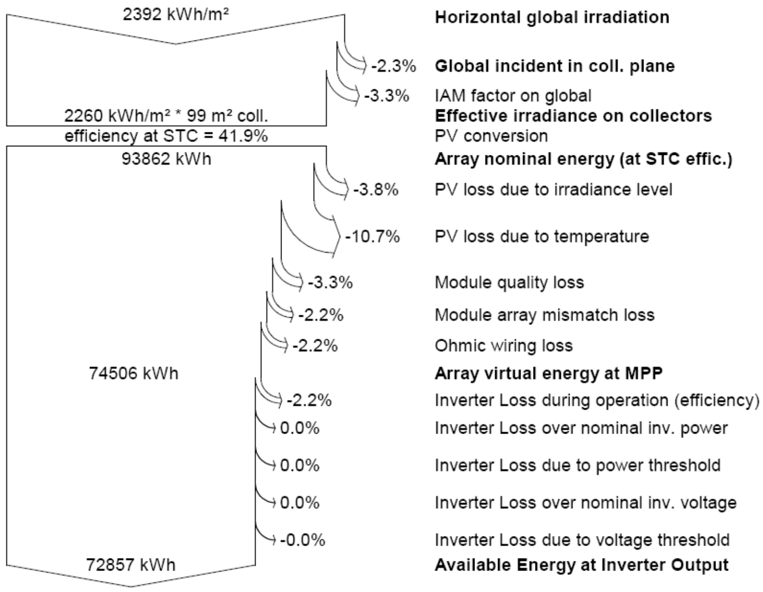
South oriented modules	North oriented modules
	

Table 38- Loss diagram of PV sub-systems

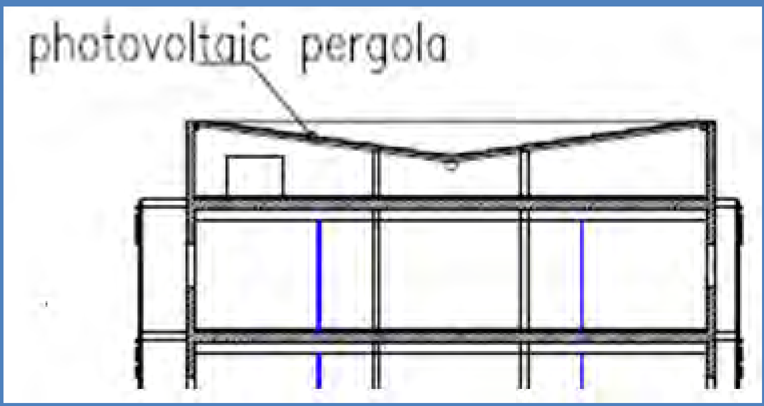
The radiation on tilted modules is higher than on the horizontal, that is why there is a preliminary gain in the diagram. The rest are losses, namely due to temperature; high temperatures of cells decrease the efficiency and thus generate losses. In this case, these are around 11%.

The inverter losses are due to the efficiency of the inverter (for the example, 98% nominal efficiency) which is not 100%.

Advantages of Photovoltaics

The integration of a photovoltaic (PV) generator into an energy efficient building is probably the most effective way, in terms of investment, to generate renewable energy locally. The improvements that such installation can deliver at the EED are:

- **Electricity production (50 kWh/m2 of useful building area per year, for this 2 level building)**
- **Shading the roof (37 kWh/m2 of useful building area per year of cooling demand reduction)**
- **Allow ventilation of roof, increase lifetime of waterproofing**
- **Harvesting clean rainwater : 0,75 m3/m2 of useful building area per year (if enough storage capacity is available)**



Solar thermal

An estimation of hot water demand has been made for both BD and EED; specifically, the areas that may have a hot water demand are the cafeteria and the dining room and kitchen for the medium sized building and only the cafeteria for the small building. A solar thermal system has been designed to meet the hot water demands of the above uses. The following tables describe the features of the systems, with different demand values:

EE Building	Useful surface*	Staff	Estimated Hot Water consumption	
	m2	people	l/person per day	l/day
Medium Building	4,586	328	8	2,624
Small Building	2,268	140	2	280

Table 39- Estimated HW demand

EE Building	Hot Water demand		Solar Thermal system			
	HW consumption	HW demand	Surface	estimated production		Solar fraction
	l/day	MJ/year	m2	MJ/year	kWh/year	%
Medium Building	2,624	134,168	36	94,740	26,309	72
Small Building	280	14,317	4.5	11,131	3,091	78

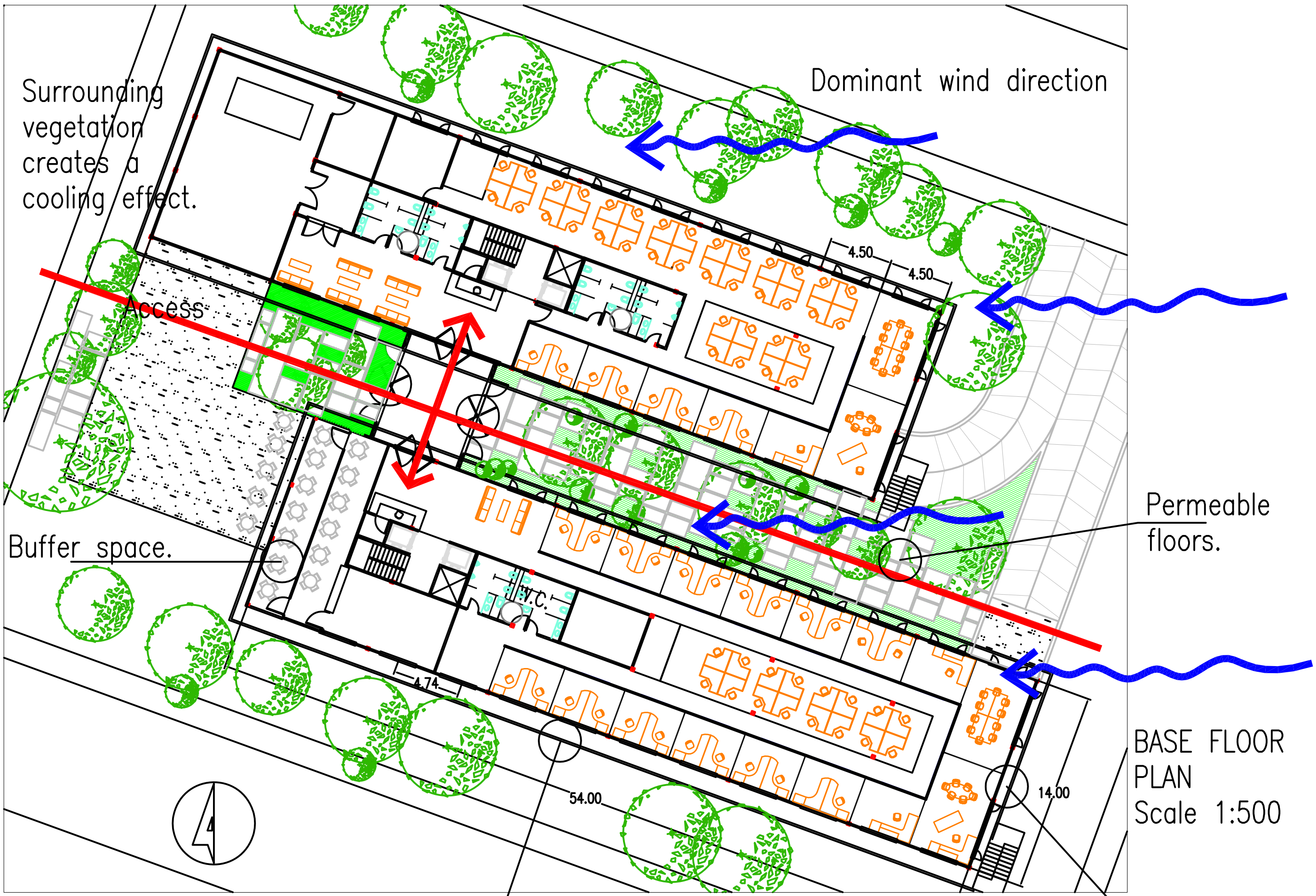
Table 40- Hot Water demand and Solar thermal systems

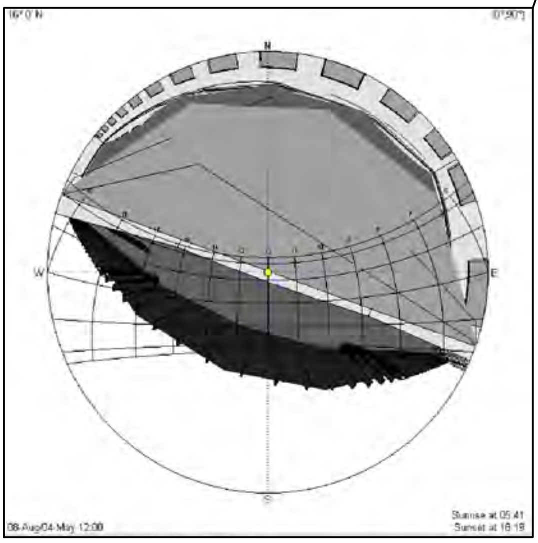
The systems for the medium and small designs are considerably different due to the differences in HW demand related to fewer staff and fewer services.

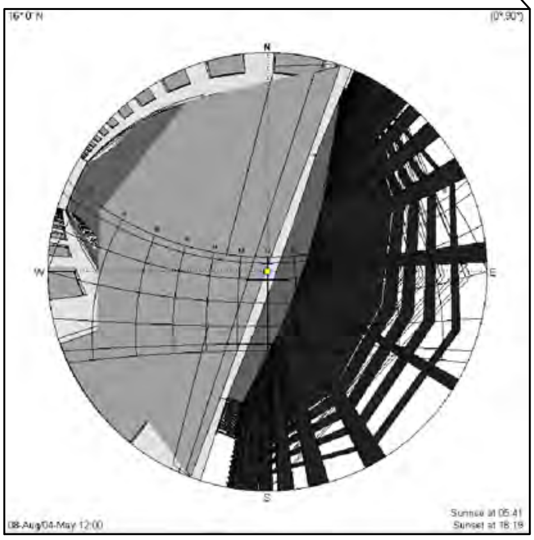
Thus, electricity is saved by using solar thermal energy. The savings amount to 26.3 and 3.1 MWh/year, for the medium and small sizes of buildings.

In yearly kWh/m2 values, the results are the following:

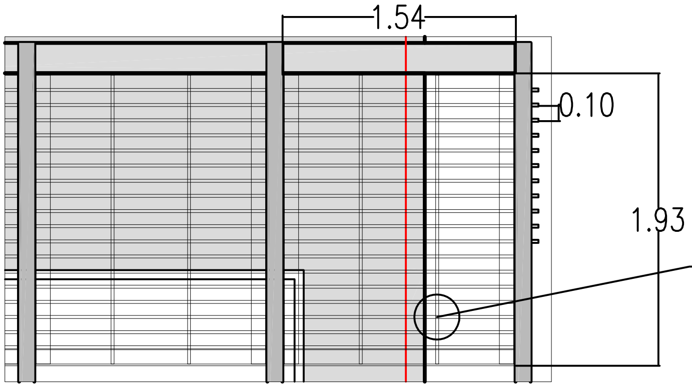
- Medium building: Demand 8.12 kWh/m2; Production 5.73 kWh/m2
- Small building: Demand 1.75 kWh/m2; Production 1.36 kWh/m2







Solar protection chart over the stereographic diagram of the location, for the South facade (left) and the East facade (right). The darkened area over the sun path means that for such sun positions the facade will be in the shade. The black area represents the protection by the external element; the gray area is the protection by the overhang; the continuous gray half circle means that the sun would be "behind" the facade.



Protections:

–the South facade has a 1,2m overhang that helps protect the windows from radiation and supports the slats modules. It's also walkable, for easy reach of the emergency stairs.

Modules

–the louvers on the module are fixed, and are reinforced by vertical elements, at every 0,5m to increase the resistance to wind.

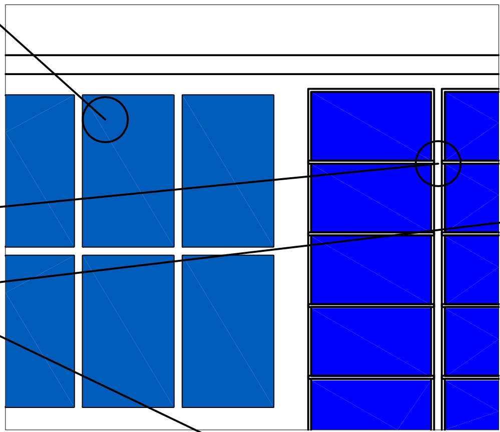
–the modules are supported by their own structure. a tubular pillar at every 1,64 m.

Perspective. no scale

Using Solar Thermal panels to supply hot water to facilities like the kitchen.

Extreme weather event considerations
–PV array separation to minimize wind overpressure.
–Ventilation holes to relief overpressure on roof
–Wall to protect PV modules

Rainwater considerations.
–Rain harvesting with PV generator



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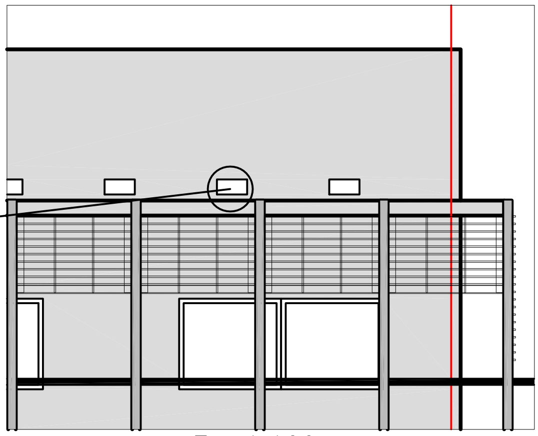

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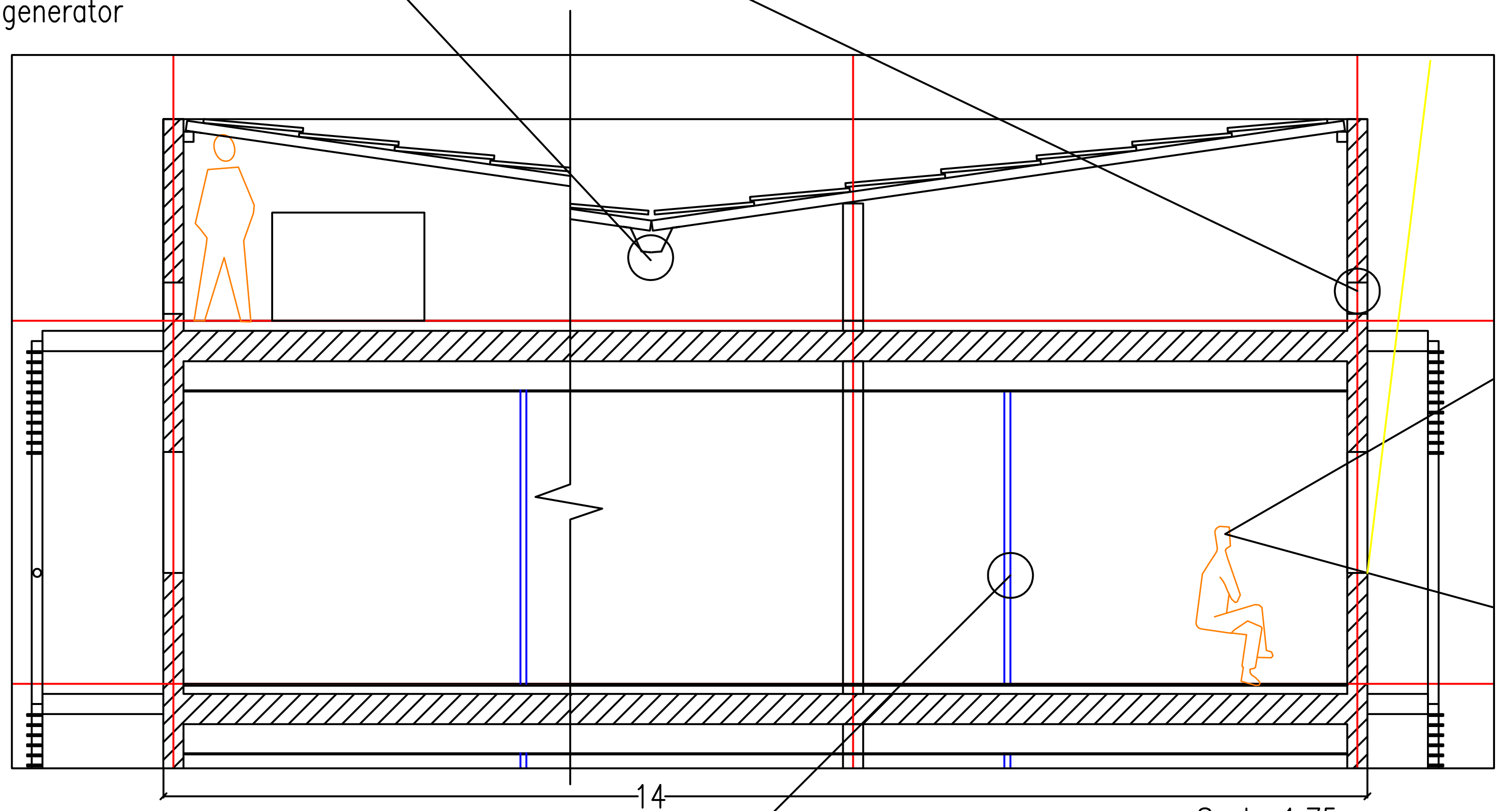


Scale 1:75

Orientation considerations: the shortest façades are oriented practically East and West, for these orientations receive the highest solar incidence troughout the year in this latitude. The 20 degrees clockwise turn from North is to take advantage of the dominant winds (East) to enhance passive ventilation of the building

Daylight considerations.
–The Building dimensions make it possible to have natural indirect radiation in the center given the 14 m width.
–Glass partitions are used so the spaces at the center also get natural light

3. Input data

3.11 Climate data

The climate data used for the simulation is the same used for the Baseline Design energy simulation, that is, using DesignBuilder-EnergyPlus software, using the climate data from Guadalupe -GLP_Basse.Terre_MN6.epw.

4. Energy Results

The energy simulation has been performed sequentially to study and isolate the effect of some non-architectural measures. Energy simulation results render electricity consumption values for lighting and cooling purposes. Later the energy generation and electricity savings will be included and deducted from the total lighting and cooling electricity demand, to obtain the total purchased electricity for each building.

Thus, the first model results in the following table are for the EED that still has the same conventional lighting as the BD.

The following models stand for:

EED	Energy Efficient Design without efficient lighting
EED+HR	EED above with Heat Recovery unit
EED+HR+LED	EED with Heat Recovery unit and LED lights
EED+HR+LC	EED with Heat Recovery unit and Lighting Control (but conventional ligthing)
EED+HR+LED+LC	EED with Heat Recovery unit and LED lights and Lighting Control

4.1 Energy simulation results

The cooling demand (thermal energy) is translated into electricity consumption of the cooling equipment, using the seasonal COP value of the cooling equipment. A seasonal COP of 2,5 (seasonal value of the COP of the cooling system) is considered for the calculations.

The influence of different seasonal COP in the total energy demand is further explained later.

The following table shows the results of the energy performance simulation for the different EED models considered and the BD:

Model	Lighting	Cooling (thermal)	Total	Improvement
	kWh/m2	kWh/m2	kWh/m2	%
Baseline*	54.0	320.5	374.5	Ref
EED*	54.0	279.3	333.3	11.0%
EED*+HR	54.0	234.2	288.2	23.0%
EED+HR+LED	20.3	191.4	211.7	43.5%
EED+HR+LC	31.3	203.2	234.5	37.4%
EED+HR+LED+LC	11.7	179.3	191.0	49.0%

Table 41. Energy simulation results, COP=1 (without light control)***

Now, considering the COP=2.5, the electricity demand for cooling and lighting for each model is:

Model	Lighting	Cooling	Total	Improvement
	kWh/m2	kWh/m2	kWh/m2	%
Baseline*	54.0	128.2	182.2	Ref
EED*	54.0	111.7	165.7	9.0%
EED*+HR	54.0	93.7	147.7	18.9%
EED+HR+LED	20.3	76.6	96.8	46.9%
EED+HR+LC	31.3	81.3	112.6	38.2%
EED+HR+LED+LC	11.7	71.7	83.4	54.2%

Table 42. Energy simulation results, COP=2,5 (without light control)***

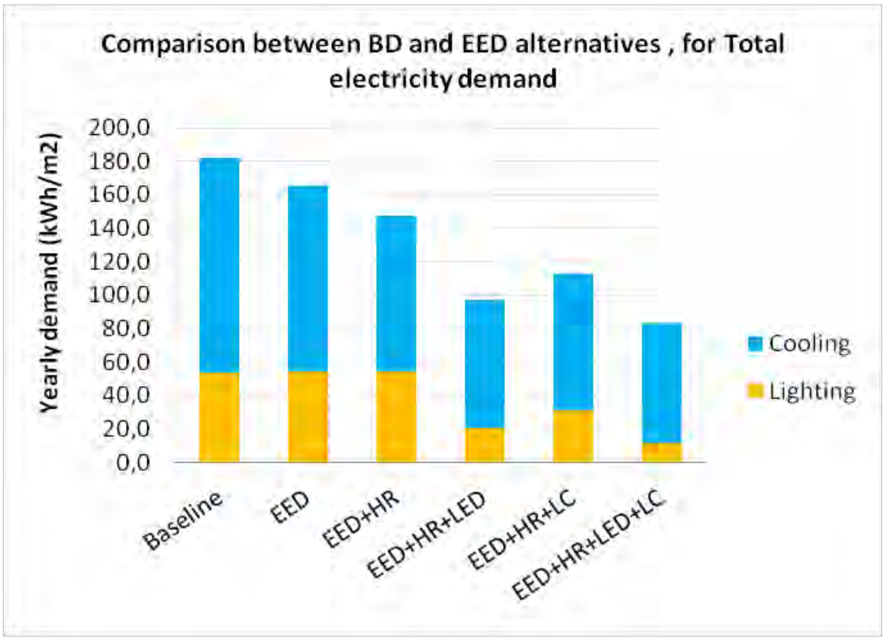


Figure 56. Comparison between BD and different EED alternatives, total electricity demand

The effect of a higher or lower COP affects the extent to which the energy demand for lighting becomes important and thus, the effectiveness of the measures related to lighting (LED and Lighting Control).

The following table compares the share of lighting and cooling energy in the total energy demand for different COP values (2.5, 3,5 and 5,5, which would be seasonal COP values of more efficient systems or performances), and the extent to which each improved EED model, with the different strategies (Heat recovery, LED lights and Lighting Control), is improved, all compared to the BD:

	COP 2,5			COP 3,5			COP 5,5		
Model	**Lighting**	**Cooling**	**Improvement**	**Lighting**	**Cooling**	**Improvement**	**Lighting**	**Cooling**	**Improvement**
-	%	%	%	%	%	%	%	%	%
Baseline*	30%	70%	Ref	37%	63%	Ref	48%	52%	Ref
EED*	33%	67%	9%	40%	60%	8%	52%	48%	6.6%
EED*+HR	37%	63%	19%	45%	55%	17%	56%	44%	13.9%
EED+HR+LED	21%	79%	47%	27%	73%	49%	37%	63%	50.9%
EED+HR+LC	28%	72%	38%	35%	65%	39%	46%	54%	39.2%
EED+HR+LED+LC	14%	86%	54%	19%	81%	57%	26%	74%	60.5%

Table 43. Comparison of improvements between EED models and BD, for different COP values (**without light control)*

The table illustrates the fact that if the performance of the cooling system is improved, with the cooling demand shown in Table 41, the share of the electricity demand for cooling, in the total electricity demand decreases significantly. For example, in the case of the BD, the Cooling share is 70% for COP 2,5 and decreases to 52% for a COP=5,5. In the case of EED, it decreases from 67% to 48%.

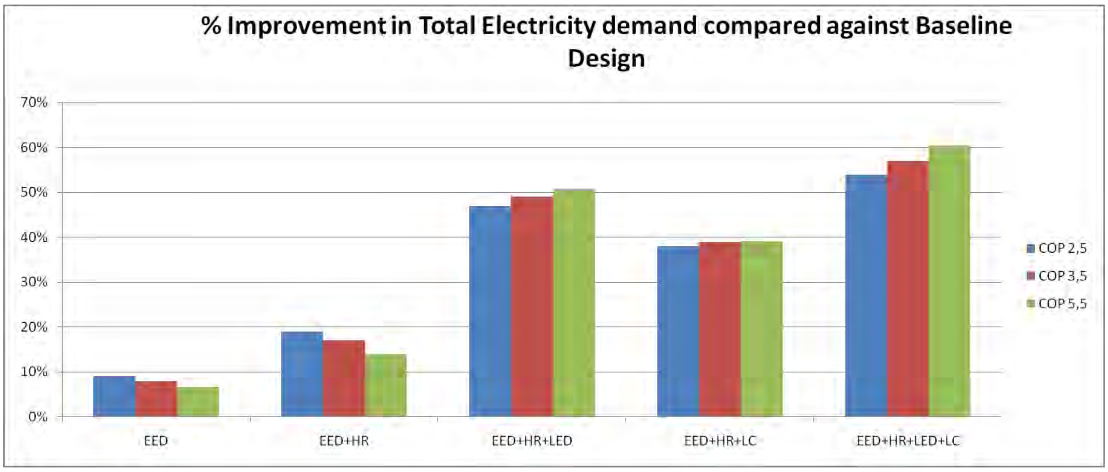


Figure 57. % Improvement vs BD, Total Electricity demand, different COP values

The best global improvement in total demand is clearly obtained when all measures are combined together in the EED. However, an interesting fact is observed: the better the COP, the more important the contributions of energy efficient lighting are, because the significance of the lighting energy becomes more important; for the case of including the Heat Recovery unit, the improvement compared to the BD is lower with increasing COP, because the share of the cooling energy it enhances is lower in the total consumption of the building. The following figure shows the decreasing % improvement of EED+HR with regards to the BD, for different COP values. The improvement varies in 18,9%, 16,9% and 13,9%:

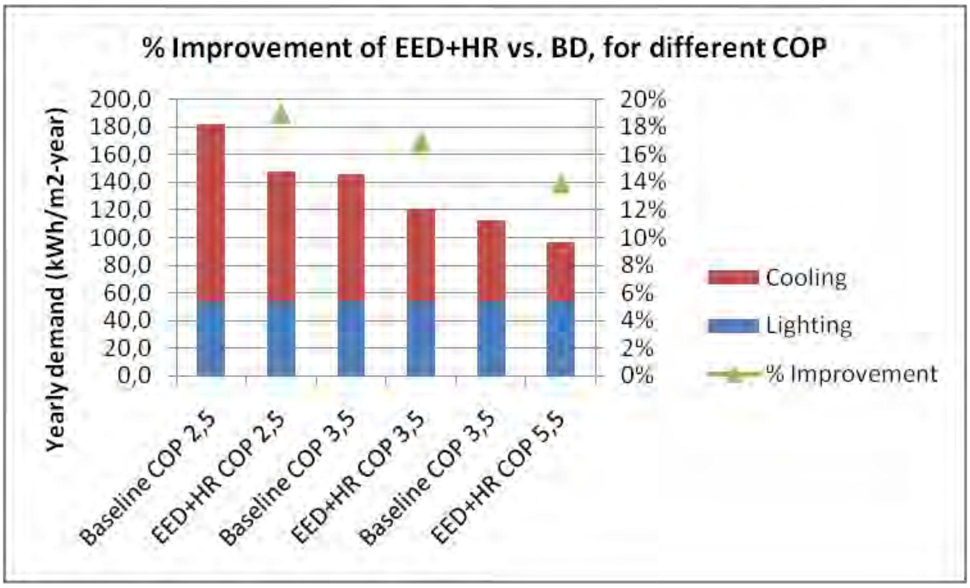


Figure 58. % Improvement of Heat Recovery incorporated to EED, compared against BD, for different COP values of the cooling system

4.2 Energy demand including energy generation

As explained in the EED design documents, two "generation" strategies are used to reduce the final electricity demand of the EED buildings.

Firstly, as shown in previous chapters, the EED has a PV generation installation whose electricity will be used within the building, reducing the yearly electricity demand.

Secondly, the production of solar hot water also reduces the electricity demand for hot water, although it does not meet the 100% of the demand. The hot water electricity demand balance, delivering the result of the amount of electricity that will have to be purchased for hot water is:

- Small building: 1.75 kWh/m2 – 1.36 kWh/m2 = 0.39 kWh/m2 per year.
- Medium building: 8.12 kWh/m2 – 5.73 kWh/m2 = 2.39 kWh/m2 per year.

It is important to clarify a hypothesis for the present calculations about PV generation; it will be considered that all the electricity produced by the PV installation will be used to meet part of the electricity demand calculated before for lighting and cooling.

This hypothesis would be true if the electricity demand in the building is simultaneous with the PV generation at all times and if the demand is always higher than the PV generation. The hypothesis will also be true if a net metering scheme is applied so that the utility balances one kWh exported to the grid with one kWh bought;

thus, the yearly balance of purchased and exported kWh would be equal to adding all electricity demand and subtracting all electricity generation.

Thus, considering the PV electricity generation and the resulting electricity demand for HW, in the EED building, the final electricity demand to be considered for the LCC analysis is:

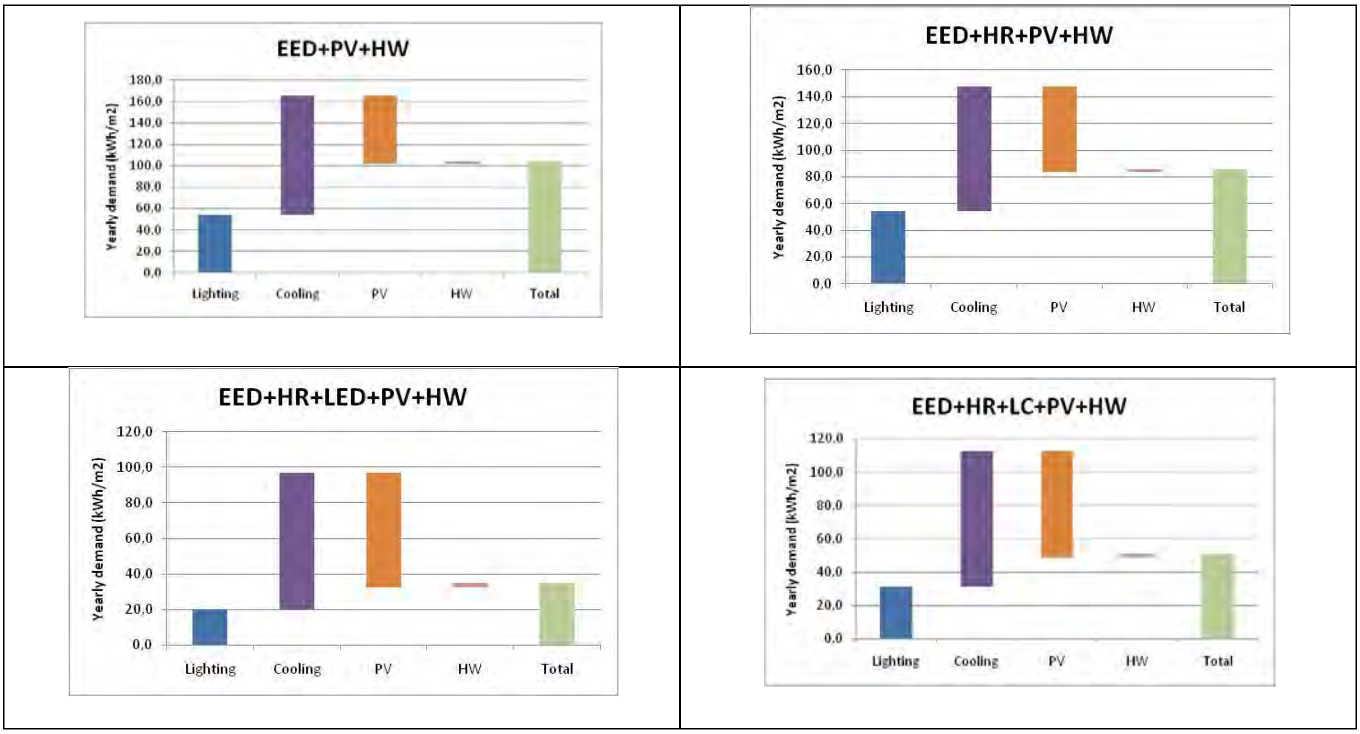
Models	Lighting	Cooling (electricity)	Cooling (thermal)	Total (light.+cool./ elect.)	Total (ligth.+cool /therm)	Improvement
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	
Baseline*(BD)	54,0	128,2	320,5	182,2	374,5	Ref (0%)
Baseline**(BD)	37,9	128,2	320,5	358,4	358,4	Ref (0%)
Energy Efficient B. (EED)**	54,0	111,7	279,3	165,7	333,3	9,1%
EED**+TR	54,0	93,7	234,2	147,7	288,2	19,0%
EED+TR+LC	31,3	81,3	203,2	112,6	234,5	38,2%
EED+TR+LL	20,3	76,6	191,4	96,8	211,7	46,9%
EED+TR+LL+LC	11,7	71,7	179,3	83,4	191,0	54,2%
EED+TR+LL+LC+PV	11,7	71,7	179,3	17,9	191,0	90,2%
EED+TR+LL+LC+PV+ST	11,7	71,7	179,3	16,5	191,0	90,9%

*without light control ** with light control (LC)

EEB: Energy Efficient Building
TR: Thermal recovery
LC: Lighting Control
LL: LED lighting
PV: Phtovoltaics
ST: Solar Thermal
COP: 2,5

Table 44. Total electricity demand considering lighting, cooling and generation

The following figure shows the contribution of each demand/generation to the final energy demand, for the medium case:



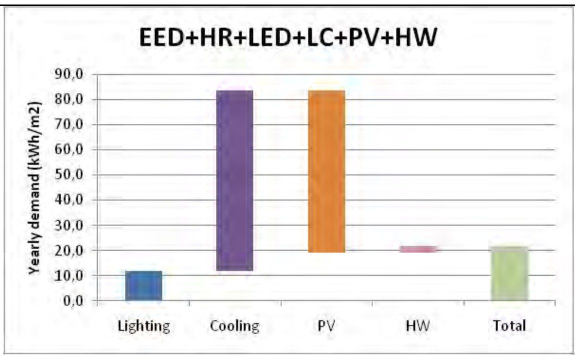


Figure 59. Medium building - Contribution of different energy services to total electricity demand (PV contribution is negative, decreasing total demand, HW is positive but lower than the real demand, due to the solar thermal contribution)

5. Life Cycle Cost

5.1 What is Life Cycle Cost Analysis

Life-cycle costs (LCCs) are all the anticipated costs associated with a project throughout its life. It considers all the cost of owning, operating, maintaining, and eventually disposing of a building, with all the costs adjusted (discounted) to reflect the time-value for money.

LCC Analysis is particularly suitable for the evaluation of building design alternatives that without compromising performance have a different initial investment cost, different operating and maintenance costs, different lifecycles and that perform differently in terms of energy savings.

Therefore, this type of analysis is especially suitable for energy conservation projects. In this way, alternative approaches for improving the thermal performance of the building, or increase their ventilation and lighting, are compared against a baseline model. They are energy efficiency measures that without compromising comfort, safety, reliability, aesthetics, and adherence to building codes and engineering standards, result in a reduction in the consumption of energy.

LCC analysis is especially useful to justify, from an economic point of view, the suggested conservation measures, especially when they involve an increase in the initial investment of a new building or incur extra costs for retrofitting them into an existing building. This is, the analysis helps to determine whether or not these measures are justified, based on the expected energy savings and other costs implications over their projected lifespan. They also help to compare measures aimed at attaining a similar result, and select the most cost-effective one (i.e. the one with the lowest life-cycle cost). And finally, it is also useful for prioritizing the allocation of funding, based on the compared economic performance of these energy efficiency measures.

5.2 Comparison with other methods

The ***Energy Payback Period*** **(EPP)** has been traditionally the method for comparing economic performance of an energy efficiency measure. This method refers to the period of time over which the energy savings of a project equal the initial investment.

For example, a measure with an initial investment of $4,000 and an expected annual savings of $1,000 has an EPP of 4 years.

This calculation has serious limitations because:

1. It does not account for the *time value of money*: the fact that the value of money does not remain constant all the time (i.e. $1,000 in the present are worth more than the same amount in the future);
2. It is not a measure of long-term economic performance because it only focuses on how quickly the initial investment can be recovered, ignoring all the costs and savings incurred after the point in time in which payback is reached;
3. It does not account for the *opportunity cost*; this is, that this money could had been invested in something else in exchange of a potentially higher return;

To overcome such limitations, alternative measures of 'return' are applied. They are measures based on the LCC analysis.

5.3 Measures based on the LCC analysis

There are three supplementary measures of economic performance that are consistent with the LCC method. These are **Net Present Value (NPV)**, **Internal Rate of Return (IRR)** and **Savings-to-Investment Ratio (SIR)**. Those measures do not simply add the expected savings or subtract the incurred costs regardless of the point in the future when they are attained, but instead they discount them to the present moment. To do this, they use the **Net Present Value (NPV)** of such potential savings and future costs.

The NPV is the current worth of a future stream of cash flows given a specified rate of return called *discount rate*. The *discount rate* operates in such a way so that the higher it is, the lower the present value of those future savings and maintenance costs, while for a *discount rate* equal to 0% this value remains constant over time. Costs are usually discounted using the investor's minimum acceptable rate of return.

Discounting the future stream of savings or costs helps these measures to overcome the first limitation of the EPP (i.e. that it does not account for the *time value of money*).

For example, imagine that the country is experiencing an annual increase in its level of prices of 3%. This rate of inflation is diminishing the future value of money as compared to their present value. At this 3% rate the present value (discounted value) of these $1,000 a year for the next four years is:

$$\$1,000/(1+3\%) + \$1,000/(1+3\%)^2 + \$1,000/(1+3\%)^3 + \$1,000/(1+3\%)^4$$

This is:

$$\$971 + \$943 + \$915 + \$888 = \$3,717$$

As it can be observed, the more far away in the future, the lower the present value of those $1,000. And when brought all of them to the present time, they do not add $4,000 anymore but $3,717 instead. Why? Because when we want to buy something in the future with those same $1,000 their purchasing power would have diminished due to a general increase in the level of prices of 3%.

Furthermore, any measure based on the LCC analysis will have to consider a larger life-cycle than simply the time it takes to recover the initiate investment. For a building it is usually around 30 years. In this way, measures based on the LCC analysis overcome the second limitation of the *payback period* (i.e. that it is not a measure of long-term economic performance).

For example, in the previous example perhaps the savings of the energy efficiency measure are expected only for the first 6 years, in which case their NPV is

$$\$1,000/(1 + 3\%) + \$1,000/(1+3\%)^{2} + \ldots + \$1,000/(1+3\%)^{6} = \mathbf{\$5,417}$$

or perhaps these savings are expected to continue all over the life-cycle of the building, with the building expected to last 30 years. In such case the NPV would be:

$$\$1,000/(1 + 3\%) + \$1,000/(1+3\%)^{2} + \ldots + \$1,000/(1+3\%)^{30} = \mathbf{\$19,600}$$

The difference in the NPV of this two streams of savings is considerable and this is why it is very important to also consider the long-term economic performance of the measure, something that the traditional EPP did not do.

Finally, to overcome the third limitation, the ***Internal Rate of Return*** **(IRR)** is used. The IRR is the rate of return that makes the net present value (NPV) of all savings (positive cash flows) and costs of maintenance (negative cash flows) from a particular energy efficiency measure equal to the original investment. This means that the higher the IRR obtained the better the measure. In this way, the IRR gives us a rate to be compared to the rate of return offered by alternative investments, thus measuring for the *opportunity cost*[6].

For example, let's imagine that the previous energy efficiency measure is expected to bring savings for the first 6 years only, in which case their NPV is $5,417. Considering that its initial investment is $4,000, what would be the rate of return (i) that equals the NPV of that stream of $1,000 a year in savings to $4,000

$$\$1,000/(1 + \mathbf{i}) + \$1,000/(1+\mathbf{i})^{2} + \ldots + \$1,000/(1+\mathbf{i})^{6} = \$4,000$$

This rate is 13%

This is:

$$\$1,000/(1 + \mathbf{13\%}) + \$1,000/(1+\mathbf{13\%})^{2} + \ldots + \$1,000/(1+\mathbf{13\%})^{6} = \$4,000$$

This 13% can then be compared to:

- *Cost of the loan required to finance such measure*
- *Weighted Average Cost of Capital (WACC)*[7] *of the organizations*
- *Alternative investments*

With what it is to be compared would depend on how this energy efficiency measure is to be financed:

- With a new loan from a financial institution (+liability) ⟶ Cost of the loan
- With a share capital increase (+equity) ⟶ WACC
- With the organization's own reserves (equity) ⟶ Alternative investments

[6] *Opportunity cost* is the cost of any activity measured in terms of the value of the next best second alternative.

[7] The WACC is the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, and other providers of capital, or they will invest elsewhere.

The third measure related to the LCC analysis that also provides valuable information is the ***Savings to Investment Ratio*** **(SIR).** Businesses use the savings-to-investment ratio to determine whether a project that aims to save money in the future is worth doing. The ratio compares the investment that the business has to put in now with the amount of saving the business will get from the project. It is calculated as the saving over the project's useful life divided by the cost of the project

SIR= Total savings / initial cost of the measure

A project has to have a saving-to-investment ratio of at least 1 to pay for itself.

> Following the above examples, for a measure with a capital cost of $4,000 and expected savings of $1,000 a year for a period of 6 years and a discount rate of 3% the SIR is:
>
> $5,417/$4,000 = 1.35
>
> The discount rate applied would had to be higher than 13% for the SIR to fall below 1, in which case it could be said that the project does not pay for itself.

5.4 Limitations of the LCC analysis

The LCC analysis is more accurate than the simple calculation of the *Energy Payback Period (EPP)*, nevertheless, it is not exempted from its own limitations, the three most important being:

1. It does not account for *externalities*
2. It is based on estimates and assumptions
3. It is not considering the increased resilience brought by an optimal design

Does not account for externalities

The LCC is a purely financial analysis that does not consider any of the costs not accounted in the financial statements of the organization. *Externalities* are an example of such costs. In economics an *externality* is "*a cost or benefit not transmitted through prices that is incurred by a party who did not agree to the action causing the cost or benefit*". A typical example is pollution. In the case of electricity generated by conventional energy, externalities come as air pollution with CO, NOx, sulfates and particulates, water pollution and soil pollution. Therefore, **when considering an energy efficiency measure, it should be taken into account that a diminution in energy consumption has always a positive effect in the environment**. For energy generated by fossil fuels, this positive effect translates in less air, water and soil pollution.

A way to overcome such limitation is by assigning a financial value to the externalities, so that they can be accounted in financial terms. The future introduction of a Carbon Tax is trying to do so, by putting a price to the CO_2 emissions associated with each kWh consumed or saved. Nevertheless, there are more externalities than these ones, and most of them are a lot more difficult to account for than CO_2 emissions.

Based on estimates and assumptions

The LCC analysis requires long-term estimations, sometimes 30 years into the future or even longer. Therefore, it is as accurate as the estimates and assumptions used in the analysis.

Estimating the future energy consumption in kWh of a building based on its design, materials and climate is easy. There are numerous software applications in the market specialized in calculating, with a good level of accuracy, such consumptions. What it is more difficult is to translate those future consumptions into future costs. This is, estimating what would be the price paid by the organization for each of these kWh consumed in the future.

In the case of the Caribbean countries, and considering how dependent they are on fossil fuels for electricity generation, these future prices of electricity correlate to a high degree to the future trend in oil prices. Caribbean countries usually base their estimations of future oil prices on the *reference case scenario* as published by the *U.S. Energy Information Administration* (EIA) on their annually published Global Energy Outlook.

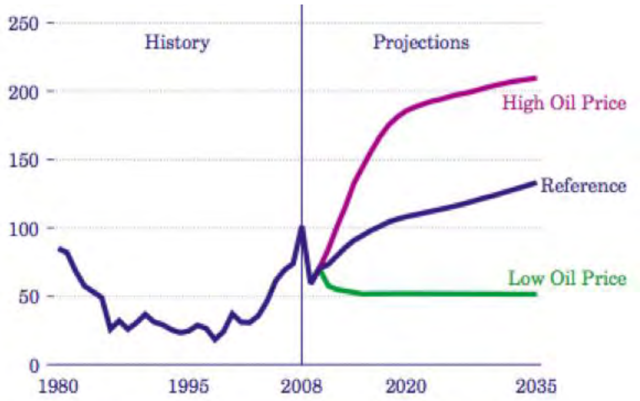


Figure 60-: Average annual world oil prices in three cases, 1980-2035 (2008 dollars per barrel)

Source: Global Energy Outlook 2011. EIA

Nevertheless, considering several different factors as explained in Annex II, it is reasonable to expect that the future trend will be rather the *High Oil Price* case instead of the *Reference* one. This means that energy efficiency alternatives that are not considered financially viable when estimated under the *Reference case scenario* might become a lot more viable when considered under the *High Oil Price* case scenario. The energy efficiency measure would not have changed. The expected savings in terms of kWh per m^2 and year will also remain the same. And the only variable that would have changed to offer a SIR that is now higher than 1, or an IRR that is now higher than the fixed interest rate paid for a loan, is an increase in the estimated future prices of electricity.

For example, an organization has to choose between two possible options:

1. A business as usual approach,
2. An energy efficient approach, which involves an additional investment of $10,000 and savings of 5,000 kWh a year for the next 15 years.

What would be the more viable option considering that the current electricity price is 20 cents of dollar per kWh?

The answer would depend on the percentages applied for the increase in electricity prices and the discount rate. For example:

For an expected increase in electricity prices of 3% a year and a discount rate of 12% a year, the business as usual approach is financially preferable, because the NPV of the future savings is $8,187, which is lower than the $10,000 in extra investment (SIR = 0.82)

But for an expected increase in electricity prices of 8% a year and the same discount rate, the energy efficiency approach is financially more viable, with a NPV of the future savings of $11,352 (SIR=1.13).

To partially overcome this limitation:

- It is best to use LCC analysis as an ongoing process that starts early in a project and is revised through all phases of a construction process, and
- It is advised to calculate it using interval arithmetic, in which each value is represented as a range of possibilities.

Does not consider the increased resilience brought by an optimal design

Resilience is defined as "*the positive ability of a system or company to adapt itself to the consequences of a catastrophic event*". Depending on the design of a building and on the building materials used in its construction, a building can become less dependent on electricity for cooling and lighting. This, in turn, makes its dwellers more resilient to climate change and to a potential disruption in energy supply. It should be taken into account that a building highly dependent on artificial cooling and lighting can be very vulnerable to an eventual power disruption to the point of not making it suitable for living.

A building that did not take into account the required climatic considerations, orientation and materials to offer passive strategies for cooling and lighting, might need to be vacated in the event of a blackout or require at least a power generator to continue making it habitable. This would create extra costs such as: the investment in power generator and the diesel used for generating the power, or the impossibility to continue working in the building due to extreme heat or lack of natural lighting. These are real costs that were not originally taken into account by a LCC analysis when considering whether to choose between a less resilient but perhaps cheaper building or one that is better adapted to its surrounding environment.

For example, the extra $10,000 of the above example are for a design that avoids the need of air-conditioning thanks to a natural ventilation system and offers a better natural light.

The organization applies a 3% increase in electricity prices at a 12% discount rate, obtaining a SIR of 0.82. As a result decides to go for the conventional (baseline) option.

Later on, due to frequent blackouts and brownouts, it quickly realizes that it needs to invest in a power generator. If the energy efficiency approach had been chosen, the building would not need air conditioning and would have a good source of natural light, without need for extra power. But as a result of choosing the conventional building, an extra investment of $1,000 is required for a power generator. The power generator produces electricity at a cost of $1 per kWh and it has to run for 10% of the time.

Under such circumstances, the difference in investment is not $10,000 anymore, but $9,000 (the original difference minus the cost of the power generator). And because the power generator produces electricity at $1 a kWh instead of 20 cents of a dollar, something that it is required for 10% of the time, the savings of the energy efficiency option become \$11,462 instead of the \$8,187 estimated at the beginning.

Therefore, due to the lesser resilience of the conventional approach, even at an expected 3% a year increase in electricity prices and 12% discount rate, the SIR of the energy efficient option increases from 0.82 to 1.27 the moment that the power generator is added into the equation. If the annual increase in electricity prices was 8%, then the SIR would then be 1.77.

This is how an option that financially looked less attractive, ends up being the more viable one thanks to the better resilience it offers to power shortages and future increases in the cost of energy.

Conclusions

The LCC analysis is a very valid method:

a. To evaluate the financial viability of investing in an energy efficiency measure and
b. To compare design alternatives that can perform the same function, in order to determine which one is the most cost effective for a certain purpose.

Nevertheless, it is not absent of its own limitation. Because of those limitations:

a. An energy efficiency measure, a better adapted design, or a more optimal material shall not be disregarded simply because it offers a SIR lower than 1 or a IRR lower than the interest rate paid for a loan or by an alternative investment;
b. Neither should it be disregarded when it involves a higher investment in the present time as compared to a less efficient alternative, with the NPV of the future savings being lower than the difference between the initial investments of both alternatives.

The purely financial approach taken by the LCC analysis is meant to guide the decision-making process, but it shall never determine alone what solution is to be taken. A more environmentally friendly approach, that consumes less energy and makes the building more resilient to climatic conditions and less dependent on artificial cooling and lighting will always be, in the long-term, the approach that pays-off at the end, even if at the beginning it was less optimal from a financial point of view.

5.5 Costs components in LCC Analysis

The typical costs to be considered in a LCC Analysis are:

1. **Initial project costs**: They include all the costs required for constructing the building. They are usually divided between 'soft' costs such as: *design fees, permits*, and 'hard' costs such as: *materials, labor, equipment, furnishing*, etc.
2. **Utility Costs**: They are usually divided between *Energy Utility Costs* such as: *electricity, gas, steam water*, and *Non-Energy Utility Costs* such as: *reticulated water, sewer services*.
3. **Maintenance cost**: they refer to those costs incurred to keep the building running properly. They are usually divided between:

a. *Preventive maintenance*: a pre-scheduled activity intended to keep the building in optimal conditions.
b. *Reactive maintenance:* also known as troubleshooting, it is performed in response to problems. Because they relate to unexpected failures, it is difficult to preview in advance the cost of such maintenance. Nevertheless, when preventive maintenance is performed properly, the need for troubleshooting shall be minimal. Usually they are considered in the LCC analysis as provisions.

4. **Service costs***:* They are costs that depend more on use it is made of a building rather than on its design or the materials utilized. For example: cleaning, pest control, etc. They are usually not considered in LCC analysis, however they should be included only if they differ according to the design alternatives.
5. **System replacements***:* it is the replacement of building systems at the end of their useful lives. Because of their planned nature, they can be easily considered in advance.

The relative weight of such costs would vary depending on a lot of factors. The graph below offers a sample distribution of such costs.

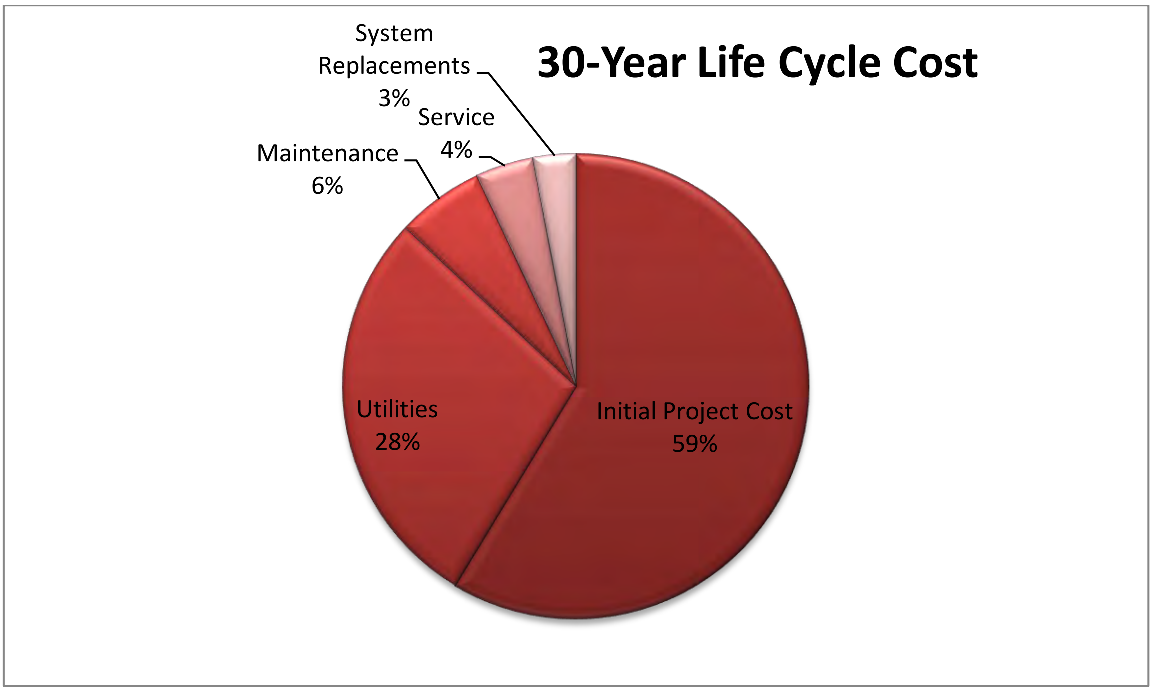


Figure 61- 30-Year Life Cycle Cost

Source: Guidelines for Life Cycle Cost Analysis. Stanford University. 2005

5.6 Base estimates for the Caribbean

Cost of living

The cost of materials and labor will not be the same in all the countries. The best method to account for these differences is by defining a cost of living indicator and indexing all costs for each country according to it.

The figures below show how much a bundle of goods and services costing US$1 in the US would cost in other countries. The data has been sourced from Global Property Guide. The figures result from the difference between the nominal GDP figures, and their purchasing power parity GDP figures for the latest year available. The information has been calculated using figures from the IMF World Economic Outlook Database.

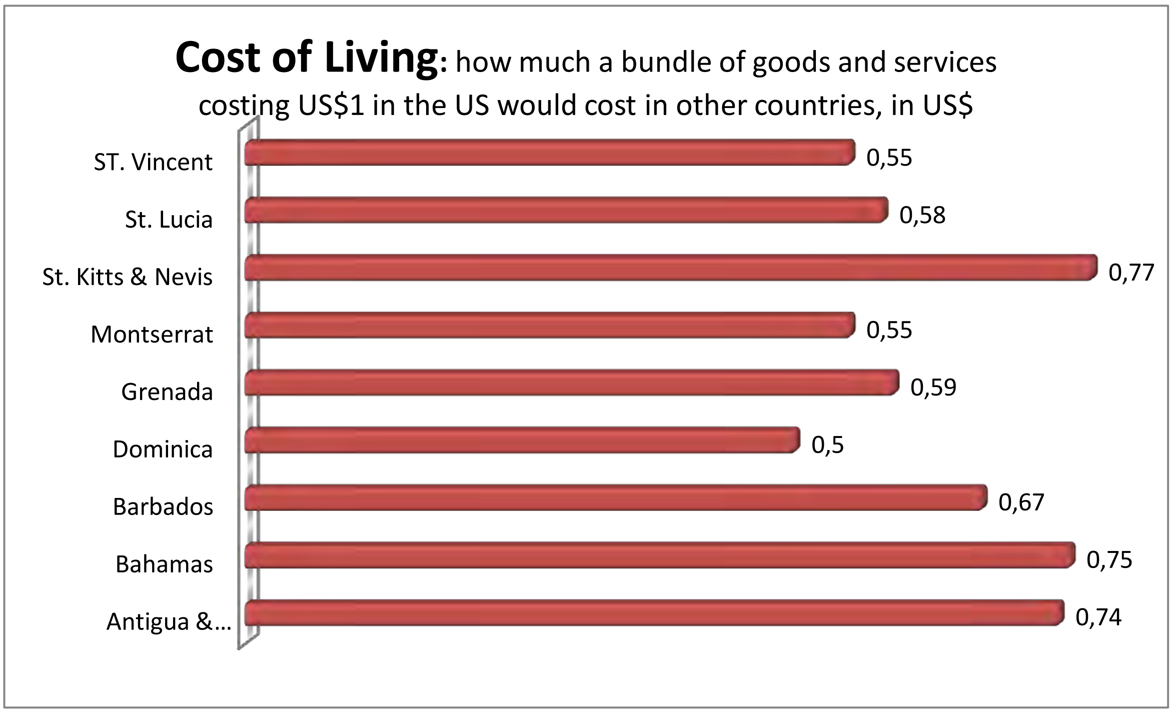


Figure 62- Comparative cost of living

Source: Global Property Guide. IMF World Economic Outlook Database

Projected future increase in general prices

In the Caribbean, those countries with 'true' floating exchange rates (Jamaica and Guyana), display a similar trend in their inflation rates, with rates oscillating around a certain average up until the 1990's, after which there is a spike in the data. While the inflation rates in countries with a fixed exchange rate (Barbados) or a managed float (Trinidad and Tobago), tend to evolve in a similar pattern to each other, which is different from those of floating exchange rate countries.[8]

All the currencies of the nine countries to be considered in this study are pledged to the US dollar[9]. Therefore, the inflation rates of those countries cannot diverge considerably from the expected inflation rate of the United States, or otherwise their economies would lose competitiveness forcing to devaluate their currencies.

Taking that into account it has been decided that instead of giving a diverging inflation rate to each country, all of them are going to be given an interval. This is a minimum inflation rate that might be expected, a reference rate and a high inflation rate.

The average inflation rate experienced for 2011 was 4.2%, with St. Kitts & Nevis as the country experiencing a higher increase in prices (9.8%) and St Vicent as the one that experienced the lowest increase (1.8%)[10]. During

[8] Kevin Greenidge and Dianna DaCosta "Determinants of Inflation in Selected Caribbean Countries".
[9] The Bahamian dollar (BSD) is pledged one to one. The Barbadian dollar (BBD) is pledged two to one. And the rest of the countries use the East Caribbean Dollar (XCD), which has been pledged to the US dollar since 1976 at the rate one USD to 2.70 XCD.
[10] Source: CIA Country Profiles

the previous period, from 2000 to 2006, the average inflation rate for the nine countries was 2.3%. The increase in prices of the last years in comparison with the early period of the last decade is due to the current monetization of the US debt and the increasing constrains in international food and energy supply.

1. The low inflationary case scenario considers the current spike in prices as a punctual event hoping that the countries will quickly return to the normality of the previous decade. Therefore, it considers an annual increase in prices of **2.5%**
2. A reference scenario considers that the monetizing of the US debt is going to take its toll on the US economy, causing inflation, which would quickly affect the Caribbean countries, especially those that have a currency pledged to the USD. The rate considered in this scenario is **5%**.
3. A third case scenario considers that the monetizing of the US debt, together with an expected increase in oil prices and constrains in international food supply due to climate change and expensive oil could cause several hyperinflationary events[11], with prices increasing an average of **10%** a year for the next 20 years.

Current electricity prices

The prices per kWh vary in each country and even in the same country, depending on the electricity supplier. According to the data provided by the Association of Caribbean Electric Utilities (CARILEC) the costs per kWh diverge from the 17 cents of USD paid in Bahamas by the customers of GB Power to the 48 cents of USD per kWh paid in Montserrat.

Name	Electricity Cost		
	Surveyed	*Year*	*2013*
	USD kWh		*USD kWh*
Antigua (APUA)	$0.38	2011	0.42
Bahamas (GB Power)	$0.16	2011	0.18
Bahamas (BEC)	$0.33	2008	0.44
Barbados (BL&P)	$0.38	2011	0.41
Dominica (DOMLEC)	$0.39	2010	0.44
Grenada (GRENLEC)	$0.39	2011	0.43
Montserrat (MUL)	$0.40	2009	0.49
Nevis (NEVLEC)	$0.31	2010	0.36
St. Kitts Electricity Department	$0.15	2007	0.21
St. Lucia (LUCELEC)	$0.32	2010	0.39
ST. Vincent (VINLEC)	$0.32	2010	0.37
Average	**$0.32**		**$0.38**

Table 45- Electricity Costs per country

Source: CARILEC. Association of Caribbean Electric Utilities

[11] Paper money only has a value because of the confidence that the money can be exchanged for a certain quantity of goods or services in the future. If this confidence is eroded, hyperinflation becomes a threat. If holders of cash start to question the future purchasing power of the currency and switch into real assets, asset prices start to rise and the purchasing power of money starts to fall. Other cash holders may realize the falling purchasing power of their money and join the exit from paper into real assets. *Source*: "Hyperinflation Revisited" from Caesar Lack

Projected future increase in electricity prices

All the nine countries are very dependent on the import of fossil fuels for electricity generation. Out of the nine countries, only Barbados produces oil, and even this amount only covers 14% of their internal consumption[12]. And out of the nine countries, only Dominica and St Vincent have hydro capacity, with a 6% and 3% of the electricity generated by this source of energy. The rest depend 100% on imported oil for electricity generation.

The relative weight of fuel imports as a percentage of the total imports vary from country to country from the 1.2% in Barbados to the 25.9% in St. Lucia or the 25.6% in Antigua & Barbuda. The average for the 9 countries is 19%.[13]

Name	Electricity from fossil fuels	Electricity from hydro	RE	Energy Self-sufficiency	Fuel imports (% of total imports)	Electricity use per capita (kWh yr)	Oil production (% consumpt.)
Antigua & Barbuda	100%	0%	0%	0%	25.6%	1,264	0%
Bahamas	100%	0%	0%	1%	23.1%	5,493	0%
Barbados	100%	0%	0%	18%	1.2%	3,481	14%
Dominica	72%	27%	1%	8%	17.2%	1,229	0%
Grenada	100%	0%	0%	7%	14.5%	1,777	0%
Montserrat	100%	0%	0%	n.a.	n.a.	n.a.	0%
St. Kitts & Nevis	100%	0%	0%	12%	n.a.	2,095	0%
St. Lucia	100%	0%	0%	2%	25.9%	2,040	0%
ST. Vincent	82%	18%	0%	6%	21.9%	634	0%
Source	*CIA*	*CIA*	*CIA*	*IRENA*	*IRENA*	*IRENA*	*CIA*

Table 46- Fuel dependency by country

Based on this, it is expected that countries with higher percentage of fuel imports and no alternative sources for the generation of electricity will experience higher increases in the prices of energy as compared to countries with oil or hydro resources. Therefore, for Barbados, the same scenario of general price increase has been considered for the scenario of increase in energy prices; for the rest the percentages are the ones above plus 2 points. This is:

1. A low inflationary scenario with a continued increase in energy prices of 3.5%, equivalent to the reference scenario published by the EIA in the Global Energy Outlook 2011.
2. A reference case scenario, characterized by an annual increase in electricity prices of 7% or 8% which would be caused by a combination of some of the events described in Annex II These events are meant to affect Caribbean countries more than the rest of the World taking into account their high

[12] Source: to CIA Country Profile.

[13] Source: IRENA Country profile. For Montserrat, St. Kitts & Nevis it has been estimated because they are not members of IRENA.

dependency on imported oil for electricity generation and the facts that they are at the end of the supply chain.

3. The third case scenario is an energy crisis, such as the ones experienced in 1973 and 1979, causing electricity prices to escalate by 18% a year. Annex II provides reasons to justify why such event is likely enough at least to be considered as one of the three potential case scenarios. It should be taken into account that this percentage reflects a nominal increase rate. As the US debt is monetized, the USD will lose value, and because oil is traded in USD, this will translate into relative increases in the oil price in USD terms. Countries with their currencies not pledged to the USD and less dependent on the import of fossil fuels for electricity generation would not experience such high increases. This is why all the countries considered in this study except Barbados (third scenario electricity inflation rate 16%) are "Extremely Vulnerable" to a future energy crisis, and only Barbados, as a producer of oil, is slightly less vulnerable than the others.

Discount rate

In LCC Analysis costs are usually discounted using the investor's minimum acceptable rate of return. For an investor that borrows the funding to finance the project, such minimum rate of return will be the rate at which commercial banks are lending money. This rate is related and always higher to the discount rate offered by the central bank. There are three centrals banks involved, one for each currency, and nine lending rates. Therefore, the discount rates to be applied will vary from country to country depending on what is the rate at which commercial banks lend money in that country.

Name	Central Bank Discount rate 2011	Commercial Bank Lending Rate
Antigua & Barbuda	6.5%	10.9%
Bahamas	4.0%	5.1%
Barbados	7.0%	8.7%
Dominica	6.5%	8.9%
Grenada	6.5%	10.7%
Montserrat	6.5%	8.6%
St. Kitts & Nevis	6.5%	9.2%
St. Lucia	6.5%	10.2%
ST. Vincent	6.5%	9.1%
Source	CIA	CIA
Average	6.3%	9.0%

Table 47- Discount rates per country

Source: CIA Country Profiles 2011

The above discount rates are expected to prevail in the low inflation case scenario of 2.5%. Nevertheless, in the event of a spike in general prices, central banks will be expected to apply a more constrained monetary policy by increasing discount rates. This, in turn, will increase the lending rates of the commercial banks. As a result the following real and nominal discount rates have been estimated for the other two case scenarios:

Name		Inflation		Discount Rate		
		General	*Electricity*	*General*	*General*	*Electricity*
		Estimated	*Estimated*	*Nominal*	*Real*	*Real*
Antigua						
USD kWh	Low Inflation	2.5%	3.5%	10.9%	8.2%	7.2%
	Reference	5.0%	8.0%	13.4%	8.0%	5.0%
	High Inflation	10.0%	18.0%	18.4%	7.7%	0.4%
Bahamas						
USD kWh	Low Inflation	2.5%	3.5%	5.1%	2.5%	1.5%
	Reference	5.0%	8.0%	7.6%	2.4%	-0.4%
	High Inflation	10.0%	18.0%	12.6%	2.3%	-4.6%
Barbados						
USD kWh	Low Inflation	2.5%	3.5%	8.7%	6.0%	5.0%
	Reference	5.0%	7.0%	11.2%	5.9%	3.9%
	High Inflation	10.0%	16.0%	16.2%	5.6%	0.2%
Dominica						
USD kWh	Low Inflation	2.5%	3.5%	8.9%	6.2%	5.2%
	Reference	5.0%	8.0%	11.4%	6.1%	3.1%
	High Inflation	10.0%	18.0%	16.4%	5.8%	-1.4%
Grenada						
USD kWh	Low Inflation	2.5%	3.5%	10.7%	8.0%	6.9%
	Reference	5.0%	8.0%	13.2%	7.8%	4.8%
	High Inflation	10.0%	18.0%	18.2%	7.4%	0.2%
Montserrat						
USD kWh	Low Inflation	2.5%	3.5%	8.6%	5.9%	4.9%
	Reference	5.0%	8.0%	11.1%	5.8%	2.8%
	High Inflation	10.0%	18.0%	16.1%	5.5%	-1.6%
St Kitts and Nevis						
USD kWh	Low Inflation	2.5%	3.5%	9.2%	6.5%	5.5%
	Reference	5.0%	8.0%	11.7%	6.4%	3.4%
	High Inflation	10.0%	18.0%	16.7%	6.1%	-1.1%
St. Lucia						
USD kWh	Low Inflation	2.5%	3.5%	10.2%	7.5%	6.5%
	Reference	5.0%	8.0%	12.7%	7.3%	4.4%
	High Inflation	10.0%	18.0%	17.7%	7.0%	-0.3%
ST. Vincent						
USD kWh	Low Inflation	2.5%	3.5%	9.1%	6.5%	5.4%
	Reference	5.0%	7.0%	11.6%	6.3%	4.3%
	High Inflation	10.0%	18.0%	16.6%	6.0%	-1.2%

Table 48- Projected future commercial bank lending rates and real discount rates – green values represent data obtained from literature or hypotheses; red values are calculations

5.7 Calculation Tool for LCC

The consultant team has developed an Excel based tool to develop the LCC calculations. The tools takes into account all of the above considerations.

D. Results – Baseline Design

The Baseline Design (BD) has been developed based on best practices gathered in several advanced codes used in the region (in terms of energy performance) and is a reference building that will be used to evaluate the performance of the Energy Efficient Design (EED) The BD has been developed to the point necessary to perform an energy simulation, The drawings of the BD can be found in Annex IV

The BD has also been strongly based on the Hall of Justice (HoJ) designs as received from the Eastern Caribbean Supreme Court stakeholders. The HoJ designs were adapted in order to begin to draft the BD drawings for the project.

Two sizes of building have been simulated: a small building of 3000 m2 and medium building of 6000 m2. . These sizes represent thoroughly the diversity of buildings that may be more frequent in the Caribbean islands.

Given the case-specific and particular architecture of the HoJ designs, which have been conceived to host the Eastern Caribbean Supreme Court buildings, a simplification and standardization of the inner distribution of the buildings has been implemented.

1. Building design

The following items describe the design considerations taken to standardize different floors:

a. Basement
   - A car parking area has been added, with road access to the street
   - The interior distribution and program has been simplified and reduced to spaces related to maintenance (trash, mail, warehouse, reception etc.)

b. First floor
   - Open office space is set in the inner areas, closed offices are set in the perimeter
   - Standard uses for office buildings are added: meeting rooms, café/lunch rooms, printer area etc.
   - Fenestration is installed at the height of sight.
   - The foyer is maintained and a reception and waiting area are added

c. Second floor
   - The medium building size includes an auditorium or room for presentations
   - Fenestration is installed at the height of sight.

d. Roof
   - The roof provides some protection to the facades; it has been defined following the rendered image provided by the reference documents about the HoJ.

2. Simulation considerations

The following are characteristics of the building operation, understood also as BD design features, that will be necessary to define in order to proceed with the energy performance simulation using Energy Plus software.

The source has either been:

- Reviewed codes (RC[14])
- Consultant team consideration (C)
- Stakeholder consultation (S)

[14] The codes establishing minimum/maximum values are Florida Building Code – Energy Conservation and the International Energy Conservation Code.

Simulation condition		Limiting Value	Unit	Source	Document
Activity/Control	Heating threshold temperature	22	ºC	RC	FBC
	Cooling threshold temperature	24	ºC	RC	FBC
Construction	External wall, above Grade	3,29	W/m2-K	RC	IECC-ASHRAE 90.1-2010
	Below Grade wall	6,47	W/m2-K	RC	IECC-ASHRAE 90.1-2011
	Flat roof	0,36	W/m2-K	RC	IECC-ASHRAE 90.1-2012
	Slab	4,15	W/m2-K	RC	IECC-ASHRAE 90.1-2012
	Infiltration	3,66	(m3/h)/m2	RC	IECC-ASHRAE 90.1-2012
Openings	Exterior glazing	40	%, WWR	RC	FBC-EC-2010
	Window transmittance	2,56	W/m2-K	RC	FBC-EC-2010
	Solar heat gain coefficient (SHGC)	0,25	-	RC	FBC-EC-2010
Lighting	Lighting energy	11,84	W/m2	RC	ASHRAE
HVAC	Mechanical ventilation on	Y	Y/N	C	-
	Cooling COP	3	COP	RC	ASHRAE

Table 49- Simulation Conditions from literature review (limiting values)

3. Input data

The following data have been determined by the consultant team in order to develop a BD simulation, using realistic building elements and hypotheses, all taking into account the values gathered during the literature review:

- Building use, occupancy and internal heat gains assumptions are used in the thermal study
- Opaque enclosures: Opaque enclosures have been defined based on the preliminary information gathered during the building code review
- Glazing: the Baseline Building has double glazing with air gap, with aluminum frame without thermal bridge break. The following table illustrates the properties of the glazing solution used

Simulation condition		**Value**	Unit
Activity	Occupation	0,110	per/m2
	Heat gain from occupation	120	W/pers
	Hot water	2-8	l/pers-day (small/medium)
	Heating threshold temperature	22	ºC
	Cooling threshold temperature	24	ºC
	Gain from computers and other elec. equ.	12	W/m2
Construction	External wall: all walls on facades.	2,402	W/m2-K
	Partitions:. Internal walls separating zones	2,116	W/m2-K
	Pitched roof. Hip roof	7,142	W/m2-K
	Flat roof. Enclosure between the building and the ventilated roof	0,359	W/m2-K
	Internal floor. Separates one floor from the other	0,597	W/m2-K
	External floor. Floor for overhanging parts (cantiliver).	0,597	W/m2-K
	Semi-exposed floor. Internal floor over underground.	0,644	W/m2-K
	Ground floor. Floor in contact with the ground.	3,39	W/m2-K
Openings	Exterior glazing		glazing type
	Exterior glazing	40	%, WWR
	Window transmittance	2,68	W/m2-K
	Solar heat gain coefficient (SHGC)	0,25	-
	Window shading	No	blinds etc.
	Local shading	Roof	overhangs etc.
Lighting	Lighting energy	11,84	W/m2
	Lighting control		type
HVAC	Mechanical ventilation on	Y	Y/N
	Cooling COP	3,1	COP

3.1 Climate data

The location selected for the energy simulation has been considered the most representative among several belonging to different islands focus of the study. This is the island of Guadeloupe (Latitude 16.00º, Longitude -61.72, Altitude 4.0 over sea level).

Computer simulations used a climate file containing climate data for such location; this file was created using Meteonorm software. The file includes hourly values of a complete year of dry bulb temperature, dew point temperature, relative humidity, solar radiation (global horizontal, direct normal and diffuse) and wind (direction and speed).

3.2 Geometry

Both buildings have two floors for office space, with an approximate surface of 2 305 m2 and 4 426 m2 respectively. There is an underground floor used for parking, which is considered not conditioned. Besides, the building has a 4 slope roof with a naturally ventilated space through a ventilation grille.

Figure 63 - Small (left) and Medium (right) buildings defining the Baseline Designs

The glazing surface from floors 0 and 1 has been determined with a proportion of 40% of the external wall surfaces. Only glazing from some walls in spaces not requiring such has been omitted. No solar shading elements have been considered, other than the roof overhang.

The following images show the 3D models created for both small and medium buildings.

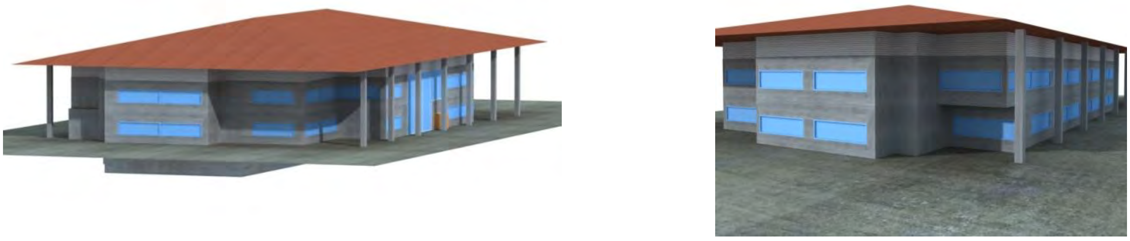


Figure 64- Perspective of the 3D Model of the Medium building

4. Results

4.1 Energy

The following results show the results for the energy needs of such buildings. This comes to cooling and lighting needs. The results are given for each month.

The results are given in terms of energy demand for lighting and energy demand for cooling.

The COP used by the simulation is equal to 1. This means that, in order to obtain the energy consumption of an HVAC equipment with a known COP or SEER, the cooling demand will simply have to be divided by such value.

Due to the climate conditions in the Caribbean, with a relatively high temperature and high relative humidity throughout the year, the cooling demand is high, especially the latent (humidity condensation and air de-humidification), as shown in the following figure.

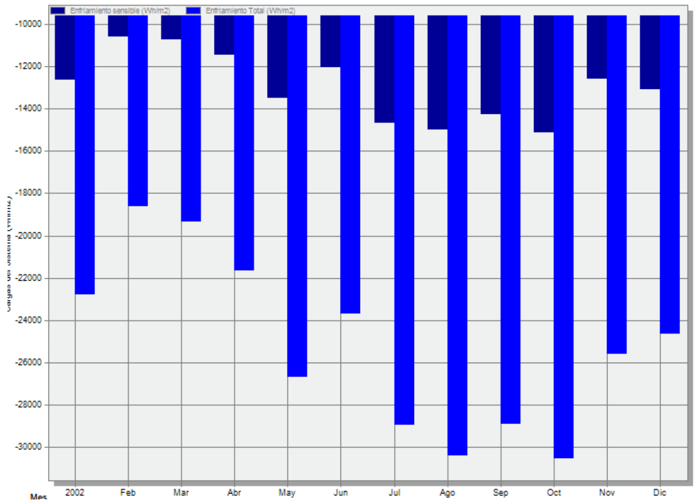


Figure 65- Cooling demand (dark blue stands for the sensible heat component, the bright blue is the total cooling demand)

To sum up, the relative and absolute and relative demand of the buildings is presented in the table below.

Both buildings have a very similar demand per square meter of HVAC area, since conceptually speaking, both buildings are very similar, the only main difference being their size. The compactness factor, as shown in the table, are very similar, they only differ 10%. In terms of electricity consumption, on top of the share related to lighting (20 W/m2 and schedules as described at the beginning of C.1.1), the HVAC system demand is calculated using the simulation result of cooling demand, assuming an average seasonal performance SEER of 2.

		Baseline Design	
		Small building	**Medium building**
Conditioned area	m2	2.305	4.426
Conditioned volume	m3	9.220	17.704
Glazed surface	m2	571	688
Compactness	m3/m2	2,59	2,88
Cooling demand, yearly	kWh/m2	302	258,00
Lighting demand, yearly	kWh/m2	37	41
Electricity demand	kWh/year	433.340	752.420
Specific electricity demand	kWh/m2	188	170

Table 50- Summary of features and energy demand of Baseline Design buildings

The Baseline Design incorporates several good practices found in current building codes from the region or other reference countries, namely:

- Solar protection of the flat roof and ventilated roof.

- Limited glazed surface (below 50%)
- Low solar heat gain factor windows.
- Daylighting controls to control artificial lighting depending on available daylight.
- The orientation given is the optimal with the North and South-oriented facades being the largest ones.

Thus, the energy demand of the Baseline Design can be considered low compared to the equivalent buildings of the building stock.

4.2 Cost

Estimated construction costs of the two baseline designs

In LCC analysis, it is the cost difference between alternatives what is usually important, rather than the absolute costs. Cost breakdowns, therefore, only need to be developed for the components that vary between alternatives. Keeping this in mind, there is no need for a detailed cost composition of the common different structural elements for each of the two buildings models (Baseline and Efficient). Instead, an estimation of the construction cost per square meter is provided.

The above information provides an expected range of the construction costs for each of the two baseline buildings of:

Baseline	Estimated Minimum Construction Cost	Estimated Maximum Construction Cost
Small Building (3,000 sqm)	US$ 4.3 Million	US$ 6.3 Million
Medium Building (6,100 sqm)	US$ 8.8 Million	US$ 12.7 Million

Table 51- Estimated construction cost (source: based on stakeholder consultations)

LCCA for the cost of electricity

The LCC analysis for the cost of electricity has been done using the values below as the estimated consumption of electricity per square meter of air-conditioned surface.

Baseline	Surface		Consumption of Electricity	
	Total	*Air-conditioned*	*Total*	*sqm*
	sqm	*sqm*	*kWh/yr*	*kWh/yr*
Small Building	3.000	2.305	433.340	188
Medium Building	6.100	4.426	752.420	170

Table 52-: Simulation results of energy demand

Then a 20-year LCC has been done considering the three case scenarios for inflation and discount rates described before. Considering the diverging price per kWh depending on the power company involved, this projection has been done for each of the 11 power companies. The results are shown in the two graphs below:

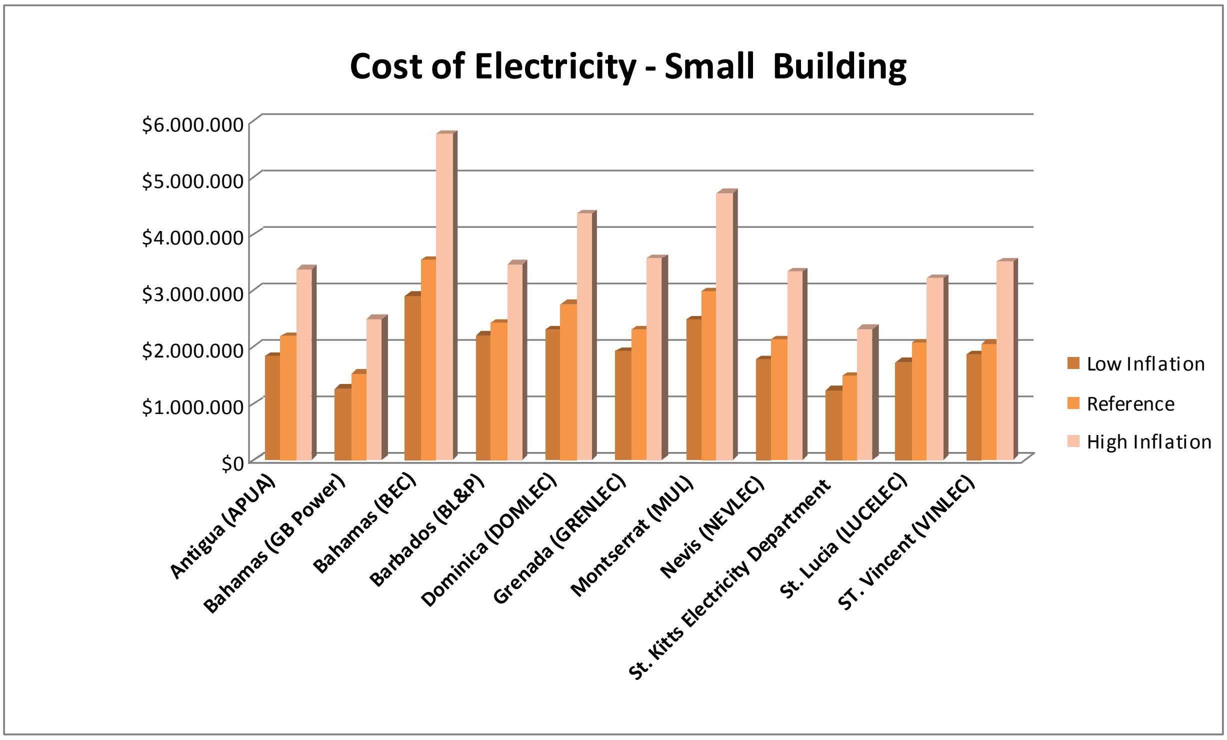


Figure 66- Estimated cost of electricity for a 20-year cycle for the small court building.

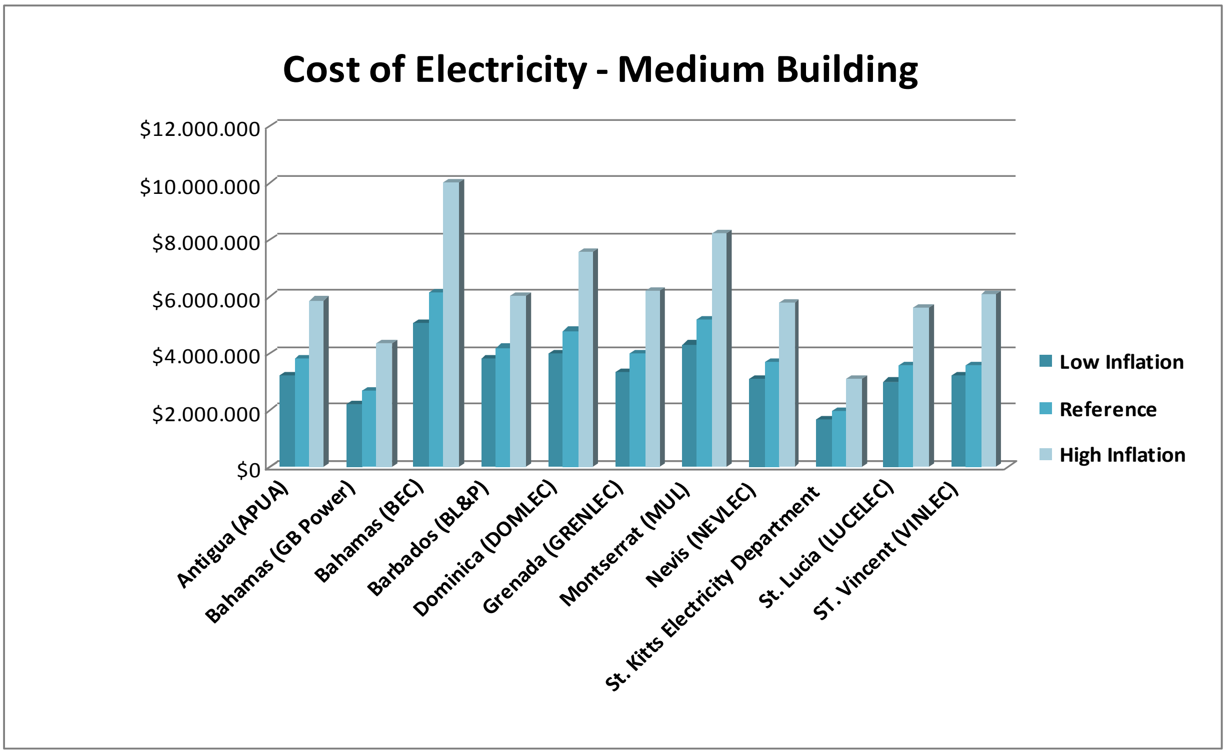


Figure 67- Estimated cost of electricity for a 20-year cycle for the medium building.

When these values are compared to the estimated construction cost for the building the results are:

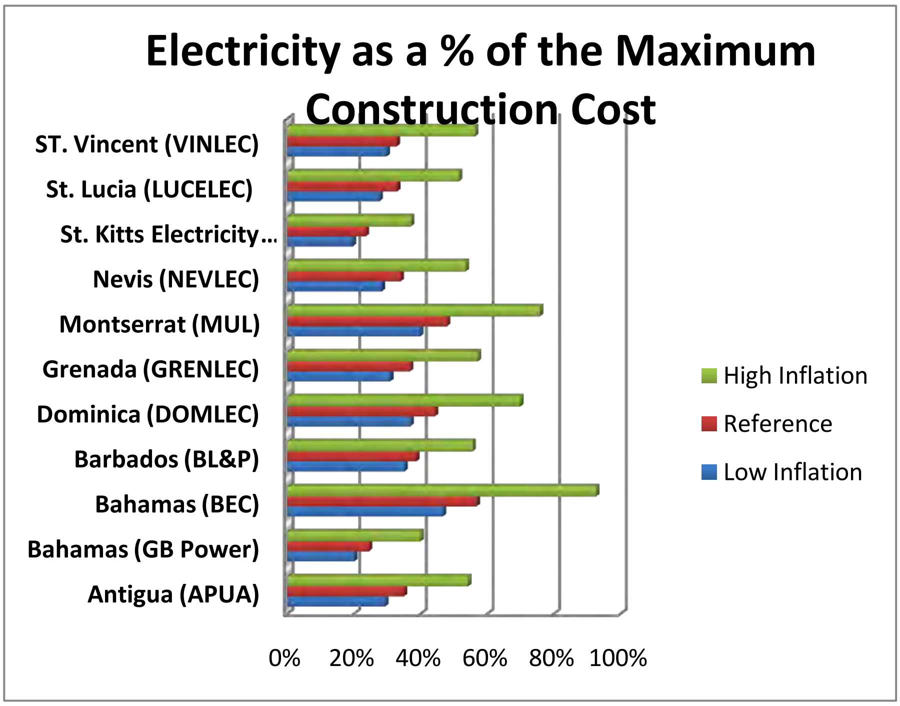


Figure 68- Estimated cost of as a percentage of the Minimum Construction Cost (Small building).

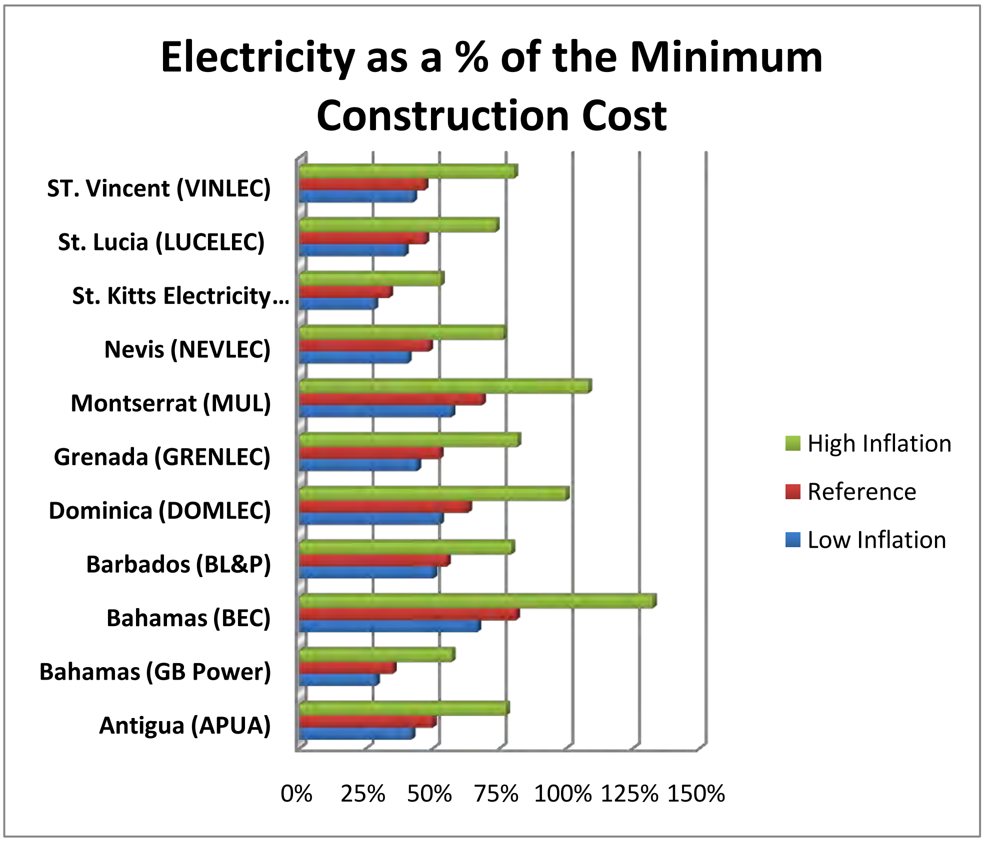


Figure 69- Estimated cost of as a percentage of the Maximum Construction Cost (Medium Building).

In some instances, such as the ones for the minimum construction cost, high inflation case scenario and power utilities with expensive electricity such as MUL (Montserrat), BEC (Bahamas) the cost of electricity for a **20-year cycle** could even be higher than the initial construction cost.

The average cost of electricity for the small building as a percentage of the construction cost for the average case scenario (*Reference*) and estimated for the mean construction cost is **45%** and for the medium size building is **37%.** The difference in values is mostly due to the fact that the medium building is using air-conditioning only in a 72% of its surface area and at an efficiency of 170 kWh/sqm per year while the small building is using air-conditioning in a 77% of its surface area and at an efficiency of 182kWh/sqm per year.

Based on all this information, the LCC analysis for all the costs categories, at the mean construction cost and as an average for all the countries is:

	Building			
	%	*Small*	*%*	*Medium*
Initial Project Cost	60%	$5,281,500	63%	$10,739,050
Utilities	26%	$2,303,980	23%	$3,948,286
Maintenance	6%	$546,362	7%	$1,110,936
Service	4%	$364,241	4%	$740,624
System Replacements	3%	$264,075	3%	$536,953
TOTAL	**100%**	**$8,760,158**	**100%**	**$17,075,849**

Table 53- Estimated costs of the LCC Analysis

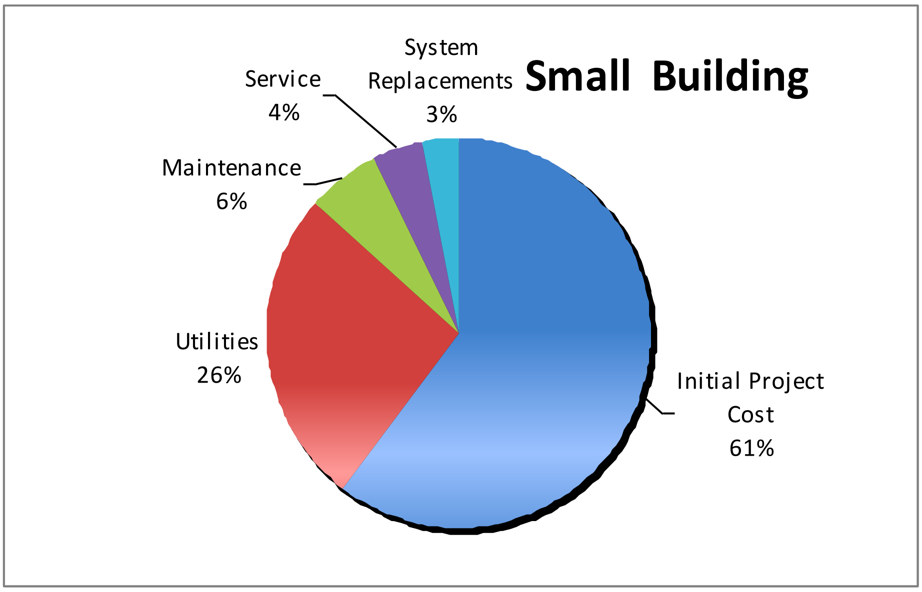


Figure 70- LCC Analysis for the small office building

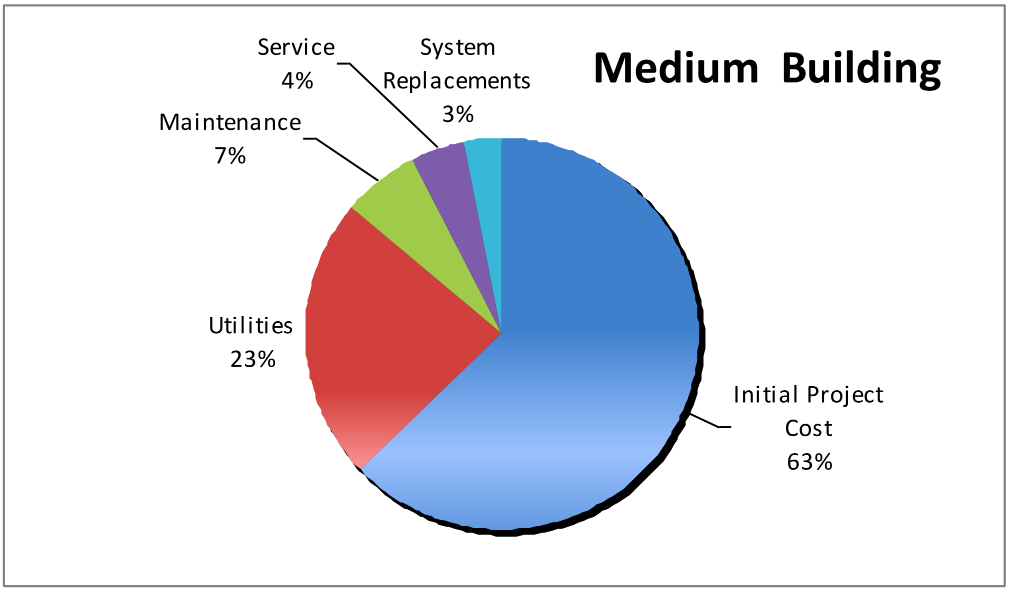


Figure 71- LCC Analysis for the medium office building

E. Life Cycle Costs Comparison

1. Introduction

In LCC analysis, it is the cost difference between alternatives what is usually important, rather than the absolute costs. Cost breakdowns, therefore, only need to be developed for the components that vary between alternatives. Keeping this in mind, there is no need for a detailed cost composition of the common different structural elements for each of the two buildings models (Baseline and Efficient). Instead, an estimation of the construction cost per square meter is provided. Instead, the breakdown of the costs that differ between the two alternatives is considered.

In this chapter, the LCC tool developed has been used to do two types of studies; when alternatives are compared, one is labeled 'the baseline' while the other is 'the energy efficient' one. The baseline technological solution generally involves a lower initial project cost, lower maintenance, service and replacement costs but higher electricity consumption.

The LCC analysis has been done in two different ways:

1. As a *Whole building*: comparing the performance of the BD against the EED, at whole building level.

   Given *the existence* of complex interaction between some variables, it was not always possible or convenient to isolate the incidence of a single variable. For example, the need and performance of a heat recovery system is not the same when fluorescent lighting is used, which dissipates more heat as compared to LED. In such cases, the analysis has been done considering the building as a whole. As a result the cost of the Baseline Design has been compared to the following five alternatives shown in chapter C.4:

   - EED: This is the Energy Efficiency Design with all the "architectural" improvements explained in chapter C.2 (but no lighting fixtures changed, for example, compared to BD).
   - EED+HR: The basic EED building plus heat recovery (HR).
   - EED+HR+LED: the basic EED plus heat recovery (HR) and LED lighting.
   - EED+HR+LC: The basic EED plus heat recovery and lighting control (LC).
   - EED+HR+LED+LC: The above EED plus heat recovery, LED lighting and light control.

   This has been done for both Small and Medium BD-EED comparisons; NPV, IRR and SIR are calculated for each of the comparisons.

2. *Isolated Incidence*: for the rest of the cases it was possible to isolate the incidence of one variable. This part of the study is done using the results from the Parametric Study presented in C.1.

   In this case, the results of the calculations are given under a different perspective. Instead of studying NPV, IRR and SIR as a result of a cost difference, the tool is used to calculate *"the cost difference for the Energy Efficient alternative compared to the Baseline alternative, so that the energy savings obtained make the investment worth (SIR=1)"*. Thus, the threshold values are sought; it is all further explained in chapter E.4.3.

2. Assumptions for LCC analysis

The LCC analysis between the two alternatives is based on the following assumptions:

1. The LCC is for a 20 year cycle
2. Three inflationary scenarios have been considered for both general prices and future prices of electricity. This made possible to work with triangular fuzzy numbers[15]. The use of fuzzy arithmetic made possible to apply the same inflationary scenarios to all the ten countries studied, since all of them are expected to experience future price increases between the interval considered and close to the reference scenario.
3. The same *real discount rate* has been considered for the three scenarios and nine countries. The rate is 4.6%. This figure is the result of comparing the average lending rate of 9% and average inflation rate of 4.2% in 2011 for the nine countries.[16] The justification for applying the same rate in the three scenarios is based on the fact that increases in the general level of prices will tend to increase both the country's interest rate and the lending rate offered by the commercial banks, thus keeping the real discount rate oscillating around the estimated figure of 4.2%. When this fixed rate is applied to the three inflationary scenarios the following *nominal discount rates* are obtained:

GENERAL	*Min*	*Ref*	*Max*
Inflation	2.5%	5.0%	10.0%
Nominal Disc. Rate	7.2%	9.8%	15.1%

Table 54. General variables for case scenarios

The justification for applying the same *real discount rate* in all the countries is based on the use of triangular fuzzy numbers for the inflation rates. Fuzzy numbers for defining inflationary scenarios already provide an interval wide enough [2.5%, 5%, 10%] to be applied in all the countries and a subsequent interval for the *nominal discount rate* [7.2%, 9.8%, 15.1%] that fits in all the countries.

4. The estimated future increase in energy prices is also based on the scenarios (low inflation, reference and high inflation) and the use of triangular fuzzy numbers. The rates are [3.8%, 8%, 18%]. Each rate is related to an inflationary scenario for the general level of prices (e.g. the reference energy inflation rate of 8% is related to the 5% annual increase in general prices). This is justified by the high correlation existing between cost of energy and inflation of general prices. This is especially true in economies that are very oil dependent for transport of goods and electricity generation such as the ones analyzed.
5. The result of applying the *nominal discount rates* of [7.2%, 9.8%, 15.1%] to the electricity inflation rates of [3.5%, 8%, 18%] is a set of three *real discount rates for energy*, which are [3.6%, 1.7%, -2.5%], each one related to a different *inflation rate*.

[15] A fuzzy number is a quantity whose value is imprecise, rather than exact as is the case with "ordinary" (single-valued) numbers. A triangular fuzzy number is an interval, with a minimum and a maximum value, plus a reference value in between, considered to be the more likely outcome.

[16] The *real discount rate* is the result of applying the formula: *real discount rate* = [(1 + *nominal discount rate*) / (1 + *inflation*)] -1. The data for estimating the average rates is based on the CIA Country Profiles.

ELECTRICITY	Min	Ref	Max
Inflation	3.5%	8.0%	18.0%
Real Discount Rate	3.6%	1.7%	-2.5%

Table 55. Energy variables for case scenarios

6. Considering that the prices per kWh diverge between the countries, these *energy inflation rates* and *real discount rates* have been applied for each of the eleven power utilities involved. The result is a different value for the NPV, IRR and SIR depending on the energy supplier for the building. This means that some measures might be viable in regions where the energy is expensive, with the savings justifying the higher initial investment of the EED solution, while in other areas or countries where energy is cheaper they might not be viable from a purely financial point of view. This made necessary to itemize the information by power utility.

Table 56. Cost of Electricity per country

3. Interpretation of Results

As explained in the previous section C.5, the use of three inflationary scenarios by applying triangular fuzzy numbers made possible to define a set of variables common to all the countries and power utilities. These variables were:

GENERAL	Min	Ref	Max
Inflation	2.5%	5.0%	10.0%
Nominal Disc. Rate	7.2%	9.8%	15.1%
ELECTRICITY	Min	Ref	Max
Inflation	3.5%	8.0%	18.0%
Real Discount Rate	3.6%	1.7%	-2.5%

Table 57. Inflation and Discount Rates

Other types of variables will vary depending on the currency, country and power utility. These variables that vary are:

1. *Interest Rate:* The interest rate applied by the central bank to the banking system varies depending on the currency used. There are a total of three currencies involved (BSD, BBD & XCD) and therefore three different rates. These rates are used for the purpose of evaluating the Internal Rate of Return (IRR) only. They are not used to calculate the *Net Present Value* (NPV) because they are not fixed, making it preferable to use a case scenario approach instead, as mentioned above. Furthermore, investors are not going to make their LCC analysis based on the interest rates offered by the central bank but by their *Weighted Average Capital Cost* (WACC) a value, which is closer to the country's lending rate than to the interest rate.
2. *Average Commercial Banking Lending Rate:* This is the average rate at which commercial banks are lending capital to businesses. There are a total of nine rates involved.
3. *Cost of electricity*: There are a total of eleven power utilities involved.

This set of data is presented in the following table:

Power Utility	Cost kWh	Year	Interest Rate	Lend. Rate
Antigua (APUA)	$0.38	*2011*	6.5%	10.9%
Bahamas (GB Power)	$0.17	*2012*	4.0%	5.1%
Bahamas (BEC)	$0.33	*2008*	4.0%	5.1%
Barbados (BL&P)	$0.38	*2011*	7.0%	8.7%
Dominica (DOMLEC)	$0.39	*2010*	6.5%	8.9%
Grenada (GRENLEC)	$0.39	*2011*	6.5%	10.7%
Montserrat (MUL)	$0.40	*2009*	6.5%	8.6%
Nevis (NEVLEC)	$0.31	*2010*	6.5%	9.2%
St. Kitts Elec. Dep.	$0.29	*2011*	6.5%	9.2%
St. Lucia (LUCELEC)	$0.32	*2010*	6.5%	10.2%
ST. Vincent (VINLEC)	$0.32	*2010*	6.5%	9.1%
Average	**$0.33**		**6.1%**	**8.7%**

Table 58. : Information itemized by locations

The result is the itemization of the data in eleven rows, according to the number of power utilities. Values are therefore offered for each of these eleven rows, three variables for the LCC analysis (i.e. NPV, IIR, and SIR) and the three case scenarios (i.e. low inflationary, reference, and high inflationary). Data is to be interpreted as follows:

Net Present Value:

The table offers the NPV according to the three case scenarios. Negative values have a red light, positive values but lower than $1,000 have an orange light, while positive values above $1,000 have a green light.

Power Utility	Net Present Value (NPV) Savings		
	Min	Ref	Max
Antigua (APUA)	$5,912	$11,351	$29,457
Bahamas (GB Power)	-$14,407	-$12,045	-$4,183
Bahamas (BEC)	$1,187	$5,910	$21,634
Barbados (BL&P)	$5,912	$11,351	$29,457
Dominica (DOMLEC)	$6,857	$12,439	$31,022
Grenada (GRENLEC)	$6,857	$12,439	$31,022
Montserrat (MUL)	$7,802	$13,528	$32,587
Nevis (NEVLEC)	-$703	$3,734	$18,505
St. Kitts Elec. Dep.	-$2,593	$1,558	$15,375
St. Lucia (LUCELEC)	$242	$4,822	$20,069
ST. Vincent (VINLEC)	$242	$4,822	$20,069
Average	**$1,573**	**$6,355**	**$22,274**

Table 59. Sample NPV analysis

For example, the above table shows that the EED solution is financially viable in all the power utilities except for Bahamas (GB Power), while for Nevis (NEVELEC) and St Kits (St Kits Elec. Dep.) it might not be viable in a low inflationary case scenario.

As a previous step for the above result, the excel tool calculates the NPV of electricity savings and then compares them to the NPV of all costs. The NPV of electricity savings is the NPV of the costs due to a reduced electricity demand for the given design alternative.

Power Utility	Cost kWh	Year	Interest Rate	Lend. Rate	NPV Electricity Savings		
					Min	Ref	Max
Antigua (APUA)	$0,38	2011	6,5%	10,9%	$96.425	$111.029	$159.644
Bahamas (GB Power)	$0,17	2012	4,0%	5,1%	$41.869	$48.210	$69.319
Bahamas (BEC)	$0,33	2008	4,0%	5,1%	$83.738	$96.420	$138.639
Barbados (BL&P)	$0,38	2011	7,0%	8,7%	$96.425	$111.029	$159.644
Dominica (DOMLEC)	$0,39	2010	6,5%	8,9%	$98.963	$113.951	$163.846
Grenada (GRENLEC)	$0,39	2011	6,5%	10,7%	$98.963	$113.951	$163.846
Montserrat (MUL)	$0,40	2009	6,5%	8,6%	$101.500	$116.873	$168.047
Nevis (NEVLEC)	$0,31	2010	6,5%	9,2%	$78.663	$90.577	$130.236
St. Kitts Elec. Dep.	$0,29	2011	6,5%	9,2%	$73.588	$84.733	$121.834
St. Lucia (LUCELEC)	$0,32	2010	6,5%	10,2%	$81.200	$93.498	$134.437
ST. Vincent (VINLEC)	$0,32	2010	6,5%	9,1%	$81.200	$93.498	$134.437
Average	**$0,33**		**6,1%**	**8,7%**	**$84.776**	**$97.615**	**$140.357**

Figure 72. NPV of electricity savings (example) – the color of the fields only means it is a calculation by the tool and not an user input value.

Internal Rate of Return

Businesses will consider the IRR an opportunity cost or a financial cost depending on whether they are applying their own equity to finance the EED solution or borrowing the funds from a financial institution.

- If they use their own equity, they will compare this value against the return offered by bonds or similar investments. The interest rate offered by the central bank is a good approximation to such value.

- If they are borrowing the funds from a financial institution, they will compare it against their own *Weighted Average Cost of Capital* (WACC). In such case, the best approximation to this value is the lending rate offered by the country's commercial banks.

This is why the color system for the IRR is based on:

1. *Red Light:* When the IRR falls below the *interest rate*.
2. *Orange rate:* When the IRR falls between the *interest rate* and the *lending rate*.
3. *Green light:* When the IRR is higher than the *lending rate*.

Power Utility	Interest Rate	Lend. Rate	Internal Rate of Return (IRR) Min	Ref	Max
Antigua (APUA)	6.5%	10.9%	8.1%	12.3%	21.5%
Bahamas (GB Power)	4.0%	5.1%	-0.2%	3.7%	12.5%
Bahamas (BEC)	4.0%	5.1%	6.5%	10.6%	19.8%
Barbados (BL&P)	7.0%	8.7%	8.1%	12.3%	21.5%
Dominica (DOMLEC)	6.5%	8.9%	8.4%	12.6%	21.8%
Grenada (GRENLEC)	6.5%	10.7%	8.4%	12.6%	21.8%
Montserrat (MUL)	6.5%	8.6%	8.7%	12.9%	22.2%
Nevis (NEVLEC)	6.5%	9.2%	5.8%	9.9%	19.0%
St. Kitts Elec. Dep.	6.5%	9.2%	5.1%	9.2%	18.3%
St. Lucia (LUCELEC)	6.5%	10.2%	6.1%	10.3%	19.4%
ST. Vincent (VINLEC)	6.5%	9.1%	6.1%	10.3%	19.4%
Average	**6.1%**	**8.7%**	**6.5%**	**10.6%**	**19.7%**

Table 60. Sample IRR analysis

In the above sample, the IRR is higher than the lending rate in all the countries for the high inflationary case scenario, but as we move to the other two case scenarios it starts falling below the lending rate first and then below the interest rate.

Savings to Investment Ratio (SIR)

The SIR, as its name indicates, is the ratio between the savings and the investment of a particular financial investment case. SIR equal to 1 mean that the savings equal the investment. Higher values are good results and lower than one results are negative results in which the investment would not be recovered.

For the SIR the criteria are:

1. *Red Light:* For a SIR below 1
2. *Orange light:* For a SIR between 1 and 2
3. *Green light:* For a SIR above 2

Power Utility	Savings to Investment Ratio (SIR)		
	Min	Ref	Max
Antigua (APUA)	1.2	1.4	2.0
Bahamas (GB Power)	0.5	0.6	0.9
Bahamas (BEC)	1.0	1.2	1.7
Barbados (BL&P)	1.2	1.4	2.0
Dominica (DOMLEC)	1.2	1.4	2.0
Grenada (GRENLEC)	1.2	1.4	2.0
Montserrat (MUL)	1.3	1.5	2.1
Nevis (NEVLEC)	1.0	1.1	1.6
St. Kitts Elec. Dep.	0.9	1.1	1.5
St. Lucia (LUCELEC)	1.0	1.2	1.7
ST. Vincent (VINLEC)	1.0	1.2	1.7
Average	**1.1**	**1.2**	**1.7**

Table 61. Sample SIR analysis

4. LCC Comparison

In order to provide an input for the LCC calculations, those cost components related to energy efficiency have been regarded, using values from a cost database; these should be checked for consistency with current Caribbean prices.

The study shown here is focused on the differences existing between the EED and BD buildings in such energy efficiency related components. The BD, as explained in chapter D**Error! Reference source not found.** does incorporate some energy efficient measures due to the fact that these are already considered in some building codes that were regarded during the initial review. However, these may not be common practice in the current constructions in the region or in the existing buildings.

Before presenting the cost data considered, the criteria for the cost analysis are presented, related to the EED energy efficiency strategies.

Shape

The shape change between the BD and EED is not big, as both are rectangular buildings. The main changes are that the EED presents 3 stories and the BD 2 and that the higher proportion of large and small facades in the EED makes it have even larger façade surface. The medium building is composed of two blocks of the small building block, connected by an access module. The cost differences due to these parts have been considered within the cost group related to the change of roof and is detailed in the following point.

Protected roof

The BD models, small and medium, have a ventilated roof that enables solar protection of the roof in the last floor and permanent ventilation. Besides, it allows for rainwater evacuation. In both models of the EED, the roof in the last floor is a flat roof, with a ventilated and floating floor. Besides, a PV pergola and solar thermal collectors are installed on top of it, covering the biggest part of the roof only leaving some free space for cooling equipment. The aim of this PV pergola is to protect the flat roof from the incident radiation and to ventilate it.

That is, both buildings have a ventilated roof.

The cost analysis has considered the structure of the flat roof, the tilted roof, the PV pergola, its protecting façade, the ventilation grilles and façades; total surface of each and cost per sqm have been regarded.

	EED	BD	Difference
Pitched roof columns	$0.00	$21,153.54	-$21,153.54
Ventilation grills	$0.00	$14,265.62	-$14,265.62
Pitched roof(PV vs vent. roof)	$193,200.00	$119,431.75	$73,768.25
Flat roof	$71,610.65	$127,876.16	-$56,265.51
Facades	$100,941.47	$67,151.01	$33,790.46
TOTAL	$365,752.12	$349,878.08	$15,874.04

Table 62. Cost breakdown comparison of roof, BD and EED small building

	EED	BD	Difference
Pitched roof columns	$0.00	$12,339.56	-$12,339.56
Ventilation grills	$0.00	$16,980.53	-$16,980.53
Pitched roof(PV vs vent. roof)	$386,280.00	$171,518.08	$214.761,92
Flat roof	$143,221.30	$215,779.18	-$72,557.88
Facades	$201,882.94	$79,858.98	$122,023.97
TOTAL	$731,384.24	$496,476.32	$234,907.92

Table 63. Cost breakdown comparison of roof, BD and EED medium size building

The above table, calculated for the small building (3034 m2) and de medium size building (5944 m2), the comparison between the absolute costs of each component considered, renders a positive difference, that is, less cost in the BD than in the EED; however, the difference is quite low, especially because the electricity generation of the EED is not still considered at this stage.

Solar screens

The BD had no external protection. The EED has solar protection screens that reduce almost completely the direct solar radiation incidence on windows and relatively on opaque facades. These fixed elements, are the overhangs as a continuation of the floors (60 cm on South and 25 cm on North facades) complemented with vertical protections and louvers.

	EED	BD	Difference
S Eave, 60 cm wide, lateral 60 cm wide, 1.20 m sep. & N Eave, 25 cm wide, lateral 20 cm wide, 1.20 m sep.	$45,773.28	$0.00	$45,773.28
E/W Louver, 14 cm wide, 10 cm separ.	$52,078.14	$0.00	$52,078.14
TOTAL	$97,851.42	$0.00	$97,851.42

Table 64. Cost breakdown comparison of Solar screen, BD and EED small size building

	EED	BD	Difference
S Eave, 60 cm wide, lateral 60 cm wide, 1.20 m sep & N Eave, 25 cm wide, lateral 20 cm wide, 1.20 m sep	$118,918.98	$0.00	$118,918.98
E/W Louver, 14 cm wide, 10 cm separ.	$135,299.01	$0.00	$135,299.01
TOTAL	$254,217.99	$0.00	$254,217.99

Table 65. Cost breakdown comparison of Solar screen, BD and EED medium size building

Since there is no comparable cost component in the BD, the whole difference is calculated as an added cost for the EED.

Efficient lighting

The use of LED lights in the EED is compared against the conventional use of fluorescent lighting in office buildings. The use of LED lights of high quality at current prices (progressively decreasing) renders a positive difference in the lighting component of the EED compared to the BD; the impact of the LED lights in the energy performance and the related economic impact will be studied in Chapter E.

	EED	BD	Difference
LED panels vs fluorescent	$93,263.78	$53,776.00	$39,487.78

Table 66. Cost comparison of efficient lighting vs fluorescent lighting, BD and EED small size building

	EED	BD	Difference
LED panels vs fluorescent	$186,527.57	$90,742.02	$95,785.54

Table 67. Cost comparison of efficient lighting vs fluorescent lighting,, BD and EED medium size building

The following table summarizes the differences between EED and BD that will be considered for the LCC study, for all the components:

	EED	BD	Difference
Pitched roof columns	$0.00	$21,153.54	-$21,153.54
Ventilation grills	$0.00	$14,265.62	-$14,265.62
Pitched roof (PV vs vent. roof)	$193,200.00	$119,431.75	$73,768.25
Flat Roof	$71,610.65	$127,876.16	-$56,265.51
Facades	$100,941.47	$67,151.01	$33,790.46
Windows	$81,651.01	$144,947.24	-$63,296.22
Solar protection	$97,851.42	$0.00	$97,851.42
Heat Recovery	$12,991.50	$0.00	$12,991.50
Lighting	$93,263.78	$53,776.00	$39,487.78
Solar thermal	$6,221.25	$0.00	$6,221.25
Light control	$5,904.00	$0.00	$5,904.00
TOTAL	**$663,635.09**	**$548,601.32**	**$115,033.77**

Table 68. Cost breakdown comparison, total, BD and EED, Small Size Building

	EED	BD	Difference
Pitched roof columns	$0.00	$12,339.56	-$12,339.56
Ventilation grills	$0.00	$16,980.53	-$16,980.53
Pitched roof (PV vs vent. roof)	$386,400.00	$171,518.08	$214,881.92
Flat Roof	$143,221.30	$215,779.18	-$72,557.88
Facades	$201,882.94	$79,858.98	$122,023.97
Windows	$163,302.03	$172,201.32	-$8,899.29
Solar protection	$254,217.99	$0.00	$254,217.99
Heat Recovery	$39,377.24	$0.00	$39,377.24
Lighting	$186,527.57	$90,742.02	$95,785.54
Solar thermal	$41,400.00	$0.00	$41,400.00
Light control	$11,808.00	$0.00	$11,808.00
TOTAL	**$1,416,329.06**	**$759,419.67**	**$668,717.39**

Table 69. Cost breakdown comparison, total, BD and EED, Medium Size Building

In order to better understand the impact and the scale of such cost differences, they should be compared against the absolute cost of the constructions. At this point, the information used in D.4.2is recalled, that is, the estimated cost, from the available information from local contacts, of the baseline buildings, within the range of minimum and maximum values:

Baseline	Estimated Minimum Construction Cost	Estimated Maximum Construction Cost
Small Building (3,000 sqm)	US$ 4.3 Million	US$ 6.3 Million
Medium Building (6,100 sqm)	US$ 8.8 Million	US$ 12.7 Million

Table 70. Estimated minimum and maximum cost of Baseline buildings;

Thus, in the case of the small building, the cost difference between BD and EED would be between the range 1,8% and 2,7% of the estimated baseline construction costs. In the case of the medium EED building, its over cost would be between 5,3% and 7,6%.

4.1 LCC Analysis of the Small Office Building

Given the existence of complex interaction between some variables, it was not always possible or convenient to isolate the incidence of a single variable. With this idea in mind, this section considers the building as a whole and compares the Baseline Design to five different EED solutions, as explained in chapter C.4. The LCC calculation considers the total electricity demands and the cost differences as explained in above. That is, in this deliverable only initial costs have been considered; however, the excel based tool is ready to receive other periodical costs such as replacement, maintenance, etc. as inputs and compute their LCC impact onto the global calculation.

The following table summarizes the results obtained, for the small building size, when BD and the different EED alternatives with several energy efficient installations are considered:

Cases compared		Difference: Efficient - Baseline		Average electricity price/Average inflation scenario		
Baseline case	Energy Efficient case	Cost, USD	Electricity demand, kWh/year	NPV, USD	IRR, %	SIR
BD	EED	$ 56.650,49	-188.832	$ 1.042.307,00	119,4	19,4
BD	EED + HR	$ 69.641,99	-230.423	$ 1.271.364,00	118,5	19,3
BD	EED + HR + LED	$109.129,77	-347.694	$ 1.914.364,00	114,4	18,5
BD	EED + HR + LC	$ 75.545,99	-311.306	$ 1.736.177,00	145,7	24
BD	EED + HR + LED + LC	$115.033,77	-378.568	$ 2.088.141,00	117,9	19,2

Table 71- Summary of LCC results of small bulidings - BD vs EED

Overall, the results of all small EED alternatives are financially very positive, showing good returns to the investment due to the high electricity prices in the region's utilities and the savings in electricity use that have been simulated.

4.2 LCC Analysis of the Medium Office Building

Analogous calculations have been performed for the Medium building comparisons between BD and EED, based on the differences in cost and differences in yearly electricity demand. The results are the following:

Cases compared		Difference: Efficient - Baseline		Average electricity price/Average inflation scenario		
Baseline case	Energy Efficient case	Cost, USD	Electricity demand, kWh/year	NPV, USD	IRR, %	SIR
BD	EED	$521.746,61	-381.866	$ 1.700.622,00	31,9	4,3
BD	EED + HR	$561.123,85	-461.728	$ 2.126.021,00	35,1	4,8
BD	EED + HR + LED	$656.909,39	-686.908	$ 3.340.728,00	42,7	6,1
BD	EED + HR + LC	$572.931,85	-617.037	$ 3.018.071,00	43,8	6,3
BD	EED + HR + LED + LC	$668.717,39	-746.192	$ 3.673.939,00	45,1	6,5

Table 72- Summary of LCC results of small buildings - BD vs EED

4.3 Parametric LCC Analysis for certain solutions

In some cases it was possible to develop a parametric analysis of the isolated EED solution, studied in the Parametric Study in chapter C.1. Nevertheless, given the difficulty to obtain detailed prices for the different specific solutions and the fact that such prices might vary among countries or even within the same country, depending on the location, a sensitivity analysis was carried out instead of an analysis based on estimated costs.

The sensitivity analysis is based on the *Net Present Value (NPV) differential of all costs between both alternatives that equals the Savings to Investment Ratio to one (SIR=1)* (always in the inflation Reference Scenario) of:

- The power utility that sells the kWh at the lowest rate. This power utility is the Grand Bahama Power Company, with a current rate of $16.50 for the first 100,000 kWh for commercial industrial, institutional, and other services exclusive of residential. At such SIR for GB Power, all the other power utilities offer positive NPV, IRR and SIRs (green lights).
- The average,
- The power utility that sells the electricity at the most expensive rate. This power utility is MUL from Montserrat.

As a result three values are obtained:

- A value in USD defining the lower threshold that makes the energy efficiency alternative financially viable for all the locations, that is, *how much more we can invest in a certain energy efficiency strategy in order to be at the balance point of the investment*.
- An average value for the same consideration and,
- A maximum difference beyond which *the energy efficiency alternative starts not being viable for any of the locations*.

This difference can then be applied to the differential in costs of the Parametric Office Building. The threshold value is the *maximum difference in investment that a designer can accept in order to pay off such additional investment with the energy saving it delivers*. Examples are given below.

Window to wall ratio

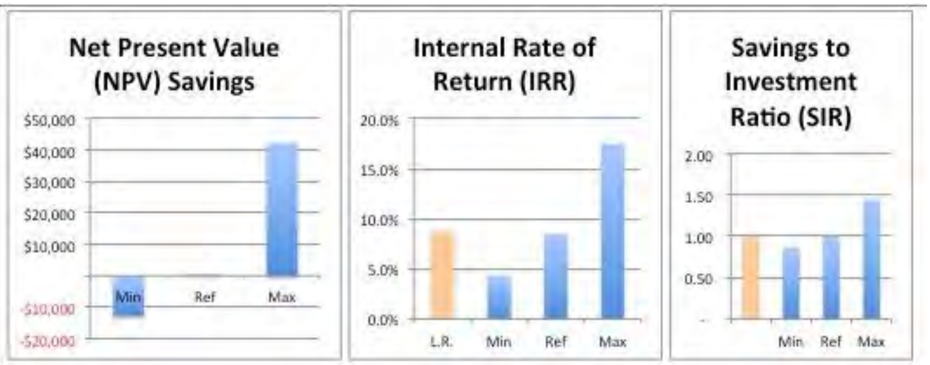
A building with a 20% window-to-wall ratio has a far lower energy demand than one with 80%. The difference in cost from 80% WW to 20% will be in having less window surface and more façade surface. Due to the considerable energy saving between 80% WW and 20% WW, from yearly 225 kWh/m2 down to 148 kWh/m2, and the meaningful saving in operative costs, the cost of the energy efficient option, in this case, the 20% WW alternative, gives a margin in cost as follows, to meet the SIR=1, for each utility:

- $500,000 for Grand Bahamas
- $1,031,000 for the average location, and
- $1,234,000 for Montserrat (cost of the 20% WW alternative could be as much as $1,234,000 more expensive than 80% WW alternative, to give a SIR=1 in Montserrat).

Glazing type

The glazing type compares between Clear Single pane and Double Single pane. The sensitivity analysis offers the following values; that is, the difference in cost that can be undertaken without compromising the result of the investment (limited to SIR=1), in different countries:

- $47,800 for Grand Bahamas
- $96,800 for the average location, and
- $116,000 for Montserrat.



Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Antigua (APUA)	-$1,150	$13,334	$61,548	5.9%	10.0%	19.2%	1.0	1.1	1.6
Bahamas (GB Power)	-$55,257	-$48,968	-$28,032	-1.8%	2.1%	10.7%	0.4	0.5	0.7
Bahamas (BEC)	-$13,733	-$1,155	$40,716	4.4%	8.5%	17.6%	0.9	1.0	1.4
Barbados (BL&P)	-$1,150	$13,334	$61,548	5.9%	10.0%	19.2%	1.0	1.1	1.6
Dominica (DOMLEC)	$1,366	$16,231	$65,715	6.2%	10.3%	19.5%	1.0	1.2	1.7
Grenada (GRENLEC)	$1,366	$16,231	$65,715	6.2%	10.3%	19.5%	1.0	1.2	1.7
Montserrat (MUL)	$3,883	$19,129	$69,881	6.5%	10.6%	19.8%	1.0	1.2	1.7
Nevis (NEVLEC)	-$18,766	-$6,950	$32,382	3.8%	7.9%	16.9%	0.8	0.9	1.3
St. Kitts Elec. Dep.	-$23,799	-$12,746	$24,049	3.1%	7.2%	16.2%	0.8	0.9	1.2
St. Lucia (LUCELEC)	-$16,250	-$4,053	$36,549	4.1%	8.2%	17.2%	0.8	1.0	1.4
ST. Vincent (VINLEC)	-$16,250	-$4,053	$36,549	4.1%	8.2%	17.2%	0.8	1.0	1.4
Average	-$12,704	$30	$42,420	4.4%	8.5%	17.5%	0.9	1.0	1.4

Table 73. Sensitivity analysis of glazing type for average location

In average, changing from single to double glazing can be as much as $96,800 more expensive; in the Reference inflation scenario, in this case, the investment would be positive (green indicators on) for few of the countries, as only Antigua, Barbados, Dominica, Grenada and Montserrat fall in this group due to the high electricity rates. In all the rest, the NPV of electricity savings would not pay off the $96,800 investment.

The same analysis can be made for the difference between Clear Single and other types of glazing. For each comparison, the economic value of the savings in energy demand should pay for the difference in cost.

As explained previously, this study determines the extent to which the more efficient option can be more expensive, in order to deliver a SIR=1 (for the Average electricity rate).

The following picture illustrates the result from the Parametric Study showing total energy demand for each case, depending on the glazing type.

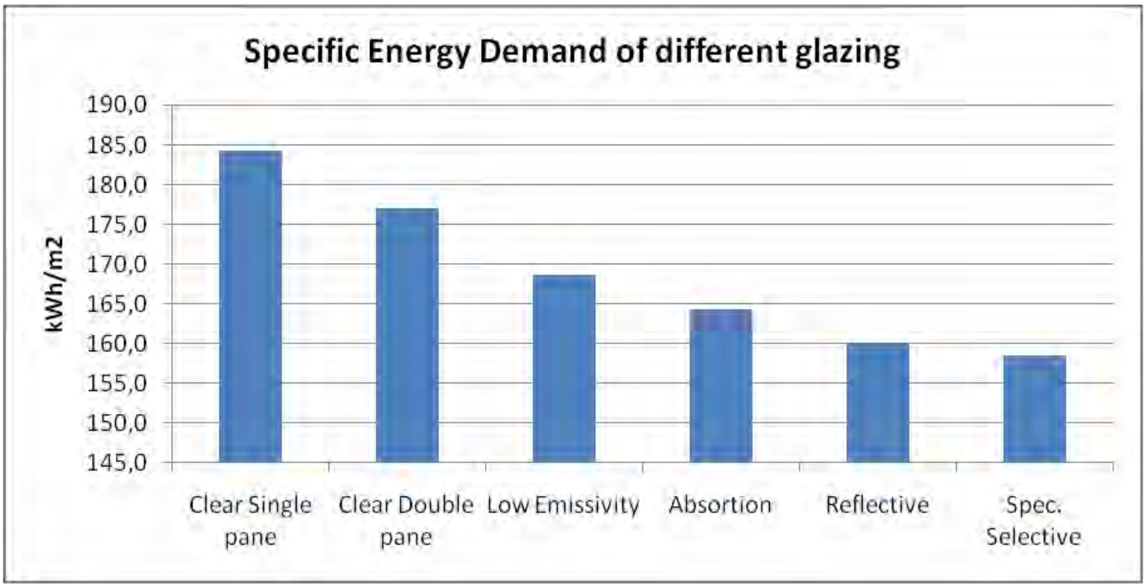


Figure 73- Specific Energy Demand of different glazing

The LCC tool determines that the affordable difference in cost can be the following:

	kWh/m2	Δcost for Average SIR=1
Clear Single pane	184,3	-
Clear Double pane	177,1	$ 96.800,00
Low Emissivity	168,7	$ 209.693,78
Absorptive	164,3	$ 268.414,41
Reflective	160,1	$ 325.022,09
Spec. Selective	158,4	$ 346.953,38

Table 74- Specific energy demand and cost difference affordable for different glazing types

This shows the amount of investment that can be afforded with each case.

Orientation

When comparing between an E-W orientated building and a N-S orientated building, it is not clear that there is necessarily any additional cost. It may be as simple as a design solution to be taken on the paper or in a preliminary design team meeting. However, the energy performance improvement of a N-S oriented building compared to an E-W orientation (as shown by the Parametric Study), allows the N-S option to have an additional cost as shown by the following results.

The difference in cost between the different orientation options could reach:

- $48,200 for Grand Bahamas
- $97,500 for the average location, and
- $116,700 for Montserrat.

Shading Coefficient

It has been shown that adding shading coefficient elements can reduce energy demand considerably without compromising access to daylighting.

The energy saving and its economic value throughout 20 years' lifespan would compensate a difference in total costs between not having any shading element at all and installing elements providing 95% shading coefficient of:

- $199,000 for Grand Bahamas
- $403,000 for the average location, and
- $482,000 for Montserrat

Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Antigua (APUA)	-$4,708	$55,554	$256,159	5.9%	10.0%	19.2%	1.0	1.1	1.6
Bahamas (GB Power)	-$229,828	-$203,661	-$116,557	-1.8%	2.1%	10.7%	0.4	0.5	0.7
Bahamas (BEC)	-$57,062	-$4,728	$169,481	4.4%	8.5%	17.6%	0.9	1.0	1.4
Barbados (BL&P)	-$4,708	$55,554	$256,159	5.9%	10.0%	19.2%	1.0	1.1	1.6
Dominica (DOMLEC)	$5,763	$67,611	$273,494	6.2%	10.3%	19.5%	1.0	1.2	1.7
Grenada (GRENLEC)	$5,763	$67,611	$273,494	6.2%	10.3%	19.5%	1.0	1.2	1.7
Montserrat (MUL)	$16,233	$79,667	$290,830	6.5%	10.6%	19.8%	1.0	1.2	1.7
Nevis (NEVLEC)	-$78,003	-$28,842	$134,810	3.8%	7.9%	16.9%	0.8	0.9	1.3
St. Kitts Elec. Dep.	-$98,944	-$52,955	$100,138	3.1%	7.2%	16.2%	0.8	0.9	1.2
St. Lucia (LUCELEC)	-$67,532	-$16,785	$152,145	4.1%	8.2%	17.2%	0.8	1.0	1.4
ST. Vincent (VINLEC)	-$67,532	-$16,785	$152,145	4.1%	8.2%	17.2%	0.8	1.0	1.4
Average	**-$52,778**	**$204**	**$176,573**	**4.4%**	**8.5%**	**17.5%**	**0.9**	**1.0**	**1.4**

Table 75. Sensitivity analysis of the shading coefficient for average location

F. Conclusions

1. Energy

1.1 Form Factor

The shape of the building has an impact on the energy demand. The shapes studied range between Form Factor (FF) values of 0,33 and 0,75 m^{-1}. Moreover, the energy demand for lighting and cooling, depends upon other characteristics such as “window to wall” (WW) ratio, areas for workplaces near glazed, daylit zones etc. Thus, energy demand does not correlate solely with the FF. Among the 6 building shapes studied, which represent the most usual types of construction, the worst performing is the tower, the best being the “long bar” with several floors (3 or 4) and not too wide, in order to take the most out of natural ventilation and daylight.

1.2 Glazed surface

The demand for cooling depends strongly upon the glazed surface proportion in a building. The demand is decreased in a 34% when WW changes from 80% (80 % of the façades is glazed) to 20%.

1.3 Glazing types

An improved glazing quality (that is, reduced transmittance), reduces the energy demand for cooling the building. Selecting double glazing with air gap instead of single glazing reduces the energy demand 4%. Special glazing can further reduce demand to 9 % and 10 % lower. However, with of special glazing, such energy savings do not compensate the increase in cost per square meter.

1.4 Orientation

In the case of a building with long and short façades the improvement of its energy performance depends strongly on the adequate orientation of these. The importance of appropriate orientation is even higher when glazed surfaces are considered on such large and short façades as orientation will make it more or less difficult to protect the glazed surfaces from incident radiation. The best results are obtained when the largest façades are oriented South and North. The aim is thus to minimize the surface oriented East and West, which are more cumbersome to protect from low angle incident radiation.

Another criterion to select the most appropriate orientation of the building is to consider the dominant wind direction at the location, especially if the external ambient temperature is adequate for natural cooling during the hours of the day in which the building is used.

1.5 Solar protection

The degree of solar protection on glazed surfaces (ratio of solar energy through glazed surfaces, protected over non-protected) is assessed using specific monthly or yearly calculations. A higher degree of solar protection is directly linked with a lower demand for cooling. Besides, although a higher protection reduces the access to daylight, going from 0% (no protection at all) to 95% only increases artificial lighting demand 7,7% and reduces cooling demand 17%.

1.6 Enhanced roof performance

Roof surface is the one that receives the most solar radiation, this gets more notorious the lower the latitude of the location. 6 thermal protection strategies of the roof have been studied in Tropical climate, based on the use of insulation and shading. Actually, shading without insulation proves to be the most energy-efficient measure. Here, a roof “shading” strategy must be understood as a ventilated roof over the uppermost floor of the building that, firstly, avoids solar incidence and secondly, the ventilation or natural convection that removes heat from both roofs. The cooling energy demand reduction achieves 15,8% compared against the alternative with no shading and no insulation; using only insulation would be half as good.

Night natural ventilation allows for the evacuation of heat from the building to the environment through the roof.

1.7 Floor

An air-conditioned building will exchange heat through the floor towards a non air-conditioned room or to the ground, depending upon the temperature difference and the conductivity of the floor layers. The results of the simulations of 5 different alternatives do not show big differences; the best option would be keeping the contact with the ground without any thermal insulation; having a non air-conditioned underground floor without insulation would be the next best performing option.

1.8 Night ventilation

This is an energy-efficient strategy to reduce demand for cooling although in the Tropical climate, with high night temperatures, the results are not very effective. Improvements of 3% and 5% can be reached with medium thermal masses, depending upon the ach value considered. A drawback is the increase of humidity within the building and thus this strategy would be limited to the dry period of the year.

1.9 Daylighting

The main strategies to enhance natural light within closed spaces during daylight hours are:

- South and North orientation of the largest façades.
- Not excessive depth (longest distance from a glazed, exterior surface) of the floors (maximum around 14 meters).
- Homogeneous distribution of glazing around 20% of the façade surface.
- Use of fixed overhangs for South and North façades or louvers for East and West façades, complemented by internal, mobile protections.

1.10 Ventilation heat recovery

Air-tight or permanently air-conditioned buildings must ensure air quality by means of forced ventilation. The thermal losses of air-conditioned spaces due to ventilation are often important due to the constant conditioned and dehumidified air extraction. Heat recovery units avoid such energy losses as heat is exchanged between the external, hot and humid air and the inside, exhaust air. Simulations have shown that cooling demand could be reduced by 17,7%. An average efficiency of recovery of 70% (sensible heat) and 65% (latent heat) has been considered.

1.11 Efficient lighting

High efficiency lighting use with LED technology allows an average power of 4 W/m2 instead of 20 W/m2 using conventional options. The effect in whole energy demand is double, as not only this means a reduction in demand for lighting, but also a reduction in heat gains from lighting and thus a lower demand for cooling. Added up, the energy demand of the building can be decreased 28%.

1.12 Lighting control

Motion control or control of artificial lighting depending on the amount of daylight can decrease overall energy demand of the building 19,3%.

1.13 HVAC equipment

The following measures would be energy-efficient strategies for HVAC equipment selection:

- selection of efficient chillers that can to work in the most usual conditions of local climate; possibility of modulating power depending upon demand (inverter).
- Possibility to combine with “free cooling” equipment if local conditions allow.
- Distribution of cooling at low temperatures; prefer radiant solutions to very low temperature air distribution.
- High degree of zoning.
- Control: possibility to turn off emitters if open windows are detected or in moments of no occupancy.

1.14 Photovoltaics

The PV installations proposed for the EEB, besides generating around 274 kWh/m2 per year (per sq. meter of PV module), besides contributes to decreasing the demand for cooling as it creates a ventilated, shaded roof. It is also an excellent solution to harvest rainwater.

1.15 Solar thermal energy

If the building has hot water demand (such as public buildings with kitchen /restaurant/ cafeteria/ toilets/ dressing rooms etc.) a solar thermal installation can provide part of such hot water demand.

1.16 Energy Efficient Design

Compared against the Baseline building with identical air-conditioned area, the EED, with architectural (passive) strategies and improved mechanical and electrical installations, has a 49% lower energy demand.

If, on top of this, renewable energy generation technologies are considered, the EED could be close to reducing 100% the Baseline design demand.

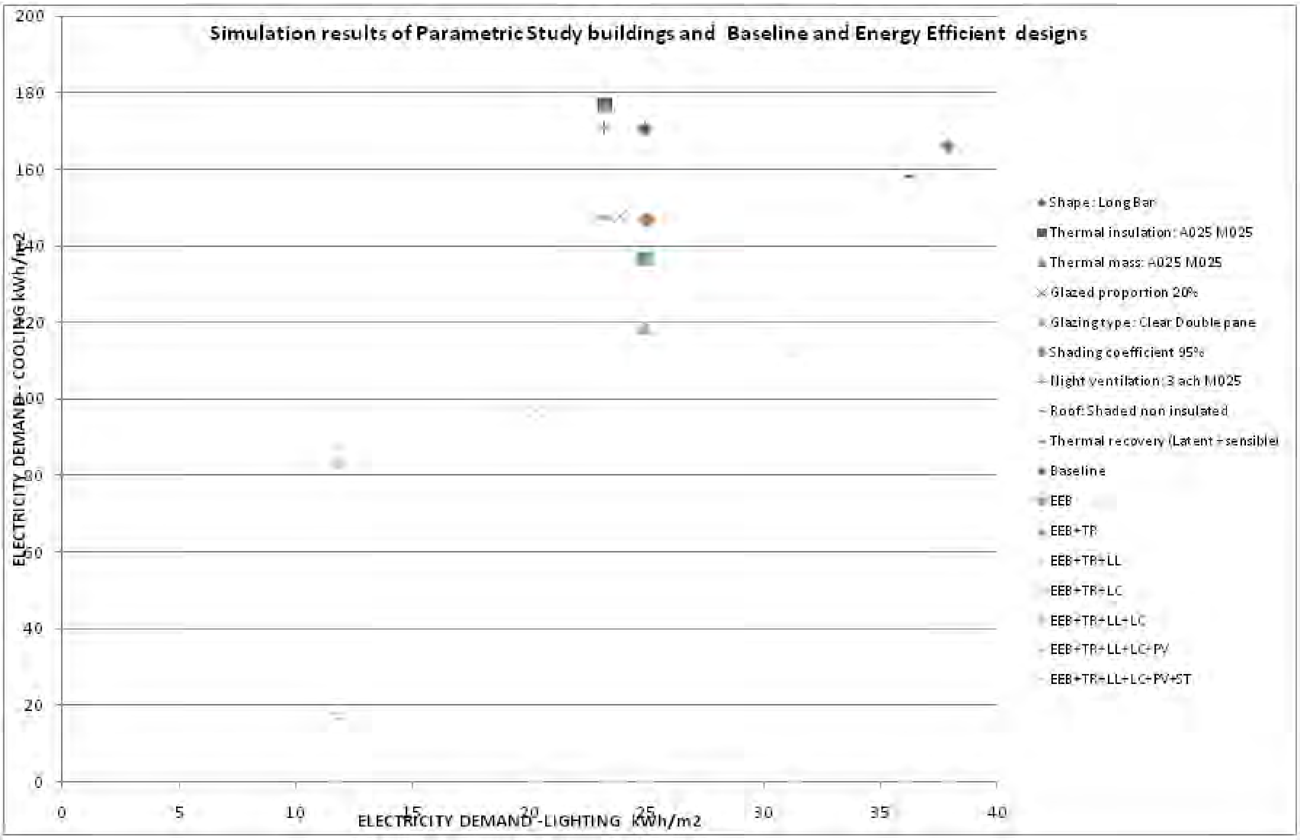


Figure 74- Simulation Results of Parametric Study buildings and Baseline and Energy Efficient designs

1.17 Influence of useful building area

The thermal analysis of both sizes of buildings, 3000 m2 and 6000 m2, shows that the specific demands are very similar. Thus, the energy saving ratios and strategies of energy efficient design can be applied to a wide range of building sizes.

1.18 Other recommendations

There are other design strategies that contribute to energy efficient buildings that should be considered when designing new buildings or renovating existing buildings although it has not been possible to quantitatively evaluate the effect of these in demand reduction and user comfort.

- Vegetation in the exterior of the building: medium of big size vegetation (e.g. trees) provide shading to walls and windows but also cool the ambient air through evapotranspiration.
- Buffer spaces: these zones, located between the external and internal spaces of the building, can provide: a decreased temperature difference, improved solar protection, can have vegetation, cool down external air temperature.
- Reducing infiltration and uncontrolled loss of conditioned air improving the building airtight.

2. LLCC conclusions

An Excel based tool has been developed in order to implement the LCC methodology and obtain results about the impact of the different energy efficient strategies in the life cycle cost of the buildings.

Overall, the high electricity rates paid in the countries do justify energy efficient design strategies, some of them being very good investments. The study shows that taking worse design decisions is a burden for the building owners during the long life of the building.

2.1 – Baseline vs. Energy Efficient Design

The differences in energy performance have shown to be significant and this has been an element of the LCC study. Due to the design methodology the single strategies applied in the EED have not been isolated for the LCC study and thus the “whole building” LCC comparison has been made. Only the effect of simultaneously incorporating Heat Recovery, LED lights and Lighting Control has been assessed separately.

The comparison has been made based on cost differences between BD and EED, for both sizes.

In both cases, small and medium, the EED performs better in energy terms and in economic terms and overall, the results of all small EED alternatives are financially very positive, showing good returns to the investment due to the high electricity prices in the region’s utilities and the savings in electricity use that have been simulated.

2.2 - LCC about selected options

In order to assess the impact of isolated energy efficient strategies of design, results from the Parametric Study have been used. Particularly, a “more efficient” strategy (that is, one with a lower energy demand) has been compared with an alternative “baseline” strategy. The savings in energy demand are given by the Parametric Study and thus, at a break-even point, the additional life cycle costs of the more efficient strategy would match the savings in energy, in economic terms.

Thus, for each comparison of alternative design options, a cost threshold has been established; if the life cycle cost of the more energy efficient solution is bigger than the margin given by such threshold, this more efficient alternative is not economically justified because the economic value of the energy savings it delivers will not pay off the cost difference. This has been done for 3 cases out of the ten countries studied.

The tool is thus flexible to adapt to different cost cases that building professionals may require to analyze.

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16. *La boîte à vent, Christian Hauvette Jerôme Nouvel, Rectorat de l'academie des Antilles et de la Guyane, Sens and Tonka editeurs.*

Annex II. Probability of high future energy prices

High future energy prices, well above the ones used in their projections by governments, international organisations and the private sector, are very likely taking into account the combination of the following factors:

1. *Dwindling unused production*

   The World currently has only 1.8 million to 2.5 million barrels a day of unused production capacity, down from 6.2 million in 2009[17]

2. *A disruption in the supply caused by geopolitical instability*

   Such event would certainly cause the punctual increase in prices with the possibility for prices to never come down. For example, a blockade in the strait of Hormuz by Iran means a halt to 17 million barrels of oil passing through it. Thus, twenty percent of world's oil would stagnate. In turn, this could send Brend crude oil prices to 240 a barrel[18]. In such case the energy shock would be similar to teh one experienced in 1979, during the time of the Islamic Revolution in Iran.

3. *Increased costs caused by peak-oil.*

   In the Executive Summary of the World Energy Outlook for 2010 the International Energy Agency (IEA) recognised that crude oil extraction peaked in 2006 at 70 mb/d. At that time their expectation was that extraction would stabilise at 68 or 69 mb/d until 2020. That oil extraction peaked in 2006 is a certitude, but whether or not after this event it will stabilise at 68 or 69 mb/d, with other sources such as non conventional oil and natural gas filling the gap for the 100 mb/d needed by 2020 is just an estimate.

   Furthermore, this estimate is based on declared reserves that might be well overestimated in most cases and on the need by the IEA to avoid the panic that would spread on the financial markets if the figures were brought down further[19]. This overestimation specially results from oil companies declaring larger reserves to keep their stock prices high[20].

   While the energy shock in 1973 was caused by the conscious decisions from the OPEC to restrict supply, an energy shock caused by peak-oil would result from geological limitations (lack of oil) rather than from political or economic ones. This means that prices would increase to never come down. Indeed, OPEC decided to start restricting supply to push prices up the moment the US reached its peak-oil production, something that happened in the early 70s. This made impossible for the US to counteract the decrease in OPEC production by increasing its own. Considering that extraction peaked in 2006 as a World average, it should not be long before prices start increasing sharply.

[17] Source: USA Today, March 23rd 2012. “Gas could hit $8 on Iran showdown, experts say”

[18] Sara Johnson, senior research director for Global Economics at IHS

[19] The Guardian 9/11/2009 “Key oil figures were distorted by US pressure, says whistleblower”

[20] For instance, the oil giant Royal Dutch / Shell admitted in 2004 overestimating its oil and gas reserves by 22% (about 4.5 billion barrels). Overestimating reserves has specially been the norm after the Securities and Exchange Commission (SEC) changed the rule in 2008 and gave these companies greater latitude in how they estimated reserves in areas that were not yet drilled. Source: NY Times, 27/06/2011 “S.E.C. Shift Leads to Worries of Overestimation of Reserves”.

4. *Increase in the demand, as a result of the world moving away from nuclear energy*

   In the World Energy Outlook for 2011 the IEA says:

   > "*We also examine the possible implications of a more substantial shift away from nuclear power in a Low Nuclear Case, which assumes that no new OECD reactors are built, that non-OECD countries build only half of the additions projected in our New Policies Scenario and that the operating lifespan of existing nuclear plants is shortened. While creating opportunities for renewables, such a low-nuclear future would also boost demand for fossil fuels: the increase in global coal demand is equal to twice the level of Australia's current steam coal exports and the rise in gas demand is equivalent to two-thirds of Russia's current natural gas exports. The net result would be to put additional upward pressure on energy prices, raise additional concerns about energy security and make it harder and more expensive to combat climate change.* " (World Energy Outlook 2011. IEA)

5. *Increased cost caused by taxation such as the introduction of a Carbon tax.*
   For example, in Australia alone electricity prices are set to increase by around 20%, while gas prices will increase by 15% after introducing the Carbon Tax[21].

[21] Energetics Pty Lld 2011

Annex III. Thermal properties of building elements for Simulations

Wall 01 - Insulation 010 / Thermal mass 025

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0100	0,040	1400,00	15
3 (Int)	Thermal mass	0,0250	1,600	1000,00	2200
2,059	W/m2-K thermal transmittance coefficient (U)				

Wall 02 - Insulation 025 / Thermal mass 025

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0250	0,040	1400,00	15
3 (Int)	Thermal mass	0,0250	1,600	1000,00	2200
1,162	W/m2-K thermal transmittance coefficient (U)				

Wall 03 - Insulation 050 / Thermal mass 025

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0500	0,040	1400,00	15
3 (Int)	Thermal mass	0,0250	1,600	1000,00	2200
0,673	W/m2-K thermal transmittance coefficient (U)				

Wall 04 - Insulation 075 / Thermal mass 025

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0750	0,040	1400,00	15
3 (Int)	Thermal mass	0,0250	1,600	1000,00	2200
0,474	W/m2-K thermal transmittance coefficient (U)				

Wall 05 - Insulation 100 / Thermal mass 025

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,1000	0,040	1400,00	15
3 (Int)	Thermal mass	0,0250	1,600	1000,00	2200
0,366	W/m2-K thermal transmittance coefficient (U)				

Wall 06 - Insulation 025 / Thermal mass 050

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0250	0,040	1400,00	15
3 (Int)	Thermal mass	0,0500	1,600	1000,00	2200
1,141	W/m2-K thermal transmittance coefficient (U)				

Wall 07 - Insulation 025 / Thermal mass 075

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0250	0,040	1400,00	15
3 (Int)	Thermal mass	0,0750	1,600	1000,00	2200
1,121	W/m2-K thermal transmittance coefficient (U)				

Wall 08 - Insulation 025 / Thermal mass 100

Layer	Material	Width (m)	Thermal cond. (W/m-K)	Specific heat (J/Kg-K)	Dens. (Kg/m^3)
1 (Ext)	External material	0,0100	0,200	1500,00	1200
2	Insulation	0,0250	0,040	1400,00	15
3 (Int)	Thermal mass	0,1000	1,600	1000,00	2200
1,102	W/m2-K thermal transmittance coefficient (U)				

Thremal Properties of Glazing:

Glazing 01 - Clear, single

Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	Clear glazing	0,006	0,900
6,257	W/m2-K thermal transmission coefficient (U)		
0,858	Solar heat gain coefficient (SGHC)		
0,837	Direct solar transmission		
0,898	Light transmission		

Glazing 02 - Clear, double

Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	Clear glazing	0,006	0,900
2	Air gap	0,012	
3 (Int)	Clear glazing	0,006	0,900
2,685	W/m2-K thermal transmission coefficient (U)		
0,703	Solar heat gain coefficient (SGHC)		
0,604	Direct solar transmission		
0,781	Light transmission		

Glazing 03 - Double, low emissivity (LoE)

Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	Vidrio LoE genérico	0,006	0,900
2	Air gap	0,012	
3 (Int)	Clear glazing	0,006	0,900
1,771	W/m2-K thermal transmission coefficient (U)		
0,568	Solar heat gain coefficient (SGHC)		
0,474	Direct solar transmission		
0,745	Light transmission		

Glazing 04 - Double, absorptive

Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	Absorptive glazing	0,006	1,000
2	Air gap	0,012	
3 (Int)	Clear glazing	0,006	0,900
2,690	W/m2-K thermal transmission coefficient (U)		
0,482	Solar heat gain coefficient (SGHC)		
0,362	Direct solar transmission		
0,469	Light transmission		

Glazing 05 - Double, reflection

Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	Reflective glazing	0,006	0,900
2	Air gap	0,012	
3 (Int)	Clear glazing	0,006	0,900
2,668	W/m2-K thermal transmission coefficient (U)		
0,426	Solar heat gain coefficient (SGHC)		
0,343	Direct solar transmission		
0,308	Light transmission		

Glazing 06 - Doble, spectrally selective

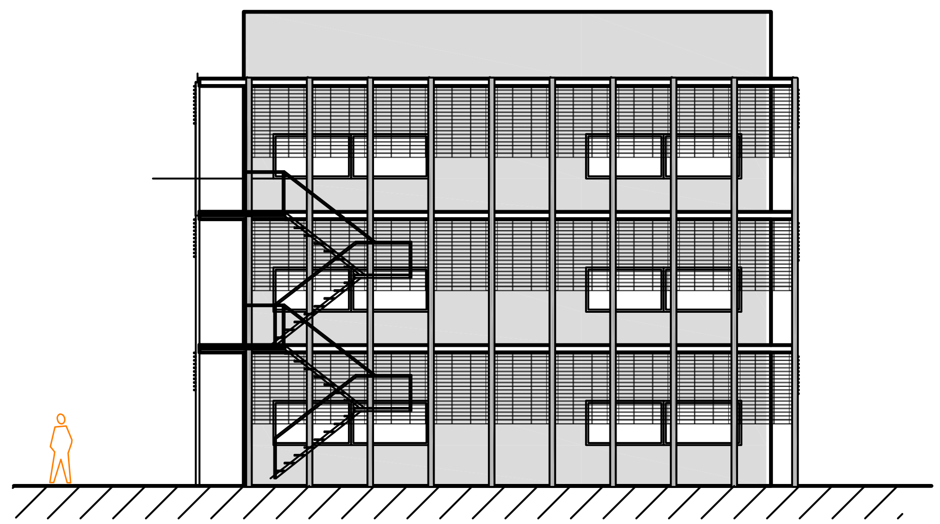
Layer		Width (m)	Thermal cond. (W/m-K)
1 (Ext)	LoE spectrally selective	0,006	0,900
2	Air gap	0,012	
3 (Int)	Clear glazing	0,006	0,900
1,635	W/m2-K thermal transmission coefficient (U)		
0,422	Solar heat gain coefficient (SGHC)		
0,345	Direct solar transmission		
0,682	Light transmission		

Annex IV. Drawings of Energy Efficient Design

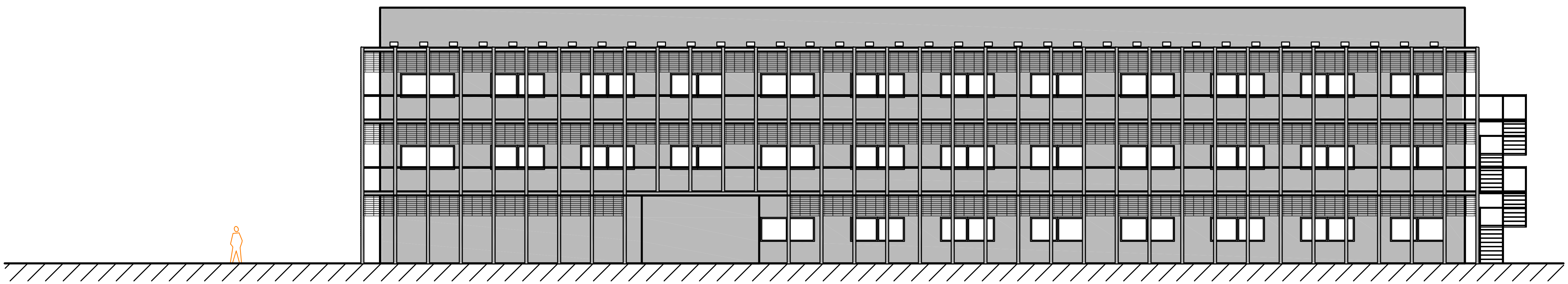
1. Small Energy Efficient Building

2. Medium Energy Efficient Building

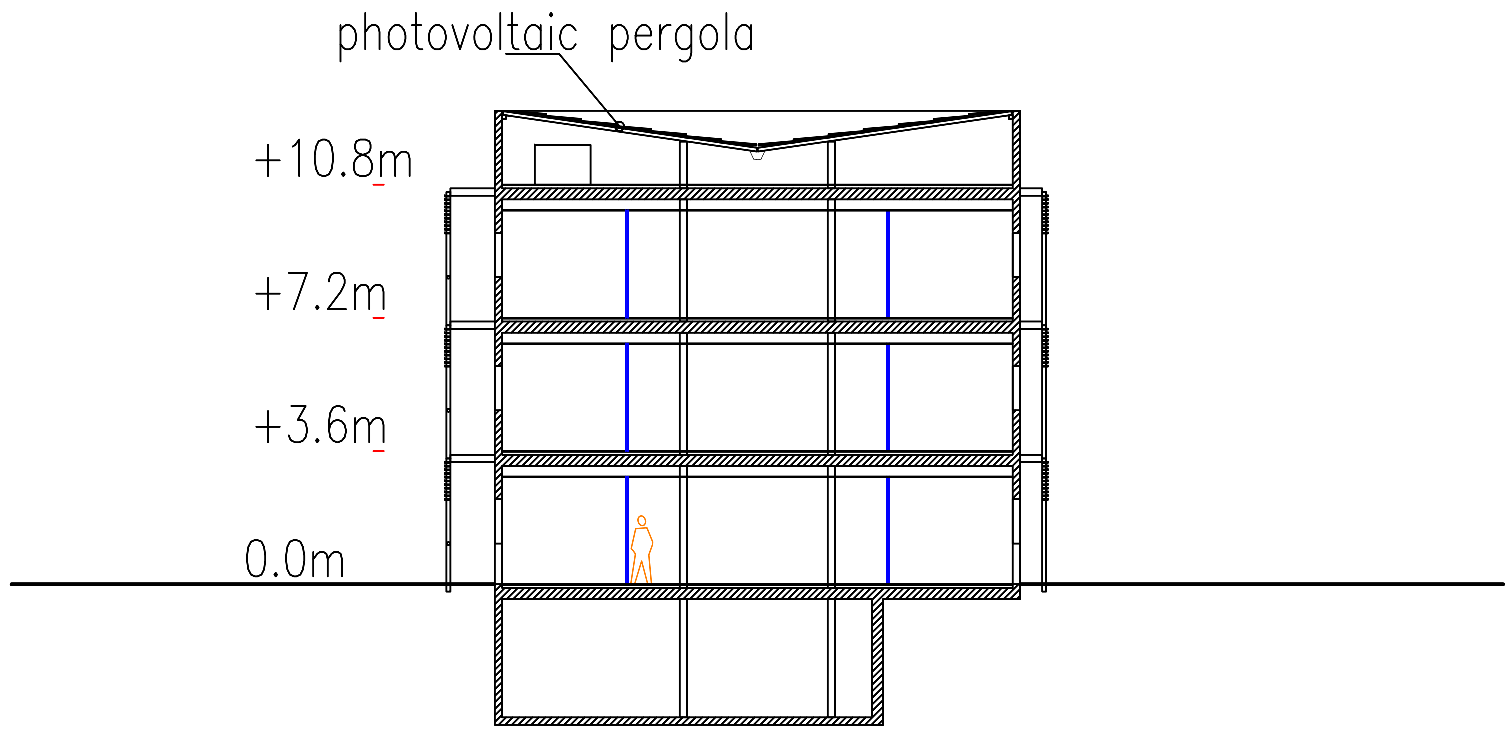
3. Efficient Building Considerations



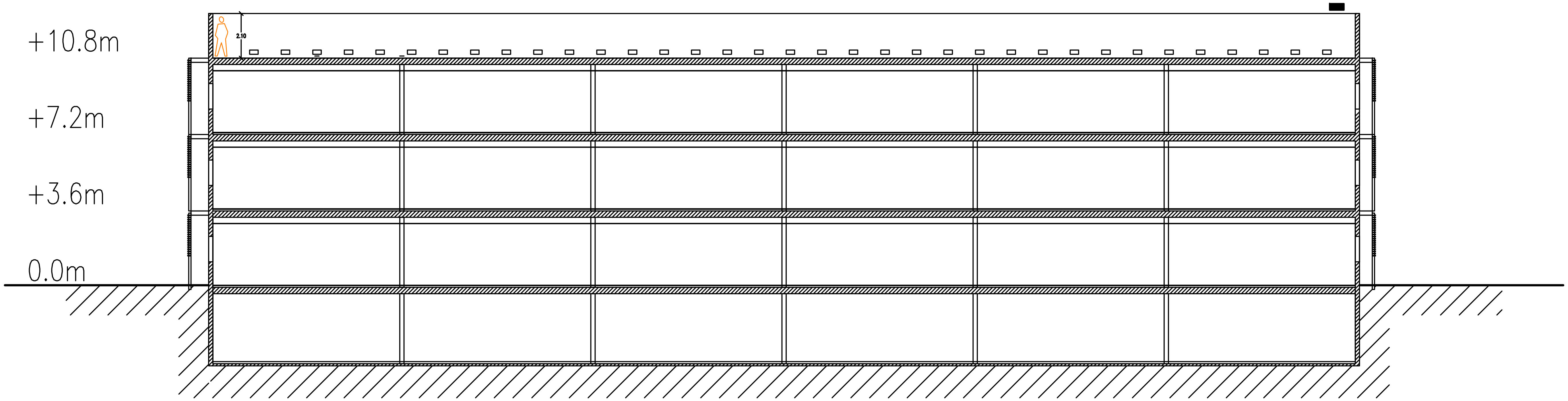
EAST FACADE ESC. 1:200



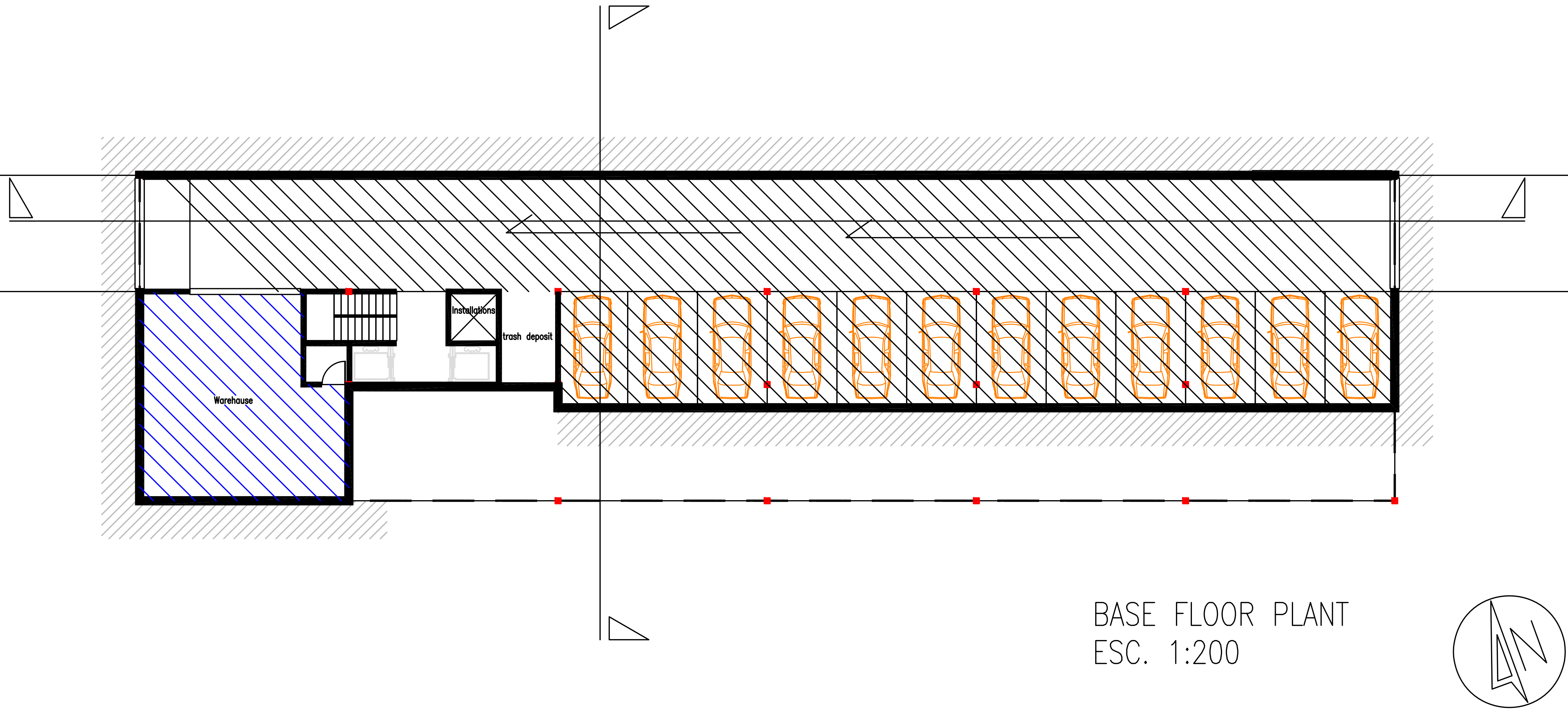
SOUTH FACADE ESC. 1:200



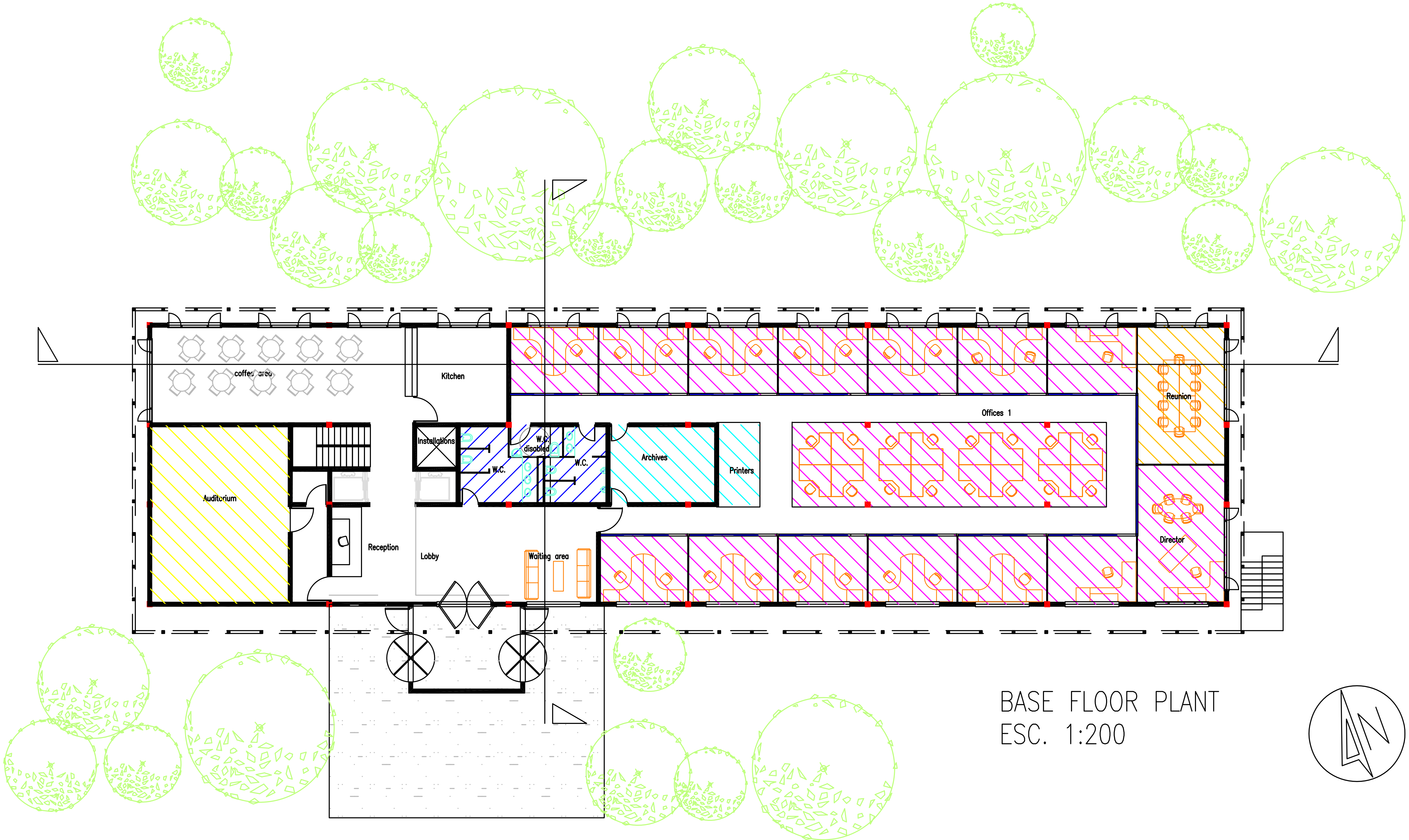
TRANSVERSAL SECTION ESC. 1:200



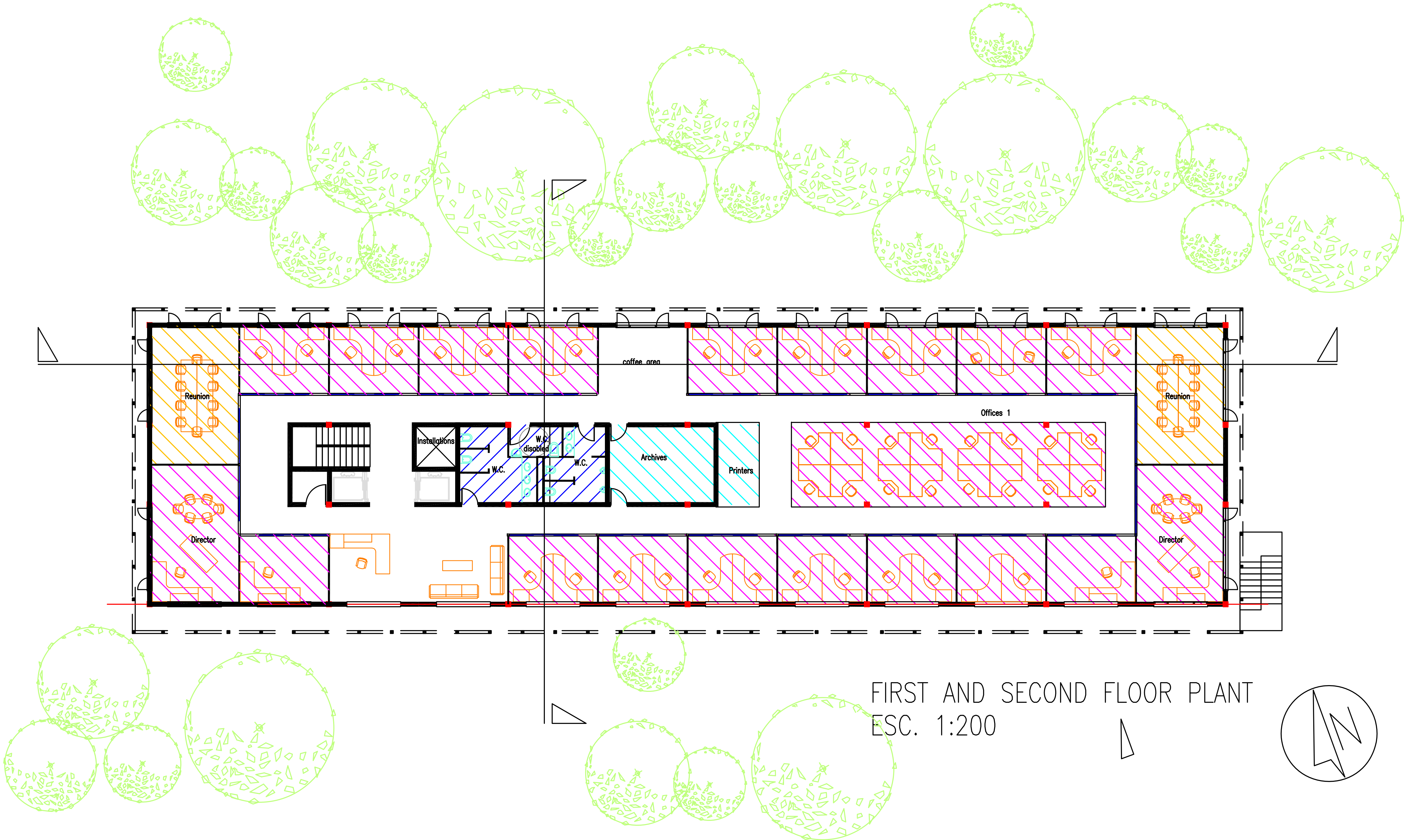
LONGITUDINAL SECTION ESC. 1:200



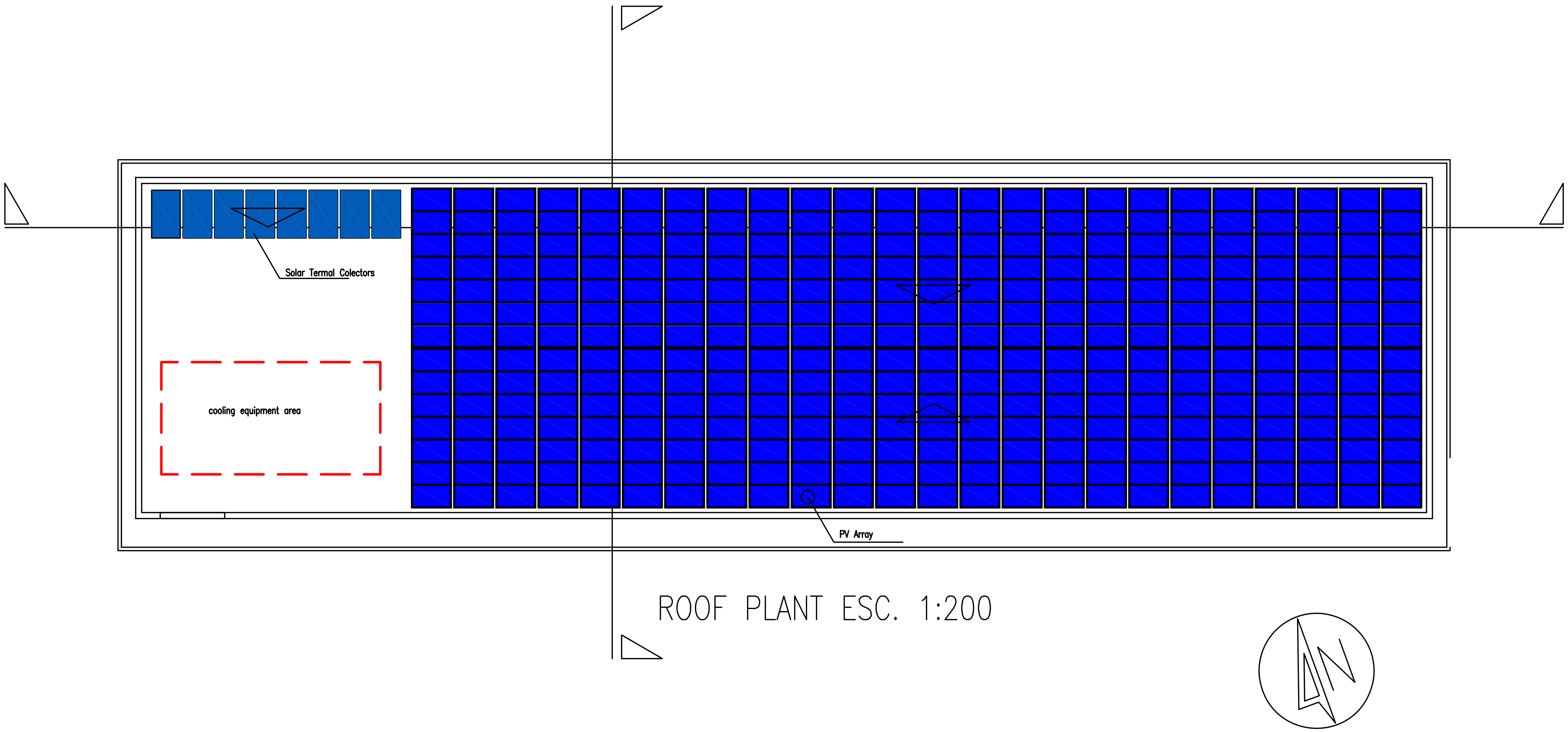
BASE FLOOR PLANT
ESC. 1:200



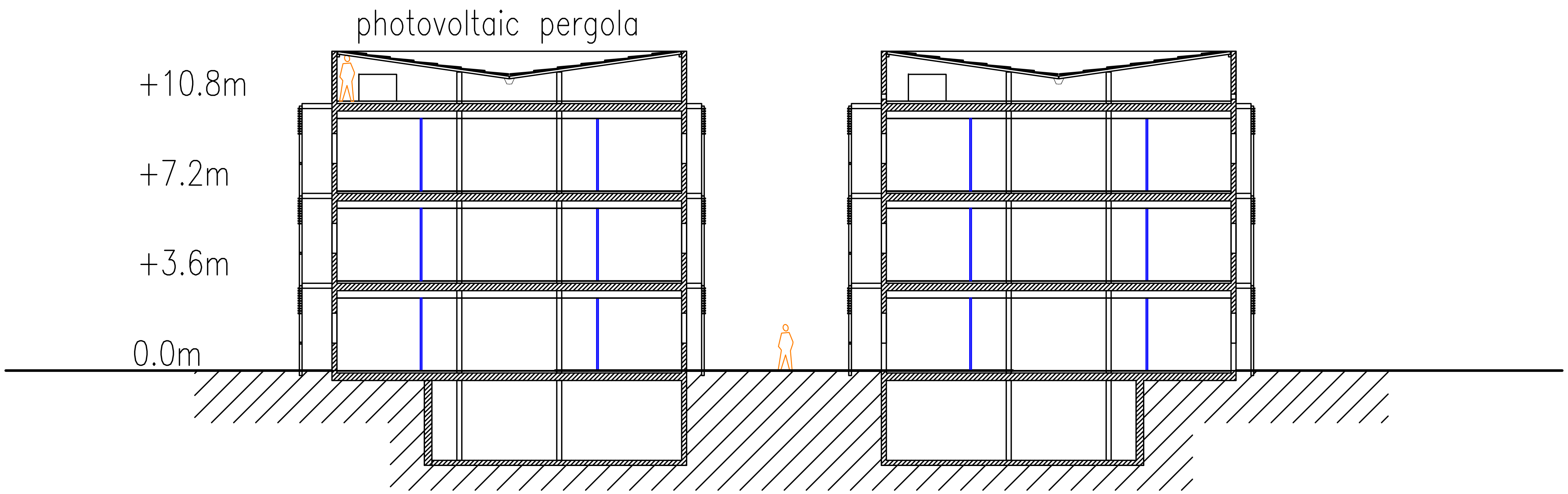
BASE FLOOR PLANT
ESC. 1:200



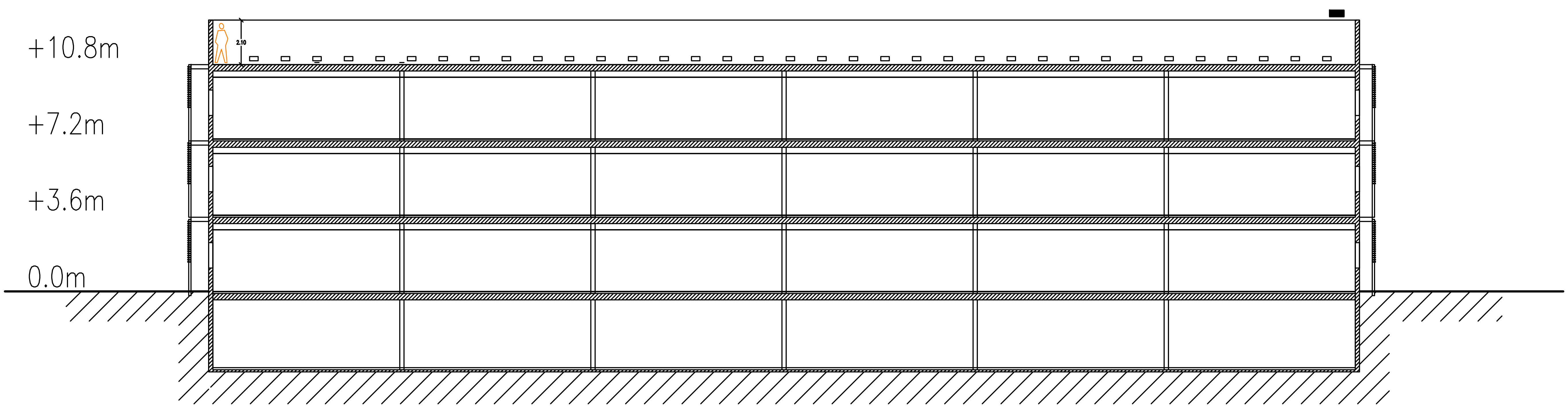
FIRST AND SECOND FLOOR PLANT
ESC. 1:200



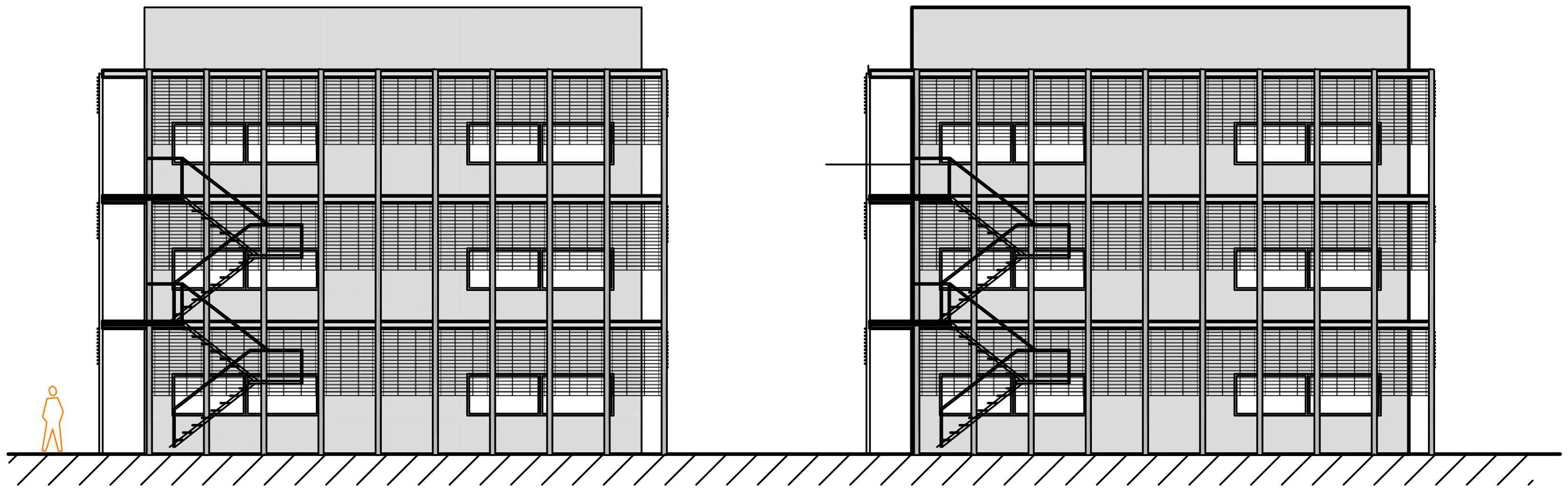
ROOF PLANT ESC. 1:200



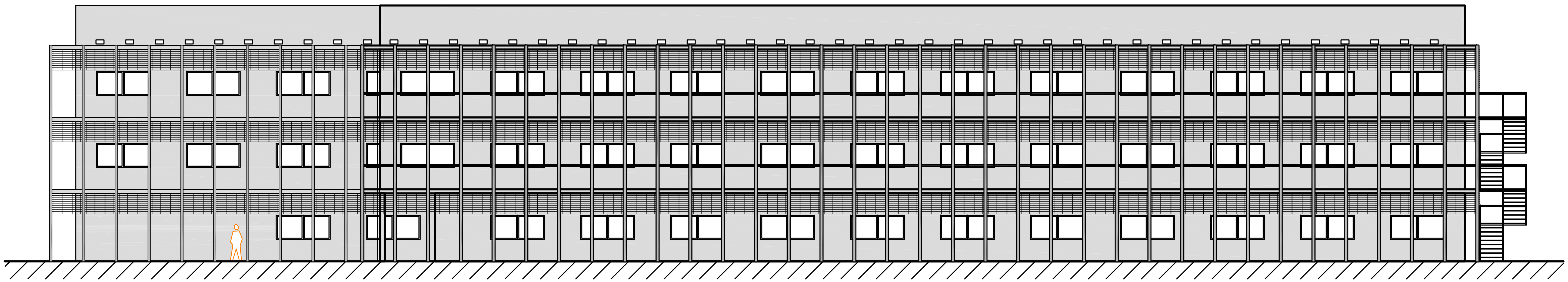
TRANSVERSAL SECTION ESC. 1:200



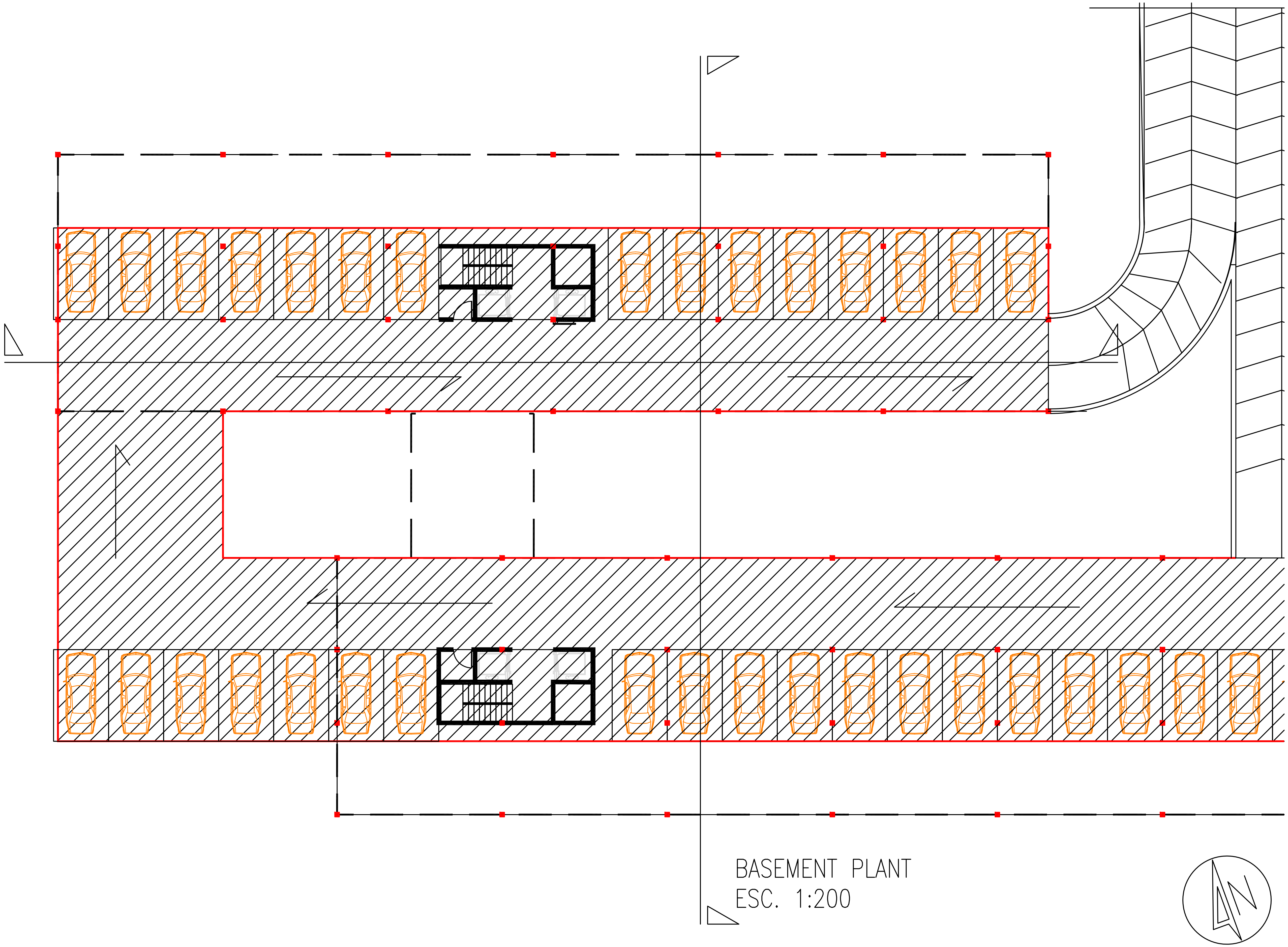
LONGITUDINAL SECTION ESC. 1:200



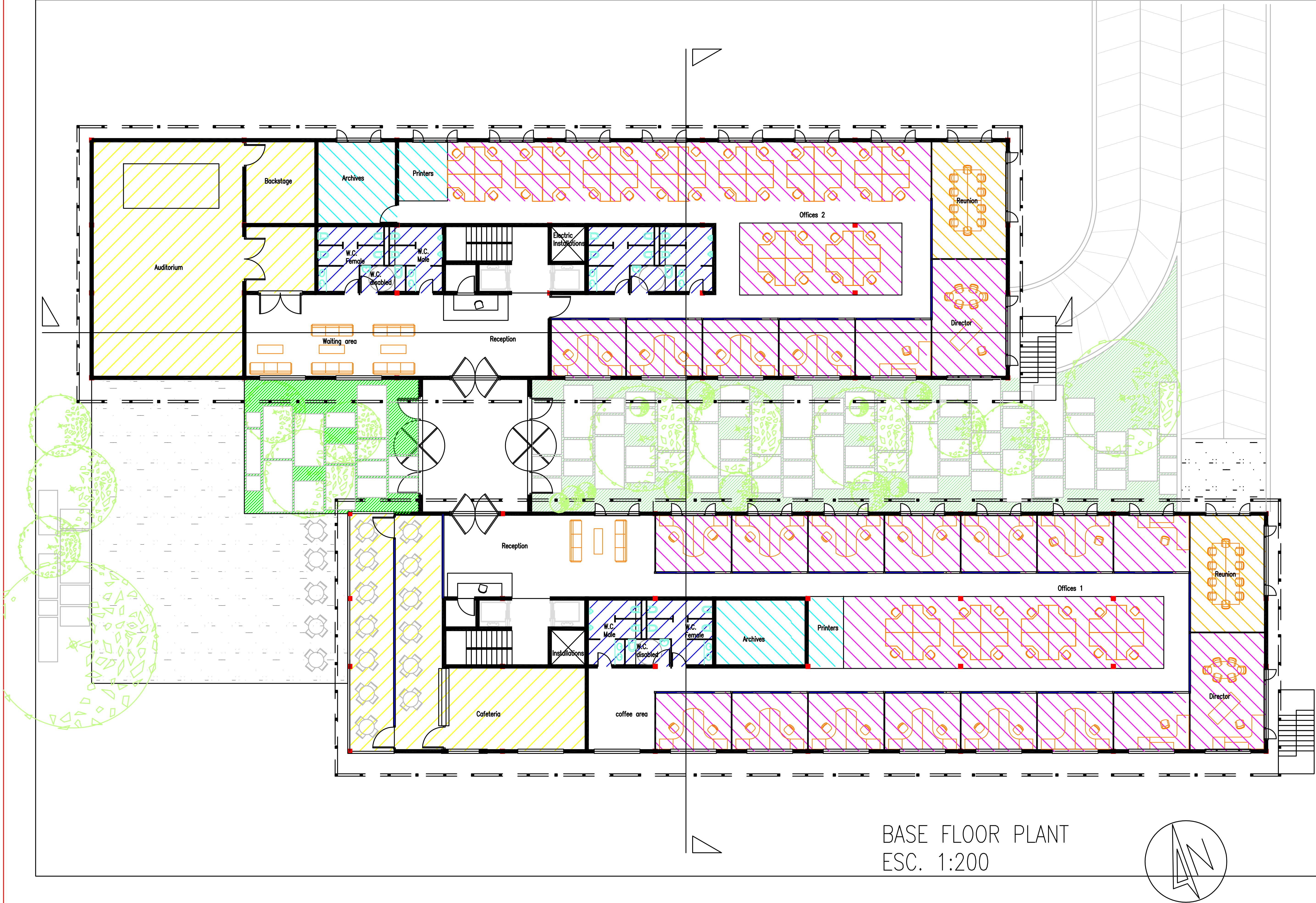
EAST FACADE ESC. 1:200



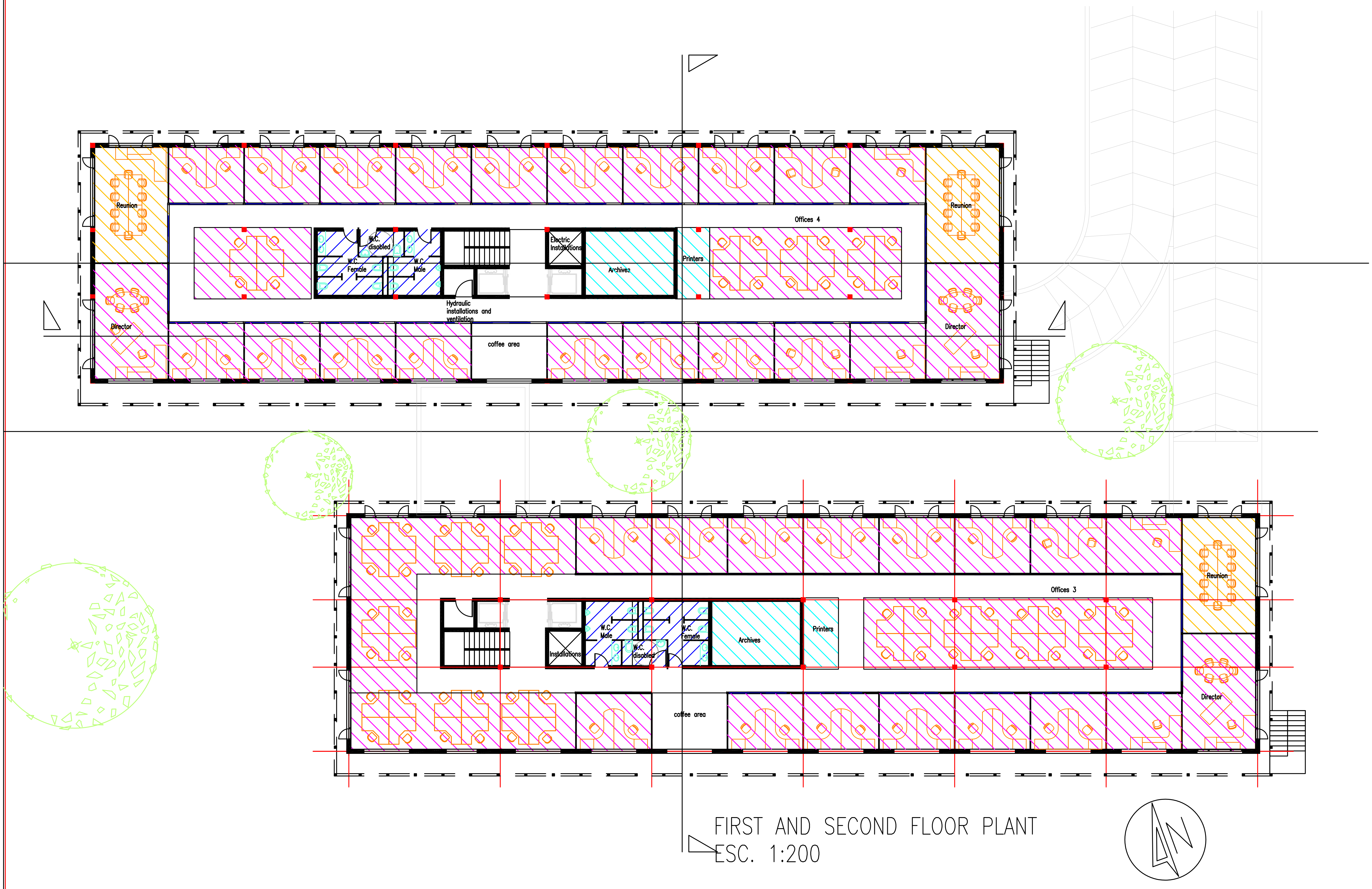
SOUTH FACADE ESC. 1:200



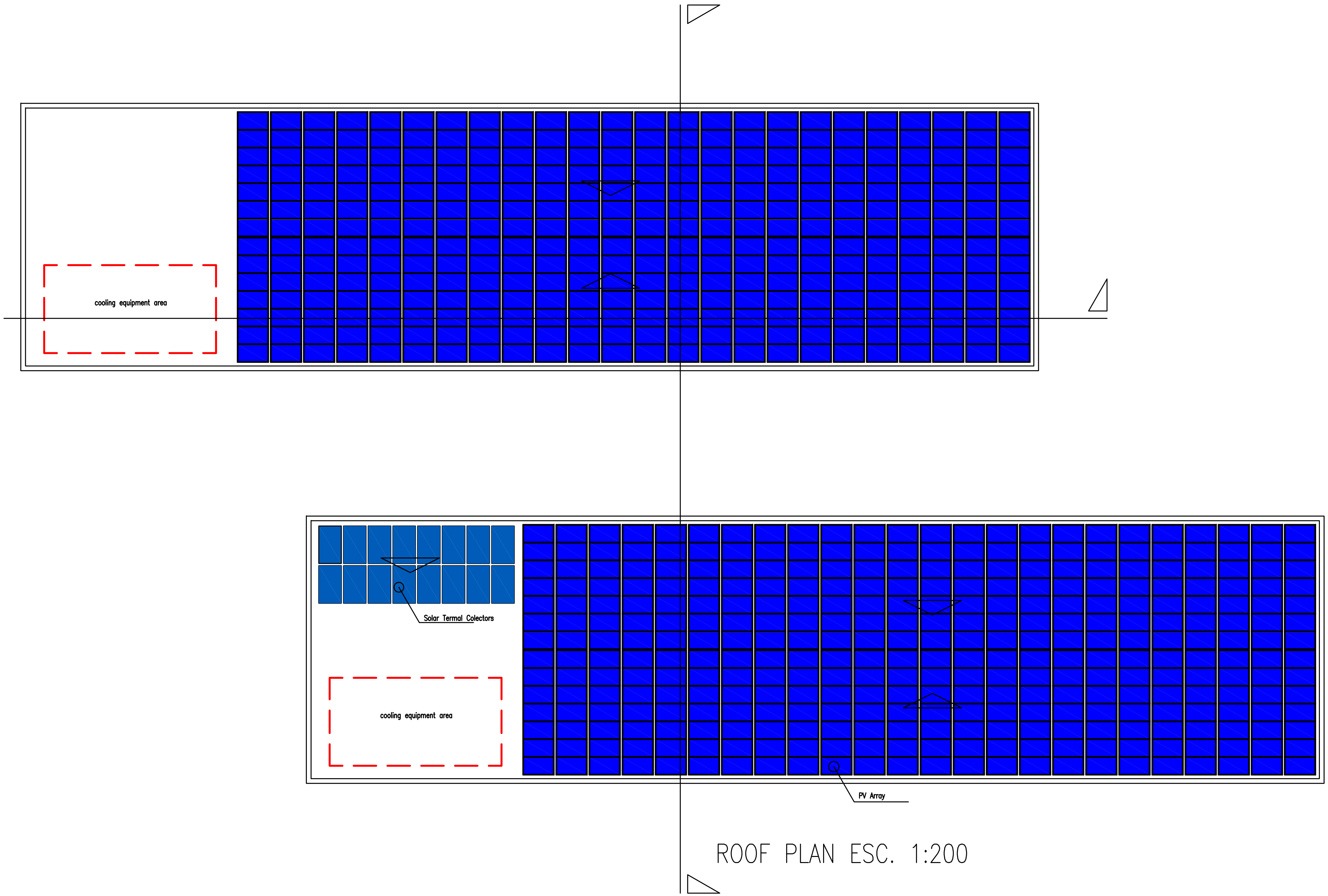
BASEMENT PLANT
ESC. 1:200



BASE FLOOR PLANT
ESC. 1:200



FIRST AND SECOND FLOOR PLANT
ESC. 1:200



ROOF PLAN ESC. 1:200

Annex V. LCC of BD compared against EED

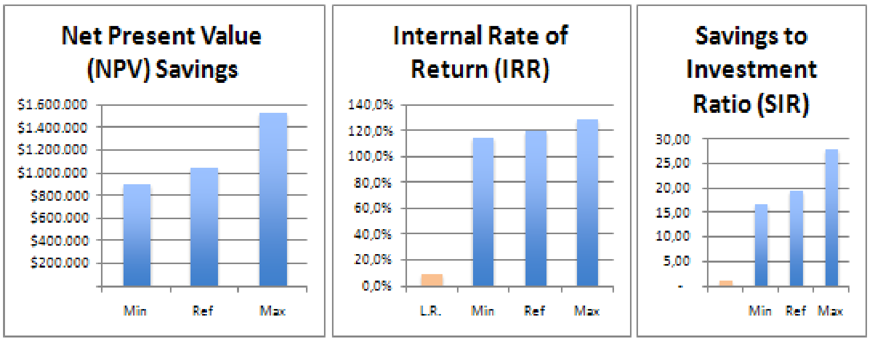
Small size

Comparison between Baseline and EED

As explained in chapter C, the final energy demand of the EED considers a reduction of 64.12 kWh/m^2/yr of external electricity consumption as a result of the power output provided by the PV solar modules that are installed in replacement of the ventilated roof of the BD. It also considers the savings in HW due to the solar thermal installation. All the following EED alternatives have such savings incorporated.

The LLC analysis of both options offers the following results:

	Design Concept	NPV of all costs	Consumption (kWh yr)
Type of solution	**Whole Building**		
Baseline	**Baseline Design**		423.986
Energy Efficiency Solution	**EED**	$56.650	235.154
	Difference	$56.650	-188.832



Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Antigua (APUA)	$1.028.906	$1.193.320	$1.740.632	130,2%	134,7%	144,7%	19,2	22,1	31,7
Bahamas (GB Power)	$414.710	$486.100	$723.748	58,5%	63,0%	73,0%	8,3	9,6	13,8
Bahamas (BEC)	$886.070	$1.028.850	$1.504.147	113,5%	118,0%	128,0%	16,6	19,2	27,6
Barbados (BL&P)	$1.028.906	$1.193.320	$1.740.632	130,2%	134,7%	144,7%	19,2	22,1	31,7
Dominica (DOMLEC)	$1.057.473	$1.226.214	$1.787.929	133,5%	138,0%	148,0%	19,7	22,6	32,6
Grenada (GRENLEC)	$1.057.473	$1.226.214	$1.787.929	133,5%	138,0%	148,0%	19,7	22,6	32,6
Montserrat (MUL)	$1.086.041	$1.259.108	$1.835.226	136,8%	141,3%	151,3%	20,2	23,2	33,4
Nevis (NEVLEC)	$828.935	$963.062	$1.409.553	106,8%	111,3%	121,3%	15,6	18,0	25,9
St. Kitts Elec. Dep.	$771.801	$897.275	$1.314.960	100,2%	104,7%	114,7%	14,6	16,8	24,2
St. Lucia (LUCELEC)	$857.502	$995.956	$1.456.850	110,2%	114,7%	124,7%	16,1	18,6	26,7
ST. Vincent (VINLEC)	$857.502	$995.956	$1.456.850	110,2%	114,7%	124,7%	16,1	18,6	26,7
Average	**$897.756**	**$1.042.307**	**$1.523.496**	**114,9%**	**119,4%**	**129,4%**	**16,8**	**19,4**	**27,9**

Table 76. LCC analysis for the compared Baseline Design and the EED, small size

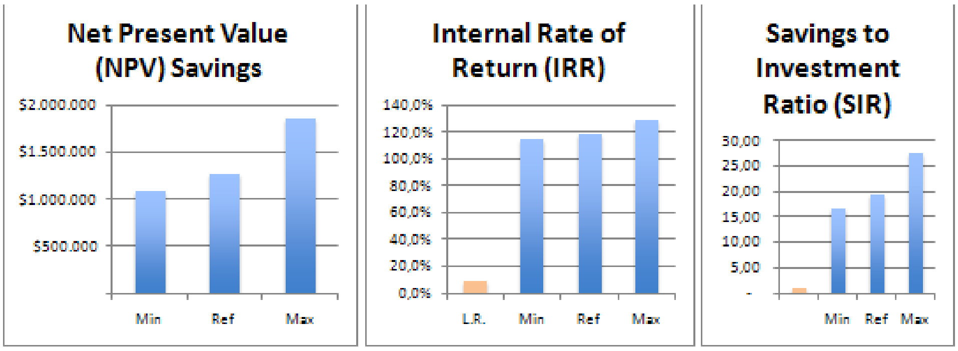
This is, in all case scenarios and for all the power utilities the three parameters (NPV, IRR and SIR) offer values that make such investment financially viable (green lights). The NPV of the savings are in the range of the one million dollars, the average IRR for the reference case scenario is close to 110% and the solution provides twenty times more savings than investment required (SIR approx. 20).

Comparison between Baseline and EED + HR

With the addition of the Heat Recovery system the investment increases by $12,991 and energy consumption is reduced from 102.0 to 84.0 kWh/m^2/yr.

As a result, the average figures for the three parameters of the LCC analysis improve to the figures given below:

Type of solution	Design Concept / Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design		423.986
Energy Efficiency Solution	EED+HR	$69.642	193.563
	Difference	$69.642	-230.423



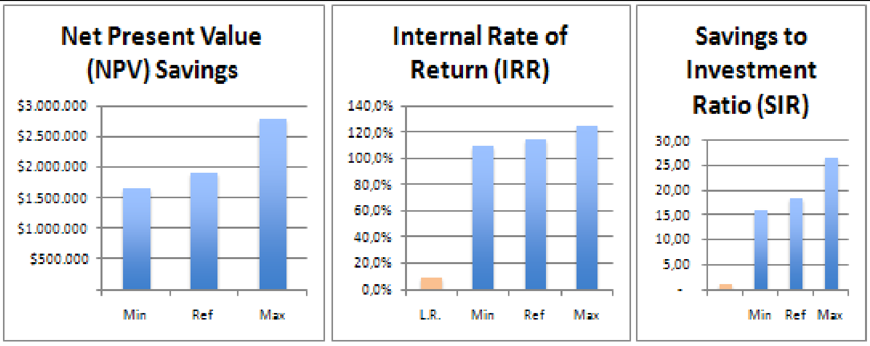
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Average	$1.094.976	$1.271.364	$1.858.537	114,0%	118,5%	128,5%	16,7	19,3	27,7

Table 77- LCC analysis for the compared Baseline Design and the EED + HR, small size

Comparison between Baseline and EED + HR + LED

The addition of LED lighting in replacement for the fluorescent lighting results is a reduction in the need for electricity for lighting and for cooling as a result of the less heat dissipated by the LED. This further diminishes the kWh consumption per m^2 from 84.0 to 33.1 kWh/ m^2/yr. At this level of consumption the average values for the three LCCA parameters are:

Type of solution	Design Concept / Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design		423.986
Energy Efficiency Solution	EED+HR+LED	$109.130	76.292
	Difference	$109.130	-347.694



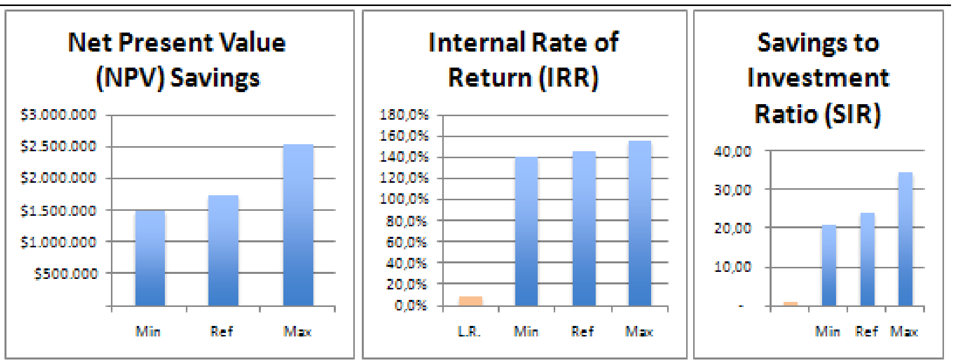
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Average	$1.648.204	$1.914.363	$2.800.369	109,9%	114,4%	124,4%	16,1	18,5	26,7

Table 78. LCC analysis for the compared Baseline Design and the EED + HR + LED, small size

Comparison between Baseline and EED + HR + LC

If instead of the LED lighting a light control system is installed, the consumption is reduced to 48.9 kWh/m^2/yr. This reduction in energy consumption is lower than the result of 33.1 kWh/m^2/yr attained with the LED, but because the investment required for the lighting control system is only $5,904 as compared to the difference of $39,487 between the fluorescent lighting and the LED, the LCC analysis parameters experience a further improvement in IRR and SIR.

Type of solution	Design Concept Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design		423.986
Energy Efficiency Solution	EED+HR+LC	$75.546	112.680
	Difference	$75.546	-311.306



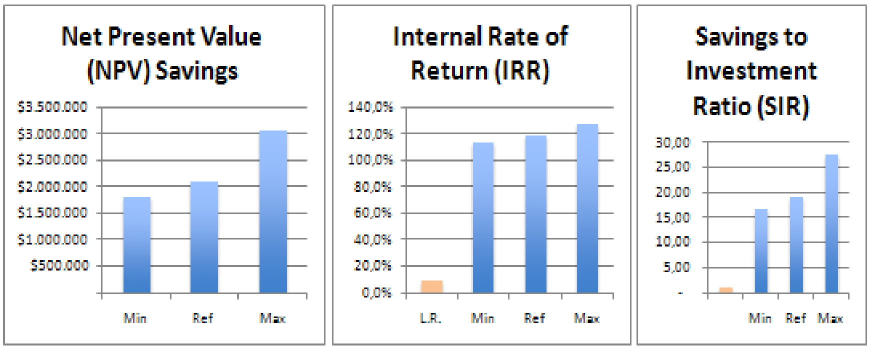
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Average	$1.497.873	$1.736.177	$2.529.458	141,2%	145,7%	155,7%	20,8	24,0	34,5

Table 79. LCC analysis for the compared Baseline Design and the EED + HR + LC, small size

Comparison between Baseline and EED + HR + LED + LC

When the three improvements are considered together, and taking into account a solar output from the grid-connected PV units of 64.12 kWh/m^2/yr, the total consumption to be supplied by external sources is only 19.3 kWh/m^2/yr. This figure, when compared to the 182.5 kWh/m^2/yr of the Baseline design, and considering that the reduction can be attained with an extra investment of $165,433, it further improves the values of the three LCCA parameters.

	Design Concept	NPV of all costs	Consumption (kWh yr)
Type of solution	**Whole Building**		
Baseline	Baseline Design		423.986
Energy Efficiency Solution	EED+HR+LED+LC	$115.034	45.418
	Difference	**$115.034**	**-378.568**



Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Antigua (APUA)	$2.061.274	$2.390.890	$3.488.132	128,6%	133,1%	143,1%	18,9	21,8	31,3
Bahamas (GB Power)	$829.942	$973.065	$1.449.499	57,8%	62,3%	72,3%	8,2	9,5	13,6
Bahamas (BEC)	$1.774.918	$2.061.163	$3.014.031	112,1%	116,6%	126,6%	16,4	18,9	27,2
Barbados (BL&P)	$2.061.274	$2.390.890	$3.488.132	128,6%	133,1%	143,1%	18,9	21,8	31,3
Dominica (DOMLEC)	$2.118.546	$2.456.835	$3.582.952	131,8%	136,3%	146,3%	19,4	22,4	32,1
Grenada (GRENLEC)	$2.118.546	$2.456.835	$3.582.952	131,8%	136,3%	146,3%	19,4	22,4	32,1
Montserrat (MUL)	$2.175.817	$2.522.780	$3.677.772	135,1%	139,6%	149,6%	19,9	22,9	33,0
Nevis (NEVLEC)	$1.660.376	$1.929.272	$2.824.391	105,5%	110,0%	120,0%	15,4	17,8	25,6
St. Kitts Elec. Dep.	$1.545.833	$1.797.381	$2.634.751	98,9%	103,4%	113,4%	14,4	16,6	23,9
St. Lucia (LUCELEC)	$1.717.647	$1.995.218	$2.919.211	108,8%	113,3%	123,3%	15,9	18,3	26,4
ST. Vincent (VINLEC)	$1.717.647	$1.995.218	$2.919.211	108,8%	113,3%	123,3%	15,9	18,3	26,4
Average	**$1.798.347**	**$2.088.141**	**$3.052.821**	**113,4%**	**117,9%**	**127,9%**	**16,6**	**19,2**	**27,5**

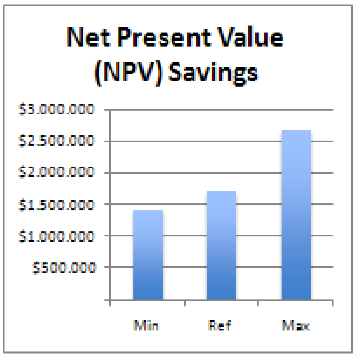
Table 80. LCC analysis for the compared Baseline Design and the EED + HR + LED + LC, small size

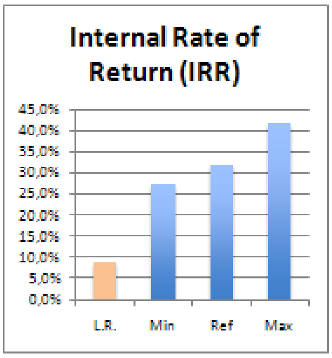
Medium size

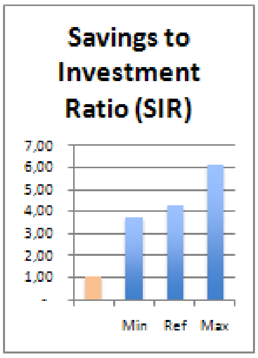
Comparison between Baseline and EED

For the Medium building, the results are the following:

Type of solution	Design Concept Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design-Medium		842.268
Energy Efficiency Solution	EED-MEDIUM	$521.747	460.401
	Difference	$521.747	-381.866







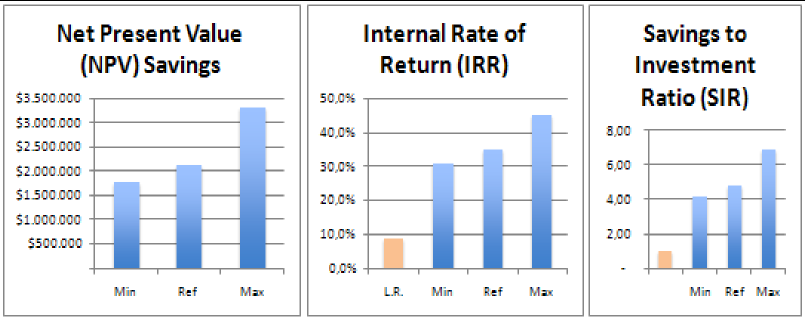
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Antigua (APUA)	$1.673.522	$2.006.009	$3.112.811	31,1%	35,5%	45,4%	4,2	4,8	7,0
Bahamas (GB Power)	$431.462	$575.831	$1.056.416	13,7%	18,0%	27,5%	1,8	2,1	3,0
Bahamas (BEC)	$1.384.671	$1.673.409	$2.634.579	27,3%	31,7%	41,5%	3,7	4,2	6,0
Barbados (BL&P)	$1.673.522	$2.006.009	$3.112.811	31,1%	35,5%	45,4%	4,2	4,8	7,0
Dominica (DOMLEC)	$1.731.292	$2.072.529	$3.208.457	31,8%	36,3%	46,1%	4,3	5,0	7,1
Grenada (GRENLEC)	$1.731.292	$2.072.529	$3.208.457	31,8%	36,3%	46,1%	4,3	5,0	7,1
Montserrat (MUL)	$1.789.062	$2.139.049	$3.304.103	32,6%	37,0%	46,9%	4,4	5,1	7,3
Nevis (NEVLEC)	$1.269.130	$1.540.370	$2.443.287	25,7%	30,1%	39,9%	3,4	4,0	5,7
St. Kitts Elec. Dep.	$1.153.590	$1.407.330	$2.251.994	24,2%	28,6%	38,3%	3,2	3,7	5,3
St. Lucia (LUCELEC)	$1.326.901	$1.606.890	$2.538.933	26,5%	30,9%	40,7%	3,5	4,1	5,9
ST. Vincent (VINLEC)	$1.326.901	$1.606.890	$2.538.933	26,5%	30,9%	40,7%	3,5	4,1	5,9
Average	**$1.408.304**	**$1.700.622**	**$2.673.707**	**27,5%**	**31,9%**	**41,7%**	**3,7**	**4,3**	**6,1**

Table 81.LCC analysis for the compared Baseline Design and the EED, medium size

The cost difference between these two alternatives is highly overcome by the economic savings obtained from the reduced yearly electricity demand. This results in positive (green color) indicators in NPV, IRR and SIR.

Comparison between Baseline and EED + HR

Type of solution	Design Concept Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design-Medium		842.268
Energy Efficiency Solution	EED+HR-MEDIUM	$561.124	380.540
	Difference	$561.124	-461.728



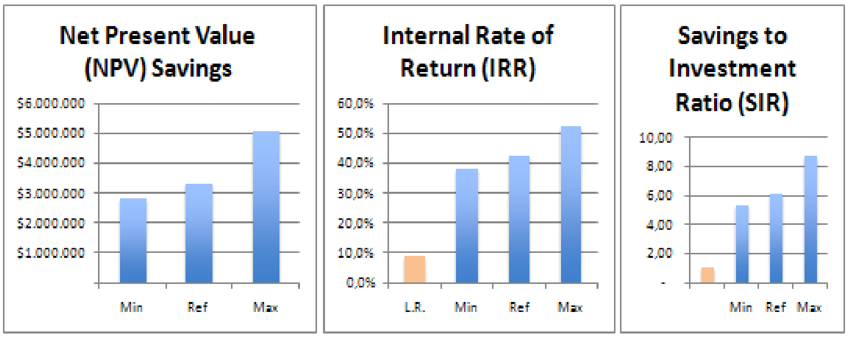
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	Ref	Max	Min	Ref	Max	Min	Ref	Max
Antigua (APUA)	$2.093.253	$2.495.275	$3.833.548	34,6%	39,1%	49,0%	4,7	5,4	7,8
Bahamas (GB Power)	$591.434	$765.997	$1.347.089	15,6%	19,9%	29,4%	2,1	2,4	3,4
Bahamas (BEC)	$1.743.993	$2.093.117	$3.255.301	30,4%	34,8%	44,7%	4,1	4,7	6,8
Barbados (BL&P)	$2.093.253	$2.495.275	$3.833.548	34,6%	39,1%	49,0%	4,7	5,4	7,8
Dominica (DOMLEC)	$2.163.105	$2.575.706	$3.949.197	35,4%	39,9%	49,8%	4,9	5,6	8,0
Grenada (GRENLEC)	$2.163.105	$2.575.706	$3.949.197	35,4%	39,9%	49,8%	4,9	5,6	8,0
Montserrat (MUL)	$2.232.957	$2.656.138	$4.064.846	36,3%	40,7%	50,7%	5,0	5,7	8,2
Nevis (NEVLEC)	$1.604.289	$1.932.254	$3.024.003	28,7%	33,1%	43,0%	3,9	4,4	6,4
St. Kitts Elec. Dep.	$1.464.585	$1.771.391	$2.792.704	27,0%	31,4%	41,2%	3,6	4,2	6,0
St. Lucia (LUCELEC)	$1.674.141	$2.012.685	$3.139.652	29,5%	34,0%	43,8%	4,0	4,6	6,6
ST. Vincent (VINLEC)	$1.674.141	$2.012.685	$3.139.652	29,5%	34,0%	43,8%	4,0	4,6	6,6
Average	**$1.772.569**	**$2.126.021**	**$3.302.612**	**30,6%**	**35,1%**	**44,9%**	**4,2**	**4,8**	**6,9**

Table 82. LCC analysis for the compared Baseline Design and the EED + HR, medium size

The increase of the cost difference due to the incorporation of the Heat Recovery unit is significantly overcome by the economic savings obtained from the reduced yearly electricity demand, which improves considerably. This results in positive (green color) indicators in NPV, IRR and SIR.

Comparison between Baseline and EED + HR + LED

	Design Concept	NPV of all costs	Consumption (kWh yr)
Type of solution	**Whole Building**		
Baseline	**Baseline Design-Medium**		842.268
Energy Efficiency Solution	**EED+HR+LED-MEDIUM**	$656.909	155.360
	Difference	**$656.909**	**-686.908**



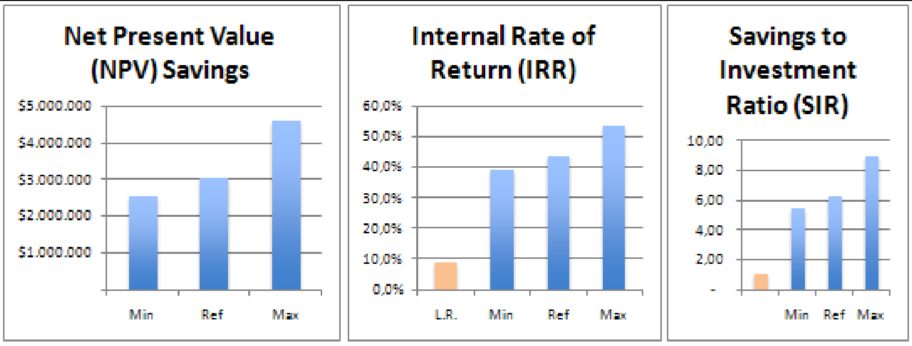
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Antigua (APUA)	$3.291.980	$3.890.063	$5.880.999	43,2%	47,7%	57,6%	6,0	6,9	10,0
Bahamas (GB Power)	$1.057.740	$1.317.434	$2.181.919	19,8%	24,2%	33,9%	2,6	3,0	4,3
Bahamas (BEC)	$2.772.389	$3.291.777	$5.020.748	37,9%	42,4%	52,3%	5,2	6,0	8,6
Barbados (BL&P)	$3.291.980	$3.890.063	$5.880.999	43,2%	47,7%	57,6%	6,0	6,9	10,0
Dominica (DOMLEC)	$3.395.898	$4.009.721	$6.053.049	44,2%	48,7%	58,7%	6,2	7,1	10,2
Grenada (GRENLEC)	$3.395.898	$4.009.721	$6.053.049	44,2%	48,7%	58,7%	6,2	7,1	10,2
Montserrat (MUL)	$3.499.816	$4.129.378	$6.225.099	45,3%	49,8%	59,7%	6,3	7,3	10,5
Nevis (NEVLEC)	$2.564.553	$3.052.463	$4.676.647	35,8%	40,2%	50,2%	4,9	5,6	8,1
St. Kitts Elec. Dep.	$2.356.717	$2.813.149	$4.332.547	33,6%	38,1%	48,0%	4,6	5,3	7,6
St. Lucia (LUCELEC)	$2.668.471	$3.172.120	$4.848.697	36,8%	41,3%	51,2%	5,1	5,8	8,4
ST. Vincent (VINLEC)	$2.668.471	$3.172.120	$4.848.697	36,8%	41,3%	51,2%	5,1	5,8	8,4
Average	**$2.814.901**	**$3.340.728**	**$5.091.132**	**38,3%**	**42,7%**	**52,6%**	**5,3**	**6,1**	**8,8**

Table 83. LCC analysis for the compared Baseline Design and the EED + HR + LED, medium size

The increase of the cost difference due to the incorporation of the LED lighting fixtures to the previous model, replacing fluorescent lighting, is significantly overcome by the economic savings obtained from the reduced yearly electricity demand. This results in positive (green color) indicators in NPV, IRR and SIR.

Comparison between Baseline and EED + HR + LC

	Design Concept	NPV of all costs	Consumption (kWh yr)
Type of solution	**Whole Building**		
Baseline	Baseline Design-Medium		842.268
Energy Efficiency Solution	EED+HR+LC-MEDIUM	$572.932	225.231
	Difference	**$572.932**	**-617.037**



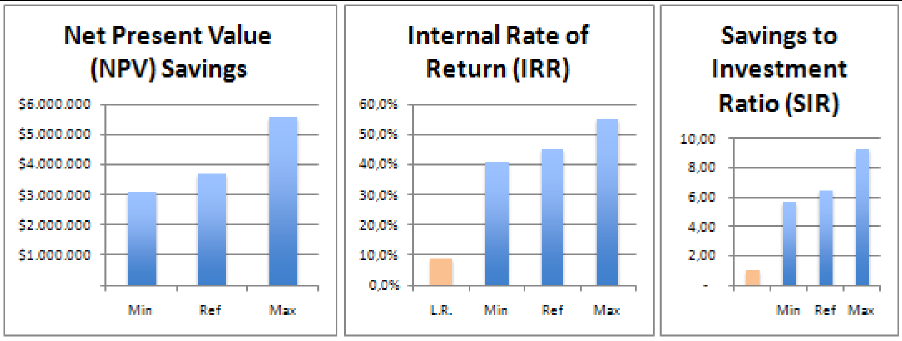
Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Antigua (APUA)	$2.974.282	$3.511.529	$5.299.949	44,4%	48,9%	58,8%	6,2	7,1	10,3
Bahamas (GB Power)	$967.306	$1.200.584	$1.977.135	20,4%	24,8%	34,5%	2,7	3,1	4,5
Bahamas (BEC)	$2.507.543	$2.974.100	$4.527.201	38,9%	43,4%	53,4%	5,4	6,2	8,9
Barbados (BL&P)	$2.974.282	$3.511.529	$5.299.949	44,4%	48,9%	58,8%	6,2	7,1	10,3
Dominica (DOMLEC)	$3.067.629	$3.619.015	$5.454.498	45,5%	49,9%	59,9%	6,4	7,3	10,5
Grenada (GRENLEC)	$3.067.629	$3.619.015	$5.454.498	45,5%	49,9%	59,9%	6,4	7,3	10,5
Montserrat (MUL)	$3.160.977	$3.726.500	$5.609.048	46,5%	51,0%	61,0%	6,5	7,5	10,8
Nevis (NEVLEC)	$2.320.848	$2.759.128	$4.218.102	36,8%	41,2%	51,2%	5,1	5,8	8,4
St. Kitts Elec. Dep.	$2.134.152	$2.544.157	$3.909.003	34,6%	39,0%	48,9%	4,7	5,4	7,8
St. Lucia (LUCELEC)	$2.414.195	$2.866.614	$4.372.652	37,9%	42,3%	52,3%	5,2	6,0	8,6
ST. Vincent (VINLEC)	$2.414.195	$2.866.614	$4.372.652	37,9%	42,3%	52,3%	5,2	6,0	8,6
Average	$2.545.731	$3.018.071	$4.590.426	39,3%	43,8%	53,7%	5,4	6,3	9,0

Table 84. LCC analysis for the compared Baseline Design and the EED + HR + LC, medium size

The increase of the cost difference due to the incorporation of the lighting control to the EED with Heat Recovery saves less energy than the previous LED case, but is also less costly. This results in positive (green color) indicators in NPV, IRR and SIR.

Comparison between Baseline and EED + HR + LED + LC

Type of solution	Design Concept Whole Building	NPV of all costs	Consumption (kWh yr)
Baseline	Baseline Design-Medium		842.268
Energy Efficiency Solution	EED+HR+LED+LC-MEDIUM	$668.717	96.075
	Difference	$668.717	-746.192



Power Utility	Net Present Value (NPV) Savings			Internal Rate of Return (IRR)			Savings to Investment Ratio (SIR)		
	Min	*Ref*	*Max*	*Min*	*Ref*	*Max*	*Min*	*Ref*	*Max*
Antigua (APUA)	$3.620.984	$4.270.685	$6.433.450	45,9%	50,3%	60,3%	6,4	7,4	10,6
Bahamas (GB Power)	$1.193.916	$1.476.023	$2.415.118	21,1%	25,5%	35,2%	2,8	3,2	4,6
Bahamas (BEC)	$3.056.549	$3.620.764	$5.498.954	40,2%	44,7%	54,7%	5,6	6,4	9,2
Barbados (BL&P)	$3.620.984	$4.270.685	$6.433.450	45,9%	50,3%	60,3%	6,4	7,4	10,6
Dominica (DOMLEC)	$3.733.871	$4.400.669	$6.620.349	47,0%	51,5%	61,4%	6,6	7,6	10,9
Grenada (GRENLEC)	$3.733.871	$4.400.669	$6.620.349	47,0%	51,5%	61,4%	6,6	7,6	10,9
Montserrat (MUL)	$3.846.757	$4.530.654	$6.807.248	48,1%	52,6%	62,6%	6,8	7,8	11,2
Nevis (NEVLEC)	$2.830.776	$3.360.795	$5.125.156	38,0%	42,5%	52,4%	5,2	6,0	8,7
St. Kitts Elec. Dep.	$2.605.002	$3.100.827	$4.751.357	35,7%	40,2%	50,1%	4,9	5,6	8,1
St. Lucia (LUCELEC)	$2.943.662	$3.490.779	$5.312.055	39,1%	43,6%	53,5%	5,4	6,2	8,9
ST. Vincent (VINLEC)	$2.943.662	$3.490.779	$5.312.055	39,1%	43,6%	53,5%	5,4	6,2	8,9
Average	**$3.102.730**	**$3.673.939**	**$5.575.413**	**40,6%**	**45,1%**	**55,0%**	**5,6**	**6,5**	**9,3**

Table 85. LCC analysis for the compared Baseline Design and the EED + HR + LED + LC, medium size

The incorporation of Heat Recovery, LED lights and lighting control is overall positive and even though more costly than the BD, this option renders positive financial results as shown by the indicators.

Annex VI. Building Codes

International Energy Conservation Code 2012 / Florida Building Code – Energy Conservation

The following figure shows the envelope requirements[22][23]:

TABLE 5.5-1 Building Envelope Requirements for Climate Zone 1 (A, B)[*]

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	Residential Assembly Maximum	Residential Insulation Min. R-Value	Semiheated Assembly Maximum	Semiheated Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.063	R-15.0 c.i.	U-0.048	R-20.0 c.i.	U-0.218	R-3.8 c.i.
Metal Building[a]	U-0.065	R-19.0	U-0.065	R-19.0	U-0.167	R-6.0
Attic and Other	U-0.034	R-30.0	U-0.027	R-38.0	U-0.081	R-13.0
Walls, Above-Grade						
Mass	U-0.580	NR	U-0.151[b]	R-5.7 c.i.[b]	U-0.580	NR
Metal Building	U-0.093	R-16.0	U-0.093	R-16.0	U-0.113	R-13.0
Steel-Framed	U-0.124	R-13.0	U-0.124	R-13.0	U-0.352	NR
Wood-Framed and Other	U-0.089	R-13.0	U-0.089	R-13.0	U-0.292	NR
Walls, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-1.140	NR	C-1.140	NR
Floors						
Mass	U-0.322	NR	U-0.322	NR	U-0.322	NR
Steel-Joist	U-0.350	NR	U-0.350	NR	U-0.350	NR
Wood-Framed and Other	U-0.282	NR	U-0.282	NR	U-0.282	NR
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.730	NR	F-0.730	NR
Heated	F-1.020	R-7.5 for 12 in.	F-1.020	R-7.5 for 12 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Nonswinging	U-1.450		U-1.450		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-1.20	SHGC-0.25 all	U-1.20	SHGC-0.25 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-1.20		U-1.20		U-1.20	
Metal framing (entrance door)[d]	U-1.20		U-1.20		U-1.20	
Metal framing (all other)[d]	U-1.20		U-1.20		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-1.98	$SHGC_{all}$-0.36	U_{all}-1.98	$SHGC_{all}$-0.19	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.98	$SHGC_{all}$-0.19	U_{all}-1.98	$SHGC_{all}$-0.16	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-1.90	$SHGC_{all}$-0.34	U_{all}-1.90	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.90	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-1.36	$SHGC_{all}$-0.36	U_{all}-1.36	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.36	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-NR

[*]The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

Figure 75: ASHRAE 90.1-2010, Standard Referenced Design (Baseline) Envelope Requirements

[22] The U-value is in IP units (Btuh/ft2-F)
[23] In previous versions there were different requirements depending on the wall orientation

CLIMATE ZONE	1	
	All other	Group R
Insulation entirely above deck	U-0.048	U-0.048
Metal buildings	U-0.044	U-0.035
Attic and other	U-0.027	U-0.027
Mass	U-0.142	U-0.142
Metal building	U-0.079	U-0.079
Metal framed	U-0.077	U-0.077
Wood framed and other	U-0.064	U-0.064
Below-grade wall[b]	C-1.140	C-1.140
Mass	U-0.322	U-0.322
Joist/framing	U-0.066	U-0.066
Unheated slabs	F-0.73	F-0.73
Heated slabs	F-0.70	F-0.70

CLIMATE ZONE	1	
	All Other	Group R
Insulation entirely above deck	R-20ci	R-20ci
Metal buildings (with R-5 thermal blocks)[a, b]	R-19 + R-11 LS	R-19 + R-11 LS
Attic and other	R-38	R-38
Mass	R-5.7ci	R-5.7ci
Metal building	R-13+ R-6.5ci	R-13 + R-6.5ci
Metal framed	R-13 + R-5ci	R-13 + R-5ci
Wood framed and other	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20
Below-grade wall[d]	NR	NR
Mass	NR	NR
Joist/framing	NR	NR
Unheated slabs	NR	NR
Heated slabs[d]	R-7.5 for 12″ below	R-7.5 for 12″ below
Swinging	U-0.61	U-0.61
Roll-up or sliding	R-4.75	R-4.75

Figure 76: IECC-2012, Standard Referenced Design (Baseline) Envelope Requirements

TABLE C402.3
BUILDING ENVELOPE REQUIREMENTS: FENESTRATION

CLIMATE ZONE	1	2	3	4 EXCEPT MARINE	5 AND MARINE 4	6	7	8
Vertical fenestration								
***U*-factor**								
Fixed fenestration	0.50	0.50	0.46	0.38	0.38	0.36	0.29	0.29
Operable fenestration	0.65	0.65	0.60	0.45	0.45	0.43	0.37	0.37
Entrance doors	1.10	0.83	0.77	0.77	0.77	0.77	0.77	0.77
SHGC								
SHGC	0.25	0.25	0.25	0.40	0.40	0.40	0.45	0.45
Skylights								
***U*-factor**	0.75	0.65	0.55	0.50	0.50	0.50	0.50	0.50
SHGC	0.35	0.35	0.35	0.40	0.40	0.40	NR	NR

NR = No requirement.

Figure 77- Figure 8: IECC-2012, Standard Referenced Design (Baseline) Fenestration Requirements

Fenestration area limitation:

The analyzed energy codes and standards have limitations of the maximum allowed fenestration. According to the codes, the maximum allowed fenestration area shall be used in the prescriptive compliance method. However, if the referred building exceeds these limits the total building compliance method must be used and the baseline building's fenestration area (Standard Reference Design) shall be limited to have the maximum allowed by the codes and standards. The following is a simplified comparison table between the three codes:

	FBC-EC-2012	ASHRAE 90.1	IECC-2012
U-factor	**< 0.45**	**≤ 1.2**	**≤0.5 fixed** **≤ 0.65 operable**
SHGC: if 0 - 40% WW Ratio	**< 0.25**	**≤ 0.25**	**≤ 0.25** (1) (2)
SHGC: if 40-50% WW Ratio	**< 0.19**	**Not allowed** Shall follow Total Blgd. Method	**Not allowed** Shall follow Total Blgd. Method
SHGC: if WW Ratio > 50%	**Not allowed** Shall follow Total Blgd. Method		

(1) Maximum allowed is 30% WW Ratio, but there is an allowance for Zone 1 thru 6 the maximum allowed WW Ration to be increase to 40% if:
- Not less than 50% of the conditioned floor area is within a daylight zone
- Automatic daylighting controls are installed in daylighting zones
- Visible Transmittance (VT) of vertical fenestration is greater than or equal to 1.1 times SHGC.

(2) Maximum SHGC when using prescriptive method can be determined based on section C402.3.3 with the application of the Projection Factor (PF). **PF=A/B**, where A is horizontal distance of any permanent overhang eve or shading device and B is distance measured vertically from the bottom of the glazing to the underside of the permanent overhang, eve or shading device.

TABLE C402.3.3.1
SHGC ADJUSTMENT MULTIPLIERS

PROJECTION FACTOR	ORIENTED WITHIN 45 DEGREES OF TRUE NORTH	ALL OTHER ORIENTATION
0.2 ≤ PF < 0.5	1.1	1.2
PF ≤ 0.5	1.2	1.6

Table 86: Comparison table for WWR (Wall to Window Ration) between the analyzed codes.

Building Air Leakage (Mandatory)

In all of the analyzed energy codes there are limitations and prescriptive requirements regulating the maximum unconditioned outdoor air infiltrating the building through the building envelope.

- The different building elements such as windows, door assemblies, curtain wall, store front, etc. have specific testing and certification requirements for limiting the air infiltration.
- Openings and penetrations in the building envelope shall be sealed with caulking materials or closed with gasketing systems compatible with the construction materials and location.
- Joints and seams shall be sealed in the same manner or taped or covered with a moisture vapor permeable wrapping material.
- Sealing materials spanning joints between construction materials shall allow for expansion and contraction of the construction materials.

The following are maximum allowed leakage rates in accordance with the Florida Energy Conservation Code:

a. Windows, skylights and sliding glass doors shall have an air infiltration rate of no more than 0.3 cfm[24] per square foot (1.5 L/s/m2), and swinging doors no more than 0.5 cfm per square foot (2.6 L/s/m2), when tested according to NFRC 400 or AAMA/WDMA/ CSA 101/I.S.2/A440 by an accredited, independent laboratory and listed and labeled by the manufacturer.
b. Recessed luminaires installed in the building thermal envelope shall be sealed to limit air leakage between conditioned and unconditioned spaces. All recessed luminaires shall be IC-rated and labeled as meeting ASTM E 283 when tested at 1.57 psf (75 Pa) pressure differential with no more than 2.0 cfm (0.944 L/s) of air movement from the conditioned space to the ceiling cavity. All recessed luminaires shall be sealed with a gasket or caulk between the housing and the interior wall or ceiling covering.

The following are maximum allowed leakage rate in accordance with the ASHRAE 90.1-2010:

[24] cfm stands for cubic feet per minute

TABLE C402.4.3
MAXIMUM AIR INFILTRATION RATE FOR FENESTRATION ASSEMBLIES

FENESTRATION ASSEMBLY	MAXIMUM RATE (CFM/FT^2)	TEST PROCEDURE
Windows	0.20[a]	AAMA/WDMA/ CSA101/I.S.2/A440 or NFRC 400
Sliding doors	0.20[a]	
Swinging doors	0.20[a]	
Skylights – with condensation weepage openings	0.30	
Skylights – all other	0.20[a]	
Curtain walls	0.06	NFRC 400 or ASTM E 283 at 1.57 psf (75 Pa)
Storefront glazing	0.06	
Commercial glazed swinging entrance doors	1.00	
Revolving doors	1.00	
Garage doors	0.40	ANSI/DASMA 105, NFRC 400, or ASTM E 283 at 1.57 psf (75 Pa)
Rolling doors	1.00	

For SI: 1 cubic foot per minute = 0.47L/s, 1 square foot = 0.093 m^2.

a. The maximum rate for windows, sliding and swinging doors, and skylights is permitted to be 0.3 cfm per square foot of fenestration or door area when tested in accordance with AAMA/WDMA/CSA101/I.S.2/A440 at 6.24 psf (300 Pa).

Mechanical Ventilation Requirements:

	People Outdoor Airflow Rate CFM/PERSON		Area Outdoor Airflow Rate CFM/FT2		Default Occupancy Density #PEOPLE/1000FT2		Exhaust Airflow Rate CFM/ft2 (for spaces other than toilets)	
	FBC 2010	ASHRAE 62.1-2007	FBC 2010	ASHRAE 62.1-2007	FBC 2010	ASHRAE 62.1-2007	FBC 2010	ASHRAE 62.1-2007
Office space	5	5	0.06	0.06	5	5	n/a	n/a
Conference Rooms	5	5	0.06	0.06	50	50	n/a	n/a
Reception Area	5	5	0.06	0.06	30	30	n/a	n/a
Telephone/data	5	5	0.06	0.06	60	60	n/a	n/a
Main Entry Lobbies	5	5	0.06	0.06	10	10	n/a	n/a
Corridors	-	-	0.06	0.06	-	-	n/a	
Toilet Rooms-public	-		-	-	-	-	50/70[(1)]	50/70[(1)]
Toilet Rooms-private	-	-	-	-	-	-	25/50[(2)]	25/50[(2)]

Courtrooms	5	5	0.06	0.06	70	70	n/a	n/a
Legislative chambers	5	5	0.06	0.06	50	50	n/a	n/a
Libraries	5	5	0.06	0.06	10	10	n/a	n/a
Lobby Assembly Space	n/a	5	n/a	0.06	n/a	150	n/a	n/a
Storage	-	-	0.06	0.12	-	-	n/a	n/a
Cafeteria, fast food	7.5	7.5	0.18	0.18	100	100	n/a	n/a
Bar, cocktail lounge	7.5	7.5	0.18	0.18	100	100	n/a	n/a
Dining rooms	7.5	7.5	0.18	0.18	100	100	n/a	n/a
Kitchen	-	-	-	-	-	-	0.7	0.7
Cells -without plumbing fixtures	5	5	0.12	0.12	25	25	n/a	n/a
Cells - with plumbing fixtures	5	n/a	0.12	n/a	25	n/a	1.0	1.0
Guard stations	5	5	0.06	0.06	15	15	n/a	n/a
Day room	5	5	0.06	0.06	30	30	n/a	n/a
Booking/waiting	7.5	7.5	0.06	0.06	50	50	n/a	n/a
Copy, printing rooms	5	n/a	0.06	n/a	4	n/a	0.5	0.5
Janitor Closets	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.0
Kitchenettes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.3
Locker/dressing room	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.25
Locker rooms	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.50
Storage rooms chemicals	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.50

Notes:

1. Rates are per water closet or urinal. The higher rate shall be provided where periods of heavy use are expected to occur, such as toilets in theaters, schools and sports facilities. The lower rate shall be permitted where periods of heavy use are not expected.
2. Rate is for a toilet room occupied one person at a time. For continuous system operation during normal hours of use, the lower rate can be used. Otherwise the higher rate shall be used.

Table 87- Mechanical Ventilation Requirements – FBC – Mechanical and ASHRAE 62.1-2007

Mechanical (HVAC) Equipment

Equipment efficiencies in baseline model if used the prescriptive method shall be as listed in the following tables:

TABLE C403.2.3(1)
MINIMUM EFFICIENCY REQUIREMENTS:
ELECTRICALLY OPERATED UNITARY AIR CONDITIONERS AND CONDENSING UNITS

EQUIPMENT TYPE	SIZE CATEGORY	HEATING SECTION TYPE	SUBCATEGORY OR RATING CONDITION	MINIMUM EFFICIENCY		TEST PROCEDURE[a]
				Before 6/1/2011	As of 6/1/2011	
Air conditioners, air cooled	< 65,000 Btu/h[b]	All	Split System	13.0 SEER	13.0 SEER	AHRI 210/240
			Single Package	13.0 SEER	13.0 SEER	
Through-the-wall (air cooled)	≤ 30,000 Btu/h[b]	All	Split system	12.0 SEER	12.0 SEER	
			Single Package	12.0 SEER	12.0 SEER	
Small-duct high-velocity (air cooled)	< 65,000 Btu/h[b]	All	Split System	10.0 SEER	10.0 SEER	
Air conditioners, air cooled	≥ 65,000 Btu/h and < 135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.2 EER 11.4 IEER	11.2 EER 11.4 IEER	AHRI 340/360
		All other	Split System and Single Package	11.0 EER 11.2 IEER	11.0 EER 11.2 IEER	
	≥ 135,000 Btu/h and < 240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.2 IEER	11.0 EER 11.2 IEER	
		All other	Split System and Single Package	10.8 EER 11.0 IEER	10.8 EER 11.0 IEER	
	≥ 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	10.0 EER 10.1 IEER	10.0 EER 10.1 IEER	
		All other	Split System and Single Package	9.8 EER 9.9 IEER	9.8 EER 9.9 IEER	
	≥ 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	9.7 EER 9.8 IEER	9.7 EER 9.8 IEER	
		All other	Split System and Single Package	9.5 EER 9.6 IEER	9.5 EER 9.6 IEER	
Air conditioners, water cooled	< 65,000 Btu/h[b]	All	Split System and Single Package	12.1 EER 12.3 IEER	12.1 EER 12.3 IEER	AHRI 210/240
	≥ 65,000 Btu/h and < 135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.5 EER 11.7 IEER	12.1 EER 12.3 IEER	AHRI 340/360
		All other	Split System and Single Package	11.3 EER 11.5 IEER	11.9 EER 12.1 IEER	
	≥ 135,000 Btu/h and < 240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.2 IEER	12.5 EER 12.7 IEER	
		All other	Split System and Single Package	10.8 EER 11.0 IEER	12.3 EER 12.5 IEER	
	≥ 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.1 IEER	12.4 EER 12.6 IEER	
		All other	Split System and Single Package	10.8 EER 10.9 IEER	12.2 EER 12.4 IEER	
	≥ 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.1 IEER	12.0 EER 12.4 IEER	
		All other	Split System and Single Package	10.8 EER 10.9 IEER	12.0 EER 12.2 IEER	

TABLE C403.2.3(1)—continued
MINIMUM EFFICIENCY REQUIREMENTS:
ELECTRICALLY OPERATED UNITARY AIR CONDITIONERS AND CONDENSING UNITS

EQUIPMENT TYPE	SIZE CATEGORY	HEATING SECTION TYPE	SUB-CATEGORY OR RATING CONDITION	MINIMUM EFFICIENCY		TEST PROCEDURE[a]
				Before 6/1/2011	As of 6/1/2011	
Air conditioners, evaporatively cooled	< 65,000 Btu/h[b]	All	Split System and Single Package	12.1 EER 12.3 IEER	12.1 EER 12.3 IEER	AHRI 210/240
	≥ 65,000 Btu/h and < 135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.5 EER 11.7 IEER	12.1 EER 12.3 IEER	AHRI 340/360
		All other	Split System and Single Package	11.3 EER 11.5 IEER	11.9 EER 12.1 IEER	
	≥ 135,000 Btu/h and < 240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.2 IEER	12.0 EER 12.2 IEER	
		All other	Split System and Single Package	10.8 EER 11.0 IEER	11.8 EER 12.0 IEER	
	≥ 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.1 IEER	11.9 EER 12.1 IEER	
		All other	Split System and Single Package	10.8 EER 10.9 IEER	12.2 EER 11.9 IEER	
	≥ 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	10.0 EER 11.1 IEER	11.7 EER 11.9 IEER	
		All other	Split System and Single Package	10.8 EER 10.9 IEER	11.5 EER 11.7 IEER	
Condensing units, air cooled	≥ 135,000 Btu/h			10.1 EER 11.4 IEER	10.5 EER 14.0 IEER	AHRI 365
Condensing units, water cooled	≥ 135,000 Btu/h			13.1 EER 13.6 IEER	13.5 EER 14.0 IEER	
Condensing units, evaporatively cooled	≥ 135,000 Btu/h			13.1 EER 13.6 IEER	13.5 EER 14.0 IEER	

For SI: 1 British thermal unit per hour = 0.2931 W.

a. Chapter 6 of the referenced standard contains a complete specification of the referenced test procedure, including the reference year version of the test procedure.

b. Single-phase, air-cooled air conditioners less than 65,000 Btu/h are regulated by NAECA. SEER values are those set by NAECA.

TABLE C403.2.3(7)
MINIMUM EFFICIENCY REQUIREMENTS:
WATER CHILLING PACKAGES[a]

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	BEFORE 1/1/2010 FULL LOAD	BEFORE 1/1/2010 IPLV	AS OF 1/1/2010[b] PATH A FULL LOAD	AS OF 1/1/2010[b] PATH A IPLV	AS OF 1/1/2010[b] PATH B FULL LOAD	AS OF 1/1/2010[b] PATH B IPLV	TEST PROCEDURE[c]
Air-cooled chillers	< 150 tons	EER	≥ 9.562	≥ 10.416	≥ 9.562	≥ 12.500	NA	NA	AHRI 550/590
	≥ 150 tons	EER			≥ 9.562	≥ 12.750	NA	NA	
Air cooled without condenser, electrical operated	All capacities	EER	≥ 10.586	≥ 11.782	Air-cooled chillers without condensers shall be rated with matching condensers and comply with the air-cooled chiller efficiency requirements				
Water cooled, electrically operated, reciprocating	All capacities	kW/ton	≤ 0.837	≤ 0.696	Reciprocating units shall comply with water cooled positive displacement efficiency requirements				
Water cooled, electrically operated, positive displacement	< 75 tons	kW/ton	≤ 0.790	≤ 0.676	≤ 0.780	≤ 0.630	≤ 0.800	≤ 0.600	
	≥ 75 tons and < 150 tons	kW/ton			≤ 0.775	≤ 0.615	≤ 0.790	≤ 0.586	
	≥ 150 tons and < 300 tons	kW/ton	≤ 0.717	≤ 0.627	≤ 0.680	≤ 0.580	≤ 0.718	≤ 0.540	
	≥ 300 tons	kW/ton	≤ 0.639	≤ 0.571	≤ 0.620	≤ 0.540	≤ 0.639	≤ 0.490	
Water cooled, electrically operated, centrifugal	< 150 tons	kW/ton	≤ 0.703	≤ 0.669	≤ 0.634	≤ 0.596	≤ 0.639	≤ 0.450	
	≥ 150 tons and < 300 tons	kW/ton	≤ 0.634	≤ 0.596					
	≥ 300 tons and < 600 tons	kW/ton	≤ 0.576	≤ 0.549	≤ 0.576	≤ 0.549	≤ 0.600	≤ 0.400	
	≥ 600 tons	kW/ton	≤ 0.576	≤ 0.549	≤ 0.570	≤ 0.539	≤ 0.590	≤ 0.400	
Air cooled, absorption single effect	All capacities	COP	≥ 0.600	NR	≥ 0.600	NR	NA	NA	AHRI 560
Water cooled, absorption single effect	All capacities	COP	≥ 0.700	NR	≥ 0.700	NR	NA	NA	
Absorption double effect, indirect fired	All capacities	COP	≥ 1.000	≥ 1.050	≥ 1.000	≥ 1.050	NA	NA	
Absorption double effect, direct fired	All capacities	COP	≥ 1.000	≥ 1.000	≥ 1.000	≥ 1.000	NA	NA	

For SI: 1 ton = 3517 W, 1 British thermal unit per hour = 0.2931 W, °C = [(°F) - 32]/1.8.

NA = Not applicable, not to be used for compliance; NR = No requirement.

a. The centrifugal chiller equipment requirements, after adjustment in accordance with Section C403.2.3.1 or Section C403.2.3.2, do not apply to chillers used in low-temperature applications where the design leaving fluid temperature is less than 36°F. The requirements do not apply to positive displacement chillers with leaving fluid temperatures less than or equal to 32°F. The requirements do not apply to absorption chillers with design leaving fluid temperatures less than 40°F.

b. Compliance with this standard can be obtained by meeting the minimum requirements of Path A or B. However, both the full load and IPLV shall be met to fulfill the requirements of Path A or B.

c. Chapter 6 of the referenced standard contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

Figure 78- IECC 2012 - HVAC performance requirements

Lighting Power Density

Lighting power density in the baseline model, if used the prescriptive method, shall be as listed in the following table:

Table Lighting Power Densities Using Space-by-Space Method

Common Space Types*	LPD, W/ft²	Building-Specific Space Types	LPD, W/ft²
Office—enclosed	1.1	Gymnasium/exercise center	
Office—open plan	1.1	Playing Area	1.4
Conference/meeting/multipurpose	1.3	Exercise Area	0.9
Classroom/lecture/training	1.4	Courthouse/police station/penitentiary	
For penitentiary	1.3	Courtroom	1.9
Lobby	1.3	Confinement cells	0.9
For hotel	1.1	Judges' chambers	1.3
For performing arts theater	3.3	Fire Stations	
For motion picture theater	1.1	Engine room	0.8
Audience/seating Area	0.9	Sleeping quarters	0.3
For gymnasium	0.4	Post office—sorting area	1.2
For exercise center	0.3	Convention center—exhibit space	1.3
For convention center	0.7	Library	
For penitentiary	0.7	Card file and cataloging	1.1
For religious buildings	1.7	Stacks	1.7
For sports arena	0.4	Reading area	1.2
For performing arts theater	2.6	Hospital	
For motion picture theater	1.2	Emergency	2.7
For transportation	0.5	Recovery	0.8
Atrium—first three floors	0.6	Nurses' station	1.0
Atrium—each additional floor	0.2	Exam/treatment	1.5
Lounge/recreation	1.2	Pharmacy	1.2
For hospital	0.8	Patient room	0.7
Dining Area	0.9	Operating room	2.2
For penitentiary	1.3	Nursery	0.6
For hotel	1.3	Medical supply	1.4
For motel	1.2	Physical therapy	0.9
For bar lounge/leisure dining	1.4	Radiology	0.4
For family dining	2.1	Laundry—washing	0.6
Food preparation	1.2	Automotive—service/repair	0.7
Laboratory	1.4	Manufacturing	
Restrooms	0.9	Low bay (<25 ft floor to ceiling height)	1.2
Dressing/locker/fitting room	0.6	High bay (≥25 ft7.6 m floor to ceiling height)	1.7
Corridor/transition	0.5	Detailed manufacturing	2.1
For hospital	1.0	Equipment room	1.2
For manufacturing facility	0.5	Control room	0.5
Stairs—active	0.6	Hotel/motel guest rooms	1.1
Active storage	0.8	Dormitory—living quarters	1.1
For hospital	0.9	Museum	
Inactive storage	0.3	General exhibition	1.0
For museum	0.8	Restoration	1.7
Electrical/mechanical	1.5	Bank/office—banking activity area	1.5
Workshop	1.9	Religious buildings:	
		Worship pulpit, choir	2.4
		Fellowship hall	0.9
Retail			
Sales Area	1.7		
Mall concourse	1.7		
Sports arena			
Ring sports area	2.7		
Court sports area	2.3		
Indoor playing field area	1.4		
Warehouse			
Fine material storage	1.4		
Medium/bulky material storage	0.9		
Parking garage—garage area	0.2		
Transportation			
Airport—concourse	0.6		
Air/train/bus—baggage area	1.0		

Table 88- Lighting power density using space-by-space method (Source: ASHRAE 90.1-2007)

RESET, Costa Rica, 2012.

RESET, “Requisitos para Edificios Sostenibles en el Trópico”, INTECO-IAT, Costa Rica, 2012.

This standard is voluntary and is based on design criteria for reduced impact and sustainable performance of the building.

The RESET assessment begins with a glossary of terms and requires, at an introductory step of the assessment, to define the category of the building, that will define the number of criteria to evaluate: red (high impact), orange (medium impact), and yellow (low impact).

The aspects that define the category are:

- type of socio-economic status
- location
- types of use
- life of the building
- building height
- building size
- building coverage on the lot (waterproofed areas)
- population density in the area
- relationship of the site with natural resources: forests, water bodies, special elements of the landscape.

The standard also establishes mechanisms for obtaining additional points called "Plus points", for example, by choosing a lot with good infrastructure and transport, achieving beyond minimum requirements or solving a broader category criteria.

7 chapters of evaluation are established:

1. Socio-economic
2. Environment and transport
3. Spatial quality and wellness
4. Soils and landscape
5. Materials and Resources
6. Efficient use of water
7. Energy optimization

Each of the above chapters has an evaluation grid such as the following:

NOMBRE CAPITULO		**OBJETIVO CAPITULO**		**PONDERACION**					Observaciones del evaluador	Evidencia aportada y razones porque NO APLICA
Objetivos	**Conceptos**	**Criterio**	**Descripción del valor de referencia**	**Categoría**			**Resultado de la evaluación**	**Plus**		
indica el objetivo final del aspecto a evaluar	especifica los objetivos	indica las medidas a tomar para ganar los puntos El color celeste indica que son criterios de DISEÑO El color verde indica que son criterios de APLICACIONES (especificaciones técnicas)	indica el parametro para evaluar.				el evaluador debe colocar si se obtiene el punto indicado en el parámetro de evaluación.	el evaluador debe colocar si se obtiene el punto PLUS (corresponde a una categoría mayor, o se logra un 50% más del valor de referencia)	Comentarios (descripción de criterio cualitativo empleado, anomalías)	Datos obtenidos en mediciones, documentos aportados, y justificación para aplicar NO APLICA

If the required criteria are met, a RESET "sun" is obtained; additional "sun"s can be obtained if additional criteria are met.

RESET criteria and considerations for energy optimization of a building

- Reduced need for mechanized transport within the building
- Building design with passive strategies:
    - Location optimizing sunlight and prevailing winds
    - Shade and natural ventilation are used for climate conditioning
    - Heat island effect is reduced using low heat absorption ceilings and pavement
    - Facade elements are used (roofs, eaves and vegetation elements) to mitigate the effect of the sun, heat, wind, noise and humidity.
    - Insulation from soil to control moisture transfer and heat transfer and not to obstruct the free passage of runoff and biodiversity
    - Daylight enters the building but direct penetration of sunlight is excluded. Artificial lighting is designed according to daylight contribution
- In case of glass exposed to sunlight, using materials that minimize its impact.
- When the weather conditions do not allow for passive comfort, fans are preferable to help create required ventilation.
- Use energy efficient equipment that minimizes the emission of pollutants into the atmosphere.
- User control is enhanced by installing control and energy use visualization equipment, regarding vents, openings, shadows and lighting and mechanical HVAC, avoiding excessively centralized solutions
- Renewable energy generation based on clean resources is installed, e.g. sun, wind, water, biomass, geothermal, electrolysis, (nuclear and / or combustion (GHG) emissions is not accepted).
- Hot water is heated using renewable energy sources
- Devices are installed to control "passive consumption", such as additional switches.
- Use equipment that meets energy efficiency standards
- Artificial lighting circuits work according to the contribution of natural lighting. Efficiency must be high during working hours. Suggested design criteria: light entering from North, proximity of working places to windows, low plant divisions. Also, use materials and finishes that maximize the use of daylight: bright, glossy colors, low-emissivity glass.
- When required, artificial lighting is designed so that activities can be adequately performed. 250-500 lm/m2 is recommended for workplaces. Include photocells, motion sensors and "timers" if it means energy savings, consider short-stay areas.
- Use lighting technology with low harmonic content generation

The following table is a design guide for passive air conditioning for warm humid climate zone (Layout criteria, spacing, air movement, openings, walls, roofs, protection from rain and provision of shade hours depending on the climate zone project):

<u>Warm humid climate</u>: Coastal Atlantic and Pacific; altitudes up to 1,000 m above sea level; annual rainfall exceeding 2500 mm; average annual temperature between 20 and 35 degrees C in the shade. Relative humidity above 80%:

Layout criteria	Buildings oriented on the North-South axis to reduce exposure to solar radiation. Protection using devices and vegetation
Spacing	Separated buildings to allow for breeze and wind penetration
Air movement	Essential. Cross-ventilation; permanent device for air movement

Openings	Large, 40-80% on North; South walls protected from the sun
Walls	Light, short thermal transmission time
Roof	Insulated, light
Protection from rain	Inner building floors are elevated based on historical records of flooding and other meteorological phenomena
Soil	Develop soil studies for geomorphological conditions at the site
Shade	All day long

Casa Azul, Brazil 2010

Casa Azul. Construç ão sustentável. Caixa Economica Federal , Brazil 2010

This label is structured as a descriptive text with an introduction about the objectives and justifications of the need for sustainable buildings, an explanation about the application of the guide with compulsory and minimum criteria to obtain the label (lowest grade, “bronze”), and further considerations to obtain higher grades, “silver” and “gold”.

The following is a summary of the categories and criteria considered by the guide, which has six chapters:

1. Urban quality
2. Project and comfort
3. Energy Efficiency
4. Conservation of material resources
5. Management of water
6. Social aspects

Each chapter is structured in the following way:

1. Objective
2. Indicator
3. Required support documents
4. Warnings
5. Support required
6. Benefits of action
7. Technical recommendations
8. Related bibliography.

Summary of the criteria for energy optimization in buildings:

- Efficient equipment, energy saving lamps and energy saving devices, such as motion sensors for common areas
- Solar water heaters and backup heat provided by gas rather than electricity
- Use of alternative energy sources such as photovoltaic, wind, biomass
- Individual metering to enhance consumer awareness
- The equipment to be used and technical solutions are suggested according to other efficiency labels (such as Procel label) and technical design solutions, as shown by the following figures.

Green Building Index, Malaysia, 2009.

GBI, Green Building Index, GBI Assessment criteria for non residential new construction, first edition 2009.

To obtain GBI certification, users require undertaking the formal certification process offered by Greenbuilding index Sdn Bhd.

The evaluation chapters of the tool are the following:

1. Energy Efficiency
2. Indoor Environmental Quality
3. Sustainable Site Planning & Management
4. Material & Resources
5. Water Efficiency
6. Innovation

Out of a possible total score of 100 points of GBI Rating, the different levels of achievement are addressed as:

86+ points Platinum

76 to 85 points Gold

66 to 75 points Silver

50 to 65 points Certified

In terms of Energy Efficiency Design criteria, the following are highlighted:

- Exceed Energy Efficiency (EE) performance better than the baseline minimum to reduce energy (minimum set to building energy intensity (BEI) < 150 kWh/m2 per year).
- Lighting Zoning: Provide flexible lighting controls to optimise energy savings. (All individual or enclosed spaces to be individually switched); provide auto-sensor controlled lighting in conjunction with daylighting strategy for all perimeter zones and daylit areas. Provide motion sensors or equivalent to complement lighting zoning.
- Electrical Sub-metering for all energy uses of ≥ 100kVA; with separate sub-metering for lighting and separately for power at each floor or tenancy
- Use Renewable Energy

Commissioning

- Enhanced Commissioning of Building Energy Systems
- Post Occupancy Commissioning: ensure building's energy related systems are designed, installed and reviewed to achieve proper commissioning as to realize their full potential and intent.
- Developing and implementing a commissioning plan and incorporating commissioning requirements into the tender documents.

Verification & Maintenance

- Verifying the installation and performance of the systems to be commissioned, verify that requirements for training operating personnel and building occupants are completed.
- Developing a systems manual that provides future operating staff the information needed to understand and optimally operate the commissioned systems.
- Verify predicted energy use of key building services: Use Energy Management System to monitor and analyze energy consumption including reading of sub-meters; fully commission energy management

system (EMS) including Maximum Demand Limiting program within 12 months of practical completion (or earlier if there is at least 50% occupancy).

Sustainable Maintenance

- Ensure the building's energy related systems will continue to perform as intended beyond the 12 months
- Provide for a designated building maintenance office that is fully equipped with facilities (including tools and instrumentation) and inventory storage.
- Provide evidence of documented plan for at least 3-year facility maintenance and preventive maintenance
- Budget (inclusive of staffing and outsourced contracts).

Annex VII.Case Studies

Case Study 1

Project Name:	ENERPOS		
Location:	Saint Pierre, La Réunion	Country:	France
Latitude:	21.2º S (Southern Hemisphere)*	* Note that the sun path is mostly on the North; this affects orientation, solar shading and other design concepts	
Use of building:	Classrooms, offices		
Design Team:	- Architect: Thierry Faessel-Boehe - General Contractor: Léon Grosse - Mechanical, Electrical Engineer: INSET - Energy Modeler: PIMENT Laboratory and Imageen - Lighting Design: Imageen - Structural Engineer, Civil Engineer: RTI - Environmental Consultant: TRIBU Paris		
Year constructed:	2008		

Total Area:	1425	m2
Conditioned Area:	246	m2
% Conditioned Area:	17%	

Design Features
Description/Pictures
Passive Architecture
- Orientation (main façades): North/South (NE 14º) - Envelope: Walls: East and West: 18 cm concrete + 8 cm mineral wool or 18 cm concrete + ventilated air gap + wooden siding North and South: 18 cm concrete + solar shading Roof: Building Integrated PV (BIPV) ventilated and shaded roof; 10 cm of polystyrene + 20 cm concrete Windows: Glazing percentage: 30% U-value=1.4 Solar Heat Gain Coefficient: North: 0.10; South: 0.15 Visual Transmittance: 0.4 - Solar shading: wooden strips on South - Natural ventilation: indoor louvers to enhance natural ventilation

Energy Efficiency
- Lighting: low energy fluorescent + LED desk lamps + timers - Ceiling fans - Other: Vegetation / Chairs ventilated back - Building management system: Energy and power meters Temperature and humidiy Presence sensors
Renewable Energy
- PV System: 350 m2 PV generator, North and South, tilted 9º Generates 71000 kWh/year; compared against an electricity consumption of the building of 9824 kWh/year: surplus energy
References: http://archive.iea-shc.org/task40/

Figure 79- Roof BIPV: Left is North orientation, right, South

Figure 80- Roof BIPV 2: Right is North orientation, left, South

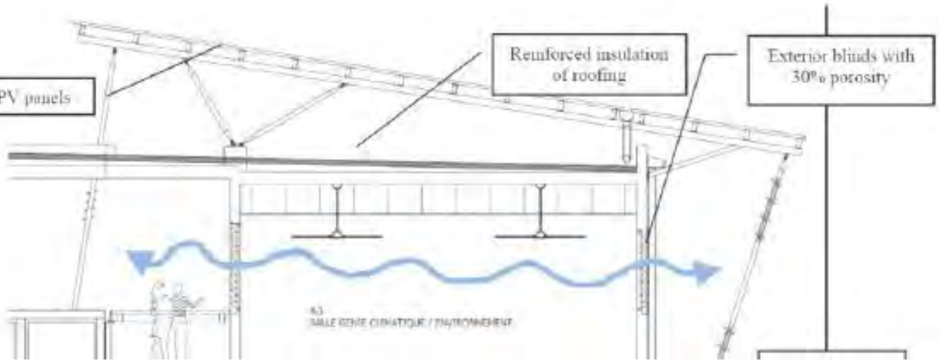


Figure 81- Detail of the roof

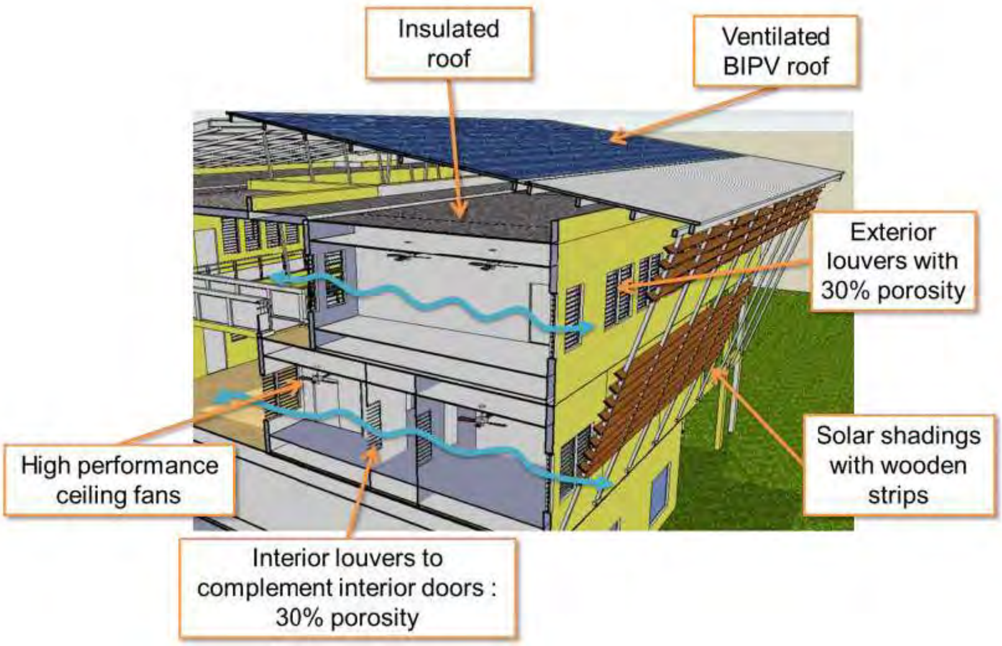


Figure 82- Passive design principles

References: High Performing Buildings magazine (http://www.hpbmagazine.org/) :
http://www.hpbmagazine.org/File%20Library/Case%20Studies/Summer%202012/042-057_ENERPOS.pdf

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