

**INTRODUCTION AND ADAPTATION OF THE ENERGY STANDARD
AKTIVPLUS FOR THE DEVELOPMENT IN COLOMBIA OF BUILDINGS
THAT GENERATE MORE ENERGY THAN THE ONE NEEDED TO OPERATE**

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A las seis mujeres que me alcahuetearon todo. Sobre todo a mi mamá que asumió la responsabilidad obligada de tomar un papel de papá sin dejar de lado su autenticidad.

Gracias al apoyo de Conconcreto y EGS-Plan.

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1. SUMMARY

The introduction of a new housing model that generates more energy than the one needed, known as Energy Plus Building, is presented in Colombia through the design of a whole building's concept for a multifamily complex that should be built in the near future in Medellín, Colombia. Integration of energy generation with renewable sources, methodologies to reduce energy demand, structure's design to enhance comfort and life cycle assessment are the main topics evaluated in this work that pretends to be one of the possible paths to follow and move towards the global Energy Transition from the construction sector. Legal environment is currently being defined to promote such projects through initiatives like Resolution 030, Resolution 0549, Law 1715 and the Colombian Strategy for Low Carbon Development (ECDBC), factors that should be used as basis to plan Energy Plus Buildings in Colombia.

2. INTRODUCTION

The present work presents an adaptation for Colombia of the German standard *Aktivplus* for the design of buildings that in a holistic way of working not only generate more energy than the one consumed in their normal operation but also satisfy interests and legal requirements in the fields of comfort, architecture and environmental care. A literal application of this standard in Colombia as it has been stipulated for the German conditions reduces the positive impact that this may produce on the interested sectors given due to differences between both countries in government incentives for this type of projects, weather conditions and the potential of resources for energy generation. Therefore, some changes in the requirements have been proposed for its introduction in Colombia mainly in the net final energy demand of the building, restricting annual CO₂ emissions per person, and natural lighting, thermal comfort and air quality levels.

To assess the adapted parameters, an evaluation is carried out in a residential building whose construction should start within the next two years in the city of Medellín, Colombia. Thus is proposed the inclusion of the so-called "Energy Plus Buildings" in the opportunities and challenges of the second chapter of sustainable construction in Colombia that has been defined by the Colombian Council for Sustainable Construction (CCCS), which begins in 2019.

3. GERMAN CONTEXT THAT ENCOURAGED THE FOUNDING OF THE *AKTIVPLUS* CONCEPT

3.1. ENERGY TRANSITION OR *ENERGIEWENDE*

In 1980 a study entitled "The Energy Transition (*Energiewende*)" was published in Germany through the Institute of Applied Ecology, in which it is assured that economic growth is possible even when methodologies of lower energy consumption are promoted. Supported by the fact that the vast majority of the German population believes that climate change is a fact and that, although anthropogenic actions accelerated this process, these same people must mitigate the impact of their activities. Therefore, Germany decides to undertake a directed project to the year 2050 in which it is planned to supply the country mainly with energy whose source is renewable together with an efficient energy management (Morris & Pehnt, 2012).

A definitive but gradual change of the paradigm of energy in society is proposed when the set goals, that are complement to each other, seek to potentiate economic growth while reducing the use of the energy necessary for this purpose. These premises, focused on both the generation and use of energy, should be treated simultaneously and not independently as partial solutions if a constant and well-balanced performance is wanted. By expressing the quotient between the global capacity to generate energy (in this particular case only related to the thermal and electrical form) and the demand for this service, it can be seen that the Energy Transition proposes a growth in the result of this division. This behavior is achieved both by promoting the numerator increase through the expansion of the installed generation capacity with non-conventional sources of energy (NCSE) and the reduction of the denominator when the global energy demand approaches as much as possible a real demand through energy efficiency initiatives as shown in Figure 1.

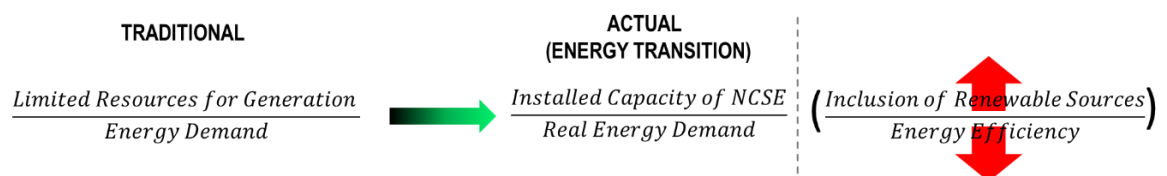


Figure 1. Energy paradigm shift proposed in the Energy Transition

Finally, this evolution aims to achieve an 80% reduction in greenhouse gases (GHG), 50% of the demand for energy resources and an 80% share in generation through NCSE by 2050, compared to the last decade of the twentieth century (ICEX, 2016). This process of definitive changes in which all sectors of society are involved has been the product of different historical facts that contribute little by little and give basis to the idea of making a definitive transition in the generation, distribution and consumption habits of energy. Although the interest in caring for the environment is an issue that has been addressed since the second half of the twentieth century by different means, initiatives and projects, the term "Energiewende" is simply one of these particular ideas that aims to contribute to this common goal through the rational management of energy. In Table 1 some events that have been fundamental for the development of these premises are determined.

Table 1. Historical events that promoted structuring and diffusion of the Energy Transition concept

Year	Event
1971	Publication of the "Bible" of anti-nuclear movements: <i>Peacefully towards the Catastrophe: Documentation of nuclear power plants</i> by Holger Stroh
1977	Publication of <i>Roads for a soft energy</i> that provides environmental and political arguments to opt for future alternatives that avoid the uncontrolled expansion of generation with coal, oil and nuclear power plants
1980	Publication of an article called <i>Energiewende</i> in Germany that promotes a new strategy for the treatment of energy based on energy efficiency and the replacement of nuclear and oil power plants with renewable sources of energy.
1986	Chernobyl accident triggers international alarm due to radioactivity levels in more than 13 European countries
1990	First objectives of CO ₂ reductions: 30% less emissions in 2005 compared to 1987
1991	First offered price for decentralized electric energy injection with renewable energies
2000	First legal limitation for nuclear power plants: Maximum 32 more years of life

Year	Event
2010	Government of Angela Merkel implements plan for transition to sustainable energies by 2050 with objectives of CO ₂ reductions by stages. Issue of Directive 2010/31 of the EU that requires new buildings to have a high energy performance no later than 2020
2011	Fukushima accident
2014	All nuclear power plants in Germany must be shut down by 2022 and goals of reducing CO ₂ emissions between 80-95% by 2050
2015	XXI Conference on climate change: Signing of the Paris Agreement to reduce greenhouse gas emissions

Source. (Evans, 2016)

Consistent with the statements, Germany is reducing both the share of conventional primary energy sources and their demand. That is, focusing on both the numerator and the denominator of this relationship, as shown in Figure 2 where, over the years, the NCSE are assuming part of the new demands¹ and the contributions that previously were supplied mainly with nuclear power plants and coal thermoelectric plants. The growth of these contributions was significantly promoted after the year 2000 when the Renewable Energy Law (EEG) was issued to enhance the integration of these sources in the country's electric power generation system. Through different reforms the law has presented, in its latest version published in 2017 it determines, for the assurance of the growth of the contributions of these sources, minimum levels of new annual installations in these technologies. Thus, for solar photovoltaic and wind technologies on land it is required a minimum annual growth of 2.5 GW, wind off shore of 6.5 GW and biomass 100 MW. By this growth, different stages are to be achieved: so that in 2020 the total electricity generation has a 35% from these sources, 2025 has 40-45%, 2035 has 55-55% and finally in 2050 achieves a 80% (Bundesministerium für Wirtschaft und Energie, 2018). It should be noted that Germany already had a contribution of 33% with renewable sources in 2015, surpassing its goal a few years earlier. On the other hand, a case that disfavors the Energy Transition in Germany, refers to the final energy² field where the

¹ This demand refers to the primary energy sources that relates to the energy sources available in nature before being transformed or converted like coal, oil, biomass, solar radiation, pressure differences in the air, among others that can be used by society through different technologies.

² The final energy is the service measured in the counters provided by the energy suppliers. It is the energy necessary for the operation of lighting, ventilation, thermal conditioning, appliances or other consumers in buildings and considers the efficiency of them. Ultimately, it is the primary energy minus the losses due to transformation and transport from the point of generation to the location of the final consumer, where different sources of energy such as oil derivatives or

country estimates that it will not reach the goal set by the European Union for the year 2020 of having a renewable energy share of 18 % (considering energy as a whole and not only electricity). The above lies in the high participation that still have the traditional energies for heating and transport in the country for what is predicted a participation of 16.7% (Energiezukunft, 2017).

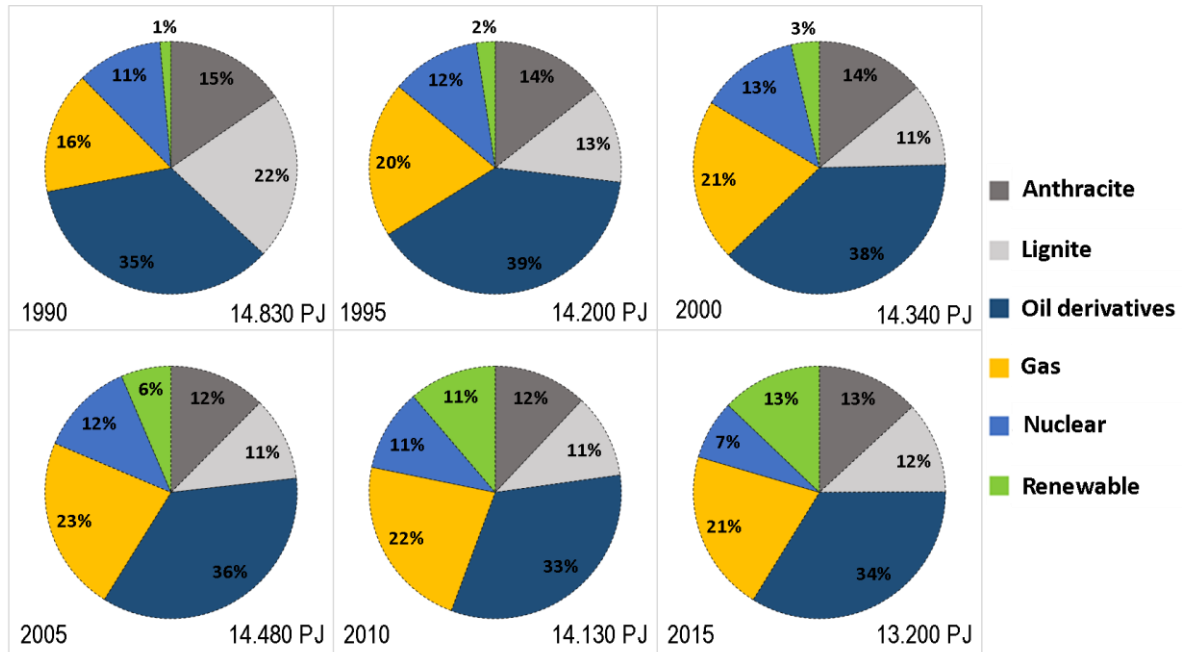


Figure 2. Evolution of primary energy in Germany.

Source. Own elaboration with data provided by (Umwelt Bundesamt, 2018)

In order to legally support the objective of the Energy Transition, the German Renewable Energy Law (EEG) since its publication has been widely copied in different countries given the strong impact it has on changing the conception of energy generation. Mainly due to the success in establishing the priority that the sale of renewable energies has over traditional ones and the minimization of bureaucratic procedures that hinder the performance of the projects involved. To avoid disputes between traditional energy suppliers, they were not given the option to enter as new "sellers of energy from renewable energies". This to avoid that when the alternative generation systems enter into a dispute with the existing ones, this last plants would continue to be promoted by the energy providers themselves and therefore might stop the expansion of these new

electricity are considered). It also refers to the energy obtained by the combustion of the oil or gas derivative whose amount is counted in a gas or filling station.

projects from the beginning. Thus, it is determined from the launch that new participants would enter to operate the renewable component of the German energy system.

In the case of small electricity generating plants with photovoltaic solar panels, which are the most common in terms of facilities, the rate at which a private individual can inject energy into the grid is based on the initial investment cost (depending on the size and location on roof or floor) and the total energy that could produce the assembly in question in a useful life of twenty years. The price at which each kWh would be paid for the twenty years of useful life is the cost of the investment for each installed kW_p plus an estimated profit for this type of projects that in Germany is already defined (BMU, 2007). Given the notable drop in prices of solar panels, investments in these projects became cheaper and therefore the sale price of electricity is reduced by this means as shown in Figure 3. In 2017, the latest version of the law was issued, completely changing the way of how renewable energies are included in the German national generation system. This modification discriminates the annual amount of energy per source that will be sold and the method by which it will be changed from being fixed by the State to entering into auctions. Therefore, electricity from the wind resource on land is allowed to auction up to 2.9 GW, off shore up to 15 GW, biomass up to 0.15 GW (plants greater than 150 kW) and solar photovoltaic 0.6 GW (plants greater than 750 kW). These capacities to be auctioned will increase each year given the expansion of the facilities of generating centers of each technology (Beatrix Massig, 2017).

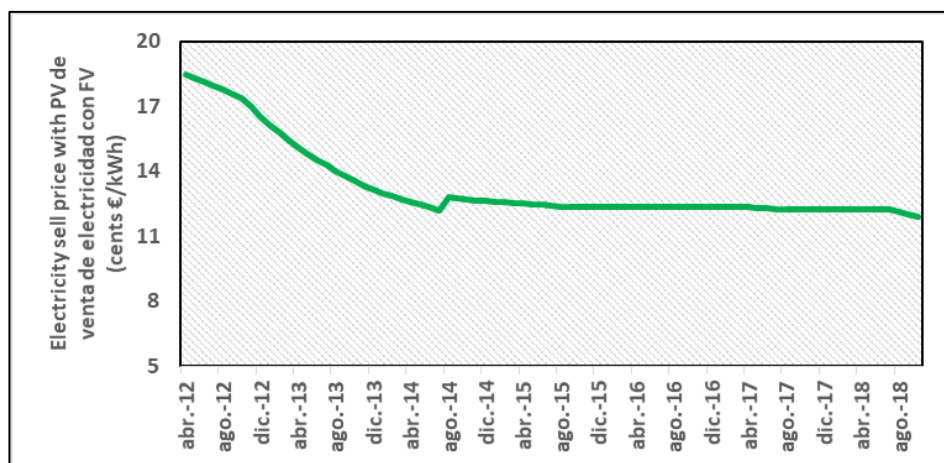


Figure 3. Electricity price generated with PV facilities.

Source. Own elaboration with data provided by (Modernus, 2018)

Transition in this case is also synonymous of replacement and therefore the gross inclusion of clean energies is only a partial solution. To fully achieve the objectives set

by the initial premise, the introduction of these unconventional sources must displace or extinguish conventional sources. Particularly in Germany, it has been decided that both the non-renewable resources that with their exploitation for energy purposes bring negative effects for the environment and those who represent potential risks to society must be replaced. This is in conclusion, nuclear and thermoelectric plants.

This first method of electricity generation in Germany has been implemented since the late sixties and in 2011 that country had 17 plants. Due to the insecurity and danger that this technology may present not only during its operation but also in the final disposition of the parts, equipment and rests involved, the German government decided to completely eradicate by 2022 the nuclear power plants from their integrated generation system like written before (Breidhardt, 2011). On the other hand, through the Kyoto Protocol, an emissions market was established in Europe to promote the reduction of GHG emissions by treating these gases as commodities exchanged in the stock market between entities that capture or avoid emissions and buyers or emitters of GHG. Entities that seek to counteract emissions from the German energy generation system (heat and electricity), that contributes with three quarters of the total emissions in the country, are thus the ones who obtain the greatest benefit from this methodology. In this way, entities that release GHG can constantly buy authorizations to discharge these gases and in case of not complying with the maximum authorized levels, fines of more than 100 euros per ton exceeded and even 500.000 euros can be imposed for fraudulent reports (Deutsche Emissionshandelsstelle, 2018).

3.2. SUSTAINABILITY AND ENERGY STANDARDS

Germany, due to its geographical location, requires the frequent use of heating for the comfort of the inhabitants, a fact that represents the highest energy consumption of buildings (Umwelt Bundesamt, 2016) and where oil and gas are generally used for this purpose because of their traditional low cost compared to other technologies. The German society lives mostly in independent houses or two-families-houses that were built towards the beginning of the second half of the twentieth century when no requirements existed to promote minimum isolation levels to compensate the energy consumption by heating. It was not until the 1970s that the first regulations were published to promote the care of energy for heating and warm water in buildings, and since then, it has been updated frequently in order to ensure a diminishing consumption of primary energy resources as seen in Figure 4.

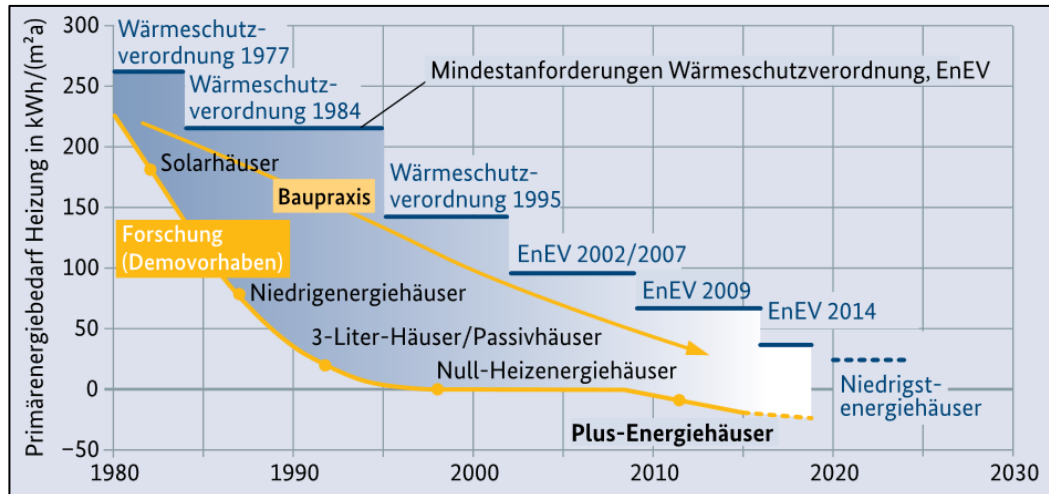


Figure 4. Evolution of primary energy requirements in Germany for heating buildings per square meter

Source. (BMUB, 2018)

In order to promote the renovation of buildings focused on the reduction of energy for its operation, the German government has been focusing on the dissemination of information and financial support. Through its own bank for the development created after the Second World War (KfW), attractive interest rates are offered to renovate buildings or build new ones that imply a decrease in the need for consumption of these energy (KfW, 2018). The main challenge in Germany to reduce the energy consumption of buildings is found in renovation more than in construction of real estate. Given the high prices of houses and apartments, most of German society lives in rented spaces and these rehabilitations to reduce energy consumption would have to be paid by the owner of the property who would not see the benefits directly since this service is covered month by month by the tenant. The challenge in this case, rather than the creation of ways for financing or financial incentives, is ethical when the goal is to demonstrate the positive effects for the welfare of society that these adjustments promote.

This interest in a notable reduction of the consumption of energy necessary for the operation of buildings is not common only in Germany but in the whole EU. Such initiatives have become so important for those governments that even since 2010 the EU issued a directive so that by the year 2020 all the housing buildings that are to be built have to have an "nearly zero energy" consumption. This is meant to be achieved through generation of energy *in situ* with renewable sources for heating, cooling, sanitary hot water, ventilation, lighting and other technical facilities of the building. Initiatives such as this aim to completely change the paradigm of energy supply and expenditure for

homes in Europe having as basis the fact that 40% of energy is used in this sector and that 75% of current buildings are classified as highly inefficient (European Parliament & Council of the European Union, 2010).

Given that the definition of "Nearly zero-energy" consumption is a relative or diffuse term since the name itself, it is determined that each country describe, according to its capacities and environmental conditions, values and goals to be chosen. A study hired from the executive organ of the European Union tries to approximate a standard of "almost null" for different climatic zones of the territory as seen in the following table:

Table 2. Approximate definitions of "Nearly zero-energy"

Consumption in building	Energy demand of a "nearly zero-energy" building [kWh/(m ² ·a)]
Heating, ventilation and air conditioning (HVAC)	<ul style="list-style-type: none"> • Zone 1: Catania, Athens, Seville: 15-45 (offices) 15-30 (homes) • Zone 2: Budapest, Milan, Vienna 15-45 (offices) <15 (homes) • Zone 3: Paris, Amsterdam, London 30-45 (offices) < 15 y 15-30 kWh/m²a (Vivienda) • Zone 4: Stockholm, Helsinki, Riga: 15-30 (offices) < 25 (Vivienda)
Warm water	<ul style="list-style-type: none"> • 12,5 (individual homes) • 15-20 (apartments building) • < 4 (offices)
Lighting (no residential)	

Consumption in building	Energy demand of a “nearly zero-energy” building [kWh/(m ² ·a)]
	<ul style="list-style-type: none"> • 6-10

Source. (Ecofys, 2012)

This situation is of special interest for Germany given its position as a leader in the construction market above countries such as Luxembourg, Sweden or Singapore and the European country with the largest number of buildings given that between 350,000 and 400,000 homes must be built annually to meet the national demand. With this great market niche, diversity of offer and competition among builders, architects, interior designers and project management involving new buildings or rehabilitations is encouraged, taking into account that a large part of its infrastructure was destroyed in the Second World War. Particularly, given the high energy consumption required for heating, these new buildings adopt concepts of low-demand for this resource such as heating through heat pumps (increased by 10% in the last 10 years) and district heating (14% more in the last 10 years) (Germany Trade and Invest, 2018). Likewise, the existence of this growing market niche encourages the implementation and expansion of certificates of sustainable buildings that cover each one particular interests and designed according to reasons of differentiation, ethics or compliance with legal requirements. The leading certification body in this country with more than 3,500 buildings certified by mid-2018 is the German Society for Sustainable Construction (DGNB), then LEED with 276 and finally BREEAM that only evaluates buildings already built.

The consulting firm Drees & Sommer divide this large number of requirements in five general modules or engagements that give basis to these standards: environment, economics, social, technical, process (start-up) and location of the building. This standardization is based on the fact that the numerous factors evaluated under each of these certification methodologies can be quite diverse and by categorizing them in these five common factors it is possible to make an objective comparison of the certificates. In

general, under this proposed analysis it is observed that the DGNB certificate is generally more rigorous and broad than its competitors in the different proposed categories.



Figure 5. Comparison of sustainable building certificates

Source. (Kleist, 2018)

In addition to these certifications based on broad sustainability concepts, there are different initiatives that seek to contribute, from the real estate sector, to reach the objectives of the Energy Transition through standards based solely on energy management. The "Passivhaus" standard that materialized its first project in 1990 exposed the idea of using passive measures³ as much as possible to save energy, so that heating as a major consumer becomes almost unnecessary. This standard, due to its emphasis on the envelope of buildings, significantly reduces the use of energy for heating and thus the total energy, which is generally operated with non-renewable resources. Before 2015, the "Passivhaus" standard, rather than making an effort to contribute to the Energy Transition, it partially sought energy efficiency by working in the envelope until over that year in its handbook were included possible sub-levels to reach by including renewable energies as shown in Table 3. The final objective of this type of initiative and the energy standards for buildings in general, are not comparable with sustainable certificates issued by LEED, BREEAM or DGNB since they have different purposes, although on the way to achieve them, they have similar factors to be evaluated. These standards are focused, as the name implies, on reaching a particular level of energy management in order to make significant contributions to the Energy Transition and be represented by an obtained label. The certifying entities present a wide

³ Procedures that are applied in the architecture of the building and do not involve the use of electrical or thermal equipment

range of factors to be met in a system of points to reach different levels of sustainability that satisfy interests different from those of the Energy Transition noting that but some might contribute.

Table 3. Passivhaus Standard requirements

Evaluated factor	Value
Energy demand for heating	< 15 kWh/(a·m ^{2*})
Total primary energy for normal operation of homes (heating, warm water and home appliances)	< 60 kWh/(a·m ^{2*})
Air renovation	0.6 h ⁻¹
Thermal comfort	No más de 10% de las horas del año por encima de 25°C
Renewable primary energy: Classic/Plus/Premium	60/45/30 kWh/(a·m ^{2*})
Renewable energy generation: Classic/Plus/Premium	-/60/120 kWh/(a·m ^{2°})

*Treated floor area

°Building footprint

Source. (Passive House Institute, 2016)

In 2011 the German government founds, through the "German High-Tech Strategy, a research initiative called "Efficiency House Plus" or "Effizienz Haus Plus" that proposes an approach to the Energy Transition through the design of buildings that generate more energy annually than they need for their usual operations. This initiative, from its definition, is not restricted to particular technologies to achieve this energy goal, but seeks through the integration of different technologies available in the market to achieve an optimal combination where both energy efficiency and unconventional energy sources are protagonists. This initiative does not intend to issue certificates, reach different levels or add points such as sustainable standards DGNB, LEED or BREEAM

but seeks to establish a level of energy to be achieved by a building to obtain a status or distinction "Effizienz Haus Plus".

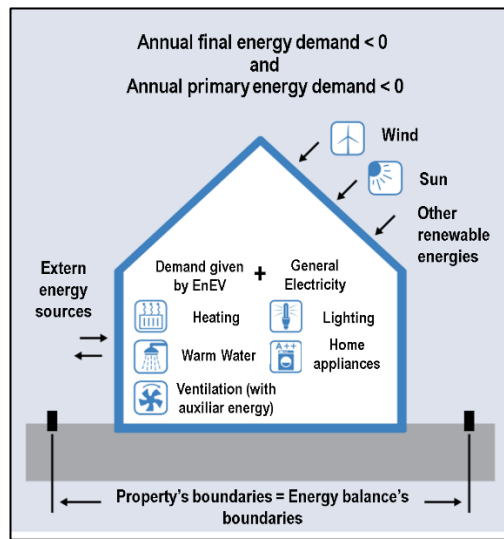


Figure 6. Energy balance of a "Energy Plus Building" based on Effizienzhausplus

Source. (BMUB, 2018)

This level is thus a complete energy balance of the building by which a negative value of both the final energy and the primary energy in the building operation stage is demonstrated and this balance that defines a building as an "Energy Plus Building" is proposed by the following group of equations:

$$\text{Net Final Energy Demand} \quad (1)$$

$$= \text{Final Energy Demand} - \text{Electricity generation on site}$$

$$\text{Net Primary Energy Demand} \quad (2)$$

$$= (\text{Final Energy Demand} - \text{Own Use of Generated Energy}) * FEP - \text{Energy Injection to Grid} * FEP_R$$

Noting that:

$$\text{Electricity Generation on site}$$

$$= \text{Own Use of Generated Energy} + \text{Energy Injection to Grid} \quad (3)$$

$$FEP = \frac{\text{Primary Energy Demand}}{\text{Final Energy Demand}} \quad (4) \leftarrow \text{Theoretical factor defined by government}$$

$$FEP_R = \frac{\text{Primary Energy Demand avoided}}{\text{Energy Injection to Net}} \quad (5) \leftarrow \text{Factor teórico determinado políticamente}$$

FEP (Primary Energy Factor) indicates how much energy must actually be generated to supply the final demand. Therefore, it is theoretically the necessary excess so that, when energy is lost along the way, the necessary amount reaches the building. FEP_R (displacement factor) shows in theory how much primary energy generation is being avoided by injecting into the grid the not consumed energy by the building itself. In addition to these energy balances, the requirements stated by the Energy Conservation Ordinance (EnEV) must also be met regarding heat generation with renewable energy sources and building envelopes. The accreditation of the met requirements to be a "Effizienz Haus Plus" building is represented with a label or identification. This mark shows the energy balance of the building and the different consumers (thermal conditioning, hot water, electrical appliances) and the on-site generation provided, comparing with the energetic behavior a building with the same geometric configuration, appearance and use of the building under study would have.

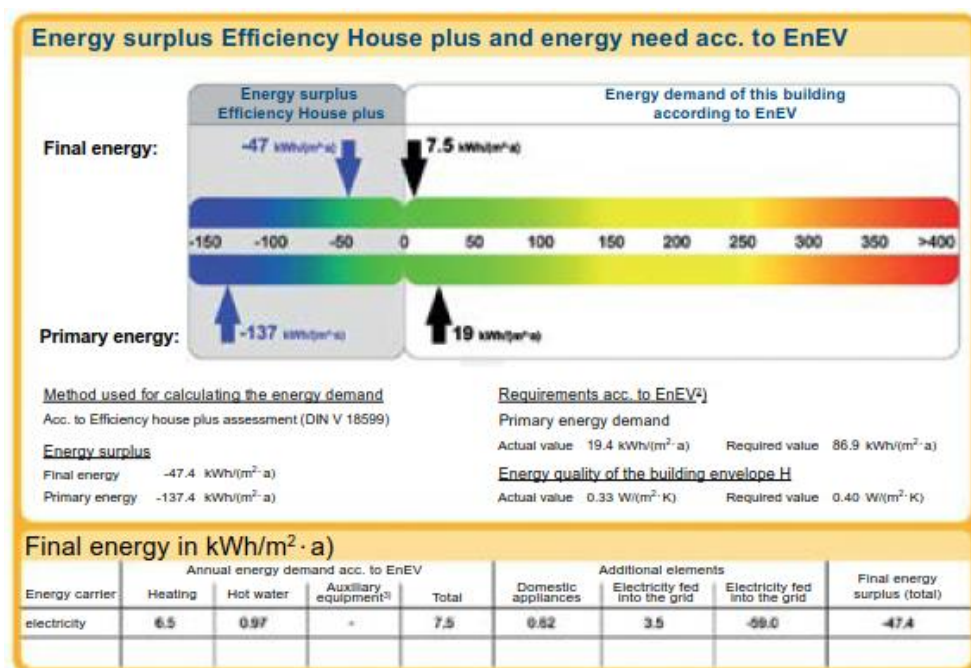


Figure 7. Label example of a Energy Plus Building under EnEV

Source. (BMUB, 2018)

In summary, this methodology states that energy demand is considerably reduced since the design of a building when:

- It has a compact shape because reduction in the area / volume ratio in only 0.1 m⁻¹ may reduce heating energy to 10 kWh/(m²·a) and construction costs

- The building is oriented towards the sun because it promotes natural heating through windows and optimal positioning of photovoltaic panels
- It has good thermal insulation in structures and windows as it reduces heat transmission losses by 50-75%
- Good workmanship reduces thermal bridges from construction, reducing energy losses by up to 25%
- The use of "top runners" or high efficiency equipment is promoted for the reduction of consumption by household appliances of up to 50%

The pilot project in Berlin was built in 2011 and after it, the government gave financial aid to 37 renovation or construction projects that complied with the described guidelines to generate more energy than the one needed to operate. These homes had a two-year monitoring by the government not only to assess the performance of consumption but also in order to keep improving the concept of "Energy Plus Buildings". The approach of this initiative is finally a fulfillment of the requirements demanded by the "Ordinance for the Saving of Energy (EnEV)" with the inclusion of an outstanding on-site power generation. This ordinance as seen in Figure 4 describes the minimum parameters in the use of energy to obtain the license of a building to be built and allow the use of those that are already built. As this parameter are relative only to the German territory with its particular climatic conditions, a literal translation of the requirements in Colombia is not applicable, mainly in terms of the complex envelope for efficient indoor heat management that may not be necessary given the weather annual conditions in Colombia. The typical behavior of the energy both consumed and generated within an Energy Plus Building in Germany is shown in Figure 8. The energy balance in countries where seasons are present consider the whole year for the evaluation due to differences between seasons mainly regarding solar radiation and air temperature. Energy generated in every season of the year are critical for these kind of projects as usually photovoltaic plants are involved as source of energy. When the building is located in the northern hemisphere of the earth, as Germany, there are fewer hours of sunlight in the periods between January and March and October to December. Therefore, these periods show a smaller slope in the curve that represents the energy generated throughout the year. This same absence of sun leads to a greater use of heating and therefore increases the energy demand that is represented by the gray curve in Figure 8 that has a greater slope towards the first and last months of the year. The difference between these two curves in the last month of the year then shows the magnitude of the excess energy that was generated and is the reason why a building can be labeled as Energy Plus.

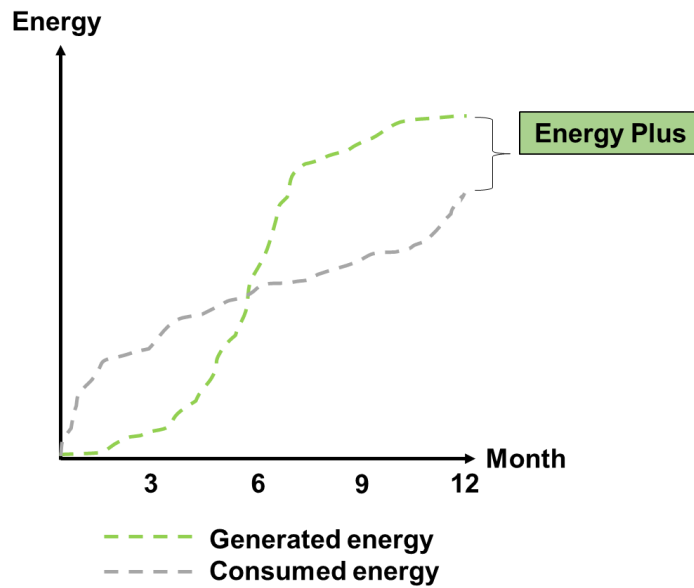


Figure 8. Common energy balance of an Energy Plus Building in Europe

3.3. **AKTIVPLUS STANDARD**

Based on the formulation of the mentioned energy standards that were pioneers in their field, the *Aktivplus* standard is designed in 2013 through a figure of a non-profit entity. The founders are part of a group of expert engineers in design of sustainable buildings that, after this foundation, issue the official manual that looks towards the establishment, quantification and qualification of the requirements that a building must meet to reach the *Aktivplus* level. Like *Passivhaus* or *Effizienz Haus Plus* it is not aimed to issue certifications and add points in a final evaluation, but states several concepts of mandatory compliance that allow aspire for a unique distinction. Additionally, it takes elements of sustainable building standards to develop a standard that, although it

focuses on technical issues, promotes in a holistic manner the market for buildings that are not only energy-active but also sustainable with their surroundings.

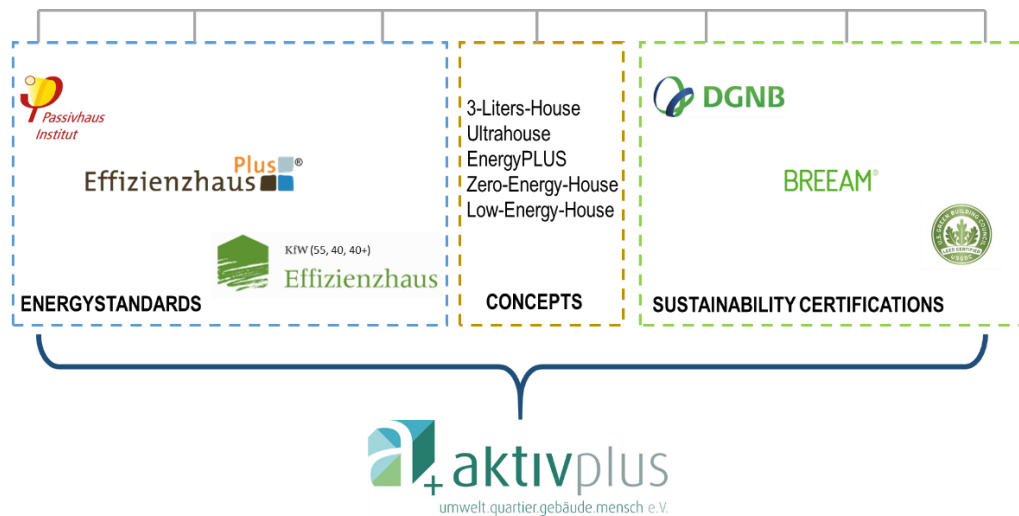



Figure 9. Basis of the Aktivplus Energy Standard.

Source. Own elaboration with data provided by (Nusser, 2017)

In short, an *Aktivplus* building generates more energy than the one needed to operate while assessing concepts of comfort, life cycle and architecture. This approach proposes an answer to the question "How can the building stock contribute to the protection of the environment without compromising the quality of life?" The sharing and adaptation of different standards both German and international through the approach of the standard is just another initiative for the global development of society through construction that involves, among different premises, the Energy Transition. In particular, the way this new standard aims to address this situation, focuses on uniting the minimization of resources with the use of different technologies and active and passive methodologies always taking as priority the welfare and comfort of the people in the building. There is a flexibility in the way of minimizing resources according to the given standard when it does not require any minimum envelope factors or particular technologies to be integrated into the design, since it fixes the final result of the energy level but not the way it has to be achieved. The design of the building is intended to be as holistic as possible taking into account not only the phase of energy consumption in the years of operation of the building but also the construction and dismantling stages (Aktivplus e.V., 2018).

It is important to emphasize that part of the axis of the methodology seeks new forms of concepts and technologies to achieve a sustainable development of the building stock, there is no single path or a series of instructions by means of which the development of

this type of projects is considered. . The possibilities are not limited to one type of building materials or specific technologies of heating, ventilation or power generation equipment for example, encouraging the formulation of unlimited process combinations for engineers, architects and planners to create a building or Even an active neighborhood that is friendly to the environment.



GROUP	FACTOR	AKTIVPLUS REQUIREMENT
ENERGY	Net final energy demand	< 30 kWh/(m ² a) AktivBasic < 0 kWh/(m ² a) AktivPlus
	Own use of produced energy	> 25%
	Building's Performance	Transparency in monitoring
USER	Day light quality	Day light Factor > 2%
	Air quality	Requirements based on DIN 1946
	Thermal comfort	Thermal confort certificate
	Arquitecture quality	Design, quality in use y longterm usability*
	Comfort Feedback	Polls and mandatory measurement the first 2 years
NEW GRIDS	E-mobility	Information*
	Smart Grid	Concept/Interfaces*
	Smart Home	Concept/Interfaces*
LIFE'S CYCLE	Life's Cycle Assessment	660 kg CO ₂ per user per year
	Life's Cycle Costs	Calculations and evidence of elaboratios *
	Costs of CO ₂ development	Transparency in operation

*Informative Factors that are not mandatory

Figure 10. Aktivplus requirements

Source. (Aktivplus e.V., 2016)

Aktivplus buildings through the optimization of energy demand, on-site generation of energy, promotion of comfort and interaction with the user and focus on the sustainable construction and deconstruction lead to benefits for different interested parties such as investors, builders, users, politics, industry and environment in order to be effectively implemented in society by satisfying various interests.

Given its creation for use in Germany, the users of the building enjoy a high comfort when the quality of the indoor air, heating of interior spaces in winter, protection against overheating in summer and encouragement of natural light every moment is controlled efficiently. These aspects measure the user satisfaction, are linked to the monitoring after the set-up of the building in order to provide the possibility of a building performance

control. Periodic surveys to users provide a constant feedback that not only serves to stimulate proposed improvements and comfort factors but also is a communication mechanism that allows to spread the principle convincingly.

Additionally, the information is freely available for the different interested sectors on the energy consumption and CO₂ emissions per square meter and per person for a continuous and transparent tracing. Likewise, when considering the full life cycle (construction, operation and disarmament) with their respective costs, it is possible to make decisions from the beginning to make a greater investment in order to reduce operating costs or negative repercussions on the environment that, with their assessment, at the end of the life cycle result in welfare in different areas. The first benefit is focused on the environment through an increase in the energy efficiency and the generation of it through NCSE, a social welfare is present when the concept development intends to achieve a change in the energy paradigm through saving technologies and ecofriendly generation of this service when users understand that "cheap may be expensive". Finally, there is also an economic benefit when at the end of the life cycle it is shown that the magnitude of the savings in energy costs thanks to the integration of the technologies installed in the building is greater than the initial capital investment (Aktivplus e.V., 2018). This energy saving, which is directly linked to the reduction of GHG, brings in the same way collateral benefits (not applied to builders, investors and users) in the political scope given that *Aktivplus* is part of the joint solution of ideas that aim society to meet the goals of the Energy Transition.

Since the integration of the building's architecture with the equipment and materials that help to minimize the negative impact on the environment can be complex and contrary, the *Aktivplus* society aims to a constant cooperation between technical aspects and outer and inner design. With a quorum of experts, the society provides support to architects and planners from the beginning to achieve an integral development of the project through cooperation in the application of the principle of the methodology and its improving through experience at the same time.

Each of the buildings that is evaluated under the *Aktivplus* standard has as result a registration, identification or document that visually relates the fulfillment of each one of the factors that are required in the standard. Additionally, this label summarizes the participation of renewable and non-renewable energy necessary for the operation of the building and an energy balance of the final energy that in summary, is the one counted by the grid operators.

To date there are 25 buildings from different purposes planned under the *Aktivplus* sustainable construction standard, ranging from independent houses, multi-family buildings, offices to kinder gardens. In 2014, the building called *Aktiv-Stadthaus* was inaugurated in Frankfurt as a 74-apartment building whose energy and envelope concept was designed by the German firm EGS-Plan, whose CEO is one of the founders of the *Aktivplus* society. The particular integration of technologies, materials and concepts that are faced towards the goal of this methodology, established this building as the flagship representation of this energy standard for buildings.

The technical evaluation of the *Aktiv-Stadthaus* under the standard and its label are shown in Appendix A of this document.



Figure 11. *Aktiv-Stadthaus*

Source. (EGS-Plan, 2018)

The *Aktivplus* energy standard works in cooperation with the *Active House alliance* when sharing the common goal of promoting the construction of buildings that lead to a healthier and more comfortable life without having a negative impact on the environment even though both standards support different factors to be evaluated. This alliance has a greater international extension given its connections in several European countries, Canada, United States and China and through the three pillars: energy, comfort and environment it grants in the same way as *Aktivplus* in Germany, a label or identification that can be commercially used to demonstrate the interest in contributing from the buildings sector to the Energy Transition. The energy standard that is intended to be adapted for Colombia through this document evaluates these three aspects as well but differs mainly from the *Active House* proposal as this first standard suggest a system for the evaluation just by compliance or not of the different factors evaluated. Meanwhile

Active House encourages achieving different levels of compliance for the evaluated aspects. Although the factors considered by *Aktivplus* are integrated in a holistic manner to encourage buildings that have a positive influence on the environment, have a notable interest mainly in energy management, by promoting buildings that generate more energy than necessary and are constantly monitored for user feedback. The alliance also promotes this type of constructions but considering that it is also possible to have buildings under the *Active House* label with more modest systems for the generation and use of energy before reaching an excess of generation that is mandatory in *Aktivplus*. Furthermore, this international standard in contrast to the German one, even assesses water consumption and noise reduction factors at least qualitatively or informatively.

The *Aktivplus* energy standard works in cooperation with the Active House Alliance, which shares the goal of encouraging the construction of buildings that lead to a healthier and more comfortable life without having an impact negative in the environment although some factors evaluated vary between these methodologies. This alliance has a great international extension given the existence of allies in several European countries, Canada, United States and China. Throughout the three pillars to assess, energy, comfort and environment it grants in the same way as *Aktivplus* in Germany an identification or label that can be used commercially to demonstrate the interest in contributing from the construction to the Energy Transition. The energy standard that is intended to be adapted for Colombia in this work also evaluates these three aspects but differs mainly from the proposal of Active House as its evaluation system is based on compliance or not of requirements and not through the possibility of reaching different levels of compliance within an evaluated item. In addition, the factors considered by *Aktivplus*, although integrated in a holistic way to encourage buildings to have a positive influence on the environment, have a marked interest in the energy management, which promotes particularly buildings that generate an excess of energy to be constantly monitored for user feedback. The international standard also promotes this type of constructions noting that this plus energy acts as the highest energetic level to reach and so it would be also possible to have buildings under the Active House brand with more lax levels in the generation and use of energy before reaching this excess that is mandatory for *Aktivplus*. This ally in contrast to the German standard assesses factors such as water consumption or noise at least qualitatively or informatively.

4. ENERGY SITUATION IN COLOMBIA

4.1. ENERGY GENERATION

It is widely known that Colombia, due to its privileged geographic location, has exploited its great water resources to cover most of the national electricity demand through hydroelectric plant projects and, therefore, greenhouse gas emissions (GHG) in electricity generation are much smaller than in European countries. In such a way that the normal contribution of these facilities represent 63.8% of the national installed capacity corresponding to 10,974 MW in Figure 12.

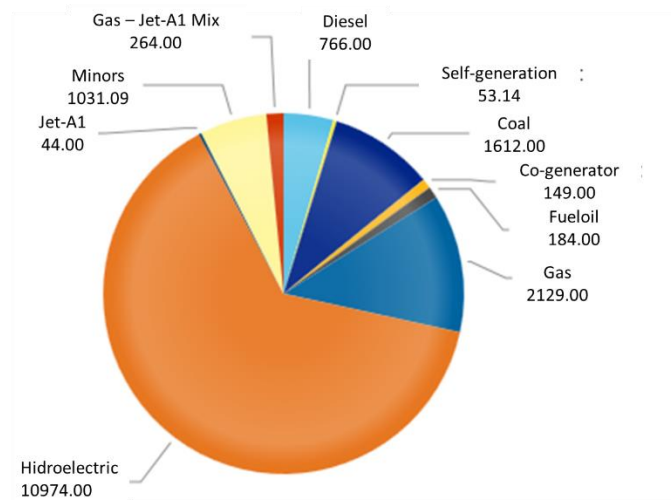


Figure 12. Capacity of the National Interconnected System (SIN) in MW

Source. (Expertos en Mercados (XM), 2018).

Paradoxically, the highest consumption of this primary energy generated in Colombia relies in the "no used of energy" or losses. By 2012 in Colombia, only four out of ten energy units produced had a final use, which leads to an unfortunate cost overrun of 5,200,000 USD (Carlos García, 2014). It is important to note that these losses are not 100 percent avoidable, given that there are processes inherent to the transformation and transport of energy in which it is technically not possible to eliminate losses but to reduce them. Another type of losses called "avoidable" or "non-technical" are highly related to illegal connections to energy distribution networks (in the form of gas, petroleum derivatives, trucks, among others) that also clearly affect this relationship that shows how much is consumable of what is produced. The reduction of these losses, both avoidable and non-avoidable, is ultimately an increase in national energy efficiency, through which

productivity and competitiveness of various sectors such as industry, commerce, transportation and housing are fostered. Furthermore, an increase in energy efficiency in the distribution and national energy generation scenario is critical for the reduction of GHG emissions and to reach the different political or ethical goals to be achieved within different deadlines.

Although the location of the country is privileged for the generation of energy with low GHG emissions, it may be sometimes also a disadvantage based on the fact that the electrical contribution from hydroelectric plants has been reduced even to 40% in times of dryness when the useful volume of water dams decreases. Figure 13 shows this behavior in recent years that, since there are no other alternatives (wind parks, photovoltaics and biogas plants are almost negligible) in the generation of electric power different to thermoelectric plants, the increase in the contributions of these power plants is required in these cases. The thermoelectric plants in Colombia not only survive as a share that complete the demand of the National Interconnected System (SIN) that is not totally covered by hydroelectric plants but also as a backup in case of climatic fluctuations. Support that is promoted through mechanisms such as the so-called Charge for Reliability that through a constant remuneration, makes worthy the existence of this plants in Colombia mainly in adverse climatic situations when are commonly used to fulfill the electricity demand.

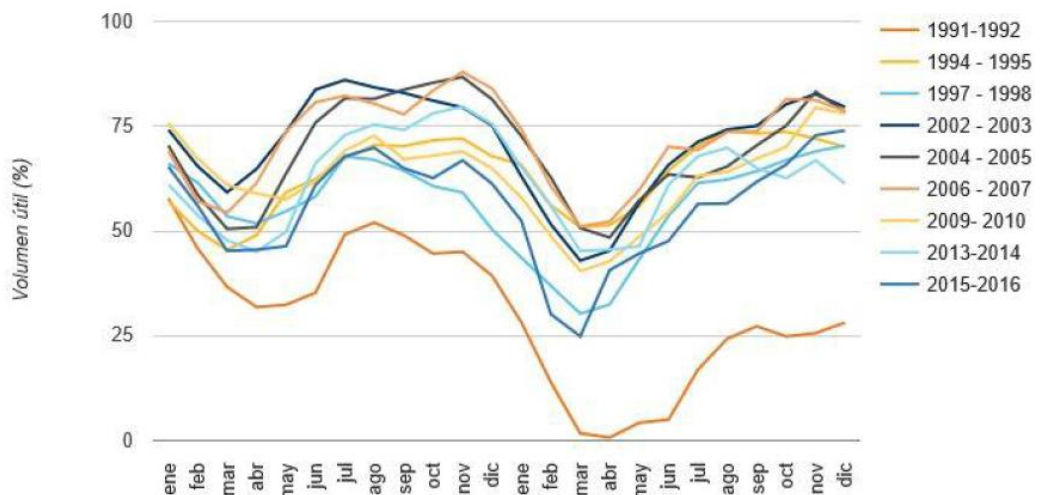


Figure 13. Useful volume of reservoirs in Colombia tracking

Source. (Expertos en Mercados (XM), 2016)

4.2. ECONOMIC DEVELOPMENT

Although the origin of the main GHG emissions in Colombia is linked to the deforestation and other uses that are given to the soil, the electric power industry also occupies an important place in these contributions. Directly, contributions could be made to the Energy Transition and the pacts made with the United Nations by granting market incentives to facilitate the economic viability of both small and large-scale projects of energy generation from biomass, solar panels and wind turbines. This increased contribution to the SIN would mean a gradual shift from the use of thermoelectric power plants to a point of minimal use or even plant shutdown that ultimately contributes to the reduction of GHG. Additionally, Colombia's medium-term outlook indicates that, given the context of the fall in prices in the global hydrocarbons sector, it will lead to a reduction in revenues of the Colombian government due to the decrease in the primary sector in mining. In order to support this profit absence, it is sought to strengthen the same primary sector with agriculture, secondary with construction and industry and tertiary with trade.

Colombia between 2010 and 2014 increased 1.6 times its average growth of 1990-1999, which includes the remarkable development in construction since 2001 with an average growth of 9.2% and therefore, in a comparison with its South American neighbors in Figure 14, Colombia has had the most notable economic growth in the last quarter of a century. This growth is defined by increases in the production of goods and services that finally show an increase in the socio-economic well-being of the country as the inhabitants have better incomes. This growth in recent years, the new scenario of low oil prices and the growth of the tertiary sector that contains a strong component of urbanism are factors that should be taken as a starting point for a transition from the Colombian energy idea towards more sophisticated and complex systems to provide more productive economies (UPME, 2015a).

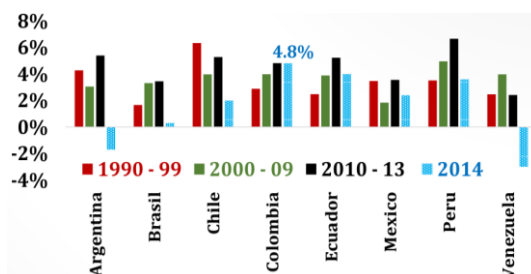


Figure 14. Historical economic growth in some Latinamerican countries

Source. (UPME, 2015b).

Aware of this situation, the Ministry of Mines and Energy through the Energy and Mining Planning Unit (UPME), in the 2050 Energy Plan presents the ideas that the country's long-term energy policy will follow. This plan relies under the growth expectations and economic development forecasts and the premise of "achieving internal and external supply of energy and minerals efficiently, with minimal environmental impact and generating value for regions and populations". Under this goal, several procedures to be followed are also established, including diversification in the electricity generation mix, promotion of energy efficiency throughout the supply chain, guaranteeing storage and transport infrastructure and, mainly, making small-scale distributed generation feasible. The introduction and development of "Energy Plus Buildings" in Colombia includes the procedures to be carried out in the Energy Plan to 2050, since:

- Provides a diversification in the traditional electricity generation system in Colombia
- Decreases the distances between the generation and consumption of energy that affect energy efficiency
- They might be coupled with the capacity to store energy (electric and / or thermal)
- Can be the main source of distributed generation in the country

These objectives mainly require a competent, informed and agile legal framework so that the guidelines can be effectively implemented and thus the great potential of energy resources that Colombia has can be exploited efficiently and sustainably. Therefore, the availability of information for the decision making of the interested parties and an increase in the available human capital will be encouraged to make the process of technical changes to be implemented more bearable. Thus this may be achieved through government institutions committed to streamlining and promoting these objectives so that they can be understood and widely spread by Colombian society (UPME, 2015c). As mentioned above, the fall in the price of photovoltaic solar energy ends up in a feasible present competition with traditional generation from other sources (in some cases like in Colombia, may occur in the near future), which promotes its wide integration into the SIN. The next step is to promote the introduction through financing schemes given the economic growth of Colombia that leads to an acceptable acquisition capacity and, on the other hand, the increase in social interest whose spreading is intended push initiatives in these fields by the Colombian society

4.3. ENERGY TRANSITION IN COLOMBIA

The initiative to cover by 2050 the global energy demand with wind, water and sun has concluded that the cost of energy through these ways will be similar to the current costs and that the only barriers to this transition will be social and political, but not technological and / or economic. This idealized scenario not only fulfills the energy needs of all the countries together but also provides benefits to the air and water quality, ecological systems and energy security at a reasonable price. The optimal design or configuration of this energy supplier system, although perhaps variable over time, will be the one that integrates transmission distances, energy storage, hydrogen production at the lowest possible cost and satisfies in a reliable and intelligent way the demand of the different populations (Mark A. Delucchi & Jacobson, 2010).

Although it is apparently a utopian scenario, it is an issue that is frequently involved in the policies, institutions and initiatives of some governments with a view to a future in which humanity has integrated sustainable development into its ethics. The most used argument in favor of a definitive change in the way of generating energy lies in the GHG emissions produced by the combustion of non-renewable resources associated with transforming the chemical energy into heat or electricity. Although this is a valid argument given the large magnitude of these gases released and the negative effect they have on the environment, it is an incomplete argument that should be reinforced considering the total emissions associated with these sources. That is, evaluating the life cycle of the plants from the extraction of components and construction to the final disposal when its working time is over. The inclusion of the water footprint as a weighting factor to opt or choose a technology over others for the generation of energy should also be assessed in this type of evaluations. This because of the quality and quantity of this resource are directly affected as well as air quality and temperature of earth by GHG emissions. The National Planning Department contracted a study in 2017 that, for the Colombian conditions determines approximate values for the carbon and water footprint from different energy generation technologies that exist or could be used in the country as a starting point for environmental assessments such as it is shown in Table 4:

Table 4. Carbon and water footprint for different energy generation technologies in Colombia

Technology	Carbon Footprint		Water Footprint	
	kg CO _{2eq} /MWh		m ³ /MWh	
	Min	Max	Min	Max
Hydroelectric with dam	1	25	1.000	3.060
Thermoelectric with gas	400	1.000	0,3	4,6
Thermoelectric with coal	600	2	0,3	8,0
Hydroelectric Run-of-the-river	1	25	1,1	500
Thermoelectric with liquids	500	900	0,8	6,6
Nuclear	10	210	-	5,2
Biomass	10	140	174	1.805
Fotovoltaics	10	200	-	1,0
Solar thermal	10	220	0,4	7,5
Geothermal	12	190	-	2,8
Wind on shore	1	50	-	0,1

Source. (enersinc, 2017)

Under the generation scheme in Colombia, where the electricity sector has a predominance of hydroelectric plants, it has a low carbon footprint (the largest amount of organic gases in this technology comes from the biomass released from the dam bottom), but this result shows in counterpart a high water footprint with respect to other technologies that are found mainly in the evaporation of said dammed water.

In European countries where "Energy Plus Buildings" projects have been developed, there are generally similar climatic conditions unlike in Colombia where there is a high plurality of climate conditions to take into account in these projects like temperature and humidity. Although Colombia has great potential for the development of this model of sustainable construction due to its high annual solar radiation, climatic conditions, economic growth and interest in the diversification of the energy mix, there are differences in the development potential of these Projects according to the different areas of the country. For example, where the high solar radiation is received, enhance in the energy generation with certain technologies and higher energy consumption by thermal conditioning due to the high temperatures are present. Other areas such as Medellín or Bogotá with historical average temperatures of 12 °C and 23 °C respectively, have

traditionally maintained the advantage of a low installation of thermal conditioning equipment to reach comfort levels inside the facilities. The use of this equipment when environmental conditions require it may represent the highest energy consumption in office, commercial or housing buildings. By implementing this energy model for buildings in different cities of the country, different patterns of this service demand would be identified given different climatic and economic conditions among the cities. Noting three general advantages in the Colombian territory as high solar radiation, large areas that required no equipment for thermal conditioning and omission in direct use of fossil fuels when thermal conditioning is needed to cool down areas and thus, an introduction of this methodology may be encouraged.

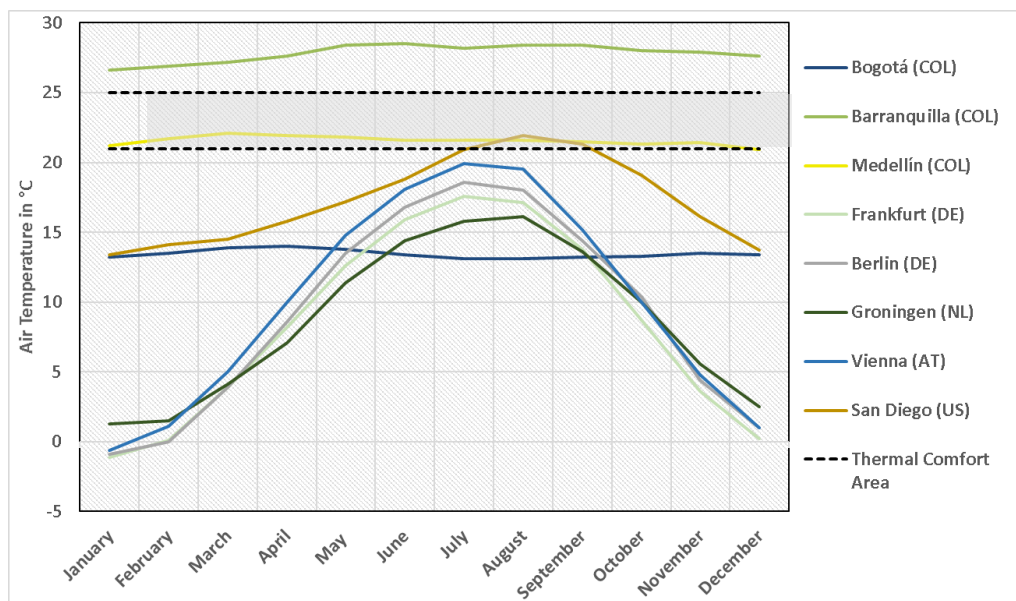


Figure 15. Mean temperature of air in cities with Energy Plus Buildings and cities in Colombia.

Source. Own elaboration with data from (Climate-Data, 2018)

This energy demand from the grid or provider is finally mitigated by generation *in situ* with non-conventional sources and specifically for Colombia due to its weather, availability of technology, permitted use of land and access to resources is determined as priority for this sort of projects the solar energy as the non-conventional sources to be bonded. The following table resumes why this technology should be chosen to carry the generation for the energy balance of Energy Plus Buildings in Colombia (both photovoltaic thermal). This type of contributions that encourage self-generation in Colombia in the sector of residential and services constructions, support the thesis of an effort to shift the self and decentralized energy generation of the country from being

100% related to the industrial sector (with conventional energy resources) to a spreading into other sectors with NCSE (Enersinc, 2017a).

Table 5. Renewable energy technologies in Medellín

Technology with renewable sources	Use with Energy Plus Buildings in Colombia	Comment
Wind turbines	No	<ul style="list-style-type: none"> • Wind speed available <5 m/s • Large space needed • Generally out of system's boundaries (Property)
Geothermal (electricity)	No	<ul style="list-style-type: none"> • Few studies in Colombia for this technology • Deep perforations may alterate topography Perforaciones profundas pueden alterar topografía • Need of facility near hotspot
Geothermal (heat)	No	<ul style="list-style-type: none"> • In temperate climates use of air as source of heat may be used for heat pumps
Biomass	No	<ul style="list-style-type: none"> • Long and expensive transportation journeys with raw matter • Depending on acquisition process, may not be CO₂ neutral • Large spaces needed for facilities
Wave Power	No	<ul style="list-style-type: none"> • No water resources available in some areas • Out of boundaries (Property)
Solar Thermal	Yes	<ul style="list-style-type: none"> • Need for same area for solar thermal and photovoltaics
Solar Photovoltaic	Yes	<ul style="list-style-type: none"> • Need for same area for solar thermal and photovoltaics

The Colombian Ministry of Mines even considers among the possible future scenarios to 2050 the possibility in which energy is replaced in all sectors and uses where possible by electricity (Esc. ME FCE and Esc. ME FNCE in Figure 16). These two plausible ways with the highest possible use of electricity as energy form differ on the generation of this service from conventional and non-conventional sources respectively, noting that the second path, should present the lowest amount of primary energy needed in comparison with all the projected scenarios to 2050.

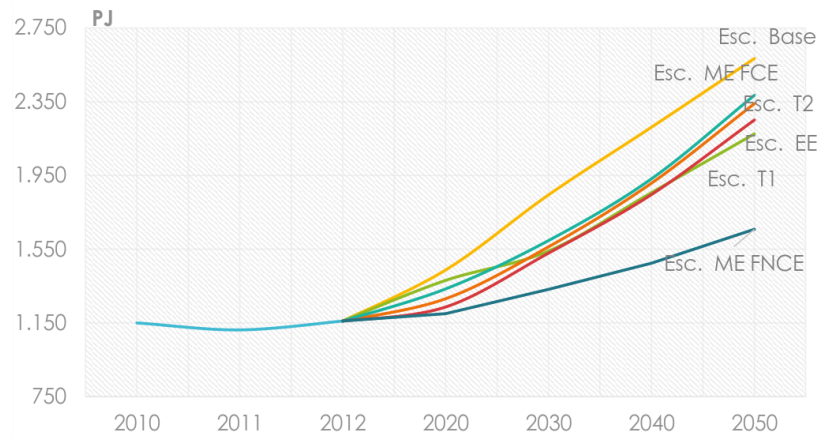


Figure 16. Primary energy required for transformation

Source. (UPME, 2015d)

The economic profitability of the different technologies for the generation of energy generally predominates over environmental profitability as a decisive factor for its implementation in different countries. This profitability is determined as the cost of each energy unit produced with the use of a specific technology and it is known as LCOE (Office of Indian Energy, 2015), 2015) by its English name "Levelized Cost of Energy":

$$\frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad (6)$$

I_t = Investment in year t

M_t = Maintenance in year t

F_t = Fuel cost in year t

E_t = Electric generation in year t

r = Discount rate

n = Life time of the system

Investment costs particularly in photovoltaic panel projects are still high for some projects compared to other generation technologies. For this specific situation it is interesting the fact that the installation price has been decreasing with high speed in the last few years,

which gradually encourages the competition of this source against conventional ones to the level of reduced price of 80% for photovoltaics and 40% for wind turbines (IRENA, 2018b). This behavior shown in Figure 17 also shows that the unit cost of electricity generation through renewable sources is already, in many cases, economically comparable with production with fossil fuels. Therefore, the lagging participation of South America in the global installed capacity of photovoltaic solar panels contributes only 16% compared to 34% that Europe provides even though this second continent has a much lower potential but may rely basically on the high price of electricity with their traditional way of generation (International Energy Agency, IEA, 2018). In addition to this economic reasons, specific governmental interests lead to the phenomenon of economic scarcity (later treated in this work) that reflects an underutilized potential in the use of non-conventional sources of energy in South America with the attenuating that in recent years such projects have been gaining popularity.

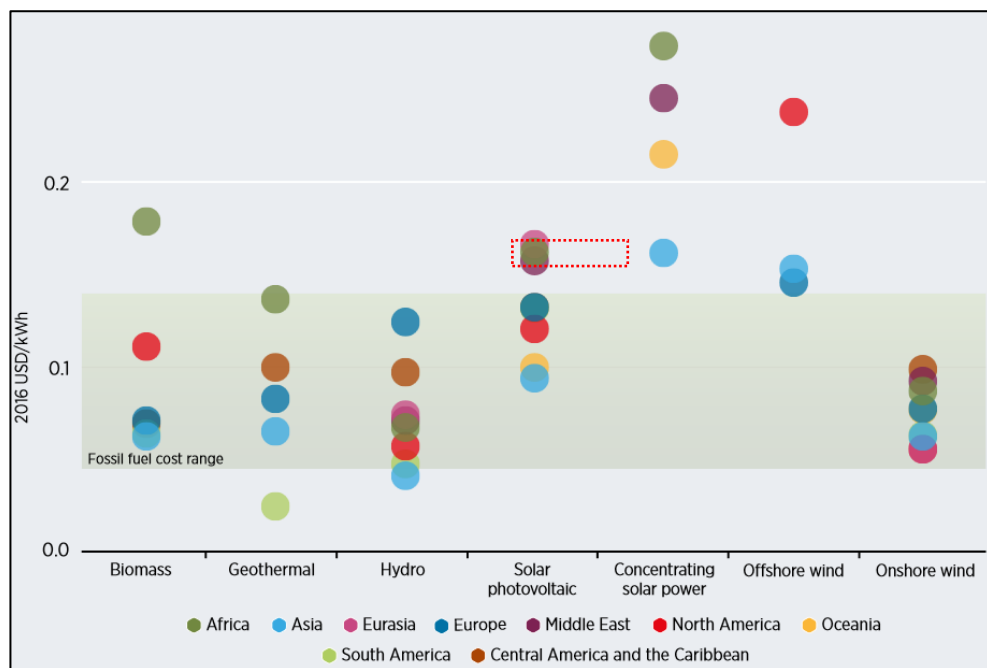


Figure 17. LCOE of different technologies with renewable sources in different zones

Source. (IRENA, 2018a)

In the study carried out by the Carbon Trust (consultancy firm whose goal is to accelerate the transition to a low-carbon world economy) in Colombia, an impartial analysis of the evolution of the NCSE is carried out. Here the experts ensure that, with the exception of biomass, the different technologies included in the study need additional incentives to those obtained with the actual regulations (Law 1715 from 2014) to achieve profitability

if externalities are not considered (Carbon Trust, 2015). These factors to be included are elements with positive or negative collateral effects that are not normally accounted in financial analysis since they are not explicitly reflected in the market price of the goods or services that in this case are NCSE facilities. According to the study, this inclusion of externalities in the financial analysis is suggested, in order to reach a point where integration of NCSE in Colombia through the above-mentioned law can be highly attractive for investors and thus encourage them to execute these type of projects. The methodology described points the following positive factors for projects with NCSE:

- savings in raw material and transport for generation with thermoelectric plants
- reduction of GHG emissions (including associated with hydroelectric plants) or sale of Reduced Emission Certificates
- reduction in costs of medical treatments due to health problems
- creation of new companies and jobs associated with satisfying this new market niche.
- Environmental Management Plan cheaper than for thermo and hydroelectric
- exemption in payment of environmental services

Given that externalities also include factors that disfavor NCSE projects, it is also quantified how investments in these projects are indirectly disadvantaged by including costs of:

- connection to the grid
- grid balance (for managing energy fluctuations)
- reinforcement of the grid (for managing energy fluctuations)
- reservation costs when there is not enough wind or during the night

It concludes with the study that, although these externalities are not paid directly by the investor are factors that can be decisive when considering profitable a project in NCSE or energy efficiency driven by the benefits of Law 1715.

From 1993 to 2017, the Colombian government's Generation and Transmission Expansion Plan has been issued on an annual basis, setting forth the possible scenarios that the country could take over the next few years in terms of energy expansion and transmission. Although this contribution is of an informative nature, it is assumed that the Government supports projects oriented towards this expansion through the issuance of Resolutions. It is stated that the demand for energy in Colombia is theoretically covered until the year 2021 with the current installed capacity, which is why the growth in energy

generation is necessary between 4.2 and 6.6 GW with a total potential of all country's regions together of 15 GW (UPME, 2017b). The greater potential foreseen for the expansion of the generation of energy in Colombia to meet the demand, is based on large-scale photovoltaic plants (greater than 1MW) with a theoretical installation of 5.8 GW. The fifth ranked potential in terms of expansion, is the generation with distributed solar panels in commercial, residential or industrial buildings. In this way, a notorious but gradual change in the way of producing energy in Colombia might be accomplished, even to the point where power generation with non-conventional renewable sources would surpass the contribution of conventional methods.

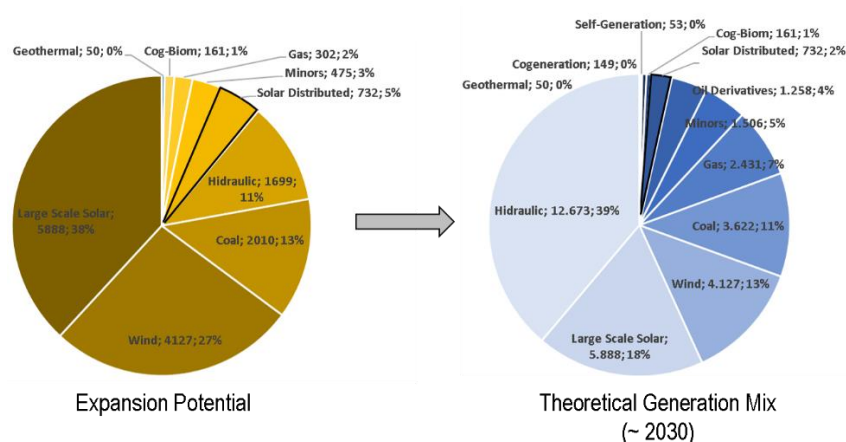


Figure 18. Generation Expansion in MW.

Source. Own elaboration with data from (UPME, 2017b)

Lately, as the government is aware of the need to have an energy transition in the country for arguments of total demand coverage, air quality, direct GHG omission, among other previously mentioned aspects, formal promotions have been issued that directly support the investment in projects of self-generation of electricity with photovoltaic panels. For this purpose, Resolution 030/2018 is written by the Energy and Gas Regulatory Commission (CREG) in order to give the civil society the possibility to assume a role as energy supplier that may sell its generation to grid operators. Initiatives like this worldwide have led to political and cultural changes that significantly promote the introduction of these methods of energy generation that finally lead to pressure the market to increase the offer of these goods. This phenomenon also extends to the investigation to increase the range of possibilities in the market, opens new businesses that reach more interested sectors and finally open a long competition of manufacturing, distribution, installation, planning and project management in this field. Finally, the

greatest benefit is received by the client given that this bidding among offering enterprises to have the possibility of satisfying the client needs, has caused the price of this technology to plummet (Figure 19) to the point of having the lowest historical selling price nowadays. Thus, it will be more profitable for the investor to take advantage of the benefits that come with the implementation of these equipment and be a participant in the global Energy Transition.

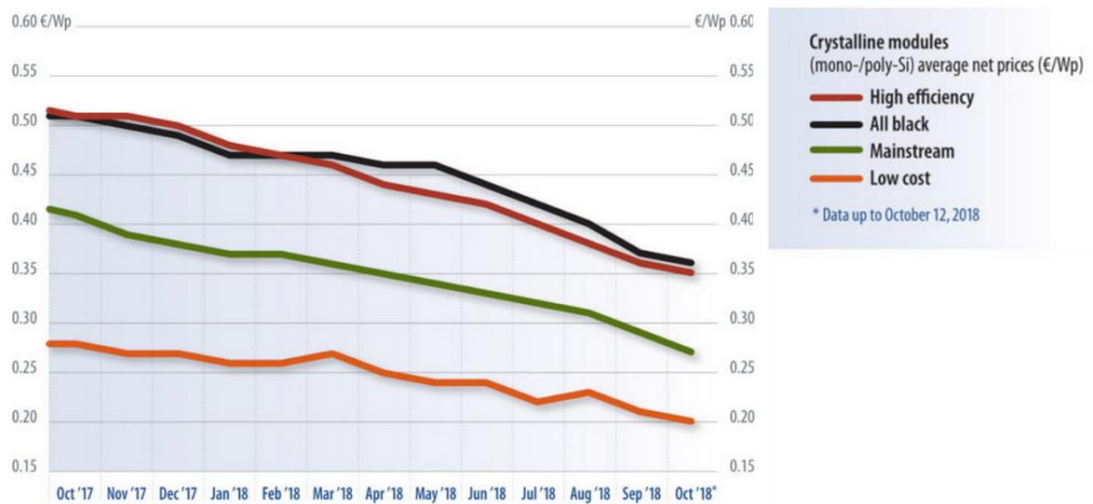


Figure 19. Modules price

Source. (PV Magazine, 2018)

In contrast to this fall in prices of photovoltaic technology that involves smaller investments for these projects and faster investment return times, in Colombia appears the phenomenon known as "economic shortage". This term does not refer to an absolute lack of a good or a service, but specifically to the fact of not having the possibility of obtaining the desired with the available resources. This concept is appreciated before the availability of a resource but given the actual conditions, it is necessary to choose between that resource and another one also desired but not both, which leads at the end to a conflict of interests. Throughout this phenomenon, the set of priorities or choices in a subjective point of view regarding different goods or services, are always present. A specific case of this type of shortage is the so-called "Economic Water Scarcity" generally in Africa due to the lack of investment, interest and human capacity in infrastructure to satisfy the demand of this resource in areas where the populations cannot opt for adequate access to it (The Water Project, 2018). To address this type of problem, more important than a monetary investment to be done is a social and political intervention in the matter. It is not news for anyone to say that Colombia has two

comparative advantages given its geographical location: abundance of water, solar and agricultural resources for the generation of clean energy and climatic conditions that, compared to several countries, lead to a fewer energy demand in buildings mainly because of low thermal conditioning use. This is how Colombia has a shortage in the generation and efficient use of energy since the country has always had abundant resources and thus energy management has not been an issue of traditional emphasis in the governments of the country. This underestimated potential can be seen in the following table where countries that have a much lower solar radiation than the one in Colombia, have been making efforts in favor of the Energy Transition through the installation of solar farms, floors and roofs. It is important to note that Colombia's electricity generation system has already low GHG emissions compared to industrialized countries but has the two disadvantages of being barely diversified (approximately 70% hydroelectric and 30% thermoelectric) and high fluctuations due to droughts that encourage increase in the use of thermoelectric plants.

Table 6. Harnessing solar radiation for photovoltaic projects.

Country	Installed capacity (GW)	Solar radiation [kWh/m² · a]
Japan	49	1.500 - 1.750
Germany	42	900 - 1.200
England	13	750 - 1.100
France	8	1.100 - 1.750
Colombia	0.03	1.100 - 2.100

Source. Own elaboration with data from (IEA, 2018) and (World Bank Group, 2018)

The low use of this resource may be based on different issues like the traditional absence of a legal framework that promotes the introduction of projects that adopt these technologies through economic and social benefits. Although gradually in the late Colombian environment for the Energy Transition a suitable structure is being constructed, several legal obstacles in the legal field have been found that diminish the inertia of the projects to be materialized mainly by long bureaucratic processes through which they must be submitted to be validated and accepted. Additionally, the abundance of resources for generation (more than double the resources needed for internal energy are exported and this abundance leads to low energy prices in the interior) and the absence of uncomfortable temperatures in important areas of the country are factors that

have been postponing the interest to create a market niche in the conscious management of energy in buildings that is the center of this work.

The following graphic representation involves the behavior of the last years of energy consumption in the residential sector for Germany and Colombia. This factor is dependent on the consumption habits and the purchasing power of people but mainly on the size of the population. By simultaneously exposing the consumption over time with the growth or decrease of the population in the upper cadres (left for Colombia and right for Germany), this dependence becomes evident, which normalizes the behavior of consumption per million of inhabitants in the lower graphs. In this case, it is identified that in Colombia every year the energy demand in housing grows in greater magnitude compared to the growth of the population or the same amount of people need a greater consumption of energy for their houses while in Germany it is evident that gradually this demand has been decreasing in the sector. This reduction may have two main reasons: in the first instance, in Germany since the seventies, measures have been implemented to reduce the demand for heating in buildings (given that it represents the highest consumption in the sector) and on the other hand, there are different initiatives that financially promote the renovation and construction of buildings in favor of the Energy Transition.

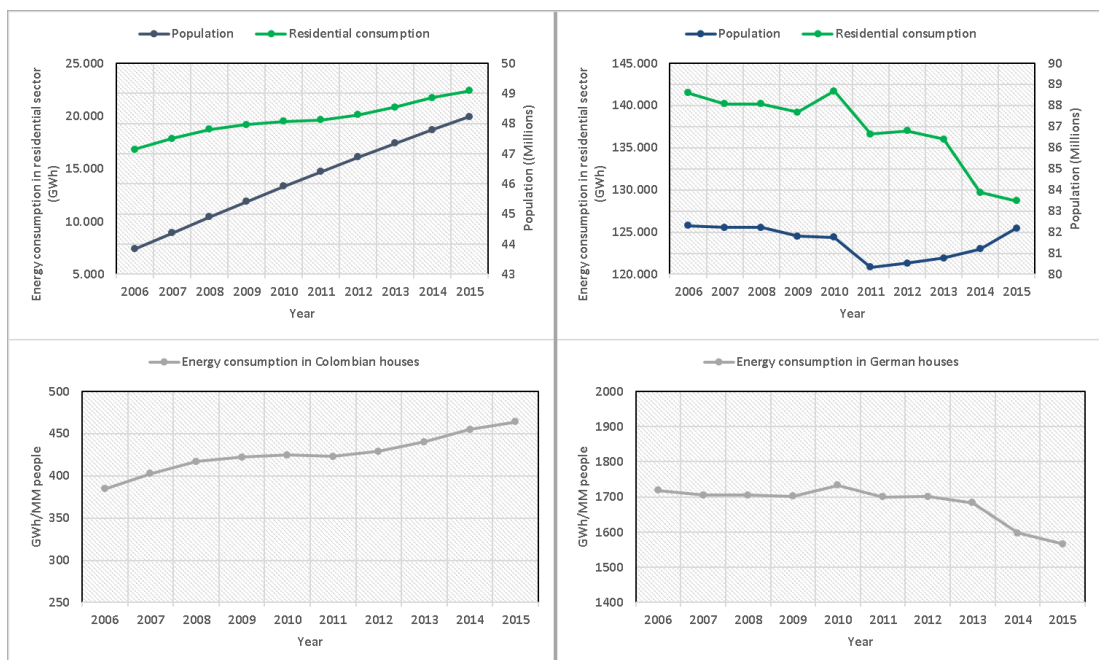


Figure 20. Electricity consumption in residential sector.

Source. Own elaboration with data from (UPME, 2017a) and (Umwelt Bundesamt, 2016)

In parallel, while Germany is concerned about decreasing the demand for this service, Colombia shows an opposite behavior given abundant sources of energy in the form of water, coal, gas and oil and a lower purchasing power that stimulate a prolonged use of home appliances. Particularly, refrigeration is the largest consumption of electrical energy in homes whose actual consumption is far above theoretical values for this task given the inefficiency of these equipment due to its longevity. Another fact that reinforces the growth in energy consumption by the residential sector in Colombia lies in the energy subsidy that low socioeconomic strata (1, 2 and 3) receive in Colombia through the CREG Resolution 079/1997. These sectors receive a monthly contribution in their energy bills, so even though the government intends to reduce the monthly expenses of these families, this aid is against the reduction in energy demand by granting benefits even when there is a high consumption. Instead, measures that not only imply a lower monthly energy cost, but also lower energy consumption, such as economic or tax incentives for the replacement of household appliances might have a better repercussion on the environment and these families (Enersinc, 2017b). The 2017-2022 Indicative Action Plan stated by the Rational and Efficient Energy Use Program (PROURE) includes the initiative to replace old refrigeration equipment in the residential sector, whose savings could amount to 2.4 TWh / year (Ministerio de Minas y Energía, 2016a) which, together with the minimum values of energy efficiency required by the RETIQ energy label for the sale of equipment for homes through Resolution 41012/2015, are particular processes that reduce the demand in this sector and spare a conscious energy use. Cooking in Colombia is usually carried out with natural gas, liquefied gas or firewood (the latter energetic only in rural areas), sources that are less efficient to provide necessary heat than electricity. In urban areas, where this work is focused, installation and use of equipment that operate with gas are widely used because of the lower cost of this resource compared to electricity and its popularity is such that the electric consumption for cooking is practically negligible. Natural and liquefied gas have short carbon chains that when burned, generate a lower amount of GHG than other fuels of a larger molecular size such as coal, gasoline or oils. By comparing cooking processes in urban homes in Colombia with cooking through electrical stoves in other countries that a great part of this generation is done with non-renewable sources, this task is cleaner for the environment in Colombia by using gas. Furthermore, as in Colombia electricity is largely generated by water resources and is meant to intensively integrate clean sources, low GHG levels emissions are present, it is possible to consider a gradual future change from non-renewable sources to electricity. This hypothesis, driven by the increasing

consideration of the Energy Transition in Colombian society, contributes to reducing the inertia of annual GHG emissions by the residential sector, that ascend to 9 million tons of which more than 4 come from cooking (Ministry of Housing, 2014). (Ministerio de Vivienda, 2014).

Appendix B contains a comparison between Germany as country with multiple buildings listed as "Energy Plus" and Colombia as country where this concept of construction wants to be introduced. This appendix shows also how little the demand for thermal conditioning is (in this case relates just to AC) related to countries with seasons. In Colombia this demand in houses represent only 4% of the total consumption and evidences the advantage on implementation of this type of projects comparing with countries where this concept has been already several times built and due to their geographical location represent the highest energy expenditure that is usually linked to the use of fossil fuels. In conclusion, there is in Colombia a set of factors that encourage the inclusion on the market of a new concept of buildings. Factors like high levels of solar radiation, low need for thermal conditioning (especially heating), new legal framework to increase use of NCSE, spread of energy self-generation to other sectors apart of industry, promotion of energy efficiency in household appliances (RETIQ energy label) and publication of sustainability standards for buildings in Colombia.

4.4. COLOMBIAN POLICIES THAT ENCOURAGE THESE PROJECTS

Sustainable development, renewable energies and energy efficiency are not new terminologies for the Colombian government since 17 years ago, the introduction, use and appropriation of an engagement that seeks to foster and last these terms in society have been encouraged through issued laws.

In 2001, the congress issued the 697 law that creates the Program for the Rational and Efficient Use of Energy and other Non-Conventional Energy Forms "PROURE" to progressively implement programs in favor of minimum requirements of energy efficiency. Additionally, in the ninth article the Ministry of Mines and Energy expresses the interest of formulating guidelines for policies, strategies and instruments that encourage the use of unconventional sources of energy and in the tenth refers to giving incentives to companies that import or produce parts or devices in in this scope (Congreso de la República de Colombia, 2001). Although this law may have served as a legislative basis for PROURE to carry out activities that promote this energy transition, it evidences a sign that the issuance of a law is not a total guarantee of compliance.

As an incentive for the sale of energy generated with wind turbines or biomass, through article 207-2 of Law 88 of 2002, the exemption of certain taxes for fifteen years was issued to companies who obtained and sold carbon dioxide emission certificates (CERs). A second mandatory aspect was that at least 50% of the profit obtained from the sale of the certificates was invested on social benefit in the area where the plant worked, which minimized the investment interest in these projects given the reduction in economic profit.

Through the PROURE, minimum energy saving values were determined to be met in the 2010-2015 period defined by the residential, industrial, commercial (public and services) and transport sectors. It should be noted that from the beginning, the PROURE was focused on achieving goals primarily of electric power efficiency in the first instance, determining that the sector with the greatest potential for saving electricity in this period was residential with 10.6%. Likewise, in the industry sector, the priority was to reduce the use of electricity by 3.43% and, secondly, only 0.25% of other energy sources, noting that this sector has the second highest energy consumption after transportation in Colombia and 67% of its consumption comes from conventional sources (gas, coal and oil products). This initiative had two major problems for its execution and therefore its validity had to be extended until 2016 through the Resolution 4 1430/2015. In the first instance, only two years after the plan was issued, through the first article of Resolution 0186/2012, the 2015 goals of energy saving in the industrial and transport sectors were adopted as "Environmental Goals". This recognition was mandatory according to literal f) of article 428 of the Tax Statute in order to be eligible for VAT payment exemption and deduction up to 20% in income tax in order to promote the renewal of technologies. The second limitation after this late conversion of the objectives, refers to the fact that not all sectors obtained this distinction in order to be eligible for economic benefits. Therefore, as stated in article 4 of decree 3172/2003 "the deduction for investments in control and improvement of the environment [...] will not be subject to the goods, equipment or machinery destined to projects, programs or activities of reduction in energy consumption and / or energy efficiency that do not correspond to the achievement of environmental goals" where the totality of gas and household appliances is included.

In 2014, the Law 1715 was issued with a promising future for the inclusion of unconventional sources of energy in Colombia, given the economic benefits obtained from investing, researching and developing use of these sources. Through this law could be obtained:

- a deduction of up to 50% in the income tax based on the investment
- an accelerated depreciation of maximum 20% per year of the value of the project assets
- exclusion of VAT payment for goods and services
- exemption from payment of import tariffs for materials, equipment and project supplies.

These four pillars that lead to an initial saving of investment and a periodic saving for the reduction of taxes, suppose a favorable argument to encourage the execution of projects in the field of clean generation and efficient use of energy but, as it has been presented previously in Colombia, when issuing legislative documents, the existence of these regulations does not ensure the effectiveness of their execution. The lack of regulation since the issuance of the law has led to situations when investors and interested entities in the benefits that want to present project proposals, find obstacles in the enrollment that lead to high desertion in this process. It was even necessary that two years passed from the issuance of the law, so that a list in Resolution 045 with goods and services susceptible to receive an exemption from VAT payment and import duties was made public. In September 2016 of 83 projects submitted, 45 were accepted in the first instance by the Energy Mining Planning Unit (UPME) and the second filter for obtaining benefits that is reviewed by the National Environmental Licenses Authority (ANLA) was exceeded by 33 proposals (Semana, 2017). By 2018, there were 370 certification applications for a capacity of close to 1.6 GW that are intended to cover around 10% of the national energy demand, where the largest source of renewable energy generation is the sun with photovoltaic projects of less than 1 MW (Ramírez, 2018).

In 2016, Resolution 41286 is issued, which adopts the 2017-2022 Indicative Action Plan national wide for the development of the Rational and Efficient Energy Use Program, given that this document defines the objectives and strategies that are intended to meet the levels established energy efficiency. After this plan was adopted, in 2017 the sectors that had not been included in Resolution 0186/2012 were included as environmental targets to opt for VAT exemption benefits. With this new plan that already contains the transport, industry, tertiary and residential sectors, new values are stipulated as energy saving goals for the year 2022 through actions and concrete measures that, if implemented in projects, the economic profitability of an investment is enhanced.

Table 7. Actions and initiatives of the Indicative Action Plan 2017-2022

SECTOR	ACTIONS AND PROCESSES
TRANSPORTATION	Reconversion to natural gas for cars, natural gas for public transportation
	Use of electricity in: government cars, taxis in main cities, motorcycles, cars and public transportation in main cities of the country
INDUSTRY	Energy efficiency in electricity (driving force, AC, refrigeration, lighting, direct and indirect heating)
	Energy efficiency in solid fuels for direct and indirect heating
	Energy efficiency in natural gas for direct and indirect heating
	Design and implementation of Energy Management Systems
TERCIARIO (COMERCIAL, PUBLIC AND SERVICES)	Energy efficiency in electricity (lighting, AC, motors and public lighting)
	Improvement in design, construction and architecture adequacy of buildings (better transference through roofs, windows and walls)
	Evaluation and implementation of thermal districts
	Implementation of new and modern measurement systems
	Implementation of Energy Management Systems
RESIDENTIAL	Energy efficiency in lighting
	Energy efficiency in buildings (no thermal paintings, wind extractors and other natural ventilation processes)
	Implementation of efficient stoves for firewood

Source. (Ministerio de Ambiente y Desarrollo Sostenible, 2017)

Through Resolution 0549/2015, the Colombian Government through its Ministry of Housing, City and Territory adopts The Guide for Saving Water and Energy in Buildings. This manual is the result of the formulation of policies about urban renovation, quality of housing and sustainable construction to which the ministry is committed and therefore establishes minimum values for energy and water saving measures that new buildings with different purposes in Colombia must meet. From the guide that is presented as an appendix to the Resolution, a baseline is defined for different climatic zones of the country and purposes of the buildings, which serves as a reference for the percentages of water and energy savings. Highlighted in red are housing buildings that are not of

social interest in which the introduction of "Energy Plus Buildings" in Colombia is made noting that Medellín's weather is categorized as mild. In addition to these required values that are between 15-45% with respect to the baseline, different measures are proposed that promote their compliance.

Table 8. Baseline for energy and water consumption and percentage to be reduced

Energy (kWh/(m ² ·a)) //Water (l/(person·day))	Cold	Mild	Warm and dry	Warm and humid
Hotels	96,1 // 188,5	151,3 // 564	132,5 // 242	217,8 // 278,9
	20% // 25%	35% // 10%	25% // 35%	45% // 45%
Hospitales	249,6 // 620,2	108,3 // 600	344,1 // 438	344,1 // 800
	35% // 10%	25% // 40%	35% // 10%	30% // 40%
Offices	81,2 // 45	132,3 // 45	318,2 // 52	221,3 // 45,8
	30% // 30%	30% // 35%	40% // 45%	30% // 20%
Malls	403,8 // 6 l/m ²	187,8 // 6 l/m ²	187,8 // 6 l/m ²	231,5 // 6 l/m ²
	25% // 25%	40% // 15%	35% // 45%	30% // 20%
Educacionales	40 // 50	44 // 50	72 // 50	29,8 // 24,8
	45% // 45%	40% // 40%	40% // 40%	35% // 40%
No DSI Dwellings	46,5 // 145,4	48,3 // 145,3	36,9 // 189,8	50,2 // 174,9
	25% // 25%	25% // 25%	25% // 20%	45% // 20%
DSI Dwellings	44,6 // 105,7	44 // 113,9	34,6 // 156,7	49,3 // 125,4
	20% // 10%	15% // 15%	20% // 10%	20% // 15%
DPI Dwellings	48,1 // 78,1	53,3 // 98,3	44,9 // 189,8	50,6 // 110,6
	15% // 10%	15% // 15%	20% // 10%	15% // 15%

Source. (Ministerio de Vivienda, Ciudad y Territorio, 2015)

DSI stands for Dwelling of Social Interest and DPI stands for Dwelling of Priority Interest. These two labels refer to buildings with different but tight budget in order to be built as cheap as possible to promote a cheaper selling price of housing units for families with lower incomes.

It should be noted that for a house in cold weather that is not of social interest, to meet the norm of sustainable buildings in Colombia the maximum energy consumption cannot exceed 34,9 kWh / (m² · a). The same document shows as model of a cold climate the city of Bogotá where temperatures between 12-18 ° C are common but use of heating, the largest energy consumer in dwellings, is not widely used given that for these temperatures a not-very-complex building envelope is enough to help reach thermal comfort levels.

At the beginning of 2018, the Energy and Gas Regulation Commission (CREG), in exercise of the constitutional powers conferred through the aforementioned Law 1715, defines the parameter to be follow to sell energy surpluses generated through small-

scale self-generation plants (<1 MW) and small-scale distributed generation with no own consumption (<0.1MW). The registering and availability procedures are determined as well as the energy sale prices and the documentation to be submitted to make a connection to the National Interconnected System (SIN) and contribute to the country's energy supply through its own generation.

Indicative targets for energy savings in the year 2022 were adopted for different sectors of Colombian society through Resolution 41286/2016 in which, particularly for the residential sector, a saving of 56,121 TJ is estimated from 2017 onwards. Particularly through the Rational and Efficient Use of Energy Program (PROURE) that is based on this Indicative targets, proposes the application in this period of national and/or international sustainable construction standards. Through these certifications or issuance of labels, among different factors, the development of projects that allow the self-generation of energy with renewable sources is included in order to reduce the energy consumption of the residential sector in Colombia by 4% by the year 2022 (Ministerio de Minas y Energía, 2016b).

A fact that complements the motivation to increase energy efficiency in the residential sector is the execution in the country of the United Nations program "Sustainable Energy for All". Through the Colombian Council of Sustainable Construction and funds of the Global Environment Facility it is stipulated to help reduce the GHG from construction to the year 2030. To accomplish this, it has begun with the development of a work plan that aims to achieve three specific goals: duplicate the energy efficiency rate of the construction sector, implement an illustrative and emblematic project and create a baseline in order to report an annual progress in increasing energy efficiency. According to regulation 0549/15, GHG emissions will be reduced by 25% according to calculations by the US Agency for International Development, which would be more than sufficient to comply with the goals of the Paris Agreement where a 20% reduction was agreed for the same year (BEA, 2016).

5. CASE STUDY

The "Energy Plus Building" model in Colombia is evaluated in this document for a future construction project in the city of Medellín as an introduction to the concept in the country for "Conconcreto", a recognized national construction company. This project is called "Contree" and will offer a punctual response to the demand for sustainable solutions in

the housing construction field that, by integrating various factors, develops a new concept that will be an icon for the city.

This project has different stages and buildings but for the present evaluation, only the first one is considered that refers to the construction of two housing buildings. These buildings, subject to changes in planning, will have around 70 and 90 apartments distributed in 15 or 17 floors. It should be noted that by interest of the client, a second floor mainly for a bedroom can be built. These apartments are sold as “lockup” homes, where just windows, door, cables and pipes are provided so that the client has a total flexibility in the interior design of its home.

In this document, B1 relates to the building whose terrace will be built on the 16th floor and B2 the building whose terrace will be on the 18th floor. B1 would have when constructed around 56 one-floor-apartments and 14 duplex and B2 would include 72 and 18 respectively. Considering only the living space to be ventilated (apartment without balcony or terrace), the average area of a one-floor-apartment consist on 82 m² and for duplex apartments consist on 111 m² for a total living space of 14.091 m². Distribution of the apartments in terms of orientation of the windows and internal rooms' partitions is identical in all even floors and likewise, there is another configuration of orientation and partitions that all uneven floors share.



Figure 21. Render of Contree and scheme of uneven level

Source. (Concreto, 2018)

This residential complex of two buildings will have a four-level covered parking area, an active zone for different activities like a gym, spa and steam bath. At the first floor a coworking area will have place, inside the parking area an electric mobility charging station for cars, bicycles and motorcycles is going to be installed and at the top of both buildings a terrace for social activities has been planned.

5.1. LOCAL ENERGY GENERATION

CONTREE is still in the final definition of its design and conception and as it is still subject to changes that can be made in this process, it is not accurate at the moment to develop only a particular idea of the energy model in order to go towards the adapted requirements to be an *Aktivplus* building. For this reason, different scenarios are proposed that vary in scope, investment, coverage and energy supply. This project will include an energy generation system with NCSE with solar panels, as explained in the previous chapter for the city of Medellín. In this way, in the area that is destined for the construction of the project towards the southeast of the city, the potential of electricity generation with this technology according to the orientation and location of the modules (90° for façade and 10° for roofs)) is shown in Figure 22:

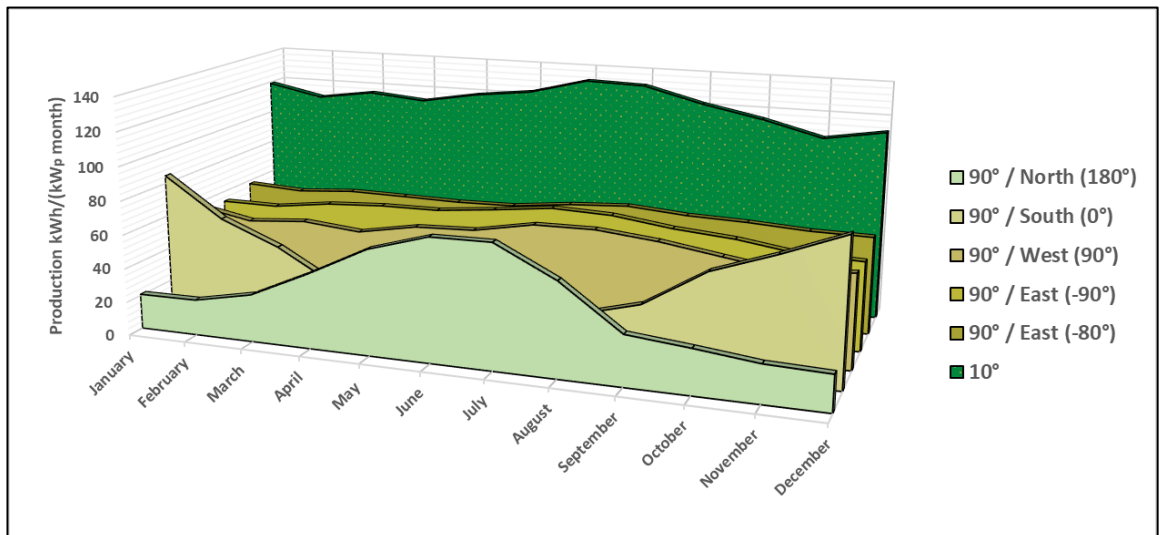


Figure 22. Monthly Energy generation potential in Contree with photovoltaic systems.

Source. Own elaboration with data from (Comisión Europea, 2018)

In the roofs a slight inclination of 10° is suggested, which is not enough to reduce the generation capacity of the modules but facilitates cleaning processes. Additionally, given the position near the equator, the difference in performance of a 10° inclined panel in different directions is practically negligible since it varies annually between 1400-1430 kWh/kW_p. The theoretical energy generation that could potentially be obtained by the installation of photovoltaic systems in these buildings is shown in the following table for each kilowatt installed on the façades and roofs where it is evident that the installation of

photovoltaic modules should be encouraged in structures parallel to the surface (roofs) due to its high generation factor.

Table 9. Generation factor for different structures in Contree

Location	Facing	Annual energy generation [kWh/kW_p]
Roofs	-	1.430
Building 1	Norwest (65°)	690
	Nor east (-25°)	601
	Southeast (155°)	500
	Southwest (115°)	660
Building 2	Norwest (45°)	650
	Nor east (-45°)	660
	Southeast (135°)	587
	Southwest (135°)	577

Under the current design of the buildings different structures have been determined to be potentially covered with solar modules. Through simulations with PVSOL the systems are characterized through factors such as amount of possible modules, energy to be produced, elements of shading and trajectories of the sun over the buildings. The points selected for potential installation of modules are specifically the roofs of the corridor and technical room of the last floor of both towers (a), the façade or floor's height of balconies (b), Terrace's façade (c), Parking's roof (d), Parking's façade (e) Trash collection Room's Roof (f).

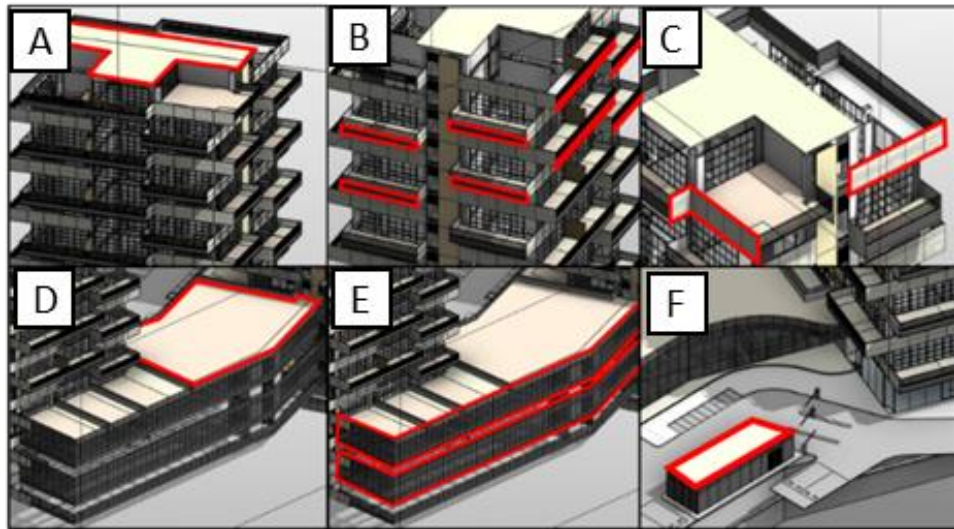


Figure 23. Location of potential installed modules

This work suggests different scenarios regarding installation of photovoltaic systems on both buildings but the definition of these systems in terms of location, size and coverage of demand are to be defined by Concreto. Generation potential for all the scenarios was calculated using PVSOL software using as basis the polycrystalline module JAP60S01-275 / SC produced by Ja Solar with a capacity of 275 W_p and dimensions of 1650 mm x 991 mm given its high commercialization in the market.

The behavior of the photovoltaic system in the different structures of the building was recreated through the simulation in terms of amount of electricity able to be produced by each specific subsystem, number of panels with the inherent configuration of inverters, shading over the system that affect generation and trajectory of the sun throughout the year. Modules located on the roof of the parking lots are modeled with an inclination of 10 ° with the surface and each row of panels is oriented in the opposite direction to the adjacent row to create peaks (image in the lower right corner of Figure 24). This arrangement facilitates cleaning processes by objects that may fall from the apartments noting that this inclination of 10° does not reduce the energy generation potential of the modules.

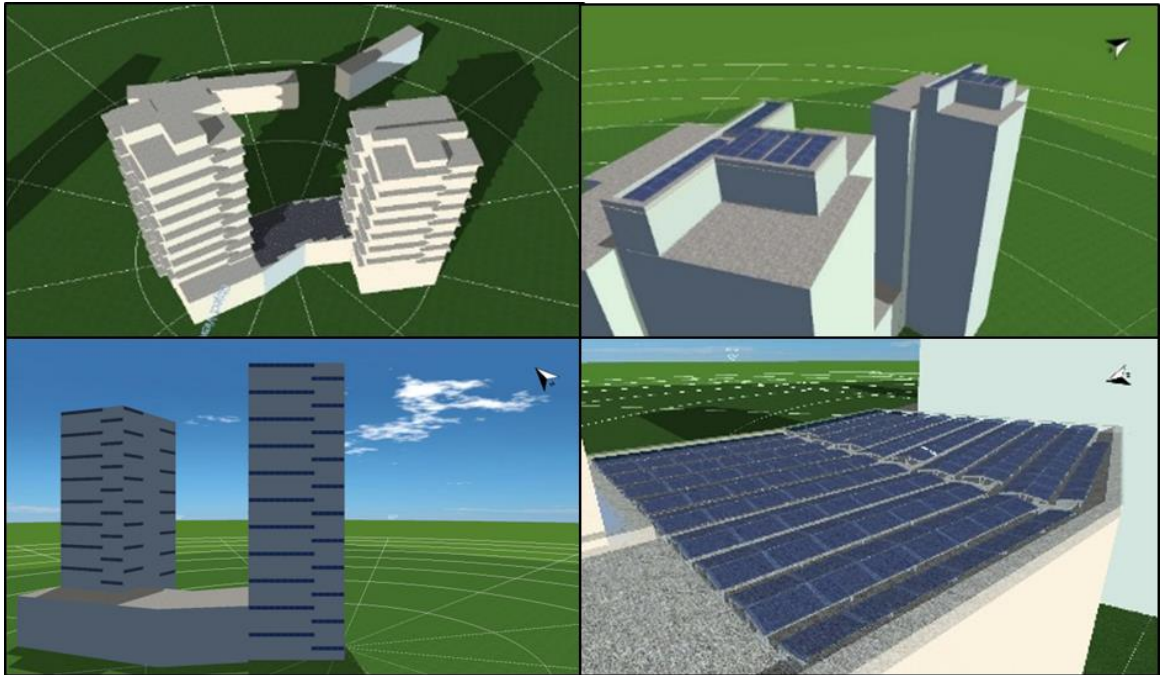


Figure 24. Modelation of photovoltaic system in CONTREE

Based on the architectural design of the buildings, the only possible structure that would carry solar modules on the façade are the balconies (image B of Figure 23). These structures have a length between 8,6 – 16,6 m and a height of 0,75 m, which is tighter than 0,99 m (wide of a standard panel if located horizontally). Therefore, two scenarios would be possible from this situation: At a first place, could be considered the installation of less efficient panels ($165 W_p / \text{panel}$) with a tight width of 650 mm that does not exceed in size the available space or does not visibly interfere with the building. The second option for the installation of modules over the façade is the use of standard panels of 990 mm whose width is only slightly larger than the available height but could be supported by a structure in the lower part as shown in Figure 25. The simulation is carried out with this second scenario or scenario B, since it presents modules of greater efficiency and the aesthetics of the building may not be negatively involved by this factor.

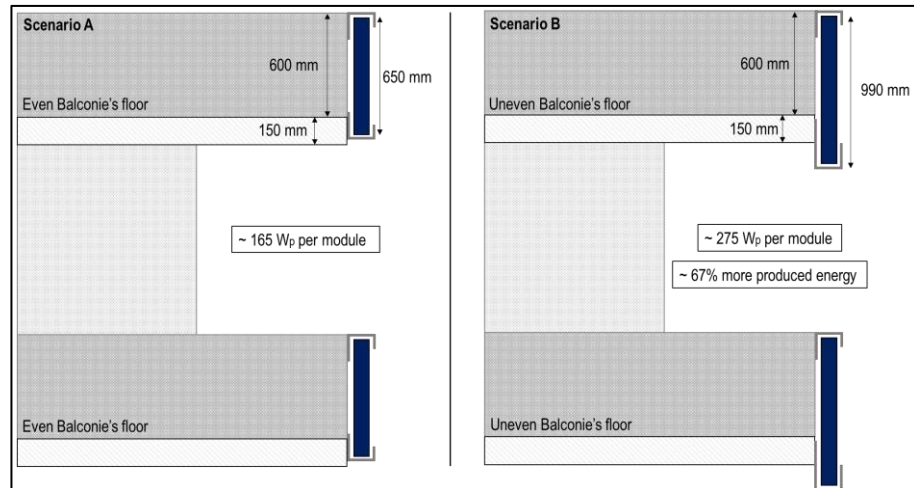


Figure 25. Possible scenarios for modules on balconies (scheme is not scaled)

Using the modules of scenario B of the previous figure in all the potential areas of the project, each zone is characterized by the number of modules that could theoretically be installed, the annual energy that would be generated and the generation factor of each installed kW_p (Table 10). For the interactive dimensioning of the potential to be installed of the modules, a spreadsheet is attached.

Table 10. Dimensioning results of potential photovoltaic installations con PVSOL

Modules location	Installed capacity	Annual electric generation	Annual electric generation	Generation factor
	[kW _p]	[kWh/a]	[kWh/m ² ·a]	[kWh/kW _p]
Balconies' Façade	237	161.292	11,4	682
Upper Terrace's Façade	29	18.128	1,3	634
Terrace's Roof	37	53.994	3,8	1.444
Parkings' Roof	84	88.880	6,3	1.063
Parkings' Façade	128	82.494	5,9	645
Trash collection Room's Roof	5	5.438	0,4	1.040
Total	519	404.788	29,1	860

This table in the second column assumes a total use of the area available for the installation of the modules that represent a total annual electrical generation of 410.226 GWh with an average weighted generation factor for each installed kW_p of 860 kWh per year. This last value is an acceptable factor for most countries where projects with photovoltaic modules in buildings are installed, generally because they have a high cost of energy, a great purchasing power and/or government incentives that encourage this type of investment. This is a relatively high value when 76% of the theoretically modules may be located on façades, structures where when capturing radiation perpendicular to the surface, it can be almost 2.2 times less than that obtained in parallel to the surface (roofs). As a reference for these relative high generation factors obtained through the simulation, the largest building in Germany under the *Aktivplus* standard shown in Appendix A, has an average factor for the roof modules with a value of 980 kWh/kW_p and on the façade 450 kWh/kW_p. The building evaluated in this document, on the other hand, presents weighted average factors of 1174 kWh/kW_p and 666 kWh/kW_p that symbolize an electrical generation that is respectively 48% and 17% higher for each module installed in this project compared to a module installed in the city of Frankfurt where this iconic project is located.

Figure 26 shows the trajectory of the sun in three hours of the day (8:00, 12:00 and 15:00) for different months of the year through the *Meteororm* database used by the software to perform this simulation in the city of Medellín.

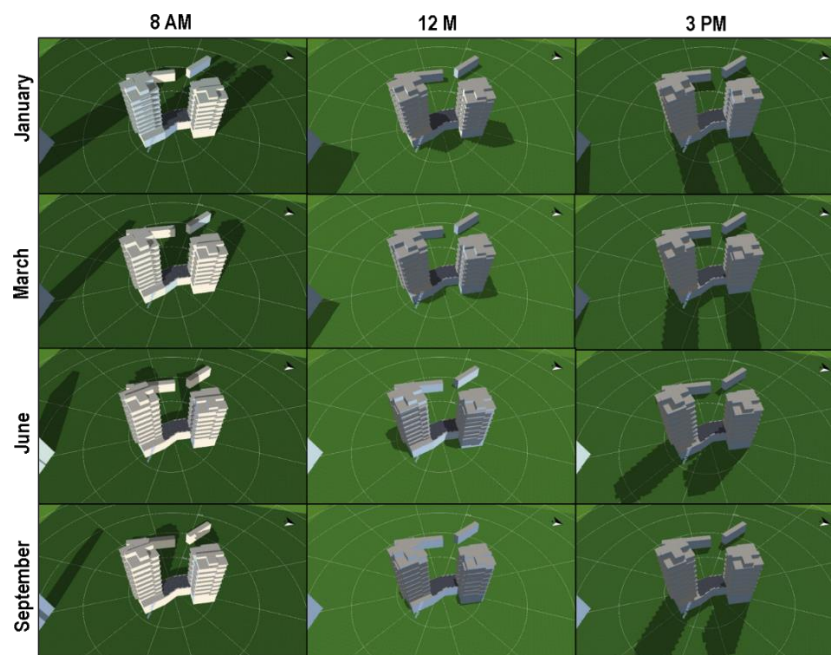


Figure 26. Sun's path over Contree

The potential in CONTREE to install a photovoltaic plant is determined by means of simulation of a total coverage with standard modules of 275 W in all available areas in buildings and common areas and *Meteonorm* data for solar radiation in Medellín. Distribution of this total generation of 410.2 MWh/year according to the different potential points to be covered with modules is represented below:

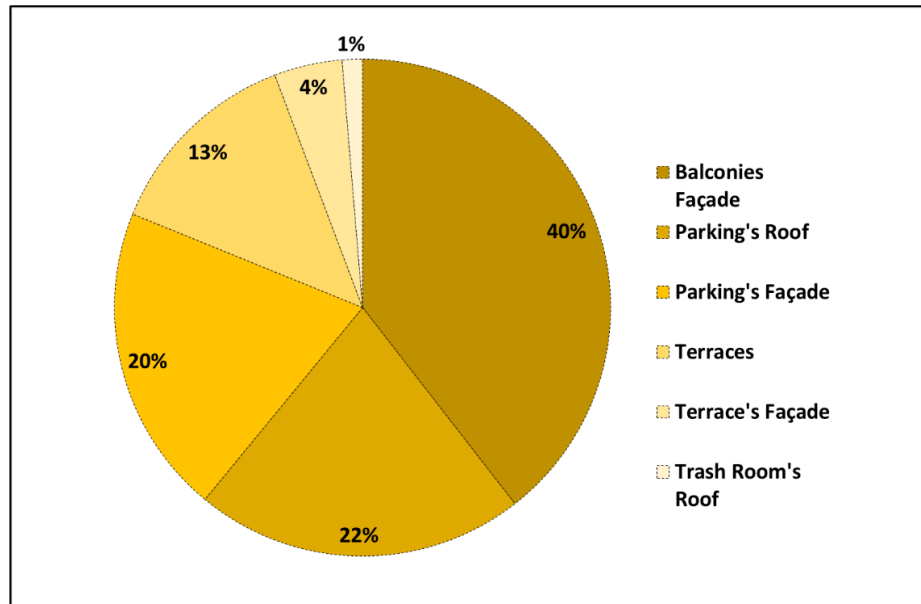


Figure 27. Potential generation distribution of each selected zone for installation of a photovoltaic system

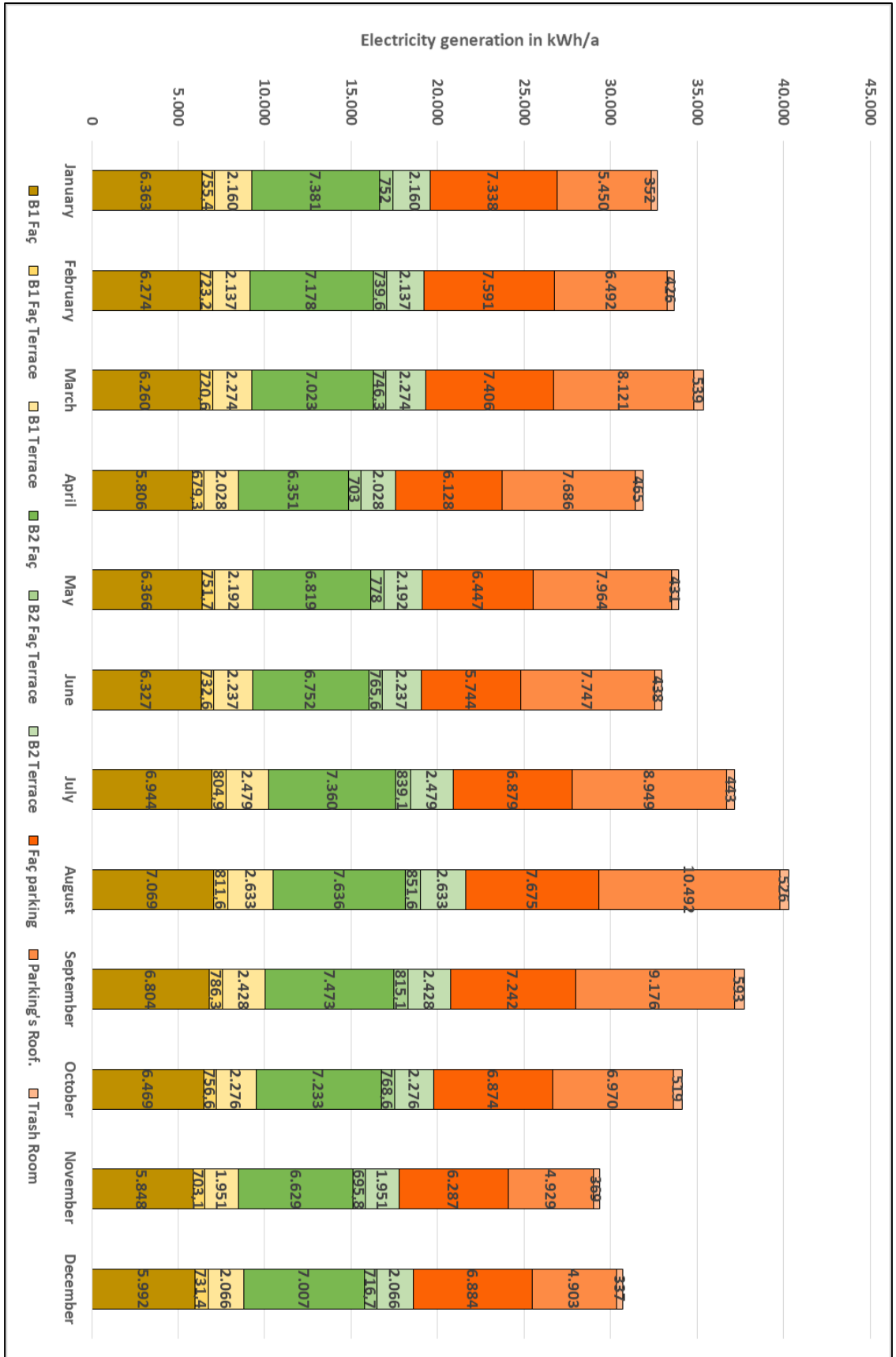


Figure 28. Monthly generation for each potential zone

Available space on parking's roof for installation of photovoltaic modules might mean a critical zone to achieve a plus energy building given its large area for this purpose. Its location between both buildings promotes shading at different times of the day and times of the year that reduce the direct uptake of solar radiation necessary for electrical generation in the cells. Reason why different scenarios were analyzed in which some shaded panels are omitted. The shading was quantified in the modules as the percentage amount of time during the sunlight hours of the year that was under shade.

To determine the influence of shadow from both buildings on the photovoltaic system that could be installed on this roof, simulations were carried out with different maximum limits on the percentage of shadow on the modules in order to observe changes in the improvement of the generation factor in kWh/a for each kW_p installed. First, a photovoltaic plant over the total available area is simulated by covering the whole roof with 275 W panels with an average total factor of 1.048 kWh/kW_p, factor that may be widely accepted in projects that use these technologies. Image A of Figure 29 shows the initial scenario with the whole area covered and where simulation results show that the majority of panels have a shading factor between 15-30% and thus, for the scenarios where gradually panels are omitted because of their shading, maximum levels of 30%, 25% and 20% are set. The factor of generation of the plant when using the entire roof, whose magnitude is 1.048 kWh/kW_p, means a production 30% lower than the factor of a system installed in the same location and with the same size that does not have any shadows (simulation without shadowing achieves a generation factor of 1.497 kWh/kW_p in the city of Medellín). Now, by considering a system where only panels whose shading factor is below 20% are installed, a new the generation factor of 1.162 kWh/kW_p equivalent to a 22% decrease in generation due to shadows is obtained. This improvement implies a significant reduction in the size of the system by only being able to use 57% of the modules and thus reducing the installation from 105,6 kW_p to 58,3 kW_p. Therefore, it is not profitable for the system to consider a reduction of just 8% in the deviation of the optimal generation factor due to the exclusion in the installation of more than 172 modules, when having an acceptable but not outstanding generation factor with this particular installation. It is concluded that, to increase this factor by the elimination of panels that contribute in a fewer magnitude to the generation by being shaded, is only a procedure to be considered if the generation system is much greater than the energy demand of the buildings. Otherwise, if this system falls short and it is necessary to install a larger system to meet the demand, it is equally valid to use the system with some

panels that are partially shaded at certain times of the day since an acceptable generation factor for each kW_p installed is still obtained.

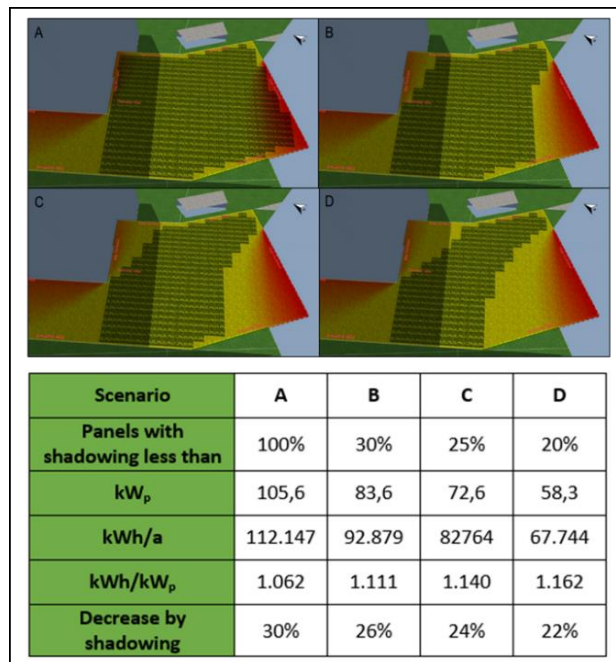


Figure 29. Decrease in the photovoltaic system on the parking's roof due to shading from the buildings

Through this generation potential, it is possible to quantify the coverage of the demand this photovoltaic system could offer. That is, how much of this services can be provided for apartments and common areas such as corridors, parking, coworking, gym, among others.

5.2. ENERGY DEMAND IN CONTREE

The *Aktivplus* standard offers an Excel tool to estimate the demand for electrical energy in a house, where a standard consumption may be defined based on parameters like type of electrical appliances or consumers, quantity of consumers, frequency of use and efficiency class are to be used as input data. Throughout this model, an average value of electrical demand is estimated (considering a standard apartment with stove and water heating operated with gas) of 280 MWh/a that, distributed in 160 apartments, that represents an average monthly demand of 140 kWh and 150 kWh for the apartments of one and two floors respectively.

In the model the following electricity consumption were assumed: washing machine, fridge with integrated freezer, dishwasher, LED lighting, oven, iron, computer, tablet, 40

"TV, pads coffee machine, microwave, router, cell phone, compact sound equipment and hair dryer as summarized in Table 11. This table shows the magnitudes suggested by the energy standard and are calculated for an apartment whose average area is 82 m² for maximum two inhabitants. In the case of the duplex apartments, there is an approximate area of 111 m² and the only considered increase in the power demand is assumed as lighting for a greater area. According to the standard, with an average of 2.3 W/m² with LED technology for all the bulbs used, the equivalent increase is determined as 86 kWh yearly.

Table 11. Electricity demand for appliances in a 82 m²-apartment.

Appliance	Use	Unit	Standard appliance			Efficient appliance		
			Unit consumption	Unit	kWh/year	Unit consumption	Unit	kWh/year
Dish washer	3	Cycles/Week	1,1	kWh/cycle	167	0,6	kWh/cycle	94
Lighting	3,5	hours/day	2,3	W/m ²	275	2,3	W/m ²	241
Wash machine	3	hours/week	450	W	70	84	W	13
Fridge	24	hours/day	55	W	482	32	W	282
Oven	2	Cycles/Week	1,2	kWh/cycle	125	0,8	kWh/cycle	83
Iron	1	hours/week	2200	W	114	2200	W	114
Computer	3	hours/day	35	W	38	35	W	38
Tablet	3	charges/week	0,3	kWh/charge	39	0,3	kWh/charge	39
TV	2	hours/day	90	W	66	35	W	26
TV (Standby)	22	hours/day	0,3	W	2	0,3	W	2
Coffee machine (Pads)	2	cups/day	0,03	kWh/cup	18	0,03	kWh/cup	18
Microwave	0,17	hours/day	1300	W	79	1300	W	79
Router	24	hours/day	20	W	175	20	W	175
Cellphone	10	charges/week	0,02	kWh/charge	10	0,02	kWh/charge	10
Speaker	1	hours/day	50	W	18	50	W	18
Hair dryer	0,07	hours/day	2200	W	54	2200	W	54

Source. Own elaboration with data from (Aktivplus e.V., 2014)

The market price of the home appliance that mean the highest energy demand was sought for both the version with an average efficiency class or B class and a high efficiency appliance or A class in order to determine how profitable it is for a user to incur in a major investment to save energy in the dwelling. The appliances considered are shown below:

- Stove Efficient: Reference CUB INDUCCION 60 220V MF with 4 spots, Brand: Haceb
- Stove standard: Reference CUB AP VITRO 60 220V MF with 4 spots, Brand: Haceb
- Oven Efficient: Reference HG 2560, Brand: Challenger
- Oven standard: Reference HE 2652, Brand: Challenger
- Dishwasher Efficient: Reference Alkimia 14 spaces, Brand: Haceb
- Dishwasher standard: Reference FBD2400, Brand: Frigidaire
- Washing machine Efficient: Reference WD1577RD, Brand: LG

- Washing machine standard: Reference WA90H4400SS, Brand: Samsung
- Dryer Efficient: Reference DV9 M52, Brand: Samsung
- Dryer standard: Reference 7MWED1800EM, Brand: Whirlpool
- Fridge Efficient: Reference LT41SGPX ,Brand: LG
- Fridge standard: Reference CR570, Brand: Challenger

Table 12 was constructed with the nominal consumption of these appliances to calculate the saved energy by using efficient devices instead of standard and according to the market price, to quantify the time necessary to recover the additional investment that might be done to buy appliances that are more efficient.

Table 12. Comparison in price and energy demand between efficient and standard home appliances

Appliance	Consumption [kWh/a]		Price (Euros)		Savings	Simple Return
	Efficient	Standard	Efficient	Standard	[Euros/kWh]	[Years]
Stove	144	198	466 €	413 €	1 €	8
Oven	83	125	238 €	223 €	0,3 €	3
Dishwasher	94	167	449 €	306 €	2 €	15
Washmachine	13	70	1.125 €	266 €	15 €	119
Fridge w. Freezer	211	481	642 €	529 €	0,4 €	3
Dryer	145	165	649 €	425 €	11 €	89

For this particular case, it is not economically profitable to buy an efficient dryer, washing machine or dishwasher to save energy. The investment would be purely based on the reduction of GHG by demanding less energy through their operation.

Three configurations for cooking and heating water were also defined: cooking with gas-fired stove, electric-stove and induction-stove. Water heating is defined with gas heater, electric heater and a central heat pump for the whole building. Scenarios where gas is used as energy sources for heating up water and/or cooking, this consumption is not considered in this model because it is purely electric and must be then added to obtain a total energy value in these cases with a volume rate of gas and its combustion power. Figure 30 quantifies the approximate electricity demand of all dwellings in CONTREE for different configurations of energy consumers. The total amount of apartments that was considered as starting point relates to the baseline give in the first designed layout of the buildings. Thus, each building's even level has two duplex-apartments and 4 simple-apartments and the uneven have 4 simple-apartments for a total of 160 apartments distributed as follows: 56 simple-apartments and 14 duplex-apartments in the Building 1 and the Building 2 has extra three apartments per level in levels N1, S1, S2 and S3,

where 2 of them are duplex. Furthermore, the area considered for the energy calculations of demand and generation per square meter relates only to the living space and does not consider balconies or terraces. These spaces have an average area of 82,2 m² and 111,6 m² for one and two-level apartments namely for a total housing area of 14.091 m².

Figure 30 defines the electricity consumptions as follows:

- Std: Standard electrical appliances in all dwellings and does not considered the energy needed to heat up water and cooking, since these tasks are carried out with natural gas in this scenario
- Ef: Efficient home appliances are used (with a minimum efficiency class “A”) noting that cooking processes use induction stoves
- BC: Water is heated with a centralized heat pump system that supplies every apartment
- Ef + BC: This is the scenario of the lowest possible electricity consumption since it considers both the installation of highly efficient household appliances where the cooking takes place with electric induction and the water heating is carried out by a central heat pump
- CI: Standard home appliances with electric induction stove and water heating with gas heater
- CE: Standard home appliances with electric stove and water heating with gas heater
- CI + BC: Standard home appliances with electric induction stove and water heating with heat pump
- CE + BC: Standard home appliances with electric stove and water heating with heat pump
- CEP: Standard home appliances with gas stove and electric water heater
- CI + CEP: Standard home appliances with electric induction cooking and electric water heater
- CE + CEP: Standard home appliances with electric cooking and electric water heater

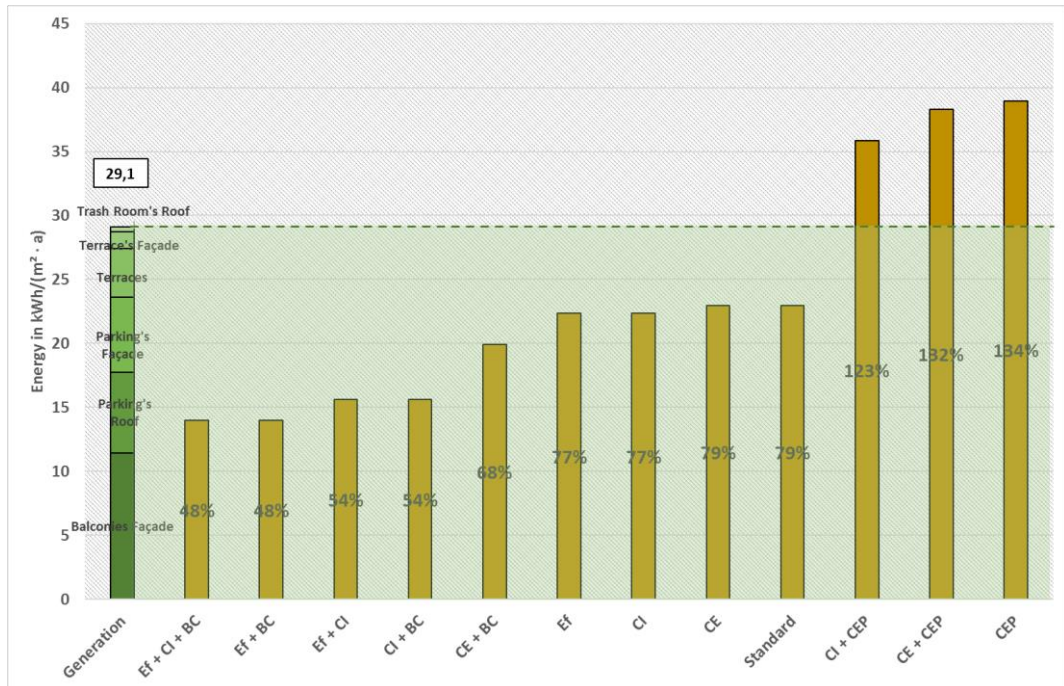


Figure 30. Electric demand coverage with photovoltaic plant in CONTREE

The hourly profile of the apartment's demand for electricity was determined in order to characterize the distribution of the export and import of energy to and from the grid throughout the year based on the generation capacity obtained in the simulation of the system in PVSOL. The German company EGS-Plan has developed an annual standard electricity demand profile based on measurements for the residential sector that, considering seasons, shows significant variations in the use of artificial lighting due to availability of natural light (EGS-Plan, n.d.). In this exercise, data from the profile is adopted from the transition periods of seasons as sunlight lasts approximately 12 hours being similar to the conditions of sunlight in Colombia. The annual consumption obtained after this consideration equals 1004 kWh/a for Germany and by means of this final value and the hourly profile, which even shows differences between working days, Saturdays and Sundays, the annual consumption is scaled according to the values previously obtained for the different consumption scenarios calculated with the tool proposed by the *Aktivplus* standard. This energy demand is relative only to the electricity meters of each apartment and therefore does not take into account external consumptions such as the heat pump for the scenarios that include it. As shown in the previous figure, these scenarios range between 14 kWh/(m²·a) and 38 kWh/(m²·a) or 197 MWh/a and 548 MWh/a respectively. For the different electricity demand scenarios proposed in the Contree apartments, the following scale factors are presented:

Table 13. Scaling factor for electricity demand profile dimensioning in apartments

Scenario	Ef	Ef + Ci	Std	Ef + BC	Ef + Ci + BC	Ci
Demand (MWh/a)	197	220	280	197	220	315
Factor [(kWh/a)/(kWh/a)]	197	220	279	197	220	314
Scenario	CE	Ci + BC	CE + BC	CEP	Ci + CEP	CE + CEP
Demand (MWh/a)	323	315	323	505	540	548
Factor [(kWh/a)/(kWh/a)]	322	315	323	503	538	546

$$DC_{h,d,e} = DA_{h,d} \cdot F = DA_{h,d} \cdot \frac{DCA_e}{DAA} \quad (7)$$

where

$DC_{h,d}$ = Electric demand for a house in Colombia at the hour h of the day d of the scenario e

$DA_{h,d}$ = Electric demand for a house in Germany at the hour h of the day d

F = Factor from Table 12 defined as quotient between DCA and DAA

DCA = Annual electric demand in Colombia from scenario e from Table 12

DAA = Annual reported electric demand for Germany = $1004 \frac{kWh}{a}$

The electrical demand curve of the 160 apartments used in this work is shown below to determine the possibility of using the energy generated locally or the exportation of this generation to the grid when it exceeds the demand.

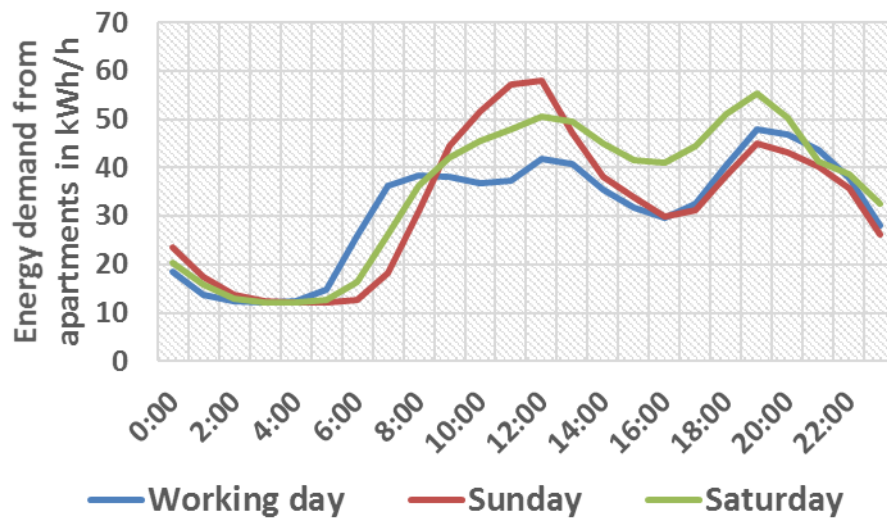


Figure 31. Electricity demand of Standard scenario (Std)

In addition to the electricity consumption regarding to every single apartment, as they are part of a two-building condominium, there are shared or common areas that also represent energy consumption. In this way, it is necessary to build a demand profile for these consumers given that an Energy Plus Building considers the entire building for the energy balance and not just the apartments. In CONTREE, additional energy consumers are identified as lighting, elevators, a vapor bath and doors activated electrically for cars and pedestrians.

The energy demand for the elevators is determined under the guidelines given by the Society of Engineers of Germany (Verein Deutscher Ingenieure) in the document VDI 4707. Under this methodology, the four elevators of CONTREE are defined under the category 4 (multifamily buildings with more than 50 apartments), a capacity to support 800 kg (Q), speed of 1 m/s (ϑ), specific energy consumption of 1.6 mWh/(kg · m) (E_{spec}) according to this load to be transported for an efficiency class C and working with a counterweight. According to the category given by the number of users, this methodology suggests a daily standby time (t_1) of 21 hours and a daily operation (t_2) of 3 hours with an inherent consumption rate for non-operation (P) of 200 W. The average daily energy required (E_{day}) for these buildings is given by the equation:

$$E_{day} = P \cdot t_1 + E_{spec} \cdot \vartheta \cdot t_2 \cdot Q \quad (8)$$

From the equation above, a daily demand for each lift of 18.456 Wh results which is equivalent for the four elevators annually to 27 MWh/a.

The demand profile of these energy consumers was plotted by scaling values of electric power measured every fifteen minutes in the Aktiv-Stadthaus project that received the Aktivplus distinction in 2016 and whose description as a flagship project of this energy standard can be seen in the Appendix A. The elevators of this project in the city of Frankfurt used as a basis have an annual energy demand per unit of 1.400 kWh and through a scale factor of 18,8 as the quotient between both end consumptions and determined under the same procedure previously carried out to scale the consumption of the apartments. An annual demand of 27 MWh is obtained through these VDI indications.

To make an hourly distribution of this annual demand, the energy demand of three elevators of the Aktiv-Stadthaus project was monitored between 2016 and 2017 throughout the year and these values are averaged for each of the seven days of the week. A differentiation is made among the different days of the working week (Monday

to Friday) in order to avoid patterns or trends associated with particular uses of building users.

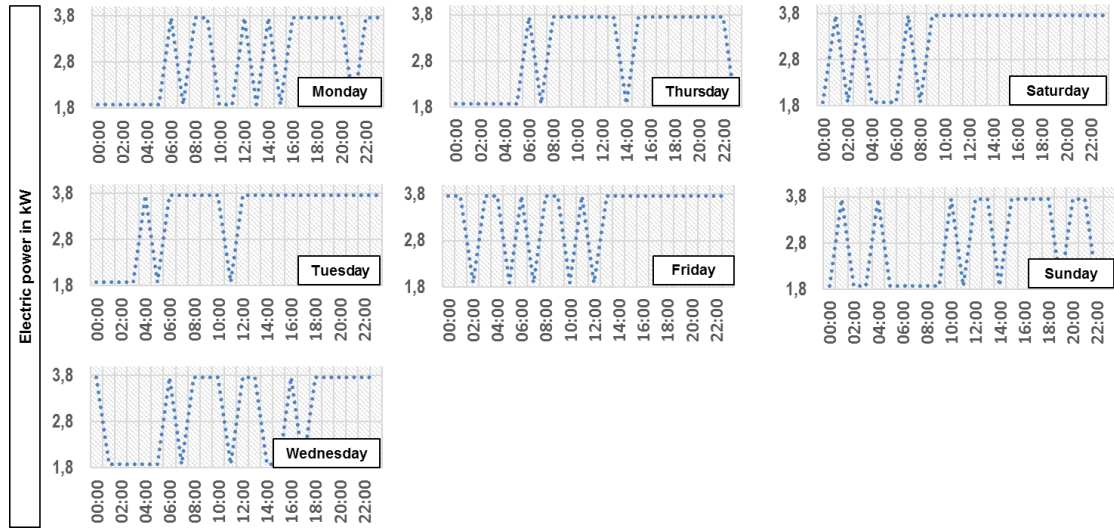


Figure 32. Energy demand profile for elevators in CONTREE

Other consumers considered for the energy balance within Contree correspond to the entrance gates to buildings that are operated remotely by the user and driven by an electric motor. For the sizing of the daily energy demand of this process of entry and exit to the buildings, the following assumptions were made: the motor that operates each gate has $\frac{1}{2}$ HP of power (P_{motor}) and the time of opening and closing is 40 seconds (t) as reported in different sales portals of these systems such as (Tractor Supply Co, 2019) and (Liftmaster, 2019). Of 160 apartments that may have approximately the project in the future, 1.7 cars per house (C) are considered given the high amount of parking lots planned to be built (around 300). During the week 80% (F_{week}) of the cars are mobilized by factors such as "Pico y Placa" and the possibility of sharing transport with the other person who lives in the apartment and 50% ($F_{weekend}$) of the cars are mobilized on weekends due to sharing possibility between inhabitants of the same apartment. With this approach the following equation for the weekly energy demand of the entrance and exit doors of the buildings (E_{week}) that represents 588 kWh/a:

$$E_{week} = P_{motor} \cdot t \cdot (C * F_{week} * 5 + C * F_{weekend} * 2) * 2 \quad (9)$$

The survey conducted by the Metropolitan Area of Aburrá Valley called "Encuesta de Origen – Destino" provides information on the hours in which the potential residents of Contree could transit through the gates. The parameters used in the survey to identify this social segment that could inhabit the buildings refer to people who use car as main

transportation type, with origin in the neighborhood El Poblado, stratum 5 and 6, independent workers, employees and employees who study at the same weather. The mobility pattern obtained for this profile is shown below as basis for building an energy demand profile.



Figure 33. Transportation hours in Área Metropolitana of potential inhabitants of CONTREE

Source. (Área Metropolitana del Valle de Aburrá, 2017)

For the lighting of the shared spaces, areas of corridors, stairs, garbage rooms, lobbies, spa, gym, bathrooms, useful rooms, indoor parking, outdoor parking, coworking, rooms for rainwater storage and technical rooms where determined based on planes provided by Concreto. With these areas and requirements of minimum illumination levels according to the Technical Regulation of Lighting and Public Lighting (Retilap) values of required electrical power are determined in luminaires to meet the requirements. The values for corridors taken were taken as 50-150 lx or lighting value per unit area given by Retilap and for stairs this value is fixed between 100-200 lx (Ministry of Mines and Energy, 2010). For the requirements of illuminance in the gym, coworking area and technical rooms the requirements proposed by the National Observatory of Optical Astronomy of the United States were taken, which mean 200 lx, 500 lx and 300 lx respectively (NOAO, 2016). For both indoor and outdoor parking lots, the value of 20 lx suggested in the Lighting Manual for Practice (Zumtobel Lighting, 2016) was taken.






Table 14. Dimensioning of lighting in shared areas of CONTREE

Section	Location	Zone	Area (m ²)	Quantity	Total area (m ²)	lx	lm	Luminary type	Luminaires	Use (h/day)	kWh/day	Presence sensor
Building 1	N2-N15	Hall	54	14	749	100	74.900	1	38	0,7	0,81	Yes
Building 1	N16	Hall	54	1	54	100	5.350	1	3	0,2	0,01	Yes
Building 1	N2-N16	Garbage rooms	4	15	60			0			0,00	
Building 1	N16	Shared area	77	1	77	200	15.300	1	8	2,0	0,46	No
Building 1	N1	Coworking	166	1	166	500	82.875	2	25	12,0	11,99	No
Building 1	N1	Hall next to Coworking	68	1	68	50	3.400	2	1	12,0	0,49	No
Building 1	N1-N16	Stairs	3	64	192	150	28.800	3	32	0,3	0,00	Yes
Building 1	S1-S2	Stairs	3	32	96	150	14.400	3	16	0,0	0,00	Yes
Building 1	S1	Hall	19	1	19	50	963	1	1	3,2	0,05	Yes
Building 1	S1	Hall storage rooms	9	2	18	50	900	3	1	0,0	0,00	No
Building 1	S1	Storage rooms	68	1	68	50	3.395	3	4	0,0	0,00	No
Building 1	S1	Main garbage room	16	1	16	50	813	3	1	0,2	0,00	No
Building 1	S2	Hall	19	1	19	50	963	1	1	3,2	0,05	Yes

Section	Location	Zone	Area (m ²)	Quantity	Total area (m ²)	lx	lm	Luminary type	Luminaires	Use (h/day)	kWh/day	Presence sensor
Building 1	S2	Hall storage rooms	9	1	9	50	450	3	1	0,0	0,00	No
Building 1	S2	Storage rooms	22	1	22	50	1.113	3	2	0,0	0,00	No
Building 1	S2	Machines room	5	1	5	200	1.058	3	2	0,1	0,00	No
Building 2	N2-N17	Hall	54	17	910	100	90.950	1	46	0,7	0,98	Yes
Building 2	N18	Hall	54	1	54	100	5.350	1	3	0,2	0,02	Yes
Building 2	S2-N18	Garbage rooms	4	22	88			0			0,00	
Building 2	N18	Shared area	77	1	77	300	22.950	1	12	3,0	1,03	No
Building 2	N1-N18	Stairs	3	72	216	150	32.400	3	36	0,3	0,00	Yes
Building 2	N1	Hall	40	1	40	50	2.013	1	2	0,4	0,01	Yes
Building 2	N1	Storage rooms	17	2	33	50	1.674	3	2	0,0	0,00	No
Building 2	N1	Machines room	4	1	4	200	800	3	1	0,1	0,00	No
Building 2	S1,S2,S3	Hall	57	3	170	50	8.475	1	5	8,1	1,03	Yes
Building 2	S1	Storage rooms	17	1	17	50	837	3	1	0,0	0,00	No
Building 2	S2,S3	Storage rooms	43	2	86	50	4.289	3	5	0,0	0,00	No
Building 2	S1,S2,S3,S3.5,S4	Stairs	3	10	30	150	4.500	3	5	0,1	0,00	Yes
Building 2	S2,S3	Hall storage rooms	8	1	8	50	413	3	1	0,0	0,00	No
Building 2	S3.5	Spa	159	1	159	300	47.775	2	15	6,0	3,46	No
Building 2	S3.5	Main garbage room	16	1	16	50	813	3	1	0,2	0,00	No
Building 2	S3.5	Hall	45	1	45	50	2.267	1	2	2,1	0,07	Yes
Building 2	S3.5	Steam bath	54	1	54	100	5.376	1	3	4,0	0,32	No
Building 2	S3.5	Gym	216	1	216	200	43.240	5	44	18,0	11,67	No
Building 2	S3.5	Machines room	576	1	576	200	115.200	3	128	0,3	0,33	No
Shared areas	Water disposal	Water disposal	56	1	56	50	2.779	3	4	1,0	0,03	No
Shared areas	N1	Outer parking lots	761	1	761	20	15.220	4	16	12,0	0,82	No
Shared areas	N1	Inner garages	1.633	1	1.633	50	81.650	3	91	6,0	4,90	Yes
Shared areas	N1	Storage rooms	4	6	23	50	1.125	3	2	0,0	0,00	No
Shared areas	S1	Inner garages	2.725	1	2.725	50	136.250	3	152	6,0	8,18	
Shared areas	S1	Storage rooms	90	1	90	50	4.485	3	5	0,0	0,00	No
Shared areas	S2	Storage rooms	64	1	64	50	3.213	3	4	0,0	0,00	No
Shared areas	S2	Rainwater room	49	1	49	50	2.438	3	3	0,1	0,00	No
Shared areas	S2	Inner garages	2.677	1	2.677	50	133.853	3	149	5,4	7,23	Yes
Shared areas	S3	Electric substation	68	1	68	200	13.600	3	16	0,1	0,01	No
Shared areas	S3	Storage rooms	5	6	27	50	1.350	3	2	0,0	0,00	No
Shared areas	S3	Inner garages	1.539	1	1.539	50	76.925	3	86	5,3	4,04	Yes

The total energy demand for lighting in shared areas in Contree was evaluated with luminaires offered by Philips for its broad participation in the current Colombian market. All the luminaires used in the modeling are LED luminaires because of the higher energy efficiency and durability compared to the fluorescent technology. For aesthetic reasons, it is modeled for corridors of each floor, spa, gym, coworking, upper terrace rooms and in general, spaces with a high flow of people, recessed luminaires. For the covered parking, the total lighting demand coverage is modeled with 600 mm long T8 tubes due to its high performance, known as the lm/W ratio. The distribution by luminaire type from 1 to 4 of Table 14 corresponds to the references shown in Table 15.

Table 15. Specification of luminaires used in dimensioning of lighting demand

Luminaire type	Power (W)	Luminous flux (lm)	lm/W	Technology	Reference / Brand	Fitting	View
1	30	2.000	67	LED	DN135B LED20S 840 PSU WH 120- 277V / Philips	Recessed	
2	41	3.400	83	LED	RC125B W60L60 LED34 840 PSD UNIV 50H / PHILIPS	Recessed	
3	9	900	100	LED	Tubo LED T8 ESSENTIAL 600mm 9W 840 T8 C W G	Tube	
4	4,5	1.000	222	LED	Stratosphere 4000K / Philips	Standing	
5	15	1.000	67	LED	DN135B LED10S 865 PSU WH 120- 277V / Philips	Recessed	

Based on these illuminance requirements, the areas measured in plans provided by Concreto and assumptions of occupation hours, a daily energy demand of 57 kWh (21 MWh/a) is determined. With the assumptions of occupation of entry and exit of the inhabitants of CONTREE, use of the gym, coworking, stairs and other common areas, the following hour demand curve for lighting was constructed:

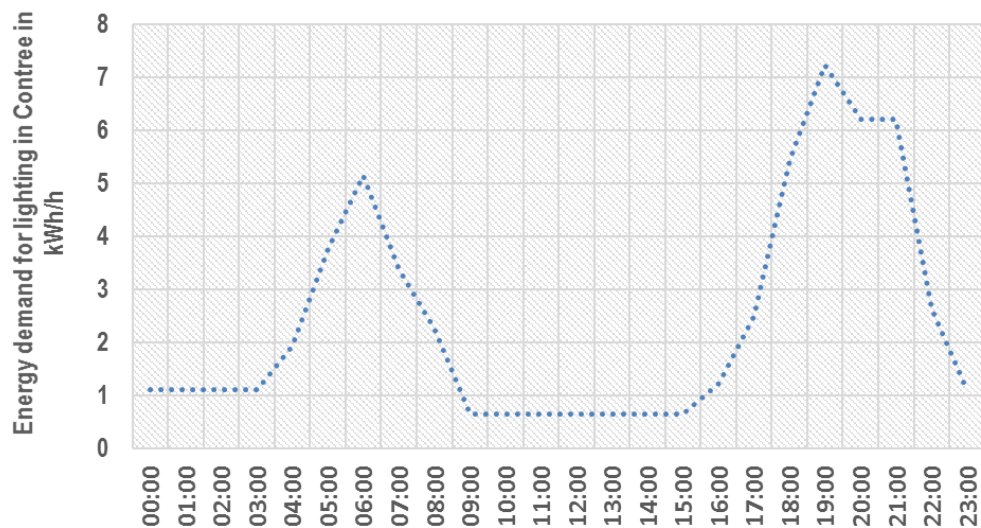


Figure 34. Energy demand profile for shared areas lighting

A steam bath is considered since the Contree planning stage in building B2 located on the S3.5 floor. Based on the sizing parameters proposed by Spa-Dampfbad and Repabad suppliers, approximate values of 1 kW electric are recommended for each m³ (repa Bad, 2018). Therefore, a volume of 8 m³ may be heated with an electric heater of 8 kW with an efficiency of 95-99% as suggested by (Energie-Experten, 2016) and a resulting electric power input of 8.4 kW. Two further considerations are also determined: a daily use of four hours between 18:00 and 22:00 including one hour of heating and maintenance of the steam bath one day every two weeks would be carried out and stop its operation that day. Under this assumptions over operation times and usage, a 33,7 kWh/day consumption or 11,4 MWh/year would be obtained.

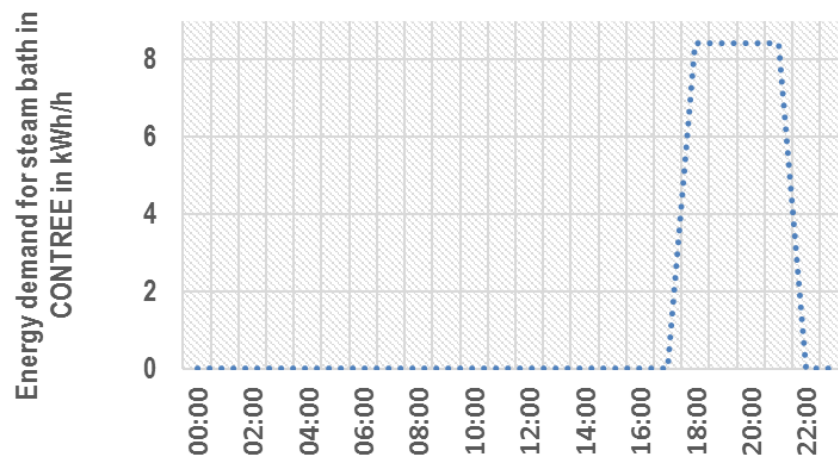


Figure 35. Energy demand profil of steam bath

In addition to the electrical energy consumers described, use of natural gas as the other energy source present within the project's boundaries is considered. This gas is mainly used in housing inside large Colombian cities for cooking and heating water as shown in Appendix B. The Quality of Life's report in Medellín presents values of average consumption of natural gas per inhabitant for the different areas of the Valle de Aburrá and its described that in Medellín, a consumption of 0,09 m³/(inhabitant · day) is shown and the largest consumer of the evaluated municipalities, Sabaneta, has a 0,17 m³/(inhabitant · day) consumption (Alcaldía de Medellín, 2016). In 2018 the Survey of Perception of Quality of Life was carried out in the municipality of Sabaneta and shows that 95% of the population perceives their home as a home in good condition, 15% of the asked population indicate that they only live with another person, 30% with other two and 29% with other three (Municipio de Sabaneta, 2018), These data has a contrast with living dynamics in Medellín where about 40% live far from collective facilities, high risk

areas or with visible signs of deterioration (Alcaldía de Medellín, 2006). Given this perception of quality of housing, natural gas consumption of Sabaneta is taken as a reference for this project and also because this municipality is also known for its fast growth in recent years in the construction of vertical multifamily housing. The Report of the natural gas sector in Antioquia of Transmetano suggests the following values for the mentioned municipalities:

Table 16. Natural gas consumption per inhabitant in Medellín and Sabaneta

Medellín	m³ (x10⁶)	75	79	77	79	126	Average m³/(inhabitant·day)
	Population (x10³)	2.393	2.417	2.441	2.464	2.486	0,10
Sabaneta	m³ (x10⁶)	2	2	2	3	4	Average m³/(inhabitant·day)
	Population (x10³)	49	50	51	51	52	0,14

Source. (Transmetano, 2016)

With the equation

$$E = V \cdot C \quad (10)$$

where

E = Energy obtained through combustion of 1 m³ of natural gas at 15,5°C and 1 atm

V = Natural gas volumen at 15,5°C and 1 atm

$C = 35 \frac{MJ}{m^3}$ Lower combustion heat of natural gas (FECOC, 2016)

Based on this Life Quality Report, the daily energy consumption for each inhabitant of natural gas is determined as 1,7 kWh (615 kWh/a). Considering that even though each housing has a bedroom for two people, a small portion of these apartments might serve just to one person. With 1,8 inhabitants per apartment assumed, energy consumption through natural gas of the 160 apartments of Contree represent 177 MWh/a or 12,6 kWh/(a · m²). The calculation tool from *Aktivplus* that determines the electrical demand of an apartment given the amount and type of home appliances approximates an energy consumption for an electrical stove of 110 kWh/(a · person). Considering an efficiency of 70% for this appliance and 40% for a similar appliance operated with natural gas as expressed by (Wilson, 2009) and (Instending, 2014), an average demand of natural gas for cooking of 197 kWh/(a · person) is obtained. This represents around 32% of 615 kWh consumed per year per person and the remaining 68%, equivalent to 393 kWh/(a · person) is relative to heating water.

Although electrical stoves with resistances or induction mechanisms can be bought in the Colombian market, gas stoves have traditionally been the most popular method for cooking in the housing sector since electricity has had a higher cost than this fuel that is widely available in the country and also because the investment costs of these electrical appliance are much greater. Currently there are different factors that are promoting the inclusion of renewable sources for electricity generation in the National Interconnected System (Expansion Plan of the UPME), the reduction of greenhouse gas emissions (Colombian Strategy for Low Carbon Development) and the reduction of energy demand in homes (Indicative Energy Efficiency Action Plan) that support the idea of transition from cooking with gas to fully electric systems. This transition might lead to benefits such as:

- Processes of cooking and heating will be increasingly cleaner because generation of electricity in Colombia is gradually moving towards the inclusion of renewable sources noting that in Colombia already about 70% of electricity comes from water sources
- Electricity will be increasingly cheaper due to the fall in prices of photovoltaic panels due to the high supply in the market thanks to the promotion of the Energy Transition worldwide
- A lower energy demand is obtained by having more efficient equipment
- Instant heaters need less space by not having water accumulation
- Electrical equipment is safer because it does not encourage the combustion of gases
- A project that completely avoids the use of non-renewable sources for domestic tasks would have a differentiating and remarkable added value

Besides the approach of the transition of gas appliances to electric ones for cooking, this change is also proposed for heating sanitary water by means of a central heat pump that uses the air that surrounds the building as a source of heat as stated in some scenarios from Table 13. The popularity of these facilities has been growing both for heating water and for heating rooms in buildings when a reduction in energy demand and the omission of direct use of fossil fuels for these tasks is sought. Since these devices do not perform a transformation of electrical energy in thermal as traditional electric heaters, it is not possible to consider an efficiency of the equipment but a performance of the energy consumption regarding the heat provided. This quantity is known as COP for its acronym in English Coefficient of Performance and indicates how many units of thermal energy

were delivered to the water for each unit of electrical power that the machine needs to operate, where the compressor carried inside is usually the main consumer as promoter of refrigeration cycles as shown in Figure 36. In this cycle, as the name implies, a fluid refrigerant moves between a heat source that is passed through the evaporator to deliver its energy to such fluid inside the pipe loop and then in the condenser transfers its energy by condensing to the objective water flow.

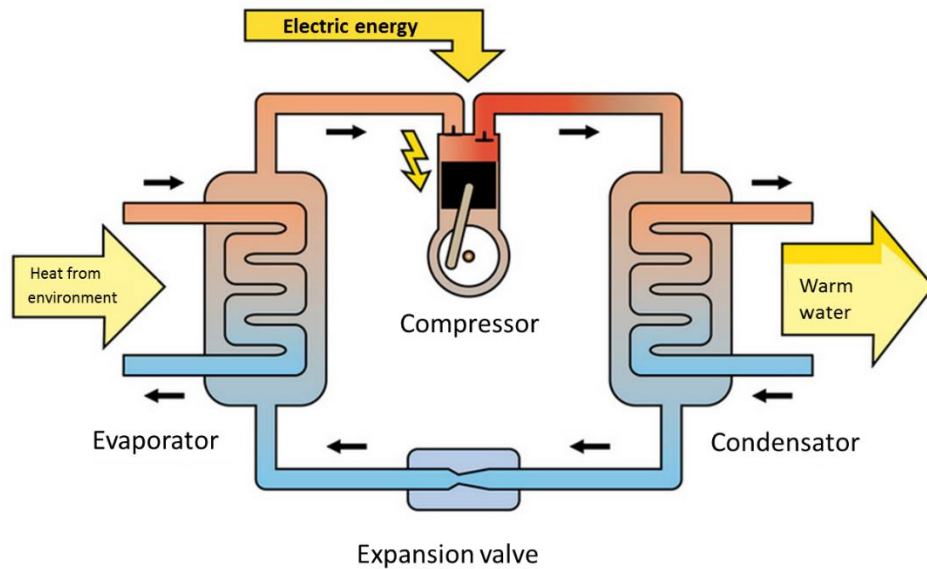


Figure 36. Scheme of a heat pump

Source. (Blasbichler, 2016)

In projects that include this technology to heat up water and/or rooms' air, choosing the heat source is critical for economic viability since the COP will highly depend on the temperature of this source and therefore could vary considerably throughout the year due to seasons. That is why in the planning of Energy Plus Buildings, preliminary studies of the area where the building is going to be built (or in the place where it already exists) are carried out in order to define the particular source of heat that feeds the machine. These sources vary according to the environmental conditions and the terrain and a wide range of sources may be considered from geothermal probes introduced at different depths to obtain heat of the earth to collectors near the surface to extract heat from the sun trapped, underground water sources or in some cases, the air itself if its temperature variation throughout the year is not critical. Since the performance of a heat pump either for sanitary water or heating is improved when the temperature of the heat source is higher as shown in Figure 37 (the magnitude of this factor varies from one manufacturer to another), the use of heat pumps have better heating results in areas like Colombia

where the average annual temperature is higher than in many European countries where these appliances are common. This figure shows in the horizontal axis the temperature of the air used as heat source, which for the city of Medellin is 21 ° C (Climate-Data, 2018) and for a heating temperature between 45 ° C and 55 ° C it presents a COP between 3 and 4. In this way, water being heated through a heat pump avoids a direct combustion of non-renewable resources and even when the power is supplied from renewable sources like a local photovoltaic plant, its operation is even more favorable for the environmental care.

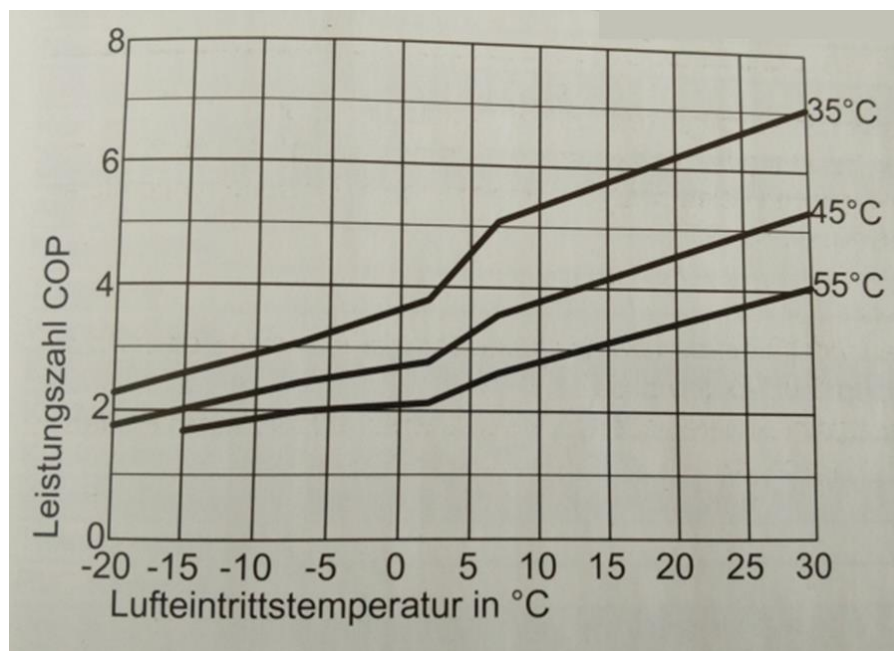


Figure 37. COP of a heat pump depending on air temperature and objective temperature

Source. (Viessmann, 2015)

In order to keep a system with optimal health conditions, in German regulations temperatures above 60 ° C are recommended to prevent growth of the bacteria known as *legionella* in the system when it is between 35 ° C and 60 ° C (Energie Experten, 2017). The Colombian Technical Guide NTC 257, which is based on UNE 100030, is more lax when it states that the minimum storage temperature must never be below 50 ° C, plus temperature losses due to the inherent transfer of heat to the environment. It still contemplates the use of chlorine in low quantities that is innocuous for the health of humans but prevents the proliferation of *legionella* (AENOR, 2005). The capacity of growth of this type of bacteria in the water of consumption for the inhabitants of the buildings, may be diminished by means of different methodologies: in the first instance, the sanitary water can be heated above 60 ° C, temperature from which, *legionella*

cannot survive, but a lower COP may result which drives to a higher electricity consumption and finally, an increase in operating expenses. In the second instance, the physical separation of the water heated in the heat pump and the water to be consumed promotes that this first stream of water can be heated at temperatures below 60 °C and thus obtain a higher COP and through small heat exchangers in the apartments, heat up the drinking water up to 40 °C in a second piping system from heat delivered by the flow that comes from the heat pump. In this way, temperatures at the output of the heat pump can be maintained below 60 °C and maintain a high COP and low operating costs but an initial investment increased by the installation of the decentralized heat exchangers or design a system with a largest central heat exchanger for all apartments. The third solution recommended by this source is a weekly thermal disinfection where water temperature exceeds 60 °C is passed through the pipes and storage tanks to deactivate any growth of bacteria that is being promoted. This heating can be originated either from the heat pump meaning a high electric power consumption or a backup system either fed traditionally with fossil fuels or other energy source. Outlines of a potential installation of systems for direct or indirect use of the water heated in the heat pump are shown below.

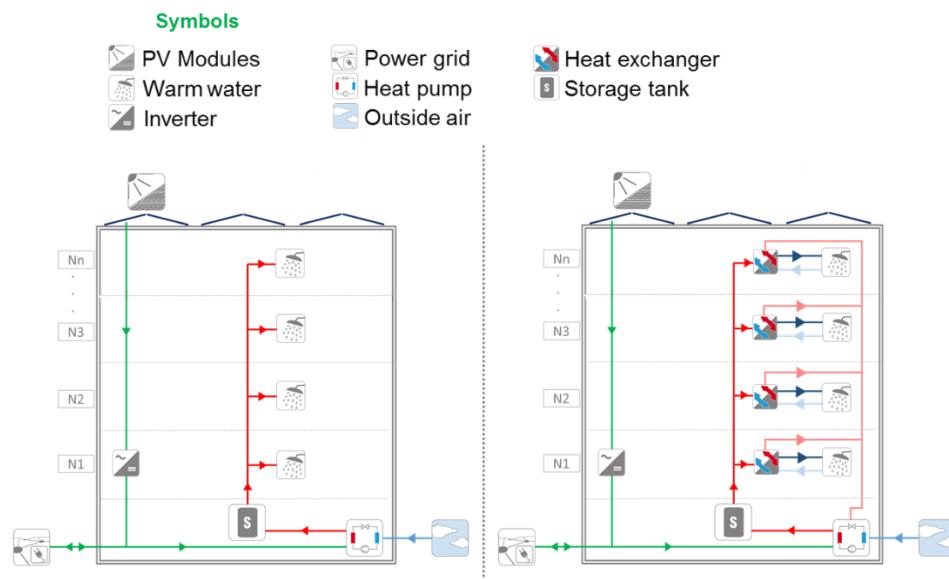


Figure 38. Outlines for possible heat pump systems for warm water in residential buildings

The Colombian Council of Sustainable Construction in its Standard CASA refers to a daily consumption per person for a shower of 76 liters at 40 ° C for a comfort sensation. By means of the equation

$$P_{thermal} = \frac{\dot{m}}{\rho} \cdot \frac{c_p}{3600} \cdot (T_2 - T_1) \quad (11)$$

where

$$\begin{aligned} \frac{\dot{m}}{\rho} &= \text{water to be heated} = 76 \frac{l}{\text{person} \cdot \text{day}} & c_p &= \text{heat capacity of water} \\ &= 4,18 \frac{kJ}{l \cdot K} \end{aligned}$$

$$T_2 = \text{temperature desired} = 313 K \quad T_1 = \text{initial water temperature} = 289 K$$

$$P_{thermal} = \text{thermal power in kWh/day}$$

Temperature of water to be heated is assumed five degrees Celsius below the average temperature of the environment for simplicity in calculations. Therefore, the total water represents a volume of 22.000 liters per day that would be heated up through two heat pumps (one per building) and a total daily thermal energy of 635 kWh. Although the desired temperature is 40 ° C for showering, a higher output temperature is necessary to compensate energy losses due to transportation to the different consumption points through pipes. This inherent loss of energy and thus temperature resulting from the temperature gradient with the surroundings should be reduced by thermal insulation in order to minimize operation of the machine. Figure 37 suggests a COP of 3.5 for a desired temperature of 55 ° C and through the equation

$$P_{electric} = \frac{P_{thermal}}{COP} \quad (12)$$

Where

$$P_{electric} = \text{Electric power of heat pump in } \frac{kWh}{\text{day}}$$

A daily electrical energy required by both buildings of 181 kWh_{electric} that split among all the housing units with an useful area of 14.091 m², a demand of 4,7 kWh_{electric}/(m² · a) is obtained.

Other scope for sizing the demand for the heat pump is shown in the DIN EN 15450 standard that states a useful energy demand per person of 0.315 kWh_{thermal}/day for dishwashers and 0.105 kWh_{thermal}/day for cleaning tasks as additional demand for hot water in the residential sector. In case of considering a scenario where all the housing units use hot water for these purposes, an energy demand of 3,73 kWh_{thermal}/day per

person or $27.8 \text{ kWh}_{\text{thermal}}/\text{m}^2$ for the entire residential complex would be obtained that had to be supplied from the heat pump.

To determine the size or power of the pump, a procedure based on the EN 15450 standard was carried out including periods of the day where warm water is needed for showering, washing dishes and cleaning. In this case, it is assumed that two people in each apartment take a shower between 7:00 AM and 8:00 AM and, after the working period, general cleaning tasks and activation of dishwashers might be made after 18:00. In this theoretical profile of hot water consumption, the greatest demand for warm water takes place during the morning when the inhabitants of the enclosure take showers. Therefore, the heat pump must be capable of supplying $2.2 \text{ kWh}_{\text{thermal}}$ for each person. If it is intended to heat the water above $60 \text{ }^\circ\text{C}$ to prevent the growth of *legionella*, and the temperature of the fresh water is assumed to be $15 \text{ }^\circ\text{C}$, the total volume of hot water that must be supplied in the mornings each heat pump rises to more than 5.3 m^3 . Therefore, it is necessary to store hot water in thermally insulated tanks so that the equipment can fill the container before this peak demand begins in the morning. The standard suggests storage energy losses around 15% of the energy stored as hot water and therefore additional heating should be considered to replace this volume that is constantly cooling down. Considering the losses, demand for storage that rises to around 6 m^3 . This volume of water that is to be taken from $15 \text{ }^\circ\text{C}$ to $65 \text{ }^\circ\text{C}$ should be heated up and stored between two peaks of demand, that is, 10 hours which is the time between 8:00 AM and 18:00 PM, equivalent at an approximate thermal power of 40 kW that the heat pump must deliver.

According to the Quality of Life Survey of the Mayor's Office of Medellin quoted before, each inhabitant of the city could be using about 50 to 60 m^3 per year of natural gas of which 70% is used just for heating water, equivalent to 400 kWh per year of gas. With a central system for the entire building, this same task could be covered only with 175 to 200 kWh per person per year. In addition to the reduction in energy demand needed to heat water inside the apartments, three further advantages might be found:

- The purpose of the National Interconnected System is to diversify its energy basket so that renewable energies have a greater participation. Therefore, by operating the pump with electricity, its operation will be increasingly clean by gradually reducing the amount of greenhouse gas emissions associated with the generation of each kWh of electricity

- When there is a photovoltaic system in the building and the pump is operated with energy from these modules, each kilowatt-hour of electric power used would be generating around 40 g of CO₂ (Krey & Masera, 2014) instead of 367 g

- The Society of Engineers and Architects of Antioquia (SAI) points out that the prices of gas and electricity have been balancing each other, given that the wells that were planned were not found (Ospina, 2016) and the supply of the National Interconnected System supposes an increase in both the diversity of sources as in generation capacity

The totality of energy consumers in common areas exposed in this section are summarized in the following table:

Table 17. Energy demand in shared areas in CONTREE

Consumer	MWh/a	kWh/(m²·a)
Electrical gates	0,6	0,04
Elevators	27	1,90
Lighting	21	1,50
Steam bath	11	0,80
Heat pump	66	4,70

These energy consumers in the common areas of the building and the energy used within the apartments make up the total energy demand of Contree in the form of electricity and natural gas. The availability of generating electricity within this system from the installation of photovoltaic modules in the different structures available in the project and consumers under the different demand scenarios are summarized in the following figure where it can be seen that under two of these proposed scenarios, it would be possible to reach a building that generates more energy than the one it needs for its operations.

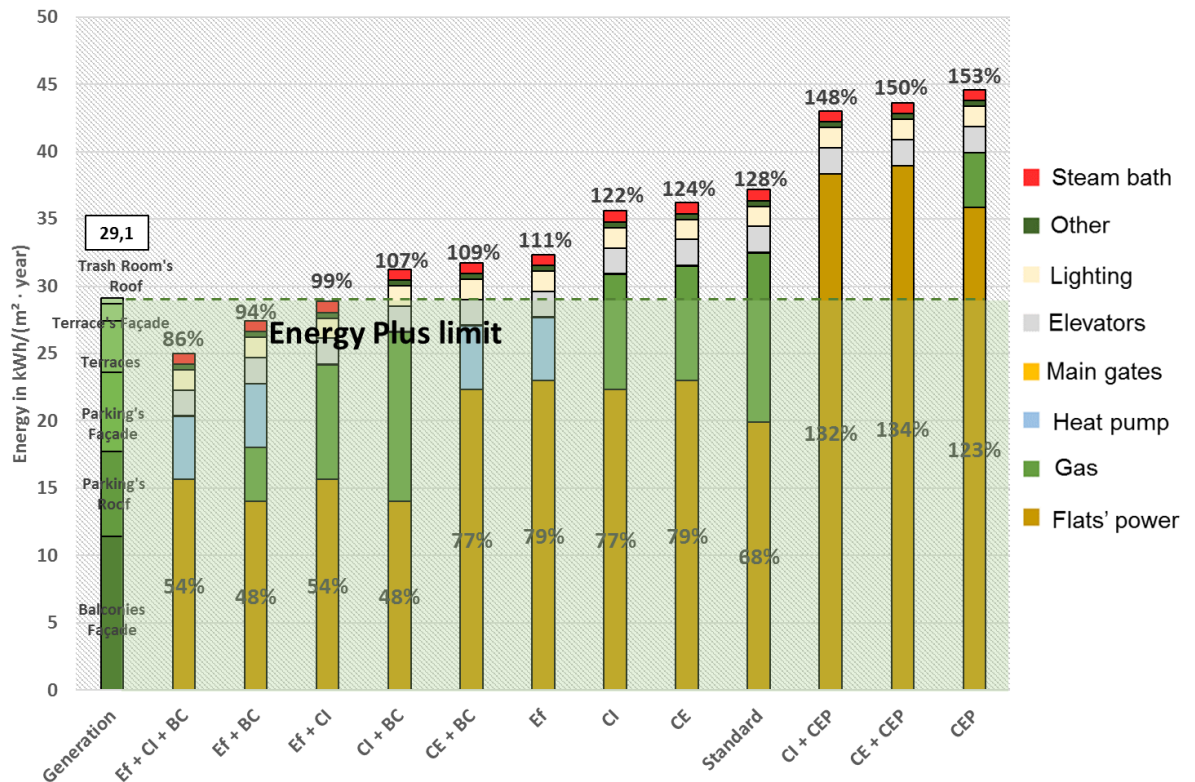


Figure 39. Energy generation and demand in CONTREE

The first scenario of energy consumption lower than the generation capacity, considers the installation of efficient appliances in the apartments, cooking with induction stoves and water heating with a central heat pump (Ef + CI + BC), shows a consumption of 25,0 kWh/(m²·a). The second scenario where an Energy Plus Building might be feasible, considers the installation of efficient household appliances and water heating with a heat pump (Ef + BC) with an energy consumption of 27,4 kWh/(m²·a). The scenario that considers the heating of water with gas heaters but the use of efficient household appliances, including cooking with induction, reaches also theoretically a condition where more energy is generated as consumed with a total demand of 28.8 kWh/(m²·a). From these scenarios, in which the installation of high efficiency household appliances is no longer considered, the demand for energy surpasses the local generation capacity. It should be noted that, according to the initial concept of CONTREE, all the apartments are for sale as “lockup” housing units. That is, the new owners are given an apartment that only has electricity connections, faucets for water supply and disposal, and natural gas access network. For this reason, the installation of appliances and / or equipment that are powered by natural gas, depends entirely on the user and under this methodology of delivery of the apartment is not the responsibility of the constructor the choice and installation of such equipment. Reason why, scenarios that propose a

building that generates more energy than it needs are theoretical. As stated in Appendix A, the energy concept proposed by Aktiv-Stadthaus does not offer the user the option of installing low energy efficiency appliances or gas appliances in the home in order to ensure a low energy demand by the different tenants of the building. This is why the apartments in this building are offered only for the rent given that they come previously equipped with these equipment. The partial and total coverage of the energy demand in CONTREE through different installation possibilities of a local power generation system with renewable sources is presented Figure 40. In the figure it is possible to appreciate that, although the total energy coverage in CONTREE (apartments + common areas) would be reached only by covering zones A, B, C, D, E and F from Figure 23, the installation of a smaller photovoltaic system could be also considered to partially cover energy requirements like consumption of shared areas or apartments. In cases where the generation equals only a fraction of the demand, the building would no longer be considered Energy Plus given its definition where the magnitude of the energy generated inside the building system must be greater than the total consumption. Even though a partially covering does not classify the building as such, the binding of the Energy Transition in construction concepts is still promoted.

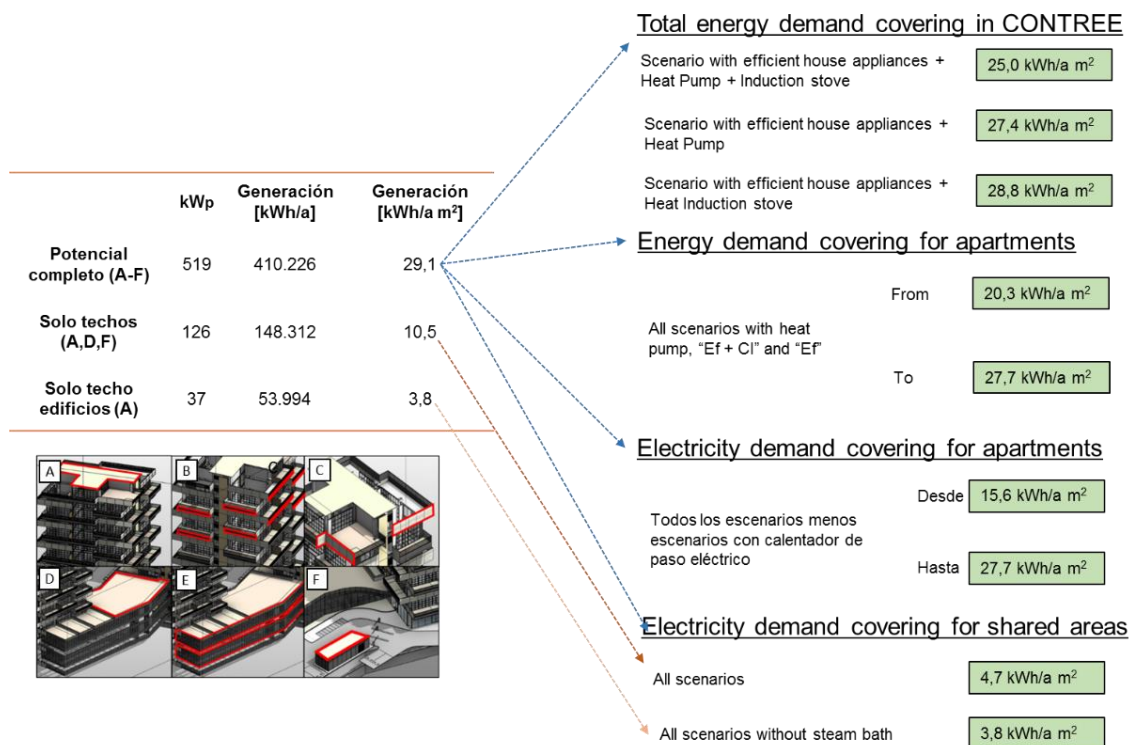


Figure 40. Demand covered with different photovoltaic systems

5.3. SELF-CONSUMPTION AND DEMAND COVERING THROUGH LOCAL ENERGY GENERATION SYSTEM WITH RENEWABLE SOURCES

The inclusion of a battery to store part of the excess energy generated by the photovoltaic system for a later use is not considered for this particular situation. This is supported by low prices of electric power in Colombia due to abundance of water resources, which, as shown in Figure 12, its share in the generation matrix can reach up to 70% of the total generation in the country. Using a power storage leads to a significant increase in the internal use of the energy generated. According to Federal German Ministerium of Interior, Construction and Homeland, buildings can even increase this value from 10% to 60%, demand coverage is might be increased from 20% to 90% and a decrease in the export to the network of this service (2018). By means of these equipment, the user partially avoids the payment of the import of energy from the grid and likewise, decreases the sale of energy for other consumers. In 2018, Empresas Públicas de Medellín (EPM) sold or imported on average for stratum 4 (a socioeconomic sector that does not receive or pay contribution from and to other strata) each kWh for 454,11 COP, while the price of each kWh exported by the photovoltaic system of this project (considering the installation of the whole potential) would be 170,63 COP (EPM, 2018a). Therefore, the use of each kWh generated locally that avoids this import payment and this exportation leads to a net profit of 283,48 COP. Although the installation of a battery promotes this self-consumption of energy and therefore increases profits, it means in most cases in Colombia, such an increase in the initial investment, that not even this promotion in profits is able to cover the initial payment. In countries like Germany, where on average for the year 2018, each electric kWh imported from the network was 1.039 COP (Strompreise, 2019), the inclusion of batteries to reduce the frequency in the use of this energy transported by the network is much more profitable as faster return rates of investment are present.

Based on the proposed demand curves for apartments and shared areas and the generation curve obtained through simulations in PVSOL, a balance between energy output and input throughout the year was developed in order to characterize the magnitude of self-consumption and energy coverage with the following inequality:

$$Energy\ generation_{i,j} > Energy\ demand_{i,j} \quad (13)$$

Where

$$i = \text{hour of the day } j = \text{day of the year}$$

If true, then the total energy is supplied and the excess is exported to the grid. Otherwise, when

$$\text{Energy generation}_{i,j} < \text{Energy demand}_{i,j} \quad (14)$$

The system presents a self-consumption of energy (when is not zero like during the night) and an import from the grid to complete the required supply of energy. Having as self-consumption the resulting quotient between the energy consumed that was generated within the system and the total energy generated and demand coverage as the quotient between the energy consumed that was generated within the system and the total energy demand.

In Colombia, the model under which the price of the purchase of electric power is calculated depends on different factors that can be variable over time. Each unit of sold energy, in this case kilowatt-hour has six components whose sum symbolizes the sale price for the end user under the equation 15 that exposes (EPM, 2018a)

$$CUv = G + T + D + Cv + PR + R \quad (15)$$

Donde

$$\begin{aligned} CUv &= \text{Single price} & G &= \text{Generación price} & T &= \text{Transmisión fee} \\ D &= \text{Distribución fee} & Cv &= \text{Commercialization fee} & PR &= \text{Losses fee} \\ R &= \text{Restrictions price} \end{aligned}$$

According to Resolution 030 of 2018 of the Ministry of Mines and Energy, photovoltaic systems with an installed capacity up to 100 kW_p have an exportation price to the grid for each kilowatt-hour equal to the sum of all the addends of the equation 15 except the commercialization fee (Comisión Reguladora de Energía y Gas, 2018). If the system has a capacity greater than 100 kW_p but it is still considered a small-scale self-generation system as indicated in Resolution 281 of 2015, (up to 1 MW_p), (Director General de la Unidad de Planeación Minero Energética-UPME, 2015) the sale price is assumed just as the “G” component or generation price.

The average value in 2018 for these six factors is shown in Table 18 where it can be seen that the sale price of energy for a photovoltaic system greater than 100 kW_p would be around 410,98 COP and 170,63 COP if it is between 100 kW_p and 1000 kW_p.

Table 18. Average price for electrical energy in 2018 in Medellín

CU	G	T	D	Cv	P	R
454,11	170,63	31,19	144,28	43,14	32,49	32,38

Source. Own elaboration with data from (EPM, 2018a).

The current Colombian legal framework promotes projects that seek the generation and use of energy through renewable sources by obtaining different financial benefits as shown in section 3.4. of this document, like exemption in payment of value added tax (VAT) in the purchase of equipment and related services. In this way, CELSIA proposes that currently in Colombia, each installed kilowatt-peak (approximately four solar panels) can have an estimated market price of USD 1.000 of which only 30% are costs associated with the panels themselves and the remaining fraction refers to the equipment required for its operation (2018). Considering the total area available in CONTREE for the installation of a photovoltaic system capable of generating more energy than that required by all the operations within the buildings, the following scenario is obtained:

Table 19. Energy distribution of CONTREE when is labeled as an Energy Plus Building

Installed Capacity (kW_p)	519,2
Energy generation (kWh/year)	410.226
Energy demand (Scenario “Ef+Ci+BC” + Shared areas) (kWh/year)	352.674
Self-consumption (kWh/año)	160.738
Use of own energy (%)	39
Demand covered (%)	46
Imported energy from grid (kWh/year)	191.936
Exported energy to grid (kWh/year)	249.489

With an average price for electrical energy imported from the grid as seen in equation 15 of 454,11 COP and selling each kWh to the grid for 170,63 COP and an investment price for each kW_p (considering additional costs as inverters, wiring, assembly, labor, among others) of approximately 3.300.000 COP or 1.000 USD the following scenario is obtained:

Table 20. Economic scenario of CONTREE when is labeled as Energy Plus Building

Energy price without photovoltaics (MM COP/year)	160
Savings by using own produced energy (MM COP/year)	73
Energy exports or sells to grid (MM COP/year)	43
Energy costs with photovoltaics (MM COP/year)	45
Yearly incomings (MM COP/year)	115
Investment (MM COP)	1.683
Simple Return Time (years)	14,6

It is then estimated that the investment made in the photovoltaic system required to label CONTREE as an Energy Plus Building would return in approximately 14 years when a battery for the electrical energy storage is not installed. The same system, with the installation of a battery that promotes internal use or self-consumption of generated energy, has a significant increase in the initial investment. The Federal German Ministerium of Interior, Construction and Homeland (2018) estimates an approximate value of € 1.200 for each kilowatt-hour of battery capacity when these devices are installed in multi-family buildings. Therefore, for different battery sizes on the same system characterized in Table 19 different possibilities may be approximated:

Table 21. Behavior of photovoltaic system with different battery sizes

Battery capacity (kWh)	Self-consumption (%)	Covered demand (%)	Simple Return Time (years)
0	39	46	14,6
50	45	49	15,5
100	48	53	16,8
200	55	60	19,1
300	60	66	21,3
400	66	72	23,4
500	71	77	25,4

As mentioned above, although the installation of the battery promotes a favorable balance for each kWh that is generated and consumed inside the system, the price of electric power in Colombia is much lower compared to the investment cost of these devices and therefore with an increase in storage capacity investments are less attractive. The optimal dimensioning of this theoretical equipment is calculated by means of the State of Charge (SOC), magnitude that shows for a certain moment the capacity of the battery or how full it is. Through the monitoring of these curves, it is intended to have a battery whose charge and discharge of electricity is as continuous as possible between the minimum level of selected load, which generally is around 20% of the capacity and the maximum level or 100%. The next figure shows for three theoretical sizes of an installed battery in the scenario of Table 19 how the SOC would be when comparing generation and demand profiles hourly. An undersized or small battery for the system (upper plot) shows that loading and unloading are immediate (almost straight trends) and therefore long periods with a discharged battery appear, a battery size according to the system (middle plot) shows wider charge and discharge cycles and most

of them are completed and finally an oversized battery for the system (lower plot) does not reach the boundaries of charge and discharge.

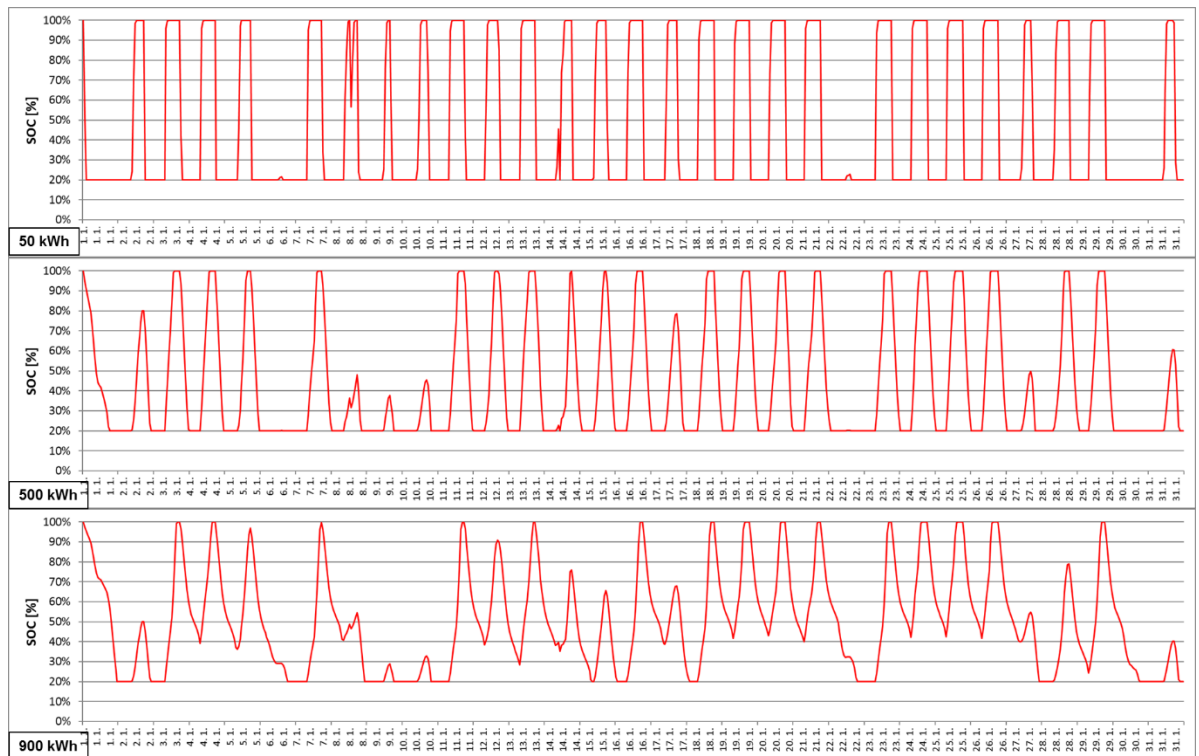


Figure 41. SOC for january with three battery sizes

Source. (EGS-Plan, 2014) with data from simulation

Under the system proposed in this work, where a photovoltaic plant is responsible for providing part of the energy demand of a residential complex, it is necessary to define an entity that is responsible of providing constant monitoring and ensuring an optimal performance of the system. Through this character, goals to reduce GHG emissions and comfort for users can be effectively met and mainly, demonstrate the validity of a new paradigm of housing construction in Colombia regarding sustainability from a technical point of view.

The scheme shown in Figure 42 points at the fact that inhabitants of the building are not owners themselves of the photovoltaic system. When energy is consumed inside the dwelling, it is indifferent for the check of the user if the source of the service is the building itself or the power grid from the provider. The intern grid to be designed in the building must therefore be configured in such a way that gives priority to the use of locally generated energy by apartments and shared areas to ensure a high level of self-consumption of this service and, given the absence of a battery, in the case of excess

generation, exporting the surplus and quantify it by means of a bidirectional power meter installed in the local grid operator's network. This plant can be operated by the construction company itself, a third party or even through an alliance with the energy supplier and thus control the annual energy generated (EG), the excess of energy (EE) that is exported and the self-consumption of the produce energy (SCE).

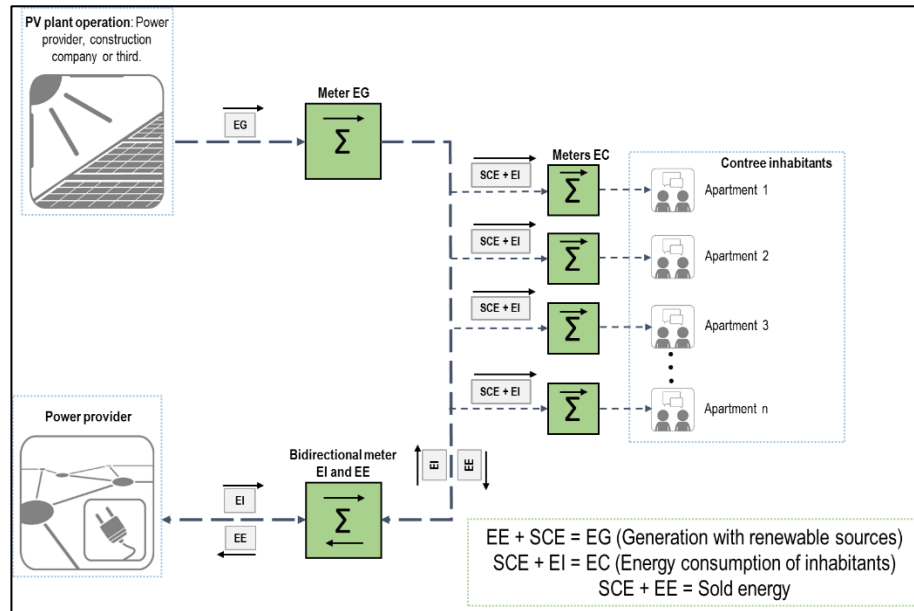


Figure 42. Outline of electrical energy use in buildings with multiple dwellings

Two energy meters are to be installed in each housing unit of CONTREE to record the monthly consumption and trace the origin of the service between the local plant and the outer power grid. The payment for all the energy consumed is to be made monthly to the operator of the plant who receives money for having provided the electricity service and in turn serves as an intermediary between the users and the grid operator by delivering the payment to this last party involved for the imported energy. Additionally, the energy that was not consumed by the residents, which is recorded by the operator of the plant, is sold to the grid's operator for distribution to other consumption points outside the building as shown in next outline:

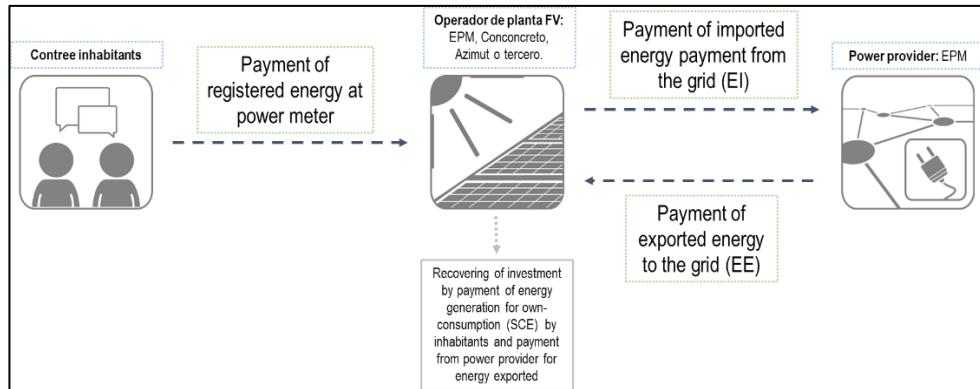


Figure 43. Payment for energy in multiple dwelling buildings with local energy production

5.4. BUILDING PHYSICS

The design of the different physical structures that shape the building such as walls, ceilings, and windows commonly known as the "envelope" is a key factor in buildings labeled as Energy Plus since their correct integration into the concept of the building is the passive method (solution that do not require devices powered by any energy source) that promotes thermal, light, acoustic and humidity comfort while providing physical insulation that reduces energy costs in conditioning the interior. This field studies the performance of the materials involved in the different parts of buildings such as ceilings, facades, windows and walls and their interaction with the user and the surrounding environment. Particularly, due to the environmental conditions of Medellín, the city where the case study is being considered, the requirements for buildings in terms of the envelope and concepts that are evaluated through building physics, have not traditionally been extensive or complex, since the distance between comfort levels and annual environmental conditions is shorter than zones with extreme temperature and humidity conditions. In general, the application of different techniques under the study of building physics focuses on how, for cold climates it is sought to keep the most energy inside the building through minimizing the three ways of heat transfer (conduction, convection and radiation), and for warm climates to reduce the flow of energy into the building. In this particular case, since the initial concept of the building, active systems (operated with any source of energy) that seek to regulate the thermal conditions within the buildings are not going to be implemented. That is, avoiding electrical or gas systems such as heating, air conditioning, fans, ventilation with heat recovery, among other demanding energy systems. The idea is that the design of the building itself promotes passive methods that promote the comfort of the inhabitants without having to use these

equipment. Particularly, the city of Medellín during sunny hours can exceed the comfort temperature range that, according to the (Ministry of Housing, City and Territory, 2015) are between 21 ° C and 25 ° C with a relative humidity between 20 % and 75%. A methodology commonly applied in building physics to avoid overheating of the interior of buildings by solar gains through windows and/or transparent surfaces, is the use of coatings or multiple layers capable to minimize both the absorption of energy into the interior and its transmission as seen in Figure 44. The energy flow from the sun on the window is represented by q_{sol} , αq_{sol} is the fraction absorbed that is then transmitted inward (q_i) or outward (q_e) and τq_{sol} finally represents the fraction that is transmitted through this surface.

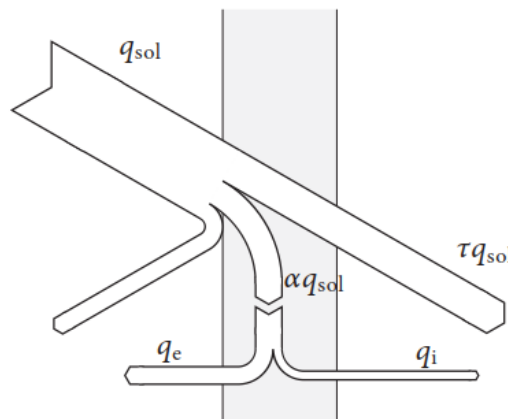


Figure 44. Heat gain through transparent surfaces

Source. (Pinterić, 2017).

Both the fraction of the incident energy called τ and q_i are considered the factors that when reduced, a decrease in the energy gain inside the building by effect of the sun is obtained. The Solar Heat Gain Coefficient (SHGC) is then known as the sum of these two fractions and finally indicates how much of the incident energy on a crystal is transferred through its surface to the room. This coefficient, as it refers to a magnitude of solar energy, is also accompanied by light and therefore, generally a high SHGC leads to a high visible transmittance. Currently, by means of particular techniques it is possible to separate these two streams that inherently come together from the sun. That is, it is possible to provide a high fraction of incident light to have a room illuminated without being overheated by having low emissivity coatings that reduce heat transfer by radiation avoiding a noticeably decrease in visibility (Glew Engineering, 2017). These factors consider the entire window and not only the glass, therefore the frame plays an important role in the quantification of the transmission of energy and light through windows. Figure

45 presents standard levels according to different glazing and materials for the frame starting at the lower side with a single layer of regular glass with an aluminum frame. This configuration presents high levels of light transmittance and solar gain, as well as a high U (global heat transfer coefficient), whose magnitude is the inverse of the thermal resistance of the window.

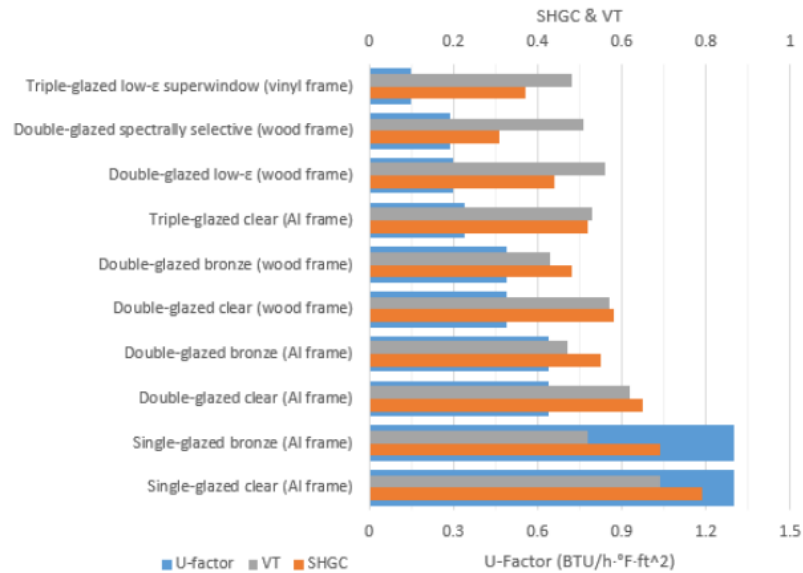


Figure 45. Standard values for SHGC, VT and U for different glazing and frames

Source. (Grondzik, Kwok, & Stein, 2009)

A high transmittance of light reduces the need for artificial lighting for the different activities inside the apartments and therefore reduces the electricity demand. Reason why installation of windows and other glass surfaces for CONTREE that have the highest VT is proposed as long as the SHGC is not too high as it promotes indoor temperatures above thermal comfort. Through the *Design Builder Software*, daytime lighting simulations of the buildings were carried out through different levels of VT by changing the glazing properties to evaluate changes in the light that would enter the housing units. Particularly, different sustainability certificates for buildings evaluate this phenomena by quantifying the daylight factor. This number is given by the equation

$$DF = \frac{\text{average illuminance due to daylight inside the building}}{\text{simultaneous outdoor illuminance on a overcast sky}} \cdot 100 \quad (16)$$

according to (Ministry of Mines and Energy, 2010) and expresses how much of the external illuminance coming from the sun enters the building at the height of the work plane. In this case, the evaluation of daylight on the apartments of CONTREE was

carried out following the usual procedure for common sustainability certifications in buildings in which the simulation is used as input parameters in an overcast day according to the international lighting commission (CIE) and with a measurement plane 75 centimeters above the ground (Mardaljevic, 2012). In these simulations different values of light transmittance were taken starting from 0.8 for a common crystal decreasing in steps from 0.1 to 0.5. This last value of VT is the most simple solar control glass or solar protection glass and complexity and prices go higher the lower the VT number.

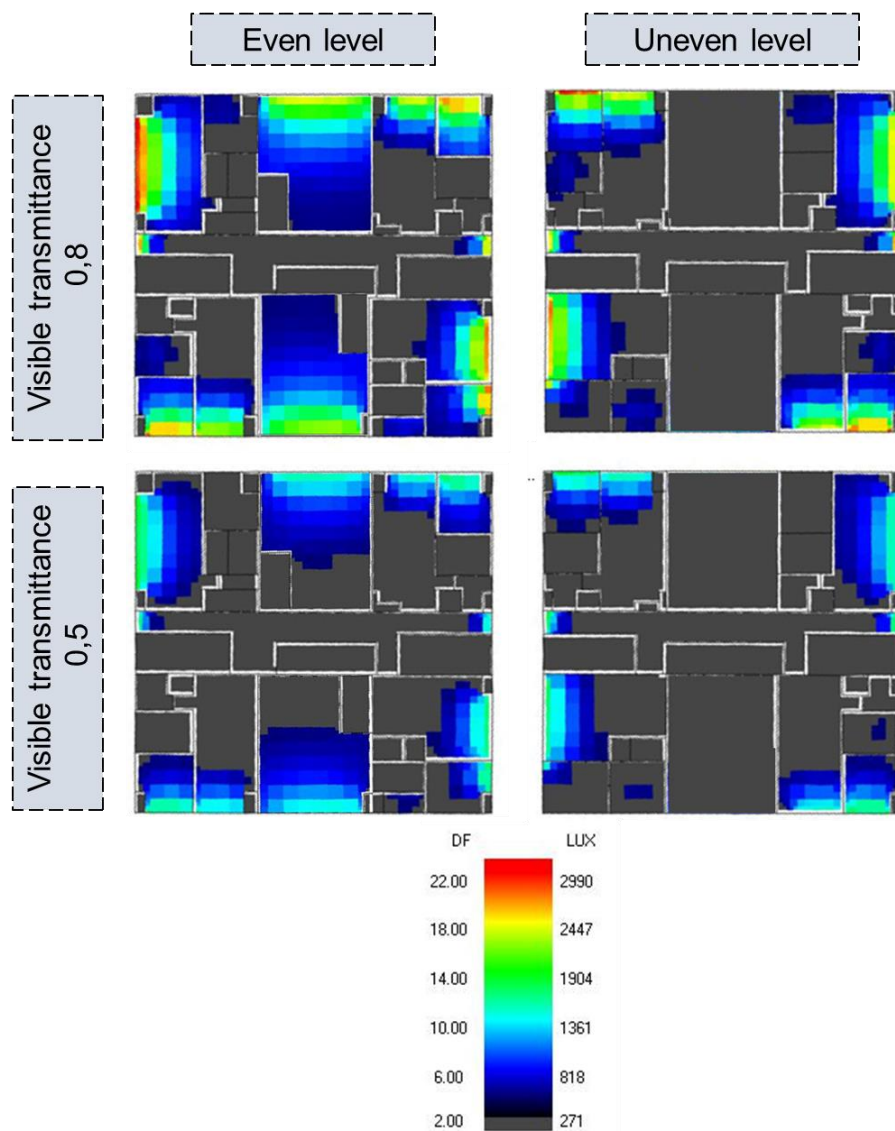


Figure 46. Daylight coefficient in even and uneven levels of CONTREE with different visual transmittance

This figure represents the apartments of CONTREE with real dimensions of rooms and windows based on plans and 3D models provided by Conconcreto. The four graphic

representations show how the incoming light is scattered through the windows of the housing units, noting that natural lighting levels are to be quantified for transit or shared rooms as kitchens, dining rooms, halls and corridors. For bathrooms and bedrooms, the prevalence of natural lighting is not promoted since during the day they are supposed to be empty rooms, short-stay rooms or relative levels of lighting for visual comfort. Simulation was carried out for both even and uneven levels, since location of the windows varies between these levels. That is, even floors have the same window orientation and all uneven floors have the same configuration but is different to the one from the even floors. It is proved with the simulations that glazing that reduces the absorption and transmission of light coming from the sun, decreases the level of interior illumination, which in this case is expressed through the International System of Units in lux or lumen/m².

The results of the natural lighting simulations from Table 22 show how, as a more complex glazing system is used, starting from a VT of 0.8 for a common crystal, the average daylight factor in the transit zones is progressively decreased and thus the percentage of these areas that have a coefficient above 2% (level suggested in standards and certificates such as Aktivplus, CASA, LEED or DGNB). Maximum lighting levels are as well lowered but constant uniformity levels are obtained as this factor depends on the size of the openings for the entry of light.

Table 22. Natural lighting in different apartments

Light transmittance		0,8	0,7	0,6	0,5	0,8	0,7	0,6	0,5
Factor		Average Daylight Factor (%)				% Area > 2%			
Impar	NE	7,7	6,4	5,7	4,7	99	96	94	87
	NO	3,4	2,8	2,4	2,0	41	34	33	29
	SE	3,2	2,6	2,4	1,9	39	38	34	28
	SO	5,6	4,7	4,1	3,3	65	60	60	51
Par	NE	3,1	2,6	2,3	1,8	35	34	30	23
	NO	8,6	7,1	6,1	4,8	100	98	97	85
	SE	5,2	4,3	3,8	2,9	63	58	55	45
	SO	3,5	3,0	2,6	2,0	38	37	35	26
-	Duplex N	6,3	5,4	4,6	3,8	100	93	81	71
	Duplex S	6,0	5,2	4,4	3,6	99	90	78	69

Light transmittance		0,8	0,7	0,6	0,5	0,8	0,7	0,6	0,5
Factor		Maximum lighting (lux)				% Uniformity (DFmin/DFavg)			
Impar	NE	2.447	2.058	1.773	1.448	16	14	17	18
	NO	2.310	1.954	1.660	1.356	4	3	3	3
	SE	2.347	1.985	1.687	1.354	4	3	4	4
	SO	2.749	2.304	1.964	1.591	16	16	16	16
Par	NE	2.292	1.951	1.652	1.328	3	3	3	3
	NO	3.031	2.542	2.152	1.705	19	18	19	18
	SE	2.737	2.285	1.968	1.546	15	15	15	16
	SO	2.503	2.111	1.795	1.438	3	3	3	3
-	Duplex N	2.342	2.005	1.696	1.373	30	32	31	31
	Duplex S	2.119	1.811	1.535	1.236	31	31	32	31

It should be highlighted that, a glazing with a VT of 0.5 in CONTREE not only maintains an average daylight coefficient greater than 2% (with the exception of the southeast apartments of the uneven floors with 1.9% and northeast of the even floor with 1.8%) but also, for these glazings, references with a low SHGC should be sought to avoid overheating the interior areas of the apartments as this VT value is the simplest level of the so-called solar control glasses.

5.5. AIR QUALITY

As mentioned above, the initiative to develop building concepts that are efficient in the management of energy in Germany arises from the need to change the course of the increasing inertia of CO₂ emissions associated with this sector. Particularly, the premise of "building as hermetically as possible" avoids mass and energy transfers to the environment in times of low temperatures that, with advantages and disadvantages, has been directing the designs of buildings both for housing and for the commercial field in that country. This statement aims to reduce the energy demand of conditioning of interior spaces since it is the main source of consumption of this service when even levels around 70% of the total demand in the housing sector are achieved as shown in Figure

47. Since an airtight building reduces the exchange of air with the environment in order to keep the heat in the interior to promote a low energy consumption by heating, in the periods when the operation of these equipment is required, opening of windows to avoid losses of warm air is considerably reduced. This commonly leads to the saturation of the capacity of the indoor air to withstand water and therefore to condensation on the different surfaces of the rooms. (Biomess, n.d.) quantifies the amount of water that can be daily released inside a housing unit as 1.0 to 1.5 liters per person, 0.5 to 1.0 liters per cooking process, 0.5 to 1.0 for a shower and 0.5 to 1.0 liters for plants. All this humidity generated daily must be released to the environment to avoid proliferation of organisms causing respiratory diseases, visual or olfactory discomfort and issues in the structure of the building. Although the simplest solution is the opening of windows to provide fresh and unsaturated air, this implies an exchange of matter and energy that reduces the temperature of the interior of the building also affecting the thermal comfort of the users and leading to an extra energy consumption to replenish the outgoing warm air. This fact founds the development of technologies in the field of ventilation in order to regulate the humidity levels with the least negative implication in the consumption of energy for heating. These technologies for replenishing the air to maintain acceptable levels of humidity and carbon dioxide are also attributed an energy expenditure whose decrease is also of special interest in this type of methodologies or energy standards for buildings. In Medellín and in other cities of Colombia, due to the climatic conditions, there is no need to adjust the internal temperature of the buildings by means of heating or cooling and therefore it is possible to regulate the levels of humidity and carbon dioxide easily through natural ventilation. Additionally, the energy associated with the operation of these technical ventilation or heating equipment by electrical means (recirculation pumps for heating by means of heat pumps) is also absent and, therefore, there is a lower monthly electricity consumption compared to the average of Germany.

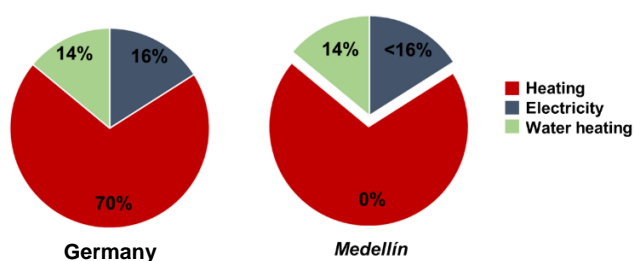


Figure 47. Energy demand distribution for housing in Germany and Medellín

Source. Own elaboration with data from (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2018)

In Germany, the DIN 1946-6 standard sets out the parameters by which the minimum levels of air renewal in the housing sector must be met according to different methodologies by both natural and mechanical methods. The main criterion to determine the minimum ventilation requirements is given by the inequality stated by the German Institute for standardization (DIN, 2018) as follows:

$$q_{v,ges,NE,FL} > q_{v,Inf,Wirk,Konzept} \quad (17)$$

Where

$$q_{v,ges,NE,FL} = \text{Minimum air volumen flow needed for humidity care in } \frac{m^3}{h}$$

$$q_{v,ges,NE,FL} = \text{Air volumen flow due to infiltration in } \frac{m^3}{h}$$

When the amount of air necessary for the care of humidity levels is not reached only with infiltrations (compliance of the inequation), it is imperative to use some ventilation system under the norm either mechanical or natural. If this condition was not met, the implementation of a particular ventilation system would only rely on hygiene reasons or user interest. Under the methodology proposed by the standard and having in CONTREE a housing area of approximately 80 m² for the one-floor-apartments and a height of 2,8 m, there is a value for the needed air for humidity care of 26,5 m³/h and a volume by infiltrations of 24 m³/h would require a mechanical or natural ventilation system if it was built within the German territory. Given the environmental conditions of the city of Medellín where the average annual temperature is 22.5 ° C and the relative humidity of 67% (IDEAM, 2012) as shown in Figure 48, it has the advantage of having a wide application of natural ventilation systems that do not mean any energy consumption.

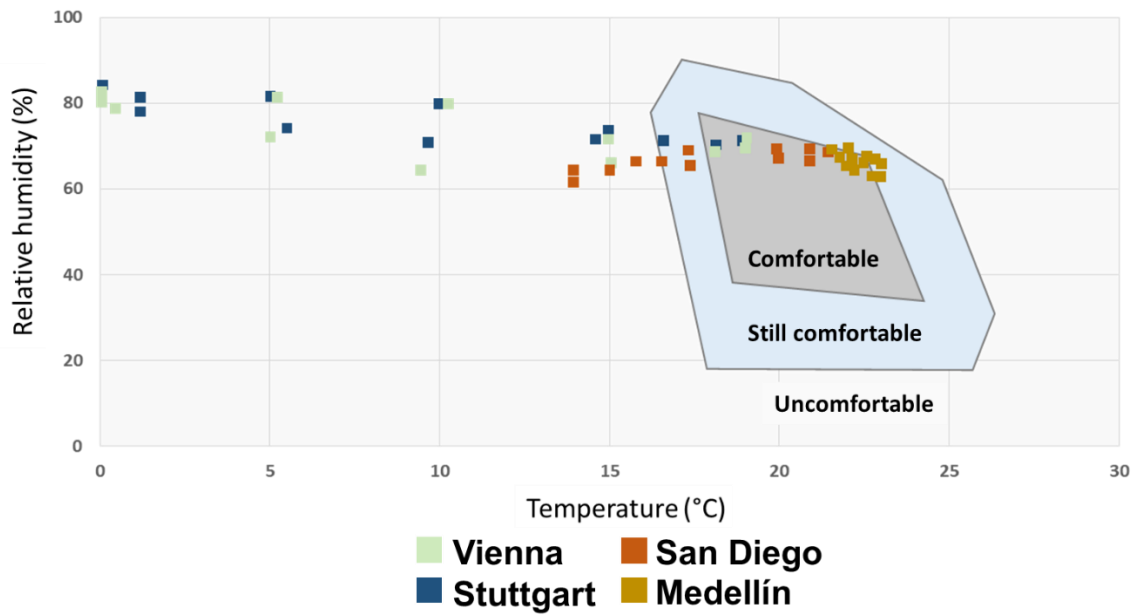


Figure 48. Climatic conditions throughout the year for cities where Energy Plus or Zero Energy projects have been development and Medellín

Source. Elaboración propia con datos de (Viessmann, 2011) para condiciones de comodidad, (IDEAM, 2012) para condiciones de Medellín y (Climate-Data, 2018) para resto de ciudades.

Institut Wohnen und Umwelt recommends for a house of 75 m² ventilate every 90 or 120 minutes to renew the indoor air and in a house of 140 m² between 3 and 4 hours given the higher air volume. Additionally, for reasons of hygiene and health it suggest that the CO₂ concentration does not exceed the *Pettenkofer* coefficient, whose value is referred to 1.000 parts per million (ppm) (2012).

Table 23. Carbon dioxide generation inside buildings and air renovation rates

Activity	CO ₂ exhaled in liters/hour	Fresh air needed in m ³ /hour
Sleeping/Resting	10 – 13	17 - 21
Read and watch T.V.	12 – 16	20-26
Writing or using a computer	19 – 26	32 – 43
Chores at home	32 – 43	55 – 72
Physical training	55 – 75	90 - 130

CONTREE has 5 different apartments types according to the distribution of its internal partitions and windows and one of them is a two-level dwelling. For all of them it is proposed from the initial concept of the building to regulate the internal temperature and

humidity through natural ventilation as it is normally carried out in all the housing buildings of the city. Although it is not considered in the initial planning of the project, for comfort reasons mechanical ventilation system in bathrooms that do not have windows could be installed to regulate odors and humidity coming from the toilet and the use of the shower.

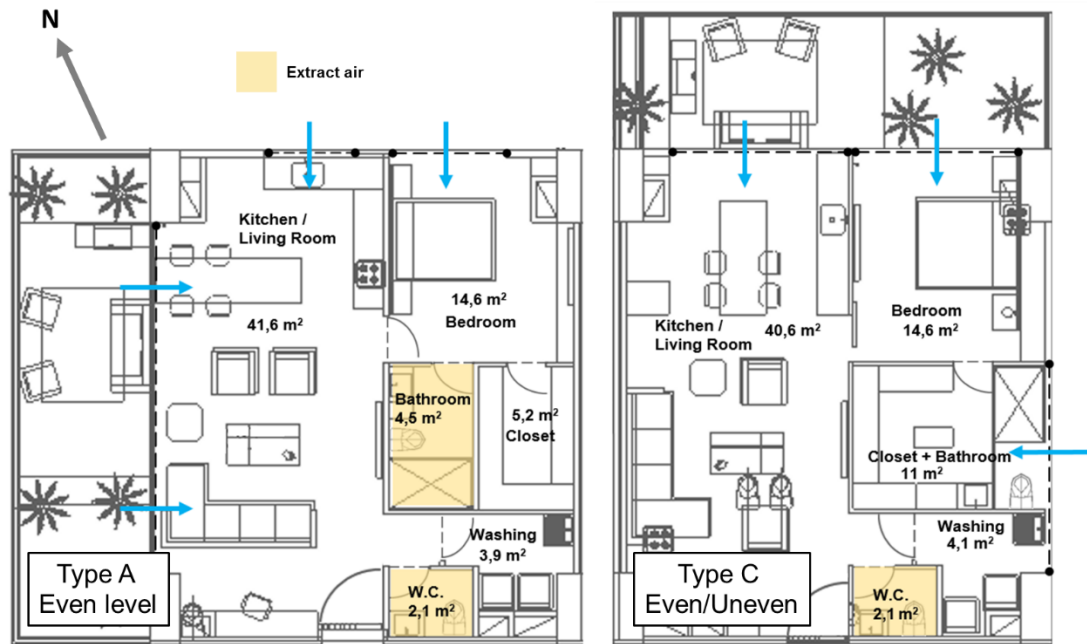


Figure 49. Ventilation outline for two model apartments

Figure 49 shows the configuration of rooms and windows of two types of apartments noting that the yellow areas are bathrooms and the use of air extractors is recommended. Likewise, it is advisable to install a hood over the kitchen stove to extract odors through a chimney. In the scheme on the right where the apartment type C is presented, it is observed that one of the bathrooms is disposed towards one of the windows and therefore the humidity and odor levels can be regulated by means of a natural ventilation.

For information purposes, the label for natural ventilation of the DIN EN 1946-6 standard was filled for the different types of apartments at different heights in the buildings (first floor, middle floor, upper floor), since the orientation with respect to wind direction and height are factors considered in this calculation that aims to define the minimum ventilation requirements to have good indoor air quality. In this way, the openings in the walls were measured, where the different windows are to be installed to determine the rate of air renewal, the direction of the apartment with respect to the historical movement of the wind, the height of the apartment, and the number of inhabitants per housing unit.

Bestimmung der Infiltration ohne Lüftungstechnische Maßnahmen (LTM) $q_{v,Inf,wirk,Querlüftung}$ (informativ)				
Luftvolumenstrom durch Infiltration (Querlüftung)	$q_{v,Inf,wirk,Quer}$	33 m ³ /h	$n_{v,Inf,wirk,Quer}$	0,16 h ⁻¹
Bestimmung der geforderten Gesamt-Außenluftvolumenströme $q_{v,ges}$				
Vergleich der Nennlast	Σ der geforderten Abluftvolumenströme der Ablufträume		notwendiger Außenluftvolumenstrom für diese Nutzereinheit	
	$q_{v,ges,R,ab,GL}$	70 m ³ /h	$q_{v,ges,NE,NL}$	98 m ³ /h
	Σ der geforderten Außenluftvolumenströme je Person		gewählter Nennlastvolumenstrom	
	$q_{v,ges,NE,GL,P}$	60 m ³ /h	$q_{v,ges,NL}$	98 m ³ /h
Minimalforderung der Volumenströme	<u>Lüftung zum Feuchteschutz LF</u>			
	$q_{v,ges,FL}$	29 m ³ /h	$n_{v,ges,LF}$	0,14 h ⁻¹
	<u>Reduzierte Lüftung RL</u>			
	$q_{v,ges,RL}$	69 m ³ /h	$n_{v,ges,RL}$	0,34 h ⁻¹
	<u>Nennlüftung NL</u>			
	$q_{v,ges,NL}$	98 m ³ /h	$n_{v,ges,NL}$	0,49 h ⁻¹
Bestimmung der Luftvolumenströme durch LTM $q_{v,LTM}$	<u>Intensivlüftung IL</u>			
	$q_{v,ges,IL}$	127 m ³ /h	$n_{v,ges,IL}$	0,63 h ⁻¹
	<u>Reduzierte Lüftung RL ALD</u>			
	$q_{v,LTM,ALD,RL}$	-38 m ³ /h	$n_{v,LTM,ALD,RL}$	-0,19 h ⁻¹
	<u>RL ÜLD</u>			
	$q_{v,LTM,ÜLD,RL}$	49 m ³ /h	$n_{v,LTM,ÜLD,RL}$	0,24 h ⁻¹
<u>RL Ventilator</u>				
$q_{v,LTM,VENT,RL}$	42 m ³ /h	$n_{v,LTM,VENT,RL}$	0,21 h ⁻¹	
<u>Nennlüftung NL ALD</u>				
$q_{v,LTM,ALD,NL}$	-9 m ³ /h	$n_{v,LTM,ALD,NL}$	-0,04 h ⁻¹	
<u>NL ÜLD</u>				
$q_{v,LTM,ÜLD,NL}$	78 m ³ /h	$n_{v,LTM,ÜLD,NL}$	0,39 h ⁻¹	
<u>NL Ventilator</u>				
$q_{v,LTM,VENT,NL}$	71 m ³ /h	$n_{v,LTM,VENT,NL}$	0,35 h ⁻¹	
<u>Intensivlüftung IL ALD</u>				
$q_{v,LTM,ALD,IL}$	20 m ³ /h	$n_{v,LTM,ALD,IL}$	0,10 h ⁻¹	
<u>IL ÜLD</u>				
$q_{v,LTM,ÜLD,IL}$	107 m ³ /h	$n_{v,LTM,ÜLD,IL}$	0,53 h ⁻¹	
<u>IL Ventilator</u>				
$q_{v,LTM,VENT,IL}$	100 m ³ /h	$n_{v,LTM,VENT,IL}$	0,50 h ⁻¹	

Figure 50. Label of DIN EN 1946-6 standard for natural ventilation

The image shows the label generated through the standard for a type A apartment in CONTREE at the top of the building to demonstrate the feasibility of a system being ventilated naturally. In the upper part highlighted with a red rectangle, according to the norm, the amount of air that enters each hour through infiltrations is shown and in the lower part highlighted with the same color, the minimum amount of air to be renewed every hour to maintain a level acceptable humidity inside. The standard shows that generally for systems where the amount of air that enters naturally through infiltrations is greater than the amount necessary for humidity care, it is not necessary to install mechanical ventilation systems. It should be noted that the lower the apartment is regarding the floors of the building, the fewer the rate of air renovation might be since obstructions could be produced by other adjacent buildings. In this way, some apartments evaluated in the lower part would not comply with the requirement stipulated

by the standard if they were constructed in Germany but as in this context the preservation of the interior hot air over the opening of windows to reduce the humidity levels does not prevail. The applicability of the standard is not entirely correct for Colombia and therefore, this evaluation through this means is merely informative.

5.6. THERMAL COMFORT

As mentioned in the previous section, the climatic conditions of the city of Medellín allow regulation of internal temperature and humidity throughout the year simply by means of natural ventilation through manipulation of openings or windows. This procedure is unthinkable in countries with climatic seasons where the care of the internal heat of the rooms prevails in order to avoid high energy consumptions by reheating rooms in case of an opened window. CONTREE, like the vast majority of residential buildings in the city of Medellín, aims to avoid the use of equipment that requires an energy expenditure to regulate the comfort conditions of users inside the facilities. There are different methodologies that suggest the quantification of thermal comfort in buildings depending on different climatic factors such as humidity or outside air temperature. For example, the Guide for Sustainable Construction for Water Saving and Energy in Buildings presented in the Resolution 0549 of 2015 for Colombia recommends that thermal comfort might be reached between 21 °C and 25 °C with a relative humidity between 20% and 75%. The second approach considered for the evaluation of thermal comfort is taken from DIN 4108-2, which determines for different regions of Germany the maximum temperature inside a building that can be considered comfortable pointing that this border could go up to 25 °C or 27 °C according to the region of this country. Additionally, depending on the type of building (housing or non-housing), a limit of non-comfortable time and temperatures is defined in hours-degrees per year permitted to be outside the comfort zone. This magnitude represents the multiplication of the time that the room is above the temperature limit by the temperature difference with said limit and then the results of the whole year are summed together. That is, if a room is at 28°C between 13:00 and 14:00 in a region where the limit is 27 °C, then $(28-27)K * 1h = 1Kh$ is obtained. The standard suggests that for housing a limit of 1.200 Kh per year should not be exceeded. Although the standard has an applicability only within the German territory, it is taken as a reference to evaluate the performance of the internal temperature of the building, setting the limit of the temperature of 27 °C because is the one indicated for the warmest areas of that country. The third and last approach considered for thermal

comfort was taken from the European standard DIN EN 15251 which characterizes thermal comfort according to the temperature of the environment so that when this magnitude is less than 16 °C the comfort is reached between 20 °C and 22 °C, when the outside temperature is above 32 °C it is reached between 24 °C and 28 °C and when the outside temperature is between 16 °C and 28 °C, the thermal comfort is calculated as

$$\text{Comfort temperature} = 18^{\circ}\text{C} + 0.25 * \text{Outside temperature} \quad (18)$$

With a margin of clearance of $\pm 2^{\circ}\text{C}$. Under this methodology, the maximum value of hours-degrees per year that the room might not be inside the comfort range is 1% of the amount of annual hours that the room is used with a tolerance of 2K. That is, if a room is used daily from 10:00 p.m. to 18:00 then the thermal comfort limit under this standard is $0.01 * 8 \text{ h/d} * 365 \text{ d/a} * 2 \text{ K} = 58 \text{ Kh/a}$. Additionally, the periods in which the room is empty, are not taken into account for this calculation. Since Resolution 0549 does not set any compliance limit for the range that suggests comfort, since they are reference values and not mandatory compliance, the latter model indicated by DIN EN 15251 is used to quantify the Kh that the Colombian approach is not met. In order to quantify the compliance degree, a working schedule of the inhabitants was assumed from 8:00 a.m. to 17:00 p.m. plus one hour of mobilization from and to the dwelling. The occupation of the weekends was assumed until 13:00 and after 21:00 and three weeks a year of vacation. From the above, 9.533 Kh are obtained, leading to an annual limit of 95,33 Kh.

Thermal comfort inside the buildings was simulated through Design Builder, the same simulation software for building performance used for daylight simulations, both approaches are considered for the characterization of the frequency of compliance with thermal comfort conditions throughout the year by avoiding temperature regulation equipment such as HVAC appliances. Additionally, given that Medellín is located in a tropical region in which the sensation of heat rather than cold is more regular, it is also reasonable to quantify the frequency with which excess temperatures occur that cause discomfort within the building. As a starting point for the simulation, the ambient temperature of Medellín is needed and the values registered every hour throughout the year supplied by the *Meteonorm* database at the Olaya Herrera airport station were considered for this. Configuration of the materials used in the construction of the different parts of the building such as external walls, internal walls, floors, windows, doors and other structures present were quantified and used as input for the simulation. The configuration of the different structures is shown in detail in the section on "Life Cycle Assessment" to determine the GHG emissions related to the production, use and final

disposal of each of the structures or equipment that are part of the whole residential set (some examples are shown in Figure 51). In addition to the characterization of the layers of materials that make up the physical structure of the building to manipulate the way in which heat exchange occurs with the environment, there are other factors to consider in the simulation of the thermal performance of the building. The domestic appliances installed in the housing units generate heat in a greater or lesser degree depending on the amount and type of tasks they perform, which promotes the increase of the interior temperature of the room where located. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in its 90.1 standard from 2013 for energy management in buildings defines a power for home appliances of 6.7 W/m^2 and 3.8 W/m^2 for lighting. These values were taken as input data in the simulation to contribute to the internal heating of the apartments. The presence of people inside the building also plays an important role in quantifying the internal heat gain and therefore, on the basis that each apartment has a single bedroom, it can be considered that a maximum of two people reside in each dwelling. The Department of Energy of the United States (DOE) presents a profile of standard occupation of apartments by its residents throughout the week to determine the hours of the day in which the internal gain of heat is increased by the use of electrical appliances or the people themselves. This profile described by this standard does not differentiate between working days and weekends:

- Until 06:45 Occupation of 100%
- Until: 07:45 Occupation of 85%
- Until: 08:45 Occupation of 39%
- Until: 15:45 Occupation of 25%
- Until: 16:45 Occupation of 3%
- Until: 17:45 Occupation of 52%
- Until: 19:45 Occupation of 87%
- Until: 24:00 Occupation of 100%

The last factor to consider is the airtightness or magnitude in which the entire building opposes the unwanted entry of air through fractures, voids or pores of building materials. The entire design of the building aims to encourage natural ventilation through openings and windows to regulate temperature and humidity. Since the care of hot air is not essential to save energy due to the absence of heating equipment, the value measured by this factor may be greater or more lax than the coefficient used in countries such as Germany. DIN V 18599-2 assigns a value of 0.28 h^{-1} for new buildings that do not have

mechanical ventilation equipment and that the infiltration of air does not mean a problem for the internal heat care when pointing out that the 28 % of the interior air volume is renewed every hour in a natural way.

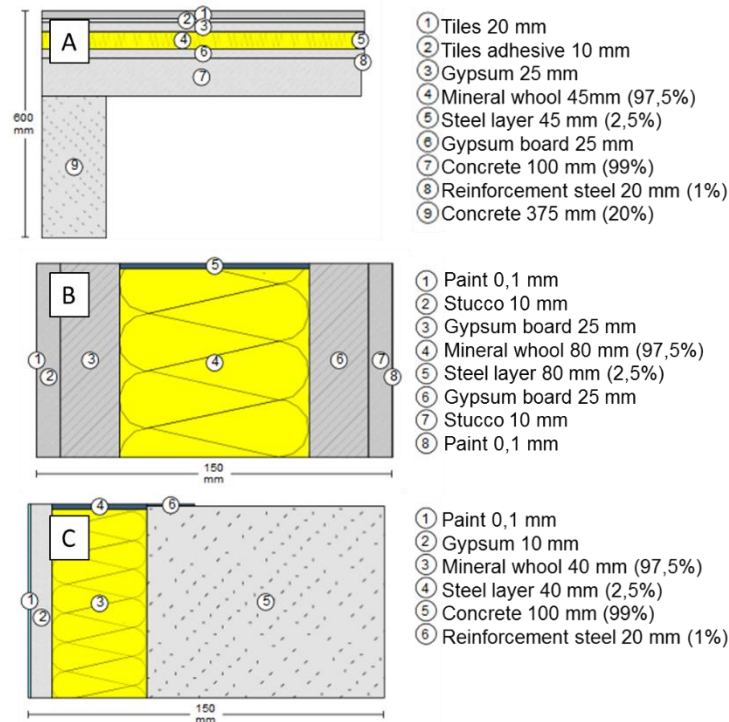


Figure 51. Common structures configuration of CONTREE: A. Apartment's floor B. Inner walls C. Outer walls

Source. Own elaboration with eLCA v 0.9.5 tool

In the same way as for the simulations of natural lighting on the different rooms inside the apartments, the building was recreated based on the dimensions given in Concreto models in the *AutoCAD* and *Revit* models regarding dimensions of areas, distribution of zones and materials. The simulated building in Design Builder together with a typical housing level are shown in Figure 52:

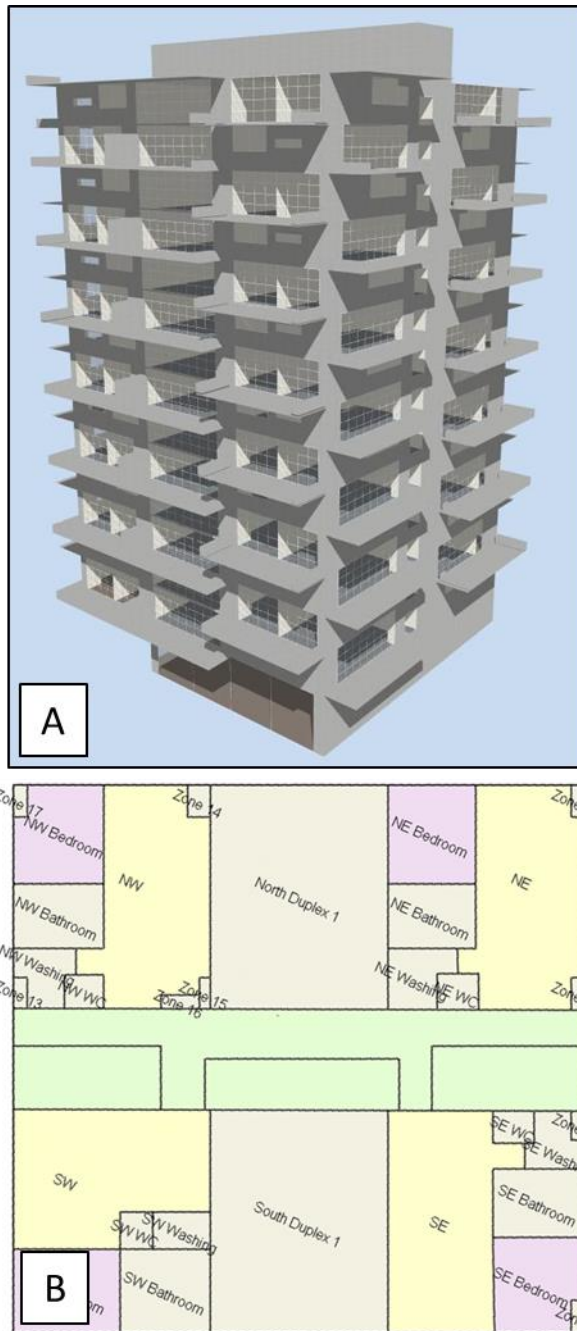


Figure 52. Simulation of building's performance. A. Renderization of simulated building. B. Scheme of a housing uneven level.

Under this approach, simulations of apartments were carried out in the lower, middle and upper part of the building, determining for each of them the interior and exterior temperature every hour from January 1 at 00:00 to 31 December at 23:00. Based on the results obtained, the hours-degrees were quantified in which the average internal temperature of the apartments was outside the comfort zone stated in DIN EN 15251 (approach A), outside the range shown by the Resolution 0549 of 2015 (focus B) and

the overtemperature stated in DIN 4108-2 as 27 °C (approach C). Each green dot in Figure 53 symbolizes a time of the year that shows the internal temperature that a user would feel with respect to the ambient temperature, with the blue zone as the comfort under each focus.

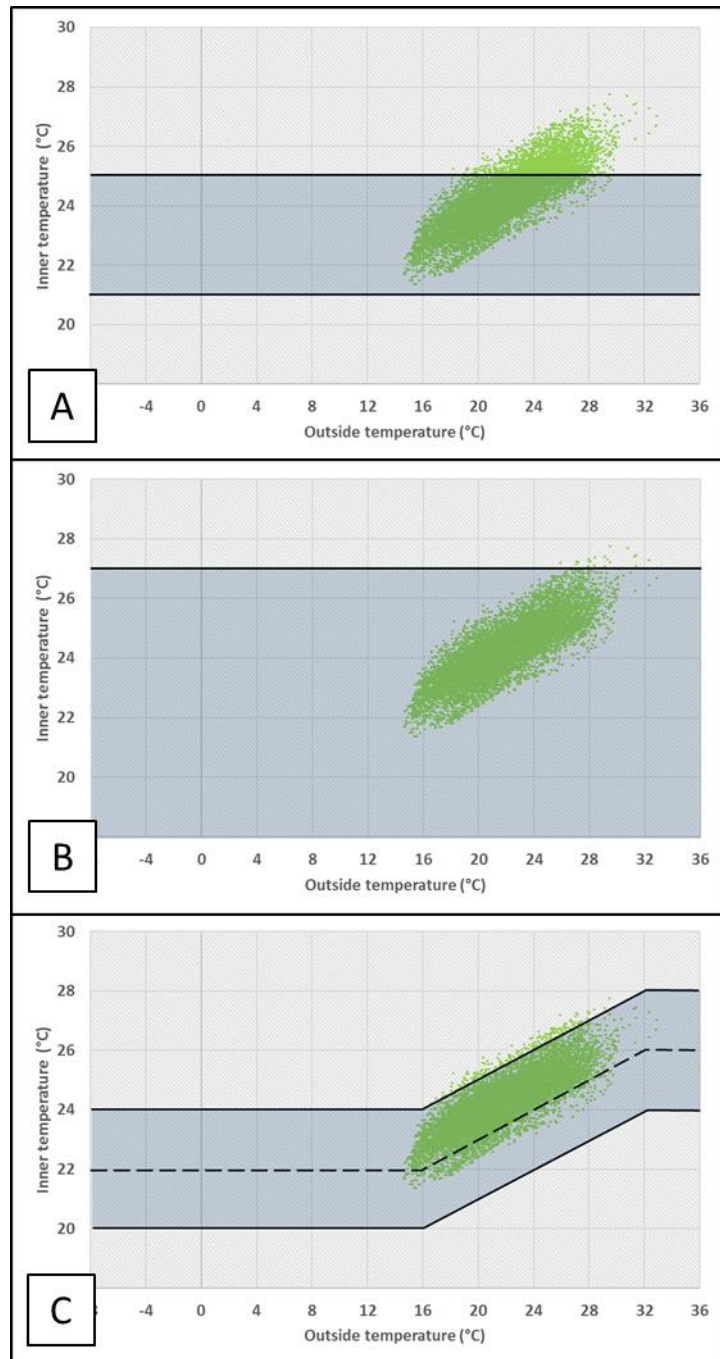


Figure 53. Thermal comfort evaluation over an apartment in the middle of the building. A. According to Res. 0549/2017 B. According to DIN 4108-2 C. According to DIN EN 15251

The figure shows the typical behavior for all the apartments where given the configuration of materials to be used in the construction and dimensions of the parts such as walls and windows, has a very good performance against low temperatures as protection from the cold but performance against warmer temperature is even slightly lower when the surrounding air temperature increases. The general behavior of the simulations shows that:

- When the ambient temperature approaches 16 °C, the internal temperature is 6 °C to 8 °C above
- When the ambient temperature approaches 20 °C, the internal temperature is 3 °C to 5 °C above
- When the ambient temperature approaches 24 °C, the internal temperature is equal to 2 °C above
- When the ambient temperature approaches 28 °C, the internal temperature is 3 °C to 1 °C below

As from the design of the building it is differentiated between even and uneven floors for the distribution of windows and internal rooms, the simulation was carried out for both types of housing floors. The results of the simulations are shown in the following table with respect to the three approaches where the amount of Kelvin-hours, that do not meet the comfort specifications, is quantified.

Table 24. Results of thermal simulation for different apartment types

Buildings' Zone	Level	Approach A		Approach B		Approach C	
		(Kh/year)	(% no comfort)	(Kh/year)	(% no comfort)	(Kh/year)	(% no comfort)
Lower	Even	1.012	11%	58	0%	222	2%
Lower	Uneven	736	8%	29	0%	159	2%
Middle	Even	1.004	11%	44	0%	292	3%
Middle	Uneven	1.096	11%	48	0%	394	4%
Upper	Even	1.055	11%	50	0%	339	4%
Upper	Uneven	3.112	33%	262	3%	2.039	21%

The previous table shows that under the approach A (values suggested in Colombia) the reference limit of 1% of the two degrees of excess or low temperature (in this case it

does not apply) is exceeded and values are close to 10%, except for the last floor of the building whose roof has faces the sun directly and thus, tends to present higher temperatures. The approach B, that shows the intensity of surpassing 27 °C with a limit set at 1.200 Kh, was highly satisfied, even for the last floor which tends to be hotter than the rest. Finally, the approach C, which like the A has a limit of 95 Kh/year or 1% of the time of use with an overtemperature of 2 °C, although it was not achieved, low values were obtained when hovering around 3% at exception of the upper level. It should be noted that these standards are only taken as a reference to approach a characterization of thermal comfort conditions given that its literal applicability in Colombia is not appropriate due to the notable differences in the construction materials used in each region. For locations where low temperatures are common throughout the year, it is intended to have structures that provide such insulation, that maintain a comfortable internal temperature for the user and also promote a reduced energy consumption of indoor heating equipment. The high thermal inertia, characteristic of these designs of tight buildings, is the reason why it is intended that the temperature of the interior vary at the least possible magnitude against external variations. In Medellín, on the other hand, the internal temperature is more susceptible to changes and tends to be more similar to the the temperature of the air outside the building. Medellín is categorized on the border between a warm average annual climate and a pleasant average annual climate, assigned by means of the "Comfort Index (IC)", whose magnitude is dependent on temperature and relative humidity. In Figure 54 indicated with red the city of Medellín and in blue the range considered as a pleasant thermal sensation, locates Medellín in the Colombian context of climatic levels. It is further evidenced through the simulation that over changes in ambient temperature, the interior of the building remains slightly warm with an average annual temperature of 24,4 °C. Noting that even the German standard DIN 4108-2 defines for the area of highest average annual temperature a limit of 1.200 Kh/year for an internal temperature of 27 °C, the simulated apartments in this project, although they are going to be built in Medellín, city of higher average temperature than this area of the norm, do not exceed this limit. The inner levels converge towards 46 Kh/year and the upper one moves towards 262 Kh/year. Likewise, in what is stated by the Guide in Resolution 0549 in matters of thermal comfort, there are no compliance requirements in terms of hours per year, Kelvin-hours or any other measure of compliance with comfort conditions. This range of 21 ° C to 25 ° C when the relative humidity is between 20% and 75% is merely informative and not mandatory.

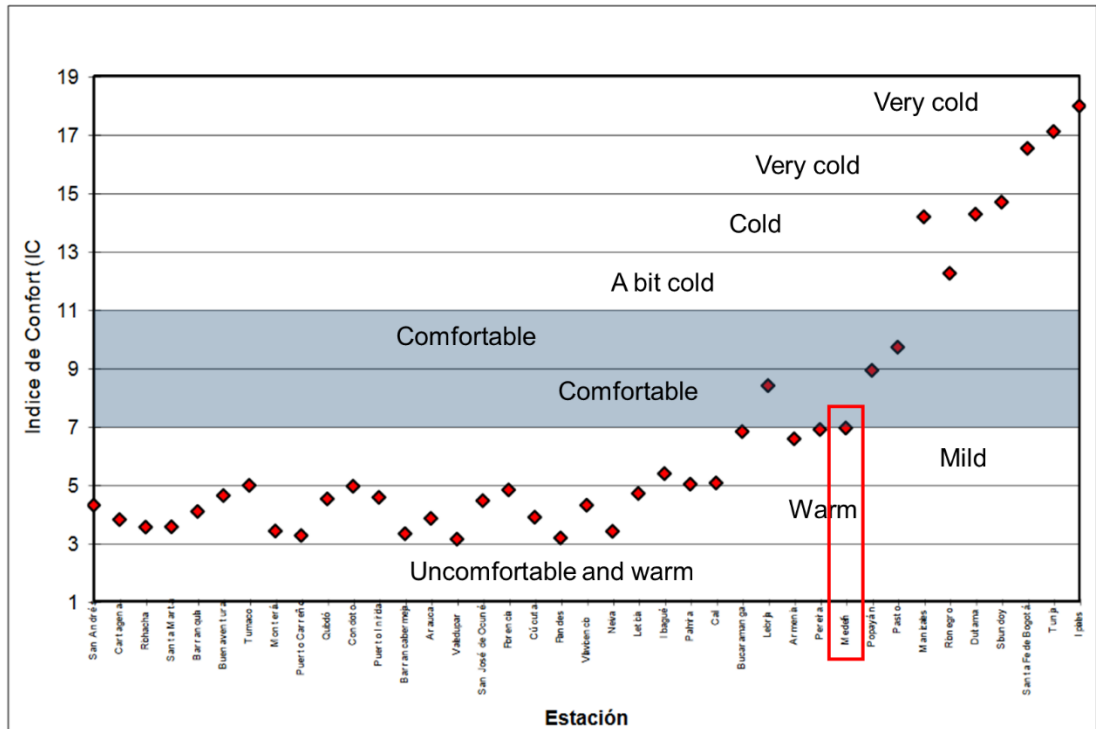


Figure 54. Average thermal comfort Sensación térmica media anual en ciudades Colombianas

Source. (González, 1998).

5.7. ARQUITECTONIC QUALITY

The integration of local energy generation technologies in buildings and methods for energy demand reduction may lead to conflicts with architectural concepts of the building with regard to space use, location of structures, weight on tiles and surfaces or aesthetics. To avoid these conflicts is promoted through the standard that from the very planning of a building, engineering and architecture have a constant communication focused on the common goal of promoting buildings with low environmental impact throughout their life cycle. Since this factor to be evaluated with the energy standard is merely qualitative, its compliance is not mandatory. When an evaluation of a building is intended through the *Aktivplus* methodology, the user is offered the possibility of presenting the project to a group of architectural experts to integrate, giving priority to the optimal development of the building, the different technologies available in the market with the structure to be built and obtain a bonus of the standard. Annually, the architectural council of the *Aktivplus* society carries out an evaluation of the different projects under the standard about the integration of technical systems with the aesthetics of the building, organization of the interior rooms, shadings or sun areas within the

project, origin and type of materials used and the use of interior and exterior space, among other factors.

5.8. USER'S FEEDBACK

The introduction of a type of housing units in Colombia that intend to integrate energy generation technologies through renewable sources and methodologies of efficient use of this resource, to reduce GHG emissions related to the construction sector, implies a total change in the housing paradigm in the country. Through these kind of projects, the goal is to promote a transition from building new homes that meet the growth of demand for housing due to the increase in population that inherently have an impact on the environment, to develop housing solutions that, through the integration of different methodologies not only have a minimal negative impact on the environment, but also have a role of active power generation plants.

The optimal performance of these buildings depends on the different stages of the life cycle such as construction, operation and disassembly taking into account that in this second stage, the user has a greater influence than the building's planners. The inhabitants of a housing building are responsible for the use of both locally generated and imported energy from the grid through using different appliances or lighting. Also are responsible for shaping patterns of consumption and taking advantage or ignoring facilities offered to use clean energy for programmed activities or charging vehicles inside the condominium. Due to this influence that users have, this energy standard for buildings makes emphasis in a constant and effective communication between project planners and users in order to monitor the performance an actual state of the project for timely decision-making processes in which comfort, rational use of energy and mainly the least impact on the environment prevail.

This monitoring promotes a conscious use of energy in the apartments and can be constantly known by users when a graphic interface is implemented that interactively allows the user to monitor their periodic energy consumption in the different domestic tasks and compare it with ideal monthly levels and annuals. Additionally, a more complex system that can be manipulated by the user may be developed in which Smart Houses concepts are involved involving functions such as:

- Intelligent use of energy that can program laundry tasks in hours of high energy generation from the solar panels, turn off energy consumers and identify potential savings
- Control the artificial lighting of the apartment not only with turning lights on and off, but promoting optimal intermediate points
- Theft and fire alarm system
- Direct access to the Carsharing platform for the CONTREE community
- Access to forecasts of generation and use of energy generated in the building

Access to this monitoring can be done in a decentralized manner with the installation of touch screens in each of the housing units as was done in the Energy Plus project called *Aktiv-Stadthaus* in the city of Frankfurt, Germany or centrally with access to a website through a user and a password.

Parallel to this monitoring that promotes contact with users and the approach to new housing models, this energy standard encourages that during the first two years of entering into operation, a questionnaire is conducted annually to characterize this stage and quarterly, a shorter questionnaire to note relevant factors of the operation more effectively. After these two years, the short questionnaire is suggested to be completed with a lower frequency and can be filled even semiannually. Through different meters installed in the project, variables necessary to monitor energy consumption, ambient temperature and air quality are constantly quantified and recorded.

Below is a base questionnaire taken from existing projects under the *Aktivplus* methodology with the addition of some questions indicated with an asterisk that were formulated in this work. The standard does not have a fixed questionnaire and suggests the questions to be designed by professionals in the social field to have a concrete impact based on the questions asked.

***What floor do you live in?**

Even floor Uneven floor

***What side is your apartment facing to?**

Northeast Northwest Southeast Southwest Middle (duplex)

How satisfied or unsatisfied do you feel about the apartment in general?

Very satisfied Satisfied A bit satisfied Neutral A bit unsatisfied Unsatisfied Very unsatisfied

Please think about the conditions in your home in the last seven days.

How was the temperature in:

Main zones like living room and kitchen?

Very cold Cold Fresh Neutral A bit warm Warm Very warm

The bed room?

Very cold Cold Fresh Neutral A bit warm Warm Very warm

How many times, within the last seven days, have you considered the temperature of the rooms...

Very warm?

Always Very frequently Frequently Some times A few times A very few times Never

Very cold?

Always Very frequently Frequently Some times A few times A very few times Never

Please think about the conditions at your place within the last seven days. How do you consider the inner air in:

Main zones like living room and kitchen?

Very dry Dry A bit dry Neutral A bit humid Humid Very humid

The bed room?

Very dry Dry A bit dry Neutral A bit humid Humid Very humid

How do you consider the quality of air in...

Main zones like living room and kitchen?

Very suffocating Suffocating A bit suffocating Neutral Good

The bed room?

Very suffocating Suffocating A bit suffocating Neutral Good

***Do you use the charging station for Bicycle, motorcycles and cars?**

Yes No

***If your answer to the last question was "Yes", please answer the next two questions. Which kind of vehicle do you use the stations for? (More than one answer is possible)**

Car Motorcycle Bicycle

***How often?**

Daily Three times a week Twice a week Once a week Twice a month Once a month

***Besides the station at your home, where do you also charge your vehicle? (More than one answer is possible)**

At work At public stations At the mall

Please make a mark where the magnitude of your answer corresponds to the next assumptions regarding your home

I am able to regulate the temperature of my apartment according to my necessities.

Always Usually Some times A few times Never

It is hard to keep my apartment fresh in warmer days

Always Usually Some times A few times Never

Some spots of my apartment get warm faster during sunny days

Always Usually Some times A few times Never

In sunny days, temperature of my apartments may vary drastically

Always Usually Some times A few times Never

Excess of temperature can be adjusted just by opening the windows

Always Usually Some times A few times Never

I can easily use my apartment as shelter from the sun

Always Usually Some times A few times Never

In sunny days when high temperature is uncomfortable just by opening the window a fresh breeze may help to cool down the apartment

Always Usually Some times A few times Never

In my apartment fresh air can pass through easily

Always Usually Some times A few times Never

It is hard to have a good air quality inside my apartment

Always Usually Some times A few times Never

Air inside the apartment can turn easily suffocating

Always Usually Some times A few times Never

In my apartment, it is possible to generate cross ventilation

Always Usually Some times A few times Never

***During the day, it is possible to do the chores just with natural light**

Always Usually Some times A few times Never

***During the day, it is possible to read, write or use the computer just with natural light**

Always Usually Some times A few times Never

I find important the own energy generation within the building with renewable sources

Very important Yes Just a bit Not very important No

***I try to accomplish activities that demand electric energy during the day so they may be carried out with the own energy generated within the building**

Always Usually Some times A few times Never

***I am conscious of of my energy consumption monthly and I try constantly to reduce it or to avoid activities that unnecessarily demand energy**

Always <input type="radio"/>	Usually <input type="radio"/>	Some times <input type="radio"/>	A few times <input type="radio"/>	Never <input type="radio"/>		
*My frequency of use of the Coworking area is						
Never <input type="radio"/>	A very few times <input type="radio"/>	Once a month <input type="radio"/>	Every two weeks <input type="radio"/>	Once a week <input type="radio"/>	Twice a week <input type="radio"/>	Daily <input type="radio"/>
* My frequency of use of the spa area is						
Never <input type="radio"/>	A very few times <input type="radio"/>	Once a month <input type="radio"/>	Every two weeks <input type="radio"/>	Once a week <input type="radio"/>	Twice a week <input type="radio"/>	Daily <input type="radio"/>
* My frequency of use of the gym is						
Never <input type="radio"/>	A very few times <input type="radio"/>	Once a month <input type="radio"/>	Once a week <input type="radio"/>	Twice a week <input type="radio"/>	Three times a week <input type="radio"/>	Daily <input type="radio"/>
* My frequency of use of the steam bath is						
Never <input type="radio"/>	A very few times <input type="radio"/>	Once a month <input type="radio"/>	Once a week <input type="radio"/>	Twice a week <input type="radio"/>	Three times a week <input type="radio"/>	Daily <input type="radio"/>

5.9. ELECTRICAL MOBILITY

The specific solution presented in this document as a contribution to the fulfillment of the objectives proposed by the global Energy Transition focuses on the field of generation and use of energy in housing buildings. Proposing a conscious interaction between the users or inhabitants of the building with this service is intended not only to reduce emissions associated with the traditional way of generating and transporting energy in Colombia but also directly reduce the emissions associated with the use itself of buildings. This also includes reduction in emissions due to its construction and disassembly, due to the use of fossil fuels to carry out cooking and heating activities and to reduce emissions in the transportation of inhabitants. Reason why it is sought to encourage from the initial concept of the building to promote charging of electrically vehicles inside the building to have a cleaner transportation within the city and the surroundings. By doing it so, comfort for the user is achieved and mobility to other places in the city do not imply high levels of emissions harmful to the health of the community and the environment. The participation in the automobile stock in Colombia of electric cars is increasing and is a reduction in the third most influential factor in the GHG emissions in Colombia that is currently occupied by transportation. This factor represents 10% of the total emissions and is only surpassed by deforestation with 39% and the agricultural sector with 19% (Ministry of Environment and Sustainable Development, 2016). Just in Medellín to September 2018 there were around 350 electric cars among Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV) and Hybrid

(HEV) (Zambrano, 2018) noting that only In December of the same year, more than 220 electric cars were sold throughout Colombia (Andemos, 2018), increasing the total amount in the country by 13%. Additionally, the El Poblado neighborhood in Medellín, where the construction of CONTREE has been planed, has the highest car rate in the city, being a zone that has more cars than people. The factor of 1.25 cars for each person living in this neighborhood (Álvarez, 2015) shows the great niche of the market that these technologies present, which are gradually being introduced into the transportation methods of Colombians. For this reason, due to the growth of the mobilization in the city with electric vehicles, the installation of charging stations within CONTREE is considered.

For the dimensioning of the energy demand profile that the charging station would have, it is necessary to characterize the consumers of this service. According to the most sold models in recent years in Colombia, the battery autonomy of different cars is identified to determine the energy needed in each charge and the frequency that the connection to the station would have.

Table 25. *Authonomy for most sold electric cars in Colombia*

Brand	Reference	Sold between 2016 y 2018	Battery (kWh)	Authonomy (km)	Performance kWh/ 100 km	Real Performance kWh/ 100 km
Renault	Twizy	285	8	100	8	11,7
Renault	Zoe	96	41	300	14	20,3
BMW	i3	164	22	200	11	20,6
BMW	330E	102	7,6	35	22	19
Mitsubishi	IMIEV	11	16	160	10	26,3
Nissan	Leaf	31	40	389	10	18,3
Kia	Soul EV	13	27	150	18	19,1

Source. Own elaboration with data from (Andemos, 2018) for sold cars and y theoretical performance in kWh/100 km and (Sedlak, 2018) for real performance.

According to the proportion of electric cars and their battery charge autonomy, there is an average of 16,3 kWh/100 km traveled. Through the Origin-Destination survey, the Metropolitan Area of the Aburrá Valley (where Medellín is) determines that for the segment of inhabitants who live in the El Poblado neighborhood, in stratum 6 and who use the private automobile as the most common transportation, the average distance of each trip is 5,3 km (2017). According to this average route, the need for a weighted average recharge is close to 1 time per week.

Table 26. Theoretical charges needed per week for the most sold electric cars in Colombia

Model	Approximate participation	Battery (kWh)	Charges per week	Avg. Charge
Twizy	41%	8	1,1	0,98
Zoe	14%	41	0,4	
i3	23%	22	0,7	
330E	15%	7,6	1,9	
Leaf	4%	40	0,5	
I Miev	2%	16	0,9	
Soul EV SX	2%	27	0,5	

Although the average indicates that it would be necessary to load the car once a week according to the distance traveled indicator, except for the BWM 330E because it is a hybrid, given the random distances and traffic conditions in the city, users would tend to load more regularly their electric car to ensure a greater coverage of the route.

Due to diversity in the models of cars that are drove in the city, could be integrated by 3 or 4 stations with the following types of loaders or connectors:

- Schuko (Renault Twizy)
- SAE J1772 (Nissan, Mitsubishi, BMW, Kia)
- Mennekes (Renault and BYD)

EGS-Plan has developed a model to approximate a weekly and annual load profile according to the number of stations to be installed, their power, the number of electric cars and the proportion of users with electric cars that would charge inside the building. The lack of indicators, statistics or surveys for Colombia related to the segment of the population that uses electric cars and specifically, the distribution within this group of people who load their cars at their own home or in the public charging stations may lie in the fact of being a mobility option whose use is still uncommon. This is why to generate this load profile, values based on a survey carried out in Germany are used and therefore this result of the energy demand profile is merely illustrative but the procedure is shown so it may be followed in the future when concrete data for Colombia is available. This survey shows that 96% of users of electric cars charge at their own place and 60% of asked people charge their cars every day, 33% 2 times a week and 7% 1 to 3 times per month (Frenzel, Jarass, Tromer, & Lenz, 2015).

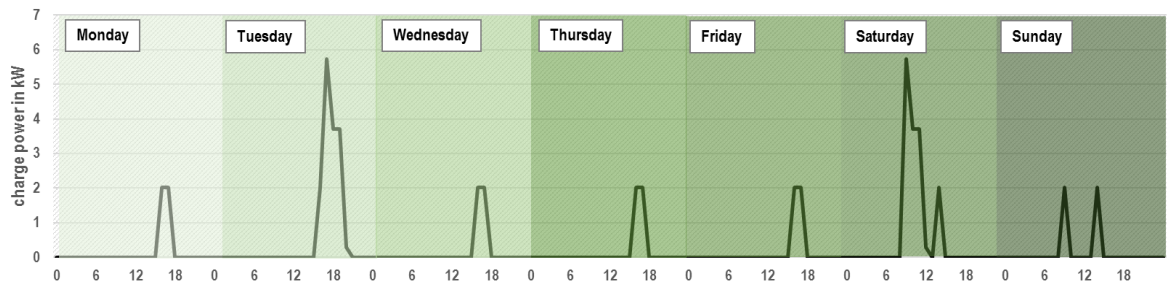


Figure 55. Weekly demand profile for charging electric cars in CONTREE

Source. Own elaboration with computer program designed by (EGS-Plan, 2019)

The current low quantity of this type of vehicles in Colombia can promote the installation of slow charging stations (3.7 kW as shown in Table 27) since working with lower current levels means a more efficient load due to less dispersion of energy and the and there is by now a low demand for these stations.

By looking forward a station connected to a higher voltage level may be considered for a faster load of the vehicles and thus have a greater flow of charged cars per day.

Table 27. Charging stations classification

Type of charge	Slow	Semifast	Fast AC	Fast DC
Power	3,3 - 3,6 kW; I= 16A 6,6 – 7,6 kW; I=32A	22 kW at 32 A	43 kW	50 kW
Voltage	208-240V Single-phase three-wire Or Two-phase	400 V three-wire AC	400 V three-wire AC	Input 400 V three-wire AC Output 500 VDC
Tiempo de recarga	16A: 6-8 hours 32A: 4-6 hours	2 hours	1 hour	30 minutes

Source. (EPM, 2018b)

5.10. LIFE CYCLE ASSESSMENT

The heating of sanitary water in CONTREE with heat pumps as a replacement for traditional heaters operated with natural gas, is assigned GHG emissions related to the generation and transportation of electrical energy that these machines need for their operation. Resolution 804 of the Mining and Energy Planning Unit (UPME) determines that for any project that represents the reduction of these emissions by the integration in technology projects that promote environmental well-being, for each kilowatt-hour used,

they are released into the atmosphere 367 grams of carbon dioxide (UPME, 2017c). Besides that, the combustion of each cubic meter of natural gas for energy is assigned a value close to 1.980 grams of CO₂ or 198 grams/kWh, noting that it can vary according to the particular composition of the gas that is burned and it depends on the well where it was obtained. As each inhabitant of Contree demands about 393 kWh/year for the heating of water with natural gas heaters, and a total of 160 apartments are considered and for each apartment 1,8 people, a total of 23 tons of CO₂ would be annually released into the atmosphere.

This same task carried out with an electric heat pump, with an average COP of 4 as shown in Figure 37 for an ambient temperature of 21 °C for the city of Medellin and a heating temperature between 45 °C and 55 °C has an energy consumption of 201 kWh/(year· person), which is less than the consumption of a natural gas system. Although the emissions per kWh from the combustion of natural gas are lower than those attributed to each electric kWh according to the Colombian generation matrix, the fact of having a lower energy consumption due to the use of the heat pump, supports a decrease also in emissions. So that for the 288 people that would be demanding this service, 21,3 tons of CO₂ would be emitted annually, reducing these gases by 1,7 tons each year. This reduction of GHG is further encouraged when the heat pump is powered by electricity generated from photovoltaic panels locally, given that the inherent emissions to the electrical generation that are attributed mainly to the thermoelectric plants are avoided. Although generation of electrical energy with photovoltaic modules does not emit directly GHG, this production process of the panels is also responsible for the release of these gases. To every kWh resulting from these systems between 70 and 90 grams of CO₂ are assigned (Wegatech, 2017). Heat pumps may be even programmed so that their operation starts in the hours of the day where with the highest solar radiation in order to operate mostly with this cleaner and local energy. In addition to this benefit, COP of the pump increases as the temperature of the heat source increases, in this case the air surrounding the building and therefore the electrical demand of the equipment is reduced. For different ratios of the local energy fed to the heat pump, the following table is obtained:

Table 28. GEG emissions reduction by heating with heat pump

Emissions	With natural gas	H.P. with 0% PV	H.P. with 25% PV	H.P. with 50% PV	H.P. with 75% PV	H.P. with 100% PV
Ton CO₂/year	23,0	21,3	17,0	12,7	8,4	4,1
Emissions reduction (%)	0	8	26	45	64	82

In buildings that generate more energy than the amount needed for their operation, a global or holistic consideration of the GHG emissions associated to the project is recommended to fulfill the goal of reducing the magnitude of these emissions notoriously by the year 2050. Reason why it is not only considered quantification and reduction of CO₂ levels related to the operation or use of the building, but also in its construction and disassembly. The acceptance of energy standards from the planning of a building in which this analysis is intended to be carried out, encourage favorable factors for the reduction of emissions of greenhouse gases into the atmosphere originated in diverse processes. In the first instance, since energy is generated locally, the use and export to the grid of a generated energy that prevented the operation of thermoelectric plants is promoted. Additionally, the efficient operation of the building, given by methodologies aimed to reduction in use of different energy sources, ultimately promotes a reduction in the generation of said emissions. The use of environmental energy by means of heat pumps avoids the direct use of fossil fuels to carry out processes of heating water. From the construction of the building, it is possible to focus on the use of construction materials used in past projects in order to reduce the demand for production of materials and thus the emissions linked to these production processes. Ultimately, the use of sustainable materials reduces the demand for non-renewable materials in construction and, in turn, the use of wood and plant material encourages the use of natural materials that during their formation captured carbon dioxide.

In addition to this type of emissions that arise throughout the project, there are potentials that are also considered in this type of environmental analysis such as ozone depletion (ODP), soil and water acidification (AP), eutrophication, photochemical smog and abiotic exhaustion. Particularly, this standard encourages each person living inside the building to not surpassing a magnitude of CO_{2equivalent} emissions of 660 kg per year taking into account for the balance, the emissions related to the production of building materials, the construction as such of the building, the useful life of the building and the

disassembly. This threshold has its background bonded to the global goals of not exceeding the average temperature of the earth for more than 2 °C by 2050. The maximum permitted emissions up to that year are quantified so that the earth's temperature only increases in this magnitude and is evenly distributed among the supposed inhabitants of the earth that there would be in this year. From these quantified permissible emissions that arise a value close to two tons per person per year, it is estimated that about a third part relies on the residential sector equivalent to 660 kg.

A Life Cycle Assessment (LCA) was carried out in CONTREE based on the scenario "Ef+CI+BC" where an Energy Plus Building is reached through implementation of efficient home appliances, cooking with induction stoves and a heat pump to deliver warm water to the housing units. This to determine the total amount of GHG emissions that could be related to the entire project from its construction to its end use and to determine in advance materials, processes or critical activities that can be intervened before being materialized in order to mitigate this inherent environmental contamination.

As a starting point for the dimensions of the components of the entire residential complex and the materials that constitute them, both a three-dimensional model made by Concreto in *Revit* and an outline in *AutoCAD* were used, both including the stipulated physical dimensions that the project and the construction materials would have. It is important to note that, since the project is subject to minor changes, such as the proportion of one-floor and two-floors apartments and some particular construction materials, it is not possible for some zones of the buildings to have specific values or dimensions. In these cases, the LCA assumes standard construction materials and indicates the materials and / or dimensions assumed. Zones of the residential complex were separated into floors (interior and exterior), external walls and columns, internal walls (dividing or supporting), openings such as windows and doors (interior and exterior), stairs and ceilings as they are categorized in the German standard DIN 276. Apart from these project structures, the LCA also considers the necessary equipment in the normal operation of the building such as elevators, heat generators (heat pump), ventilation equipment, interior thermal conditioning, local power generation plants, electrical installations, among others.

For instance, dimensions of the exterior walls were particularly taken from the model in *AutoCAD* by measuring the four faces of both buildings by extracting the spaces corresponding to the openings in the windows and the columns as shown in Figure 56 indicated with yellow color.

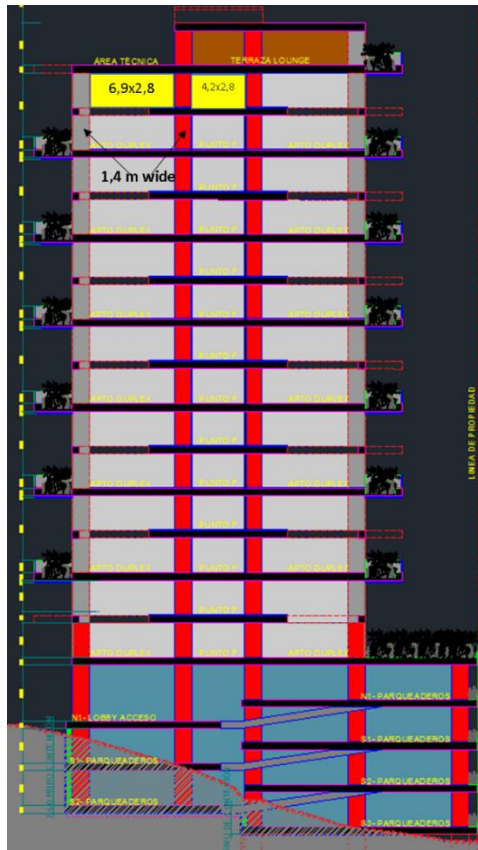


Figure 56. Outer walls of CONTREE

The *Revit* model shows a thickness for these structures of 15 centimeters whose configuration of layers of materials is assumed from the inside to the inside as paint (0.1 mm), stucco (0.2 cm), mineral wool (4.7 cm) and reinforced concrete with 1% steel (10 cm) for a total weight of 242 kg per square meter of this 15 cm deep structure. Similar configuration of layers are found in the internal walls of buildings. The layout in these walls from the inside out consists of a first layer of paint of 0.1 mm, a layer of stucco of 0.2 cm, superboard 2.5 cm, mineral wool 9.6 cm, superboard 2.5 cm, stucco 0.2 cm and paint 0.1 mm for a total of 15 cm thickness. Figure 57 highlights interior walls corresponding to the divisions of the rooms, apartments and corridors of both buildings.

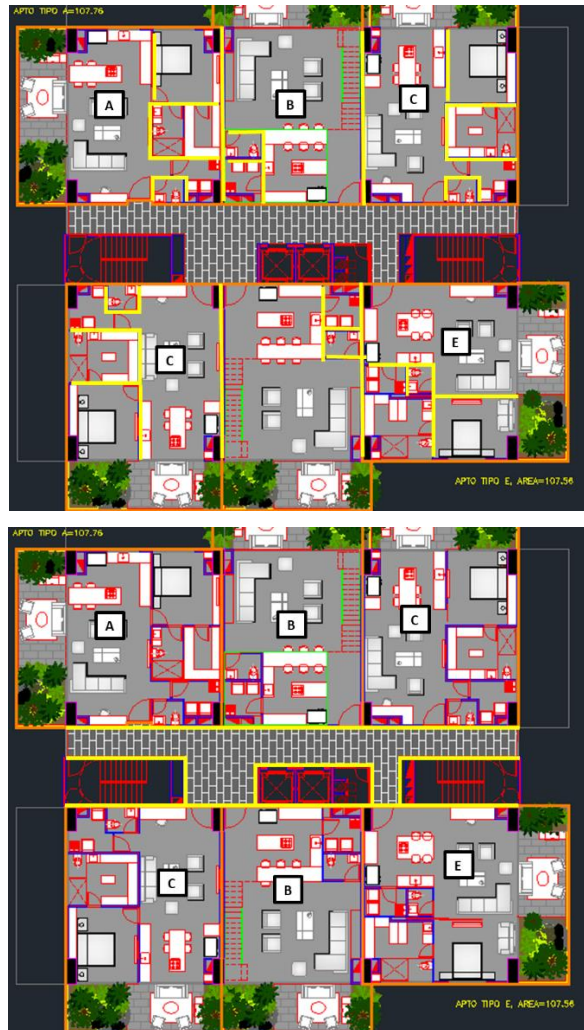


Figure 57. Inner walls of CONTREE

Windows of both buildings are located in the apartments, corridors and shared areas. For the apartments, four sizes of windows are found:

- 2 meters long by 0.5 meters high
- 2.8 meters long by 1.6 meters high
- 1.15 meters long by 1.15 meters high
- 6.95 meters long by 2.65 meters high (balconies)

At the end of both sides of corridors between apartments in every level there is a window 1.5 meters long by 1.7 meters high. The coworking area, by promoting natural lighting, has a large area of crystals. The glass door of this area is 4,5 meters high and a total length of 29 meters. In all the windows, a standard aluminum frame of 5 centimeters in

width was considered given that both the material and the thickness of the frames to be installed have not yet been defined.

The CONTREE model in *AutoCAD* shows that the duct adjacent to the stairs on the right will be used for water piping. For the distribution of warm and cold water, a potential scheme was drawn up for all the floors measuring the necessary lengths of pipes were determined for their inclusion in the LCA. It is proposed to transport warm water in polypropylene or polyethylene pipes that are capable of transporting water at a higher temperature than PVC and cold water in PVC because it is cheaper and still may realize this task.

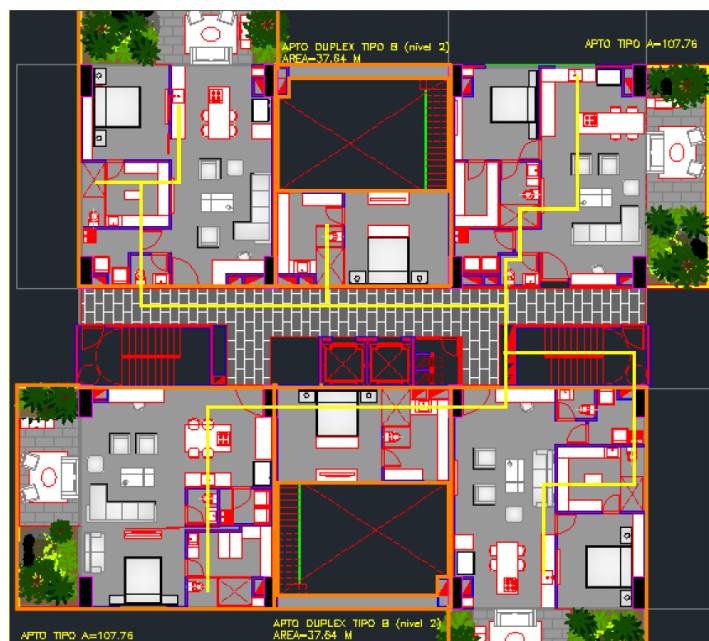


Figure 58. Potential distribution of water for dwellings

For each one of the foundation types present in the project, a particular organization of the layers that compose them was defined in order sum up this parts of the building to the LCA. For the 14.091 square meters corresponding to the totality of the apartments, an up-down configuration of 2 cm of tile, 1 cm of tiles adhesive, 2,5 cm of anhydrous gypsum, 4,5 cm of mineral wool, 2,5 cm of anhydrous gypsum, 10 cm of reinforced concrete and 37,5 cm of concrete molded in howoll cubes was used as input for a total thickness of 60 cm given in the *AutoCAD* model. This last layer is represented as occupying only 20% of the total thickness of the structure. That is, from a side view of the floor with a thickness of 60 cm, the concrete layer is present only in 20% of the total floor given the architectural design that Conconcreto proposes for a structure that forms

a kind of "hollow" squares whose depth corresponds at 37,5 cm of the layer as shown in Figure 59.



Figure 59. Floor/roof structure in building with hollow cubes structures

Under this configuration of hollow squares, the total amount of concrete to be used in the apartment floors is reduced. The configuration of the 1.720 square meters corresponding to the corridors of all the levels of the apartments is considered equal to that of the housing units with the only difference in the appearance of the tiles to be used. The floor of the covered garages has a total area of 12.870 square meters and it is assumed an alignment of 5 cm of asphalt or bitumen, a first layer of reinforced concrete with a thickness of 5 cm and a 50 cm layer of concrete distributed with the hollow cubes configuration (20% of the length) for a total of 60 cm. The *Revit* model shows for the external parking a floor layout from cobble of 4 cm on top of a layer of concrete assumed the same as for the other foundations as a 5 cm of reinforced concrete that relies on a 50 cm layer of concrete distributed along the area with hollow cubes representing 20% of the total length, complementing the total 60 cm structure shown in the *AutoCAD* model for an area of 1,020 m². The project contains 167 balconies found in all the apartments including 7 in the basements and upper terraces, that share a configuration of layers composed of a first layer of with 8 cm thickness of cedar wood located only in 50% of the area since the remaining area is used for the location of earth for plants as suggested in the *AutoCAD* model. The second layer is a reinforced concrete structure and a third and last layer of wood agglomerate of 15 cm thickness lays underneath for aesthetic reasons. Additionally, these balconies have a steel structure of 90 centimeters high around the perimeter that serves as a separator for the safety of users distributed as 0,4% of this perimeter. The second level of both buildings (N2) presents a shared surface

between them that can be used for a terrace or for the location of plants. This structure is composed like the balconies of a first layer of cedar wood 8 centimeters thick over a layer of reinforced concrete of 5 cm and a lower one of 47 cm which, like other structures, is spread over the entire area in the form of hollow squares so that it is present in only 20% of the total area of this structure. The apartments that are on this same level also have terraces that have the same positioning of wood and concrete. The last structure defined as a floor in the project is the coworking located on the first level (N1) of B1. The *Revit* model suggests a surface of 250 m² covered in porcelain tile of 3 centimeters thick, 1 cm adhesive, 2,5 anhydrous gypsum, 4 mineral wool, 2,5 anhydrous gypsum, 5 cm reinforcement concrete and 40 cm of concrete with a hollow cubes configuration representing 20% of the area of the floor for a total thickness of 60 cm.

The upper terraces of the buildings that are intended for social activities such as grills, have a first layer of cedar wood 8 centimeters thick on a gravel layer of 10 cm supported by 5 centimeters of concrete to end in a final section of molded concrete in hollow squares of 37 cm of depth also representing 20% of the total area with this arrangement. Additionally, this last level of each building has an additional structure that serves as a roof for the corridor, stairs, common area and machines room. This roof will serve as a structure for the local electrical generation plant of the reinforced concrete project of 59 centimeters and a lower layer of stucco of 1 centimeter to give a homogeneous finish to the roof. In the first level where the outdoor parking is located, a room is going to be built for collecting waste from the apartments with an area of 12 square meters and a height of 2.8 meters. The roof of this construction is supposed to be a 60-centimeter layer of reinforced concrete.

The project has different types of doors according to the room to be accessed through them. The vast majority of these doors are made of wood and for the following is assumed a thickness of 8 centimeters:

- 2 doors to enter the spa
- 34 doors to enter the rooms for garbage disposal at each level
- 73 doors to enter the stairs of the buildings
- 657 doors that divide the different rooms inside the apartments
- 112 doors for storage rooms in garages

In addition, the 160 doors to enter the apartments are assumed with a thickness of 10 centimeters and, according to the *Revit* model, the door that leads to the gym is made with glass with a thickness of 2 centimeters.

These structures make up the whole KG 300 group of the DIN 276 standard on which the standard for performing the LCA is based and are summarized in the following table:

Table 29. Physical structures components or KG 300 group

Structure	Part	Area (m ²)	Thickness (m)
Foundations	Apartments	14.091	0,6
Foundations	Hallways	1.722	0,6
Foundations	Garages	12.870	0,6
Foundations	Outside parking	1.020	0,6
Foundations	Balconies	4.019	0,6
Foundations	Terraces of flats	122	0,6
Foundations	Terraces in first level	730	0,6
Foundations	Coworking	250	0,6
Outer walls	West walls	811	0,15
Outer walls	East walls	815	0,15
Outer walls	North walls	614	0,15
Outer walls	South walls	614	0,15
Outer walls	Room for waste	95	0,15
Outer walls	Balconies separation	122	0,15
Columns	Building 1	438	1,4
Columns	Building 2	716	1,4
Columns	Building 1 basement	228	1,4
Columns	Building 2 basement	252	1,4
Balconies	Metal separator (0,4% steel)	2.074	0,9
Inner walls	Apartments	7.802	0,15
Inner walls	Hallways	2.329	0,15
Inner walls	Storage rooms	941	0,15
Inner walls	S3.5 Level	183	0,15
Stairs	Stairs	459	0,165
Roofs	Upper terraces	1.066	0,6
Roofs	Room for waste	12	0,6
Door	Apartments	538	0,1
Door	Rooms in apartments	1.156	0,08
Door	Stairs	161	0,08
Door	Garbage disposal rooms	60	0,08
Door	Storage rooms	197	0,08
Door	Gym	3	0,08
Door	Spa	5	0,08

In addition to these structures contained in the KG 300 group, the LCA proposed in this work, based on the *Aktivplus* standard methodology, considers the appliances included and equipment included in the KG 400 group of the standard such as elevators, water transport systems, heat pumps, local power generation plants, among others.

Therefore, the GHG emissions corresponding to a photovoltaic system of 519 kW_p, two electric heat pumps of approximately 40 kW thermal, warm water storage tanks of approximately 7 m³ each, a piping system for warm and cold water isolated and without isolation respectively and four elevators are taken into account within this group.

Generally, for construction projects in Colombia, given the scarcity of information related to the environmental impact of the production, use and final disposal of the materials used in the construction sector, the particular values for the LCA are taken mostly as global, South American or other values of the world. Through databases such as *Ecoinvent* or *GaBi* that have extensive content to perform this type of analysis, the values assigned for greenhouse gas emissions, ozone layer deterioration, eutrophication, photochemical smog, among other factors Environmental impact is generally applied to global values given that they have not yet been quantified specifically for Colombia. Access to these two databases must be done through a payment license, which restricts the accuracy of the result obtained from the LCA performed in this work regarding the availability of information, since a free database with a shorter extension was used. The information used in this LCA was obtained from *Exiobase*, a global database of the year 2007 that contains information for about 40 countries, 5 world regions and 200 products (Tukker et al., 2013). Through *Exiobase* and the information provided for Latin America (WL), the GHG emissions related to most of the project components were determined, with some exceptions that were not included in the database. The main disadvantage of using these so-called "input-output" databases is the categorization of products in higher families or groups that does not allow specificity for some similar materials. For example, defining global warming potential related to implementation of specifically PVC or PP piping is not possible as the database only offers a common value denominated "plastics" where other plastic materials may be included that move the GWP value to a better or worse magnitude. A few particular values for the emissions that were already determined for Colombia related to the construction processes were obtained from a study of the Universidad de los Andes for cement, steel, brick, glass and cement transport as shown in the following table:

Table 30. GHG emissions from production of construction materials in Colombia

Material	kg CO _{2eq} /kg material
Cement	0,69
Steel	2,94
Brick	0,23
Glass	1,47
Concrete transportation*	0,703

*This factor is measured per kilometer traveled and not per kilogram of material. The authors suggest an average distance of 25 km per trip of the mixer that contains six m³ of concrete, that contains one third of cement.

For the missing cases in which there is no data either for Colombia or Latin America, values of GHG emissions from construction materials were taken from European standards as EGS-Plan had access to data banks that provide such values. This in order to at least pretend a leveling or normalization on production and disposal methods by avoiding the use of specific values for a single country such as Germany and therefor complete the analysis. These European values were obtained through the SBS Building Sustainability application that allows LCA to be made under the criteria of the German sustainability standard DGNB. Using this tool, the relative values of the missing materials were obtained from the European Sustainable Construction Database (ESUCO). The emissions related to the production of a photovoltaic plant per m², including panels, cables, inverters and structures, were obtained from the study called Sustainability Evaluation of Solar Energy Systems (SENSE) that makes a weighted average of the different photovoltaic technologies available in the market (monocrystalline and polycrystalline modules of silicon, cadmium and tellurium, amorphous silicon, mixtures of copper, indium and gallium, among others) to quantify the impact of the production of these goods on the environment (European Commission, 2006). The study then quantifies a total GHG of 208 kg CO_{2eq}/m²_{modules}. Additionally, emissions originated from generation of electric power in Colombia according to the current generation matrix, amount to 367 grams of CO_{2eq} for each kilowatt-hour generated as stated in the Resolution 804 of 2017 from the Unit for Mining and Energy Planning from Colombia (UPME).

The GHG emissions of all the materials present in the project are shown in the following table with their source (for Colombia, Latin America, Europe or global).

Source. (Cadena Á. et al., 2012)

Table 31. Specific GHG emission factors of physical components of the project

Location	Element	Unit	Kg CO _{2eq} /Unit
Colombia	Reinforcement steel	kg	2,94
Colombia	Cement	kg	0,69
Colombia	Brick	kg	0,23
Colombia	Glass	kg	1,47
Colombia	Concrete transportation	km	0,70
Colombia	Electric mobility	kWh	-0,89
Colombia	Use of electricity	kWh	0,367
Latin America	Plastic piping	kg	0,72
Latin America	Incineration of plastics	kg	1,74
Latin America	Incineration of wood	kg	0,30
Latin America	Incineration of construction materiales	kg	0,43
Latin America	Aluminum profiles	kg	1,32
Latin America	Tiles	kg	0,48
Latin America	Drywall or gypsum board	kg	0,43
Latin America	Gypsum	kg	0,48
Latin America	Sea transportation	Euro	0,413
Latin America	Land transportation	Euro	0,189
Europe	Paint	kg	2,53
Europe	Tiles adhesive	kg	0,35
Europe	Handle window/door	Piece	0,13
Europe	Wood	kg	0,02
Europe	Aluminum frame	m	14,33
Europe	Building materials disposal	kg	0,02
Europe	Heat pump(up to 70 kW)	piece	2852
Europe	Concrete C20/25	m ³	259
Europe	Mineral wool	m ³	69
Europe	Elevators	piece	992
Europe	Steel sheet	kg	1,13
Europe	Asphalt	kg	0,13
Europe	Warm water storage tank	kg	2,88
Global	Photovoltaic power station	m ²	208

Emissions for both sea and land transport are available with respect to each euro that the shipment costs. Quotations were made on shipping websites with different suppliers

for the photovoltaic system and for the heat pumps that would be imported to Colombia, as there is no local production of these goods. For shipment by ship, a trip from China (where such equipment is widely produced) to the Colombian port of Cartagena was calculated on the *Freightos* and *Worldfreightrates* portals and for the shipment from the coast to the city of Medellín by trucks, prices were generated through local shipment providers like *TCC* and *Coordinadora*.

Table 32. Quotations for shipping of imported equipment to Colombia

System	Type of shipment	Price (Euro)	Volume (m ³)	Weight (kg)
PV plant	Sea	8.800 – 12.500	12	34.000
PV plant	Land	9.500	12	34.000
Heat pump	Sea	620 - 790	2	200
Heat pump	Land	300	2	200

Source. Own elaboration with quotation from (Freightos, 2017) and (World Freight Rates, 2013) for sea transportation and (TCC, 2019) and (Coordinadora, 2019) for land transportation.

Finally, the amount of emissions that promote global warming, attributed to this whole project of a residential complex in Colombia considering its construction, operation and disassembly, within the first 20 years of service is 790.2 kg CO_{2eq}/(person · a). This figure is a net value, since it also considers “negative” emissions or avoided CO_{2eq} generation by means of the generation of electric power locally and the emissions that would not be released to the atmosphere for having charged automobiles electrically.

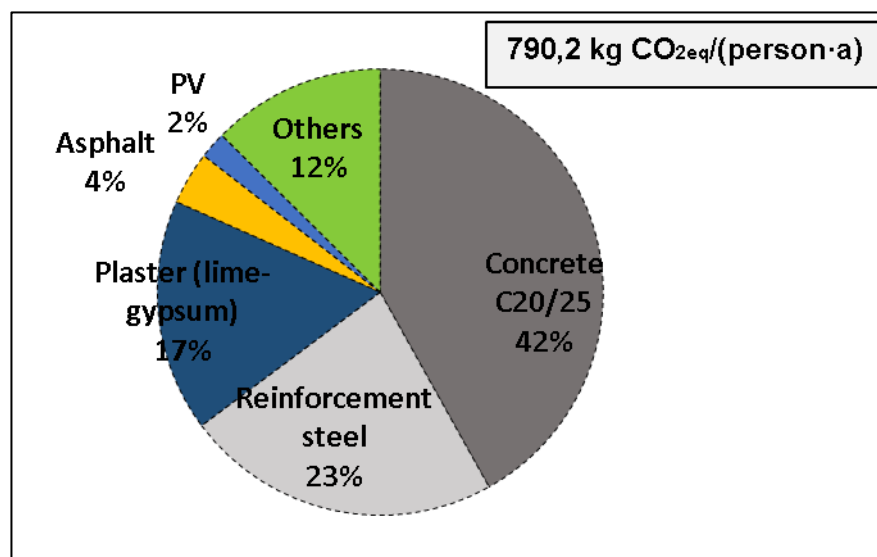


Figure 60. Global warming potential of used materials in CONTREE

Regarding the emissions avoided by the generation of electric power, under the scenario that has been considered, denominated as "Ef + CI + BC", the energy demand is 375.140 kWh annually regarding operations of both the apartments and the shared areas. Following the statement of the Resolution 804 of 2017, that determinates a GHG emission factor of 367 grams for each electric kilowatt-hour generated in Colombia, total emissions of 478 kg CO_{2eq} per person per year are to be released. The power plant designed in this work would be able to generate 410.048 kWh per year equivalent to avoiding 523 CO_{2eq} per person each year, higher than the emissions that arise from the same demand of the entire building as it would be exported to further use outside the project.

Considering the electric mobility promoted by the project, the energy company Codensa states that for every kilometer traveled in a private car in Colombia driven with traditional fuels, an average of 190 grams of CO_{2eq} are being emitted into the atmosphere due to the combustion of gasoline (2015). According to the electric cars stock in Medellín, exposed in the previous section, there is a performance of 16.3 kWh/100 km with a resulting equivalency of 60 gCO₂/km. In this way, for every kilometer traveled by an electric car charged in the station of CONTREE, 130 g of GHG are being avoided or for every kWh injected into the vehicle, 790 g of GHG are avoided.

It is widely known that main origin of GHG emissions in the construction sector is concrete due to its high demand in any type of project, as it has been traditionally used as the component par excellence to give shape, resistance and protection in buildings. This project pretends to implement around 19 thousand tons of concrete to compose parts of the walls, floors, paths, roofs and balconies. Factor 0.1 kg CO_{2eq}/kg of concrete or 260 kg CO_{2eq}/m³ relies mainly on the so-called process of "decarbonation" of limestone to obtain lime, a component of cement that in turn constitutes about a third of the concrete. In addition to this release of CO₂ by the calcination of this raw material, the massive transport of concrete mixtures is also attributed to considerable emissions of these gases.

Mitigation measures against this fact refer to the partial integration of other binders in construction such as expanded clay, which, as the name implies, expands in its production process, achieving greater volume and requiring a lower extraction rate of the resource to fill the same volume in the building. This material, whose application in construction has been widely known by society, satisfies characteristics required by construction standards to be implemented in projects such as low thermal conductivity

and resistance to compression for different types of construction at the same time that has a density almost seven times smaller than the concrete, allowing, with its partial application, a reduction in the weight of the work.

Additionally, in order to reduce emissions that would be related to the demand for cement and therefore for concrete, it is reasonable to consider the inclusion of construction and demolition waste (CDW) in the production of the structural binder. Given that properties of the final product where a mixture of new and reused materials is implemented, depend on their origin and the function they had before being a waste, a lack on homogeneity of the result might easily show up. A mixture of different CDW could be at least used in sections that do not require a greater complexity in the final properties of the material. Such as walls, whose function is only separating zones but do not mean a support in the structure, for example in the more than 115 storage rooms located in the basements that would traditionally be built with concrete.

To mitigate the 4% of the total GHG emissions of the project that refer to the asphalt of the external parking lots and covered parking areas, the partial use of plastic waste, whose currently use worldwide is around 40% for the composition of sidewalks and tiles, might be considered due to its proven well performance. High-density polyethylene (HDPE) and polyvinyl chloride (PVC) are widely recycled plastics for this purpose.

Techniques of the well-known Lean Construction method to minimize losses and maximize utilization of resources are also relevant to aim to reduce emissions relative to the project. Through the continuous improvement proposed by the methodology, a focus is given to avoiding inefficiencies in matters of leftover materials, planning of shipments and mobilizations according only to the need or specifications and clear designs to avoid reprocessing, among other specificities that aim diminishing the volume of used materials.

The costs associated with the construction materials of this project were taken from information on standard unit prices exposed by the Colombian Chamber of Construction (CAMACOL) for the year 2017 and in a few cases for 2010 where recent data was not available. Through the Index of Consumer Prices (CPI), these prices were scaled up to April 2019. The Bank of the Republic of Colombia indicates that this price increase from the date when these standard construction prices were exposed until 2019, is 8,75% for prices from 2017 and 35,62% for 2010. Price for the construction materials is given in Colombian pesos (COP) and an average exchange rate of 3.600COP/Euro is used to

show in the next table a summary of the implemented materials original prices and scaled to 2019:

Table 33. Specific costs of building materials

Year	Building material	Unit	Price (Euros)	Price + IPC
2017	Hollow Bricks (Balcony separator of 15 cm)	m ²	8,2 €	8,9 €
2017	Steel bar 40000 psi	kg	0,7 €	0,8 €
2017	Slab up to 15 cm	m ²	17,9 €	19,5 €
2017	Concrete stairs	m ³	176,2 €	191,6 €
2017	Stones for parking flooring	m ²	14,3 €	15,5 €
2017	Tiles	m ²	18,7 €	20,3 €
2017	Porcelanate tiles	m ²	21,2 €	23,1 €
2017	Piping 4" (dwelling sewage)	m	7,3 €	7,9 €
2017	Piping 6" (main sewage)	m	21,5 €	23,4 €
2017	Piping 2 1/2" (distribution cold water)	m	21,2 €	23,1 €
2017	Piping 4" (main cold water)	m	25,4 €	27,6 €
2017	Piping fittings	Unit	2,8 €	3,0 €
2017	Wooden door	Unit	31,5 €	34,3 €
2017	Wooden door (apartments)	Unit	48,2 €	52,4 €
2017	Aluminium frame	m ²	26,6 €	28,9 €
2017	Aluminium banister	m	15,9 €	17,3 €
2017	Garbage disposal piping	m	55,4 €	60,2 €
2017	Doors lock	Unit	23,8 €	25,9 €
2017	Stucco walls	m ²	1,2 €	1,3 €
2017	Paint	m ²	1,3 €	1,5 €
2017	Superboard (Gips)	m ²	19,6 €	21,3 €
2010	Tiles adhesive	gal	8,2 €	11,1 €
2010	Asphalt	gal	1,5 €	2,0 €
2010	Mineral wool	m ³	151,2 €	205,1 €
2010	Concrete 3000 psi	m ³	96,2 €	130,4 €
2010	Mortar	m ³	136,5 €	185,1 €

2010	Glass	m ²	12,2 €	16,6 €
2010	Flat Wood sheet (8cm)	m ²	13,6 €	18,5 €
	PV Plant*	kW _p	1.100 €	1.100 €
	Heat pump^	Unit	20.000 €	20.000 €
	Warm water storage tank^	Unit	6.000 €	6.000 €

*Based on prices given by (CELSIA, 2018)

^Based on projects developed by EGS-Plan

Source. (Camacol, 2017a)

Table 34. Quantity of materials stipulated for the building's construction

Material	Unit	Quantity	Total Price (€)
Hollow Bricks (Balcony separator of 15 cm)	m ²	97	863 €
Steel bar 40000 psi	kg	222.318	171.848 €
Slab up to 15 cm	m ²	18.817	366.425 €
Concrete stairs	m ³	76	14.510 €
Stones for parking flooring	m ²	1.020	15.832 €
Tiles	m ²	16.271	330.866 €
Porcelanate tiles	m ²	250	5.763 €
Piping 4" (dwelling sewage)	m	1.860	14.779 €
Piping 6" (main sewage)	m	120	2.809 €
Piping 2 1/2" (distribution cold water)	m	3.720	85.863 €
Piping 4" (main cold water)	m	240	6.631 €
Piping fittings	und	279	841 €
Wooden door	und	2.298	78.809 €
Wooden door (apartments)	und	538	28.161 €
Aluminium frame	m ²	749	21.673 €
Aluminium banister	m	383	6.602 €
Garbage disposal piping	m	120	7.228 €
Doors lock	und	747	19.318 €
Stucco walls	m ²	20.915	27.336 €
Paint	m ²	20.915	30.696 €
Superboard (Gips)	m ²	19.045	406.447 €

Tiles adhesive	gal	42.492	470.819 €
Asphalt	gal	170.238	334.772 €
Mineral wool	m ³	437	89.726 €
Concrete 3000 psi	m ³	5.218	680.494 €
Mortar	m ³	24	4.497 €
Glass	m ²	4.443	73.776 €
Flat Wood sheet (8cm)	m ²	8.829	162.978 €
PV Plant	kW _p	519	570.900 €
Heat pump	und	2	40.000 €
Warm water storage tank	und	2	12.000 €
Total construction materias			4.067.403 €
Total equipment (PV and warm water)			622.900 €
Total Project budget			4.690.303 €

An approximate of 4.7 million euros for the construction of CONTREE is calculated, of which 13% corresponds only to the local renewable energy generation plant and thermal energy generation. Additionally, considering the first 20 years of the building's life, other necessary outcomes are considered, such as electricity, water supply and sewerage services. Since this investment approximation is made regarding the scenario defined as "Ef + Cl + BC" that implies just an energy expenditure of electricity, by covering the demand for hot water with heat pumps and cooking by means of induction stoves, the consumption of natural gas is not required.

According to the prices of Empresas Públicas de Medellín, provider of the aqueduct and sewerage service, to April of 2019 for socioeconomic stratum 6 (where CONTREE is going to be built), price per cubic meter per household for aqueduct, reaches 1.12 € plus a fixed monthly charge of 2,74 € per housing unit and for the sewer system for 0,98 € per m³ with a fixed charge of \$ 1,57 € per housing unit (EPM, 2019). Table 19 shows that, according to the annual pattern of power generation and consumption within CONTREE, in order to satisfy the demand that is not covered with the local plant, 204 MWh have to be imported at a price of 0,13 €/kWh and the total generation excess reaches a value of 240 MWh each year with a sale price of 0,05 €/kWh. The costs summary of the first twenty years of the building, time that considers the standard for this type of evaluation is shown in Figure 61. This total cost value distributed in the 160 apartments that equals 14,091 m² leads to a value of \$ 431/m².

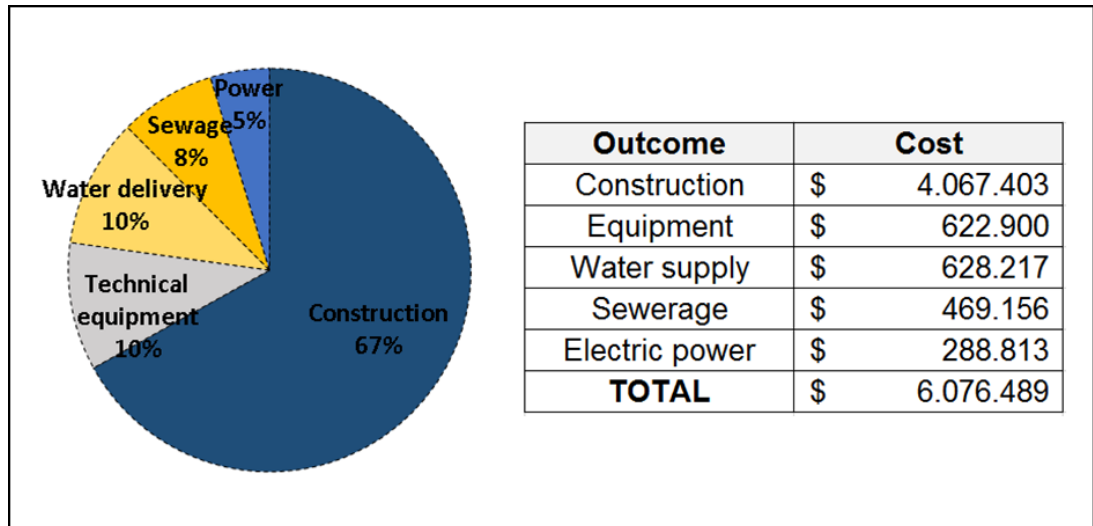


Figure 61. Costs distribution from Life's cycle of the building

6. CONCLUSIONS OF THIS WORK

This work aims to expose, through a specific methodology, the reasons why it is relevant for Colombia's sustainable development goals for the year 2050, the consideration of a model of buildings that serve as housing for society and at the same have a positive impact on the environment. The integration of decentralized energy generation technologies from renewable sources with a reciprocal efficient use of this resource by means of specific methods here exposed, encompass from the construction sector the two goals of the global Energy Transition. Through the introduction and implementation of building designs that generate more energy than the one needed for their operation in the Colombian context, an initiative focused on reducing the existing gap between different needs or problems of different sectors and their coverage or end solution. Specifically, in a first place, the influence of the Energy Plus Buildings in Colombia in the decrease of the peak in the use of thermoelectric plants for the generation of electrical energy in times of drought due to the high dependence on water resources. Parallel to this is the second need that is pretended to be covered by setting out an initiative that reduces greenhouse gases which is already of governmental interest through the Colombian Strategy of Low Carbon Development for the housing sector whose formulation is not yet finished and could integrate methodologies like the one exposed by *Aktivplus*.

This multifamily housing project proposes to be the pilot in Colombia under this German construction standard in Colombia and serve as a reference for future conceptions of

buildings interested in developing similar ideas for housing that do not have a negative impact in the environment. Broadening of construction of buildings that generate more energy than the one need for their operations will be encouraged by the Colombian context, since it will encourage a legal and economic framework for interested parties to speed up the materialization of such projects. The second chapter of sustainable construction in Colombia that begins in 2019 may allow future proposed concepts by energy standards to be widely spread along the country. Colombia's remarkable economic growth in the last two decades can mean a viability for financing plans, supporting paths or investment of the government in building these initiatives. By last, the Colombian legislative scope through actions such as the Law 1715, implemented in Energy Plus Buildings concepts, aim to break the paradigm that renewable energy technologies are not yet economic competition against traditional generation methods.

7. APPENDIX

A. EXAMPLE OF AN ENERGY PLUS BUILDING THROUGH THE *AKTIVPLUS* CONCEPT

As mentioned in section 2.2.1. the developed concept of an Energy Plus Building is presented under the *Aktivplus* energy standard whose operation time started in 2015 in the city of Frankfurt, Germany.

The boundaries for an energy balance under this methodology are defined as the size itself of the ground where the building or buildings (when a neighborhood is evaluated) are constructed. In this project, the electrical energy generated within the system is given by the installation of 251 kW_p of photovoltaic modules on the roof and 118 kW_p on the south façade for an annual generation of 299 MWh or 34 kWh/m² and a final energy consumption per year of 251 MWh or 28.6 kWh/m². Respectively this facilities have a generation factor of 980 kWh/(kW_p · a) and 450 kWh/(kW_p · a). It has a 250 kWh battery to encourage excess generation to be used inside the building before being sent to the electricity grid. Additionally, as the clean generation of electric power just by itself is only a partial solution to achieve the goals stated in the Energy Transition, it is imperative to use energy efficiently in the building. This is why all the energy required for heating and water heating is provided by a 120 kW_{th} heat pump that uses the city's wastewater as a heat source through a heat exchanger installed in the ducts of the city. In this way the use of oils and combustible gases as a source of thermal energy for these tasks is avoided. A condensing boiler that uses natural gas is only available as backup against failures, repairs or maintenance of the heat pump. To continue with an efficient use of energy and promote that in the annual energy balance a surplus in the generated overcomes the required energy, all the apartments (which are entirely for lease may not be bought), are equipped with high efficiency appliances in order to prevent tenants from installing old equipment with low efficiencies that significantly increase the final energy consumption. Apartment's ventilation is developed through heat recovery systems that are a simple and efficient measure to preserve the heat especially in winter, when the air inside the apartment that was already thermally conditioned transfers heat to the new fresh air in order to avoid wasting warm air into the atmosphere. A general outline of the different technologies integrated in the "Aktiv-Stadthaus" project in Frankfurt can be found in the following figure.

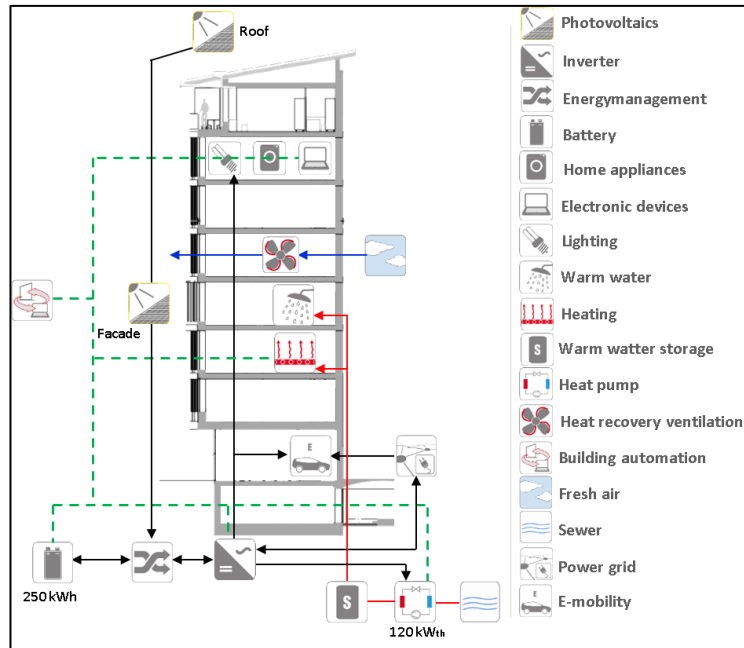


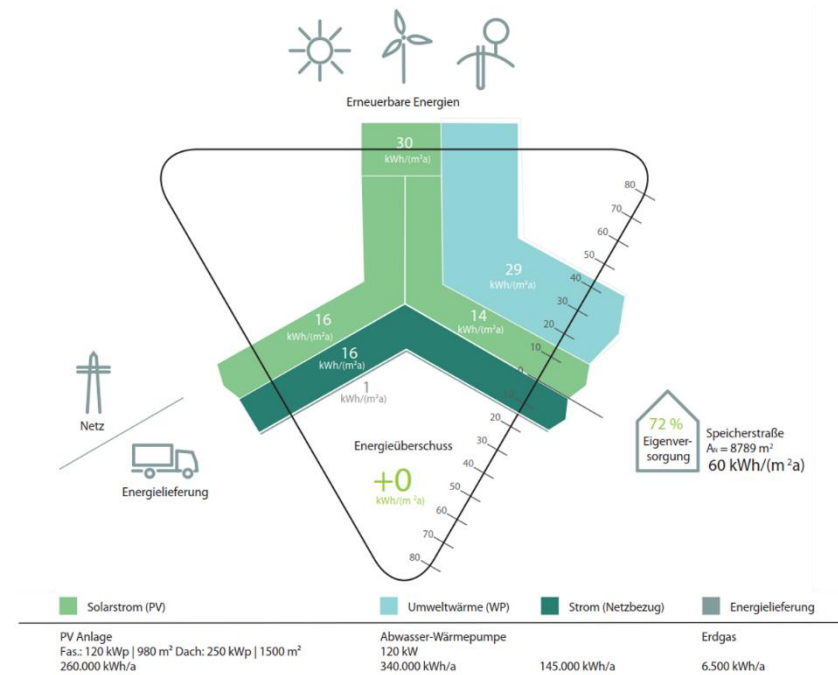
Figure 62. Energy scheme of Aktiv-Stadthaus in Frankfurt

Source. (EGS-Plan, 2018)

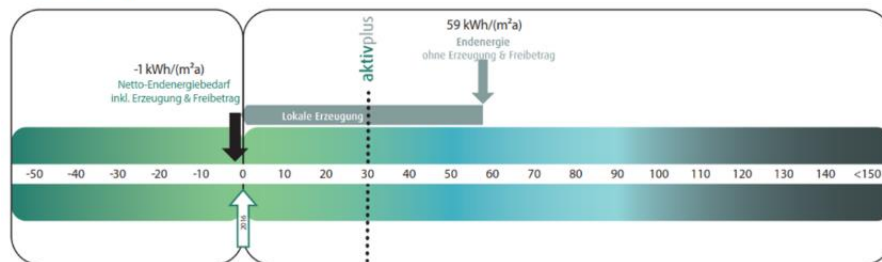
Energy consumption monitoring of in each housing unit is possible through a graphic interface in an installed Tablet that leads to exposing historical behavior in demands of this resource, and compares with ideal values in order to make decisions when they can still have a positive impact on consumption habits in each house. Another important concept to highlight is the inclusion of electric mobility inside the building, where there are places for charging cars and a platform for car sharing by residents of the building in order to reduce traffic in the city and the energy needed for each person's mobility.

Finally, the label obtained by this project evaluated with this methodology is shown in Figure 63 when evaluating the performance of the building after the first year of operation. The energy balance is shown in a triangle that pictures in green the energy generated within the system and in the distribution proportion between the own consumption and injection to the grid, in light gray it is shown how much thermal energy was provided through the heat pump for warm water and room's heating, in red is drawn how much energy was taken from the grid and finally the thin dark gray line shows other energetics required (in this case natural gas was used for the condensing boiler used when repairing the heat pump). The lower part shows a first bar with the annual energy demand per square meter of the building with a gray arrow and the left side shows this same demand when considering the self-supply with energy from the photovoltaic

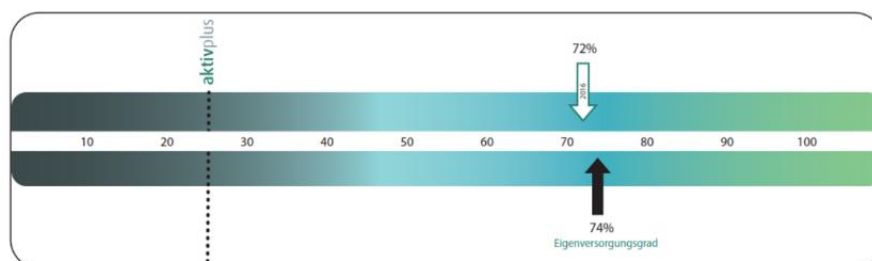
system of the building with a black arrow and a white arrow. These arrows indicate the value calculated in the design of the building or theoretical value and the measured value obtained after the first year of operation respectively. The second bar shows the percentage of the energy demand was contributed by the generation in situ by means of modules and heat pump with the same pointing of the arrows.



ENDENERGIEBILANZ*



EIGENVERSORGUNG WÄRME UND STROM*



*Inklusive E-mobilität und Gewerbestrom

Figure 63. Aktivplus label of Aktiv-Stadthaus

Source. (EGS-Plan, 2017)

The following figure shows the excess energy generated in the “Aktiv-Stadthaus” building in Frankfurt and a theoretical behavior if the same building was built in the city of Medellín where energy demand is not necessary for housing heating and annual solar radiation is greater.

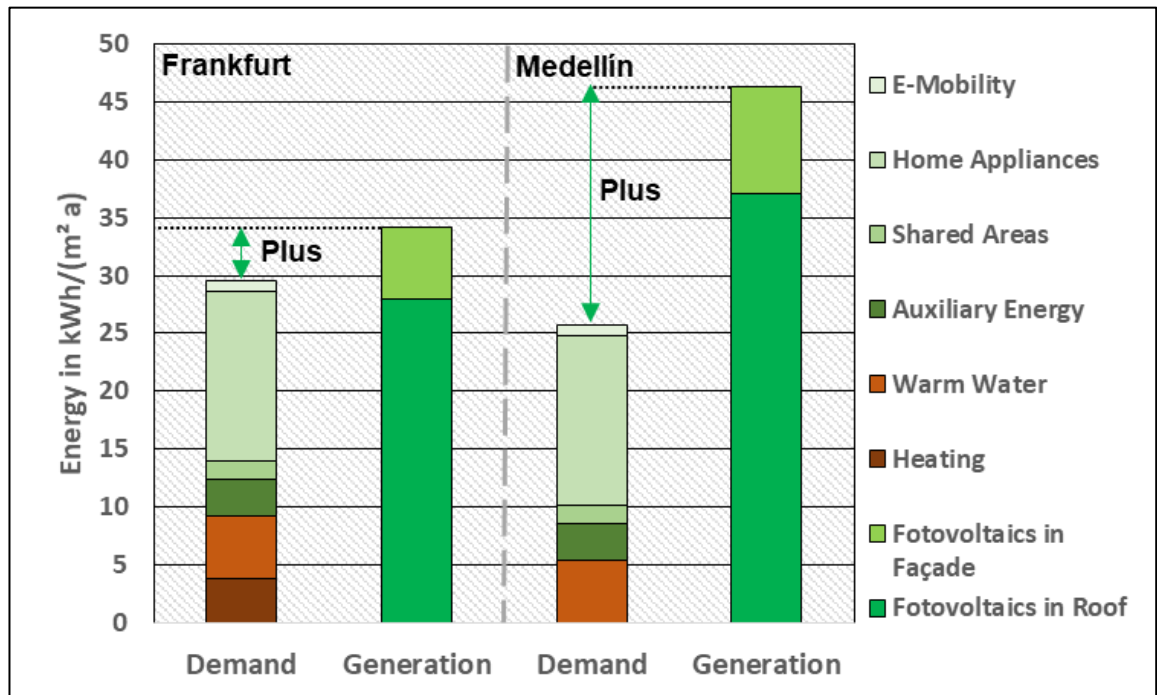


Figure 64. Energy demand and generation of Aktiv-Stadthaus in Frankfurt and theoretical values in Medellín. Own elaboration with data from

Source. (EGS-Plan, 2018)

B. ENERGY COMPARISON BETWEEN GERMANY AND COLOMBIA

	Factor	Colombia	Germany
Generalities	Population (MM)	49,07	82,79
	Primary Energy demand (GWh/year)	488231	3.736.389
	Final Energy demand (GWh/year)	338.841	2.542.000
	% Technical and no technical losses	31%	32%
	Sector with highest demand (GWh/year)	Transportation - 138.586 (40,9%)	Transportation - 749.000 (29,5%)
	Demand in residential sector (GWh/year)	56.654	665.000
	Demand in residential sector (MWh/person year)	1,2	8,1
	Mayor consumidor en residencial	Cooking: Urban (46%) Rural (77%)	Heating: 69%
	Legal Framework for new buildings	Resolution 549/2015	EnEV and Directive 2010/31/EU
	Sustainability standards for buildings	LEED and CASA	DGNB, LEED, BREEAM
Renewable energies	Initiatives of energy standards for buildings	-	Passivhaus, Aktivplus, KfW Effizienzhaus, Effizienzhaus Plus
	g CO _{2eq} /kWh _{electric}	367	489
	Sustainability Index	48	7
	PV installed power (MW)	30	42980
	PV Potencial	Average radiation: 4,5 kWh/(m ² d) and 40 GW	Average radiation: 3,0 kWh/(m ² d) and 200 GW
	Wind Installed power (MW)	19,5	56.154
	Wind Potential (MW)	29.500	285.000
	Bioenergy installed (MW)	92	36
	Bioenergy potential (MW)	14228,4	5.330 (45.000 if crops for energy are considered)
	Geothermal electricity Installed (MW)	-	34,83
	Geothermal heat Installed (MW)	-	4.600
	Geothermal electricity Potential (MW)	-	35.616
	Geothermal heat Potential (MW)	10.000	-
	Hydroelectric Installed (MW)	11.722	5.490
Hydroelectric Potential (MW)	56.187	3.790 - 4.806	

Figure 65. Energy comparison between Germany and Colombia

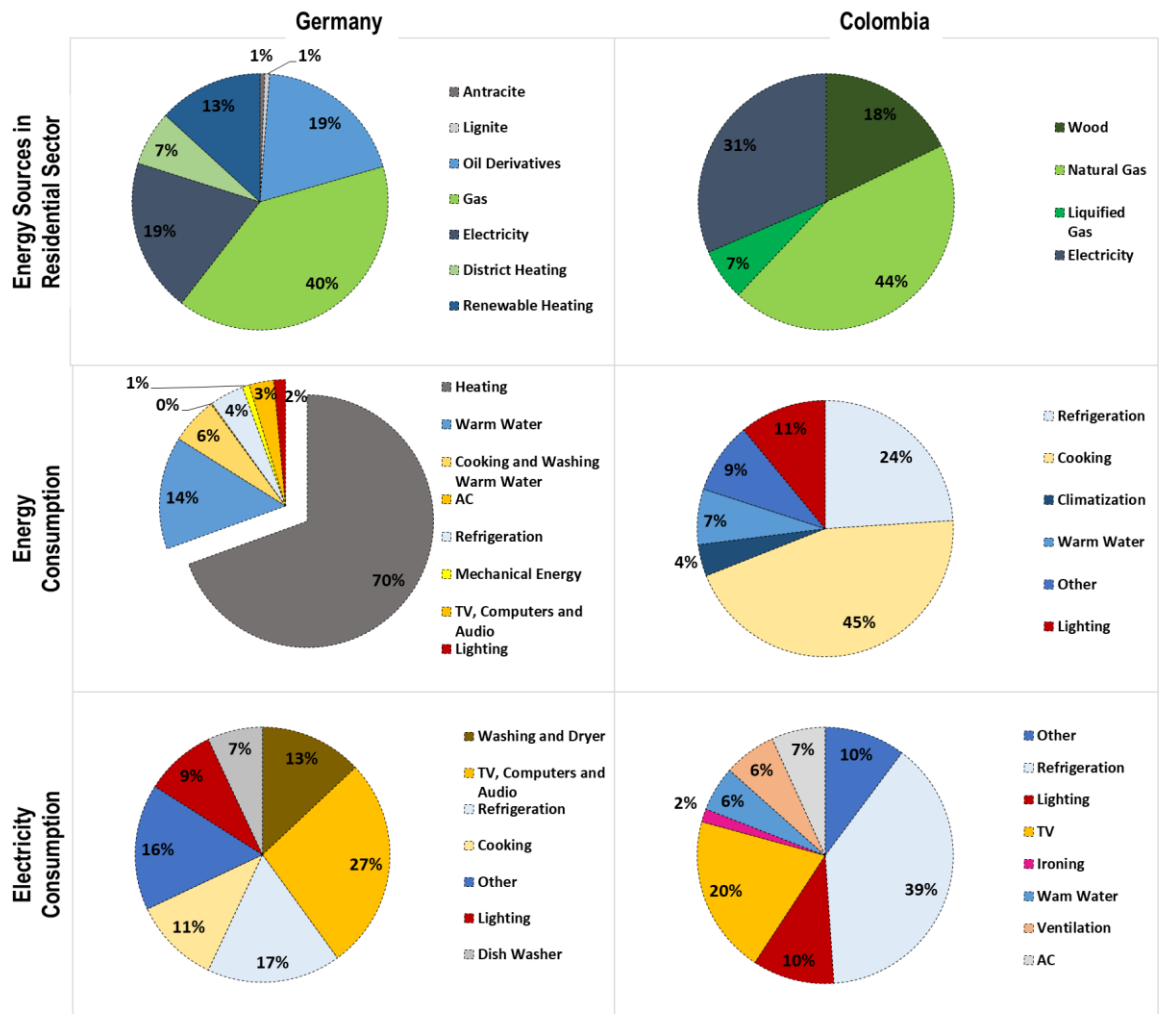
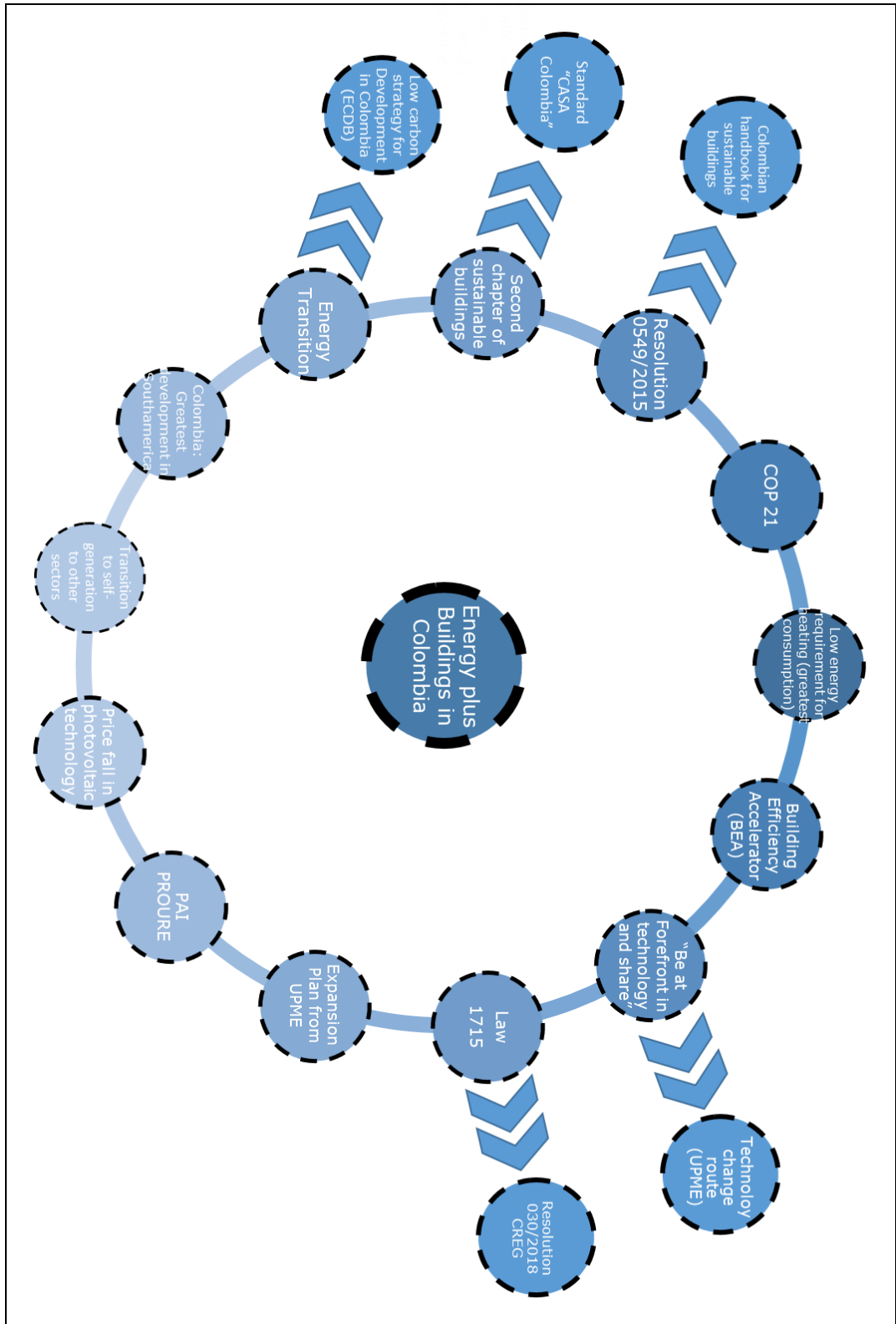


Figure 66. Energy demand characterization in colombian and German dwellings.

Source. Own elaboration with data for Colombia from (UPME, 2017a) and (Ministerio de Minas y Energía, 2016b) and (Umwelt Bundesamt, 2016) and (Stromspiegel, 2016) for Germany.

C. FACTORS THAT ENCOURAGE THE DEVELOPMENT IN COLOMBIA OF BUILDINGS THAT GENERATE MORE ENERGY THAN THE ONE THEY NEED FOR THEIR OPERATION



D. COMMENTARIES FOR THE DEFINITION OF A COLOMBIAN ENERGY STANDARD FOR BUILDINGS

From different points of view it is possible to argue the validity of the application of sustainability standards and furthermore, energy standards in the buildings sector as one of the particular ways to encourage the establishment of the Energy Transition as an inherent component of the economic development of society. In particular, this document adopts the arguments of the preservation of the environment, the introduction of new technologies and the ethical component present when a new paradigm for the sources of energy generation is to be expanded.

Possibly most of the factors that incentivize this methodology are inclined towards a position where the care of the ecosystems is favored by means of the omission of fossil materials combustion and transportation of energy to consumption points. In addition to change in the way of generating energy, the use of this service is reduced by combining active and passive measures that lead to the implementation of efficient consumption equipment, appropriate monitoring for on-time decision-making, alternatives for the mobility of users, among others.

The standard that is intended to be adapted for Colombian conditions due to their differences with Germany in terms of climate, legislation and purchasing power is to be flexible in the chosen path to achieve a building that its annually generated energy within its borders is greater than the amount that was necessary for its operation. Unlike energy curves presented by Energy Plus Buildings in countries of the northern hemisphere with seasons as shown in Figure 8, an energy balance for a building designed under this methodology in Colombia could have a behavior similar to the one proposed in Figure 67. There not only would be possible to have a greater excess energy generated by the higher levels of annual solar radiation but also a relatively constant demand of energy throughout the year.

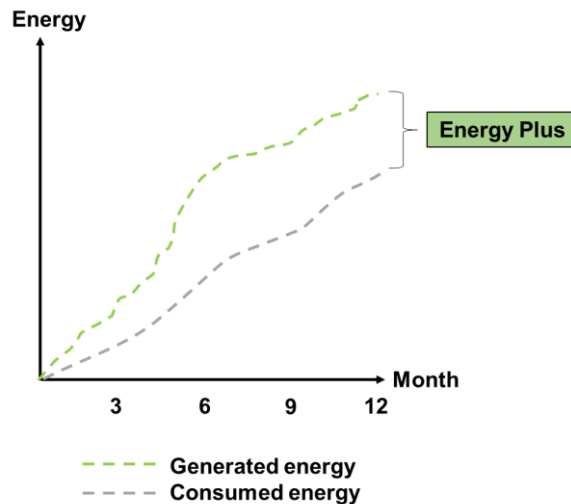


Figure 67. Energy balance of an Energy Plus Building in Colombia

This energy balance expressed in the standard is a net balance as it considers both the energy inputs and outputs through the system boundaries. The annual energy generation is subtracted from demand and when the result is negative, an Energy Plus Building is obtained. This first requirement of the Aktivplus standard also encourages the design of buildings with nearly zero energy use as required by the European Union for new constructions by also granting a distinction to buildings with a net energy demand lower than 30 kWh/(m²·year). Even if it is not enough to have a negative energy balance, achieving this energy demand value in German building is still a challenge given that the average energy consumption in this country in the housing sector amounts to 172 kWh/(m²·year) of which 70% is demanded just by heating processes that are usually carried out through fossil fuels and 6% of the electricity is needed to operate the appliances related to this process (Umwelt Bundesamt, 2016). This consumption value per unit area is the result of the distribution of German society in their homes, where it is estimated that each inhabitant of the country lives on 46,5 m² (Institut der deutschen Wirtschaft, n.d.). This energy standard then gives the label *Aktivplus* to buildings that do not have a generation greater than their energy consumption, but in the same way, through the integration of a rational use of energy and generation through renewable sources, reduce their consumption energy in more than 80% of the country's average.

A literal translation of this requirement to set a Colombian standard would be very lax and the challenge of significantly mitigating the energy demand would be easier to comply given the absence in most of the populated areas of the country of the largest energy consumer in the housing sector. By means of different procedures it is proposed

to give an estimate of the average consumption in Colombia per square meter of housing. First, Annex I of Resolution 459 of 2015 or the Colombian Regulation for Sustainable Construction estimates for four climatic zones of the country the values expressed in Table 8 for dwellings that are not classified as social interest housing:

- 46,5 kWh/(m² · year) for cold weather
- 48,3 kWh/(m² · year) for mild weather
- 36,9 kWh/(m² · year) for warm and dry weather
- 50,2 kWh/(m² · year) for warm and humid weather



On the other hand, the Indicative Energy Efficiency Action Plan 2017 -2022 indicates that in Colombia the housing sector annually consumes an average of 17% of the country's energy, equivalent to 57 TWh. Camacol says that a formal Colombian home has an average size of 70 m² (2017) where 3,3 people live according to data from DANE as shown by Asobancaria (2017). Therefore, when each Colombian occupies an average area of 21.2 m², there is an estimated consumption of 55,7 kWh/(m² · year) or 1.174 kWh/(person · year). Particularly for the city of Medellín, according to the Quality of Life Report that calculates the per capita consumption of electric power and natural gas as 1,52 kWh / (day · person) and 0,09 m³/(day · person) respectively, a consumption of 894 kWh/(person · year) or 43 kWh/(m² · a) is obtained and for Sabaneta, (suburbs of Medellín) with the highest energy consumption, presents average consumptions of 1.638 kWh/(person · year) or 77 kWh/(m² · a). Particularly for CONTREE the average energy consumption per square meter of housing was determined by means of the tool provided by the *Aktivplus* standard as shown in Table 11 for the most common apartment of the project (single-storey) and for two-storey apartments an average electric power consumption of 1.831 kWh/a was calculated. In addition to these values, the demand suggested by the energy standard of 100 kWh/(person · year) for cooking and 550 kWh/(person · year) for water heating must be also considered in the energy balance. The distribution of the area per person for this particular project is 40 m² for single-storey apartments and 55 m² for two-storey apartments, obtaining then energy demand values of 1.517 kWh/(person · year) or 38.9 kWh / (m² · year) for a single-storey apartment and 1.565 kWh/(person · year) and 28 kWh/(m² · year).

These low energy demand values show that reaching a net energy consumption of less than 30 kWh/(m² · year) as proposed by *Aktivplus* means fewer efforts compared to the ones in a Project in Germany with an average demand of 172 kWh/(m² · year). As the installation of 1 kW_p in a building's roof in Colombia can generate between 1.400 and

1.500 kWh/year when no interceptions are found between modules and sunlight and the average consumption calculated for CONTREE is found around 1.500 kWh/(person · year) it would be possible to establish a "thumb rule" by stating that if each person commits to install 1 kW_p in his roof, the magnitude of the generated energy would be equivalent to the annual energy demand or even in some cases, reach an Energy Plus Building. Even the annual average energy demand in Medellín per person is lower than the potential generation when 900 kWh/(person · year) are needed.

A comparison in Table 35 between Colombia and Germany shows two main differences regarding energy generation and consumption: German housing has a greater energy demand due to the need for heating and electricity to support the auxiliary equipment to this process. Furthermore, the annual solar radiation is reduced by its location in the northern hemisphere decreasing the power generation capacity with solar panels. The equivalence to this demand with an amount of panels per person per year is also shown.

Table 35. Needed panels to equivalent to energy demand for housing in Germany and Colombia

Factor	Germany	Colombia
Generation [kWh/(kW _p ·a)]	1.000 (°30 to south)	1.400 (°10)
Demand [(kWh/(Person·a))*]	8.200	1.200 to 1.500
Demand [(kWh/(m ² ·a)]	170	30 to 55
Equivalent modules on roof to meet demand ⁺		

Source. Own elaboration with data from (European Commission, 2018) for the generation of each kW_p installed.

*This factor refers to the amount of energy that could generate 1 kilowatt-peak installed normally (90°) to the position of the sun without any obstacle between this light emitter and the module like a tree or an adjacent building. For Colombia, it is considered an angle with respect to the surface of 10° and for Germany of 30° towards the south.

*It is considered a standard panel of 250 W_p of power and therefore four of these modules are equivalent to 1 kW_p.

An initiative in Colombia to promote through different means such as the spreading of information or particular financing mechanisms, so that each person installs 1 kW_p on the roof of their home could lead to a situation where a large proportion of the housing stock in that country would even generate more energy than the one needed. This fact would be easily reached in houses but the main inconvenient though, that this premise could face, would be present in Colombian large cities. Here most of the inhabitants live in buildings where the roof/height ratio is quite low. That is, in the cities where it is common to build tall buildings that serve as shelter for a large number of people vertically, avoiding the least possible occupation of the area of the ground, the available area on the roof falls short in relation to the amount of people that would be interested on installing one kW_p. Therefore, it would not be rare that available areas in several buildings are not enough to install a system whose power in kW_p is equal to the number of people in the building. A suggestion for a future Colombian energy standard for buildings is associated, consequently, with the net energy demand requirements. The scope of 30 kWh/(m² · a) might not be as challenging as for Germany in Colombia due to its lower demand and higher solar radiation and thus would not make an important contribution to the Energy Transition. It is suggested through this appendix of the work that the requirement of the net energy demand for active buildings in Colombia consider its fulfilment mainly through just covering roofs with PV plants. Given that participation of decentralized photovoltaic panels in the Colombian electric generation mix is practically null, it would be counterproductive for the expansion of the implementation of this technology to promote installations of large systems as a minimum requirement. Greater generation systems would mean a higher investment whereas in the country not even small generation plants are widely used.

A comparison regarding this suggestion is made below between a theoretical exact residential building that would be built both in Colombia and Germany consisting on 100 m².and denominated as Building 1. A second theoretical building is considered to be identical but with a larger living room and dining room consisting on an enlarged area of 120 m² but the same amount of total apartments and inhabitants of the building stay the same. This second residential building is denominated as Building 2. Both buildings consist of 40 housing units, two per floor and therefore 20 levels. The average Colombian inhabitants per housing, as previously stated in this work, is 3,3 and the average

distribution for living in Germany is 46,5 m² (Aktivplus e.V., 2016). Therefore the total number of inhabitants per building. (Zukunft Bau, 2018) points an end energy demand of 20 kWh/(m²·year) for home appliances and 5 kWh/(m²·year) for auxiliary energy and ventilation. Furthermore, (CO2 Online, 2018) suggests an average gas consumption for heating and warm water of 149 kWh/(m²·year) in apartments in Germany whereas the use of this energetic in Colombia is related to cooking and warm water and for this tasks a value of 615 kWh/(person ·year) is obtained as explained in section 4.2. Roof available area for the installation of a photovoltaic plant was assumed as 60% of the ground area (sum of both apartment's area + 5% related to a theoretical between them). A factor of 6,5 m²/kW_p was used to dimension the potential size of the plant. Regarding generation through the PV plant, average factor are taken as 1.400 kWh/(kW_p ·year) was used for Colombia and 1.100 kWh/(kW_p ·year) for Germany.

Tabla 36. Comparison of energy generation and demand in buildings in Colombia and Germany

Characteristic	Colombia		Germany	
	Building 1	Building 2	Building 1	Building 2
Area per apartment	100	120	100	120
Apartments in building	40	40	40	40
Inhabitants	132	132	86	86
Levels of building	20	20	20	20
Apartments per level	2	2	2	2
Energy demand [kWh/a]	161.180	177.180	700.000	840.000
Energy demand [kWh/m ²]	40	37	175	175
Increase in demand	10%		20%	
Roof's area [m ²]	126	151	126	151
kW _p	19	23	19	23
kW _p /person	0,15	0,18	0,23	0,27
Generation	27.138	32.566	21.323	25.588
Demand covered	17%	18%	3%	3%
Net demand	34	30	170	170

From the example it is noted that the specific energy demand or the demand per m² is reduced in Colombia as the area of each house increases. This given that gas demand for cooking and warm water are merely related to the amount of inhabitants and not the area itself alike heating. Increase in energy demand in Colombia due to a larger area is only related to a higher electric energy use that could be originated by more illumination or additional home appliances. This increase in energy demand in Colombia symbolizes

a 10% in this particular case, half of the increase in Germany as heating is not needed. The figure below shows the rate of increase of final energy demand for gas (heating and warm water together) based on (CO2 Online, 2018) and electricity demand increase per each square meter according to the model suggested by Aktivplus as

$$\text{Energy demand for electricity} = 500 * \left(1,4 + \frac{\text{Area in m}^2}{50} \right) \left[\frac{\text{kWh}}{\text{a}} \right]$$

And the scope of 20 kWh/(m²·year) suggested by the Effizienzhaus Plus methodology.

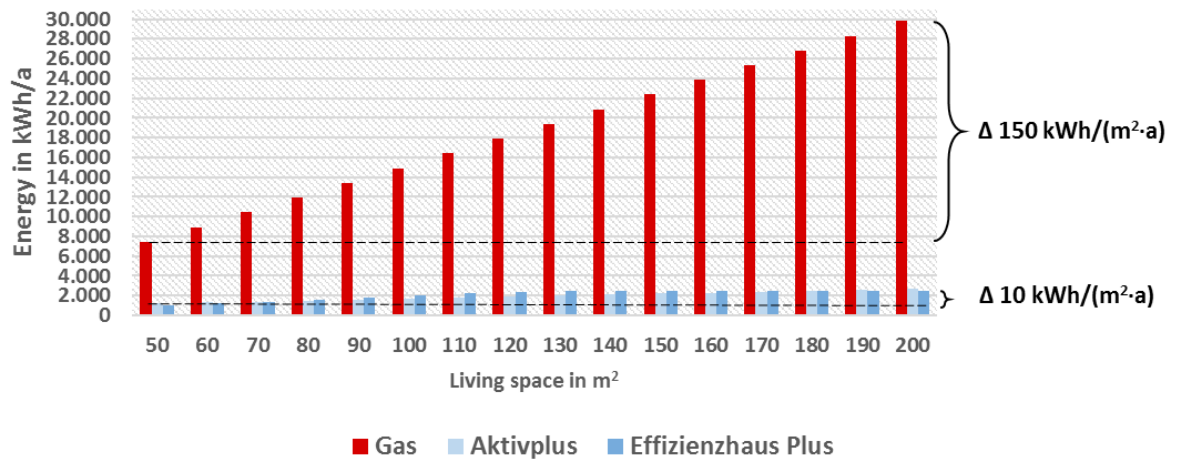


Figure 68. Increase in electricity and heating demand as living space rises

Increase of just 10 kWh per square meter every year is a relatively small magnitude as even though the total energy used for operations inside an apartment in Colombia is increased as a larger area is used for living, the specific demand per square meter is reduced. This situation does not apply in Germany as both energy and area rise where a larger area in a house is a synonym of a higher energy demand due to a larger air volume to be heated. It is also seen that in Colombia, even though both buildings cover the whole roof with solar modules, the Building 2 could fulfill the first criteria of the *Aktivplus* Standard by having a net energy demand of 30 kWh/(m²·year) just by having a larger area. Such case would not happened in Germany, were the standard was designed as an increase in area is strictly related with an increase of energy given the bigger volume of air to be heated up. For this reason, it is suggested that according to the energy demand in Colombia, a requirement for an energy standard in Colombia for buildings that evaluates the net energy obtained by installing local generation plants is not area dependent. In such case, a fraction of the energy demand can be used as reference so that the generation matches its magnitude. Fraction of the energy demand measured in a base case before installation of a generation plant can be determined in

further studies that consider other factors such as purchasing power of Colombians and usually available areas regarding the building stocks of the cities.

The second aspect evaluated in the standard is related to the fraction of demand that can be directly covered with the energy generated within the system. An *Aktivplus* building must cover at least 25% of its demand and the remaining 75% could be injected or exported to the grid.

This coverage depends both on the generation capacity of the system (size) and on the energy demand profile, so that it is possible to provide a greater coverage when more panels are installed and/or when the energy is demanded in periods when the system is generating energy. It is shown in Figure 69 that as the installed capacity of the photovoltaic system increases, the slope of the dome turns greater and therefore it can cover a greater fraction of the demand but there are periods of the day that without a battery is not physically possible to cover this demand no matter how big the system is.

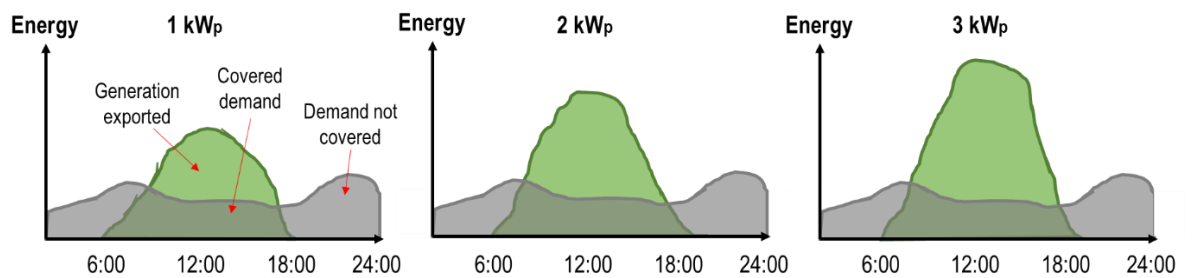


Figure 69. Energy generation and demand behavior after increasing size of PV system

For the particular consumption and generation profiles developed for Colombia in this work it is simulated below the energy consumption and demand of a single apartment according to the “standard” consumption scenario in Contree which is the situation that better describes a normal Colombian apartment. That is, use of standard home appliances, cooking with a gas stove and heating up water with a gas heater. That is, an energy consumption in an apartment with average efficiency class appliances, stove fed with natural gas and water heating also with gas. For different sizes of a local generation plant on the roof of the building, it is intended to determine how the proportion of this demand can be directly covered with the local generation. For this scenario, an electricity consumption of 1,149 kWh/(a · apartment), 650 kWh/(a · person) of natural gas and an apartment area of 80 m² in the case of a single plant are considered.

Table 37. Energy demand covering with different sizes for the PV system on roof

kW _p /Person	Net energy demand (kWh/m ² ·a)	Self-consumption of energy	Energy demand covered
0	44	-	-
0,1	40	100%	10%
0,25	35	88%	21%
0,4	29	72%	25%
0,5	25	57%	27%
1	6	32%	31%
2	-32	17%	32%
3	-69	11%	33%
4	-107	9%	33%

When the size of the generation system is big enough to equalize the amount of energy demanded (almost met with just 1 kW_p on the roof for each person in the building), a demand covering greater than 30% is obtained noting that according to these profiles the maximum possible coverage without the use of a battery converges to 33%. Then for Energy Plus Buildings it could be proposed to maintain the equivalence of the requirement for Germany in its introduction to the Colombian context. For buildings that make an effort to generate energy within its boundaries but is not sufficient to be labeled as Energy Plus Buildings, such as the theoretical buildings described in the Tabla 36, when covering the whole roof in Colombia leads to a maximum of 18% of coverage as seen in Figure 70. Thus, it could be suggested for the enhancement of decentralized energy generation in Colombia with smaller systems consisting in covering the roof buildings, at least a use of around 15% of the produced energy inside the building. This as mentioned, just for cases where the building's generated energy is fewer than the energy needed to operate.

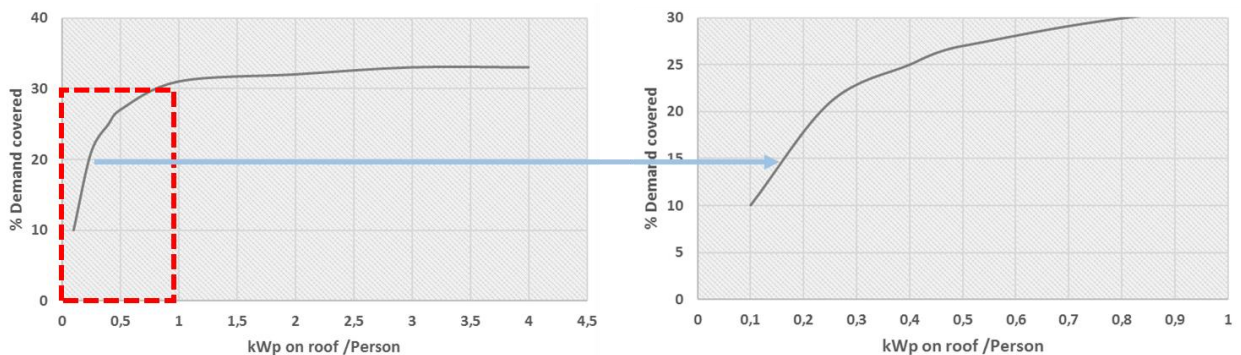


Figure 70. Demand covered according to different PV plant sizes in Colombian roofs.

One of the most abundant but valued resources in Colombia is water. Therefore, Resolution 0549 included minimum values that new buildings must meet regarding strategies to save up water. Even the Active House Alliance in its specifications to obtain their label in a building, improvement on minimization of freshwater consumption during building's use is encouraged from 10% to 50% of the national average consumption. Simplest method to save water is the one where users have the least influence on and it is the previous installation of efficient devices throughout the building so the users do not have the chance to choose for cheaper ones to save money but not water. Three particular devices would be encouraged to be installed in this adaption for Colombia:

- Sinks with a 2 LPM flow
- Showers with a 6 LPM flow
- Dual Toilets with 6 and 4,5 LPM

Furthermore, harvesting of rainwater for uses that do not imply a significant purity of water such as care of gardens, cleaning tasks or toilettes flushing could be fed with this flows. Roofs and slabs of the project may be used for collecting area for rainwater bearing in mind that the material of the surface plays an important role on the effectivity of the harvesting due to porosity and measured by the so-called "Runoff coefficient". This Harvesting potential would be quantified as

Rainwater harvesting potential

$$= \text{Annual rainfall (m)} * \text{Potential area(m}^2\text{)} * \text{Runoff coefficient}$$

This runoff coefficient varies for each surface but mainly could be found between 0,7-0,95 for asphalt surfaces and 0,8-0,95 for concrete.

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