SMART BUILDINGS: STATE OF THE ART OF SMART SYSTEMS FOR ENERGY EFFICIENCY AND ASSESSMENT OF THEIR ECONOMIC SUSTAINABILITY

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Abstract

Buildings contribute with values between 20% and 40% of the global energy consumption (Perez-Lombard et al, 2008), values that are higher than the consumption generated by the industry and transportation sectors. The growing in population and the migration of people to cities, especially in developing countries, have increased the necessity for building stock. For that reason, focusing on energy reduction in buildings through energy efficiency and smart systems is becoming an increasing priority.

However, one of the main barriers to a faster implementation are the economic concerns. That is why we decided to make this project. To explain clearly what a Smart Building is and all the factors that affect energy consumption in one way or another, and how the implementation of different technologies and smart systems can generate positive financial results based, mainly, on the reduction in energy consumption.

For this purpose, we first did research on the relation between green buildings, smart buildings, and energy efficiency. To realize how do they relate each other together with energy usage, and consequently putting deeper attention on the factors that have a direct impact on consumption. We also generated an economic model based on information concerning: energy consumption and distribution in different types of buildings, prices of energy, average savings due to the implementation of smart technologies, and prices of smart technologies. Obtaining indicators like Net Present Value, Payback Time (PT) and Internal Rate of Return (IRR).

PT oscillated between 3 and 5 years, while the IRR between 24% and 54%. Values that would be optimistic when seen from a long-term point of view, without considering the additional benefits (markups in selling and renting rates) that it would bring. However, it is clear that in many companies, investments with PT higher than 2 years are not attractive, especially when pressure from shareholders is applied. Another important aspect to highlight is that the model can be easily reproducible, by replacing data on consumption by the building under question,
local prices of energy and smart technologies, available budget, and priorities. Finally, HVAC systems play an important role, consuming between 30% and 50% of the total energy in buildings, and so, it is the area where improvements would generate, not just, most of the savings, but also improvements in comfort and health.

This project shows a variety of possibilities and clarifications that would help some players on the construction and real estate industry to pay more attention and be more open to the use of smart buildings that are friendly with the environment. Also, it could help tenants on deciding themselves on implementing smart technologies on already existing buildings, either in an integrated way or simply individually, depending on their limitations and priorities.
1. Global influencers

European climate strategies and targets

This is the strategy proposed made by the EU members to meet their targets in the following decades, starting by 2020, then 2030 and finalizing with plans for 2050 (European Commission, 2017). The goals are with respect to the values present to the year 2007. To make clear the exact goals approved in 2009, Figure 1 is presented.

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<th>2020</th>
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<tr>
<td><strong>GREENHOUSE GAS REDUCTION</strong></td>
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<td>40%</td>
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<td><strong>ENERGY PRODUCTION FROM RENEWABLES</strong></td>
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<td><strong>ENERGY EFFICIENCY IMPROVEMENT</strong></td>
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*Figure 1. Climate targets of the EU*

Our focus during this introductory section will be on the energy efficiency improvement targets since a big part on these goals should be met through the implementation of energy efficiency measures in buildings, and we consider that this is the main driver of the urgent implementation of smart buildings in Europe. However, it is important to mention the other two targets since under many scenarios there are different relationships between each other, especially when talking about buildings, which at the end, are the ones forming basically most of the civilization and therefore, the main creators of climate change in one way or another.

On one hand, reductions in greenhouse gases are expected to be accomplished through two mechanisms, first, the creation of an emission trading system (ETS), which is basically to impose a tax on the emissions of CO2 produced. And second, set a target to reduce the CO2 production coming from housing, agriculture, waste, and transportation.

The industries that seen their business more affected by the ETS are the ones that have high production of CO2, between each, we find the iron, steel and cement (Herzog et al, 2005)
industries that are the ones where the building industry most depend on. An, so we find a first connection, where smart buildings can have an impact. For example, the implementation of smart systems on already existing buildings would cause savings on these contaminating construction materials. Or, the usage of smart systems during the building process, or future functioning, would optimize the use of materials.

Now, housing and waste are two sectors that are directly related to buildings and reduction on greenhouse gases. Housing, as an obvious one since the implementation of smart houses, is becoming more and more common thanks to the benefits that are producing and the interest of many private companies in developing the market. Waste thought, is less obvious until it is known that construction is one of the industries that produce more wastes in the world (Llatas, 2011), that mainly comes from deconstruction processes. Smart deconstruction, use of old systems and the revamping of existing buildings with smart systems are all ways to reduce the impact in this sense through the use of smart building systems.

Passing to the next goal, increase the energy production from renewables, is something we will go deeper in a future section of this project, but as an introduction, the relation between renewables and smart buildings is intrinsic. First, because buildings are responsible for more than the 40% of energy consumed worldwide (Perez-Lombard, 2008), and logically, reduction in consumption through smart buildings, will reduce the share of energy coming from fossil sources while augmenting the share coming from renewables. And second, installation of renewable energy sources directly in buildings should be part of smart buildings as a whole. Optimization of energy coming from intermittent sources like solar or wind can just be achieved through smart systems, and therefore, helping in achieving positive financial results.

**Energy efficiency improvement**

Emissions reductions in the last years have been reduced mainly thanks to progress on renewables and on energy efficiency measures. However, from the three targets of the European Union, the only one that will not be achieved by 2020 will be the one regarding improvement in energy efficiency (European Commission, 2017). It is due to a number of barriers that go out
of the scope of this project, but in general, they are related with financial uncertainty, cultural behaviors and lack of knowledge on energy efficiency measures.

Additionally, to that, and more interestingly to us, the European energy efficiency plan, consists of five points (cogeneration, EE products, financing EE, heating, and cooling), where “Buildings” is one of them, as fundamental milestones in the way to achieve the continental goals. Moreover, in the European energy efficiency directive, buildings are one of the two aspects where there are specific regulations in order to improve the energetic performance of buildings in all the countries that are part of the EU.

Between its tools, the European commission counts with the building stock observatory, on a charge of monitor the energy performance in buildings across the of the EU, specifically, they measure energy efficiency levels, certification schemes, and financing opportunities. The nearly zero-energy buildings, that has as a goal turning all the official buildings of the EU into non-consuming energy buildings, and to consume from renewable sources what is left. The other two tools left are related to the certifications available for buildings with energy efficiency implementations, the process, and their advantages, and finally, one dedicated to open an attractive scenario for financing projects.

The conclusion of this section is that smart buildings will play a very important role in the coming years, especially in Europe. The goals on reduction of energy use have to be met soon, and to do so, the governments of the EU will have to make plans to finance and promote investments. Therefore, it looks like a promising industry to invest and to develop new knowledge, business, certifications, and jobs.

**Sustainable development goals**

In 2016, a United Nations (UN) summit established 17 goals with three aims: end all forms of poverty, fight inequalities and stop climate change by protecting the environment (United Nations, 2015). We mention this in our introduction because buildings and internally, smart buildings can have important impacts on them, especially in what concern to stop climate
change. Consequently, we will talk about two of the seventeen goals, because they are directly related to the main goal of this project.

**Affordable and clean energy**

According to the United Nations (UN), energy contributes to the 60% of climate change worldwide (United Nations, 2015). But energy also helps supporting many different sectors like medicine, education, infrastructure, etc. which are fundamental to keep our lives going in a smooth manner. Even though energy is included in our normal life, it is not the same scenario in the whole planet, 20% percent of the global population does not have access to electricity (United Nations, 2015). On top of it, around 40% of the global population relies on coal, wood, animal waste for heating and cooking purposes (United Nations, 2015).

The problems mentioned in the previous paragraph conducted global leaders to establish certain goals to be met by 2030. Ensure universal access to energy at affordable prices, increase the share of energy coming from renewables, improve energy efficiency globally and increase investment directed to research, technology, and energy infrastructure.

Coming back to the subject of the project, we can easily find several links between green buildings and this UN goal. For example, highly efficient designs in buildings, with low energy consumption would facilitate access to isolated communities to better living conditions at a very affordable process. As it will be mentioned on many occasions, the integration between renewable energy production and buildings is fundamental to achieve savings in energy and all types of costs. Finally, and more easily related, the use of energy efficiency in buildings, play one of the most important roles when using smart buildings.

To conclude this section, it is important to make a couple more comments related to how smart buildings would help in achieving the goal of having cleaner and more affordable energy. In general, one of the main goals of smart buildings is to reduce energy consumption and consequently, to reduce costs. And as they say sometimes, the best way to save energy is by not using it. In this sense, the few energy to be used that remains should be generated in a clean way, and then we have cleaner and more affordable energy.
**Sustainable, resilient, safe, and inclusive cities**

As in the previous case, we can also find fast and a direct relationship between the implementation of smart buildings and this goal. Cities are fundamental to the world since half of the global population live in cities and the trend will continue growing fast during the following decades. Similar, cities account for something between 60% and 80% of the global energy consumption and carbon emissions (United Nations, 2015). Additional to this, the cities with the highest growth are the one present in the developed world and therefore many of them are presenting problems related with sewage, lack of fresh water, health and living environment in general.

Being said that, it is clear that there is a number of challenges to be solved to guarantee keeping cities as centers of science, culture and social development while proportioning energy, housing, basic service and many more. And so, the UN has proposed some targets between which, we find: safe, affordable, and provided with basic services’ houses. Implement sustainable and inclusive urbanization by planning and well management of plans. Protect cultural and natural heritage. Reduce deaths and affected communities by natural disaster, especially poor communities. Reduce the environmental impact of cities, especially the one related to air pollution and waste production. Access to green spaces for the city inhabitants. Support regional development by strengthening links between urban and rural areas.

In general, the goals go around the implementation of plans to achieve cities with inclusion, resource efficiency and mitigation of climate change. And here is where we would like to relate some of these goals with green buildings and how they can help achieve them. To do so, we would like to start with an example, for European cities is of great importance to achieve economic development by still maintaining their heritage, and that is why we will explain further in this project, how the implementation of smart systems in existing buildings can be so beneficial by reducing costs with relatively low investments, improving efficiency, comfort, and health and maintaining old buildings.
In terms of reducing environmental impact, it is clear that smart buildings will reduce not just the emissions generated by consuming energy, but also wastes, and light and sound pollution. In other cases, when urbanization is the strategy to take (instead of remodeling), is when smart buildings must be mostly considered since they are not just important by they own, but also as an interconnected network which would allow optimization of resources in a bigger scale.

To finalize, it important to mention that a well-integrated smart building will also guarantee higher safety and security of the users of the building and its surroundings. On the other hand, smart buildings are great options when built in isolated places thanks to their autonomy and therefore they could play a role in helping to develop rural areas and their links to urban centers.

**Combination of global goals**

It is clear that in both, the global and European goals have a lot of attention on the production of energy, either by reducing it or by producing it in a cleaner way. Therefore, during the following years, the attention on these subjects will keep grabbing attention from governments, companies, consumers and many other stakeholders. Together with this, investments coming from private and public players, and the creation of new business will route a lot of resources to subjects like the one treated in this project.

Growing population will require the creation of new spaces for living, growing, and entertainment, but it is not just enough to find the resources to do so, it is also important to do it in a sustainable and smart way since the more the humans consume, the less will be left in the planet and there is where we believe, green and smart buildings will play a fundamental role.

**Smart cities**

Harrison et al (2010) define a smart city is a city “connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city”, which is a very global definition that leaves a clear explanation of a big
A smart city is the composition of many smart systems that should end working as a single and harmonious system to exploit all the advantages of them. Smart energy, transportation, smart communications and networks, environmental awareness and, especially, smart buildings are essential in order to achieve the final goal. That is why we would like to make a mention of smart cities in this section. As it is not just a matter of thinking merely about energy efficiency measures of the implementation of single HVAC systems in a building for reducing energy consumption, in a bigger context, it is not just about implement independent smart buildings filling personal necessities of the owners and users of them. It is always crucial to keep in mind that the benefits obtained by an integrated system of smart buildings and other systems will be better than everything doing it alone.

Many of the necessary technologies that allow smart buildings are the same technologies that would be necessary for achieving smart cities. We are talking about smart lighting systems and LED technologies, smart building controls, demand response, renewable energy sources, sensors, etc. We could find many complementing factors between smart buildings and smart cities, in the industrial sector is also common to find companies offering conjoint solutions for both, so in conclusion, it is important to mention it and always keeping it in mind, especially from a governmental point of view.
2. Introduction to Buildings

Before starting talking about many different aspects related with smart buildings and the energy savings generated thanks to the implementation of its systems, it is very important to make clarifications related to the interrelation to the main terms that move around this subject and to do so, an image is presented.

![Image of interrelation between green buildings, smart buildings, and energy efficiency](image)

*Figure 2. The interrelation between green buildings, smart buildings, and energy efficiency*

As shown in the figure, the biggest circle is the one corresponding to green buildings, and that is why the end goal is to achieve buildings that help have a more sustainable world through a friendlier environment building. So, it is the global idea that contains many other areas that help to achieve the main goal. These areas that go further smart buildings, like design, materials, renewables, decoration, and so on.

Smart buildings, on the other hand, play probably the most important role in achieving green buildings. And therefore, many of the necessities of green buildings can be covered by the
intelligent systems that compose a smart building, it would actually be almost impossible to find a smart building that does not have between its main goals, environmental awareness. The integration needed to achieve smart buildings are a pre-requisite for green buildings for example. The savings in energy, the comfort, health, and security provided by smart buildings are also some of the pillars of smart buildings.

Finally, energy efficiency is an area that is huge and has a role in many more other sectors different to construction and buildings itself. Actually, we could say that the role that it plays in smart buildings is minimum compared with its total scope. After that being said, it is clear that every single smart system that has an impact on energy consumption has the most of its impact coming from energy efficiency measures, like modern HVAC and lighting systems. However, it is also important to consider that many of the improvements in energy consumptions happen thanks to the integration and harmonious working of smart and interconnected systems.

**Energy efficiency**

Here we will mention some interesting energy efficiency measures that are strictly related to the energy consumption in buildings and that would be close to composing all the aspects related with that in a project like this. Figure 3 shows a general classification of the influencing systems.

![Figure 3. Applications of energy efficiency in Buildings](image-url)
HVAC

Sizing: The HVAC systems are usually designed for the worst scenario in terms of climate and occupancy. For example, the designers design the system to maintain the building at 22° on the hottest day of summer when it is at its maximum capacity (heat produced from people), with the equipment at full functioning (heat produced from equipment). This situation would not even occur during 1% of the time of the year. And so, the over-costs due to initial investment and operation will be higher than if the equipment is designed to cover the 95% (instead of 99%) of the time of the year instead. The levels of health and comfort will be still as high as before during the whole year (Mathews, 2001).

Heating systems: First of all, it is important to mention the main standards used to measure the efficiency of heating systems in the market: Combustion Efficiency (CE), which refers to the amount of fuel consumed when a boiler is working under stable conditions during the certain period of time Annual Fuel Utilization Efficiency (AFUE), instead, refers to the general fuel consumption of the boiler along a certain period, including all its phases (U.S. Department of Energy, 2012).

Being said that, we can mention two kinds of boilers, under standard efficiency and under high-efficiency conditions. Both, hot water and steam boilers have a standard efficiency of 80% (CE) while the oil or gas units with high efficiencies can achieve 87% (CE) (U.S. Department of Energy, 2012) in the case of hot water and 84% (CE) in the case of steam (U.S. Department of Energy, 2012).

Then we have the makeup systems which more than heaters, are in charge of providing fresh air into the building. And they instead, are evaluated under AFUE. In their standard version, they can efficiencies up to 85% (AFUE), while the high-efficiency systems can achieve up to 95% (AFUE) (U.S. Department of Energy, 2012).

Finally, in this section, we found some recommendations or systems that would improve the efficiency of heating systems like the decentralization of the systems, in order to avoid transportation losses. Install an economizer heater that preheats the water that is feed into the
boiler. And lastly, modernize the controls of the boilers, with controls that are able to monitor the system and calculate the usage of water and steam in real time, rather than by physical reactions.

Floor heat and low temperatures: Even if the installation costs of big surface heating systems are higher, the efficiency of the system can increase up to the double compared with traditional ones. This is thanks to the use of water at lower temperatures, which requires lower burning on fuel, in one hand, an, on the other hand, the floor is able to retain heat for longer periods of time and create even temperatures in the heated areas (Mathews, 2001).

Heat recovery: The use of heat/enthalpy wheels and energy recovery ventilator allow them to absorb moisture from the air while at the same time cooling the air that is absorbed, to finally exhaust heated air. It is a system that allows the capacity of the HVAC system to be reduced since it can be used in both summer and winter months. In summer it would take the heat and humidity outside the building while in winter it would exhaust the recovered heat inside the building (Cuce et al, 2015).

Infrared heaters: These alternative devices can be powered electrically, by propane or with natural gas. The increase in efficiency is due to the higher emissivity the can produce compared with traditional heaters, even if in most of the cases their combustion efficiency is lower.

Solar systems: Using the sun to heat water and use this thermal storage to heat the building is both cost and energy efficient.

Cooling systems: When talking about this, we have to also mention the refrigeration systems. And there are three things when considering efficiency in these systems: energy usage, type and quantity of heat exhausted and refrigerant type. The air-cooled systems are the most spread used and as in many cases, the traditional equipment is not optimal in terms of energy efficiency (Reddy et al, 2017).

Evaporative and water cooling: With difference to air-cooled systems, this system water as a medium to transfer heat, generating a bigger temperature differential, and therefore a higher efficiency. It also allows re-using the water from previous cycles.
Cooling towers: It is used in big surfaces and therefore it is used for big areas or big buildings, improving the efficiency of the heat removal when its application is possible. It also opens the possibility to use recycled water instead of clean water, reducing the costs due to a second aspect.

Mechanical cooling systems: In this section, we would not like to go deeper since it is out of the scope of the project, but, as an example, air-conditioning fueled by natural gas can generate up to 35% savings (Reddy et al, 2017) in energy consumption.

**Lighting**

Daylight usage: Finding a good balance between reflectivity and heat gain can generate energy savings up to 60% (Delaney et al, 2009) of the total lighting usage.

Proper wattage: Using lamps with the lower wattage is fundamental. It is important to find which lamps will ideally cover the light necessities to avoid overspend energy. Usually, newer technologies produce the same light with less wattage.

Turn-off: Probably the simplest and most energy-efficiency method. It can be achieved through the use of sensors, timers, and photocells. It is also important to interiorize in the culture of the people this practice.

Maintenance: It is not just important to maintain the lamps and fixtures in good shape. But it is also very important to maintain roofs and walls in good shape in order to promote reflexivity and clarity in the room.

Design: In general, there are three fundamental aspects to consider: First, the reflectivity in the ceiling, walls, and furniture. Second, well the distribution of the lights to avoid hot and cold points. Third, kind of lamps, suggesting LEDs that count with long lives and low energy costs.
Windows
Low emissivity: Windows that have the capacity to stop the radiant rays coming from the sun will allow to reduce the heating effects and therefore, reduce the cooling necessities.

Heat mirror: A very cheap solution that can work together with windows with low emissivity

Opaque windows (Azens et al, 2003): The more expensive option is this, which allow to the absorption of light without absorbing heat and therefore, the client gets the best of both worlds.

Films: Sometimes the big worry of these implementations is the investment cost related to the installation of new windows. However, there are options that produce low emissivity by adding films to already existing windows.

External walls and roof
Insulation: The first and most recommended measure to take is the application of insulation. It will be fast, easy to apply, suitable for already existing buildings and cost-effective. Its goal is to reduce the impacts of the exterior weather inside the building, reducing the energy usage significantly (Sadineni et al, 2011). On the other hand, surfaces with insulation will reduce the risk from moisture and other damaging processes, reducing the maintenance costs and enlarging the useful life of the surface.

Active walls and roofs: The usage of solar panels or double glass on these surfaces could have a huge impact on costs, by having multiple functionalities. It would collect solar energy while isolating the building from the outside heat, and function as façade.

Reflectivity: As in the case of windows, low emissivity facades and roofs will reduce the heat inside the building.

Green surfaces: At first, the developers of a project with living roofs and walls must have more consideration than usual, increasing the initial prices. But as in many cases, the economic and aesthetic benefits surpass the inconvenience. The living surfaces work as insulators, air cleaners, protection and so on. Generating a great amount of costs savings along the life-cycle.
**Doors**

Seals: The easiest, cheapest and fastest way to get energy savings indoors is to guarantee proper sealing of doors that connect two areas with high differentials in temperatures.

Vestibules: The easiest to identify measure in the day to day life in this space between two doors, that will help isolate external temperatures in buildings with a high flux of people. It is estimated that the reduction in energy usage in the areas with vestibules can achieve up to a 40% (Cho, 2010) when the differential in temperature between external and internal spaces are high.

Air doors: it is important to say that most of the applications indoors are related to industrial facilities. In this particular case, the creation of air screen on the exit of a room that must remain open to allow the flux of people or loads will stop the change in temperatures between the spaces.

Curtains: An easy and cheap of saving energy in places where it is important to maintain a certain temperature, is to install plastic curtains that will work similarly as a door but with the much higher flexibility to flux.

Fast closing doors: Different to the case of curtains, the fast-closing doors will guarantee the maintenance of cold vapors inside the desired place, saving energy in the same proportion as these vapors are maintained inside.

**Renewable systems**

Renewable energy sources are not particularly efficient and cheap nowadays and therefore the biggest barriers they have is the initial costs investment and then, the generated financial returning. However, due to this, it is a great option when implemented together with smart buildings that aim to reduce its energy consumption at its maximum. Leaving less space to energy coming from the grid, and finally turning the investment into a more feasible option.
Here, we will present the most common and suitable options for renewable energy sources for buildings with smart systems implementation. Figure 4 presents a scheme of the possible renewable energy sources.

Figure 4. Renewable energy sources suitable for smart buildings

Photovoltaics: Even though photovoltaics requires large investments due to the large areas of function and its still low efficiency transforming solar light into energy, it is the most commonly used way of generating energy for buildings. This is caused because it allows buildings to use unused space, on the roofs or yards, that can transform the financial scenario way more attractive pulled by turning these areas into productive ones. Geographical location will also determine the attractiveness of the project, close to the equator the source is more available, but it is also important to consider the infrastructure situation in the area. Isolated areas with high energy costs have better returns. Batteries systems or in given cases, systems connected to the grid will allow using the solar energy at its maximum, for instance, the building will be able to consume at night, the energy-producing during the day. That will have an impact as well.

Finally, the so-called Building Integrated Photovoltaics (BIPV) is defined by National Institute of Building Sciences (2016) as a “system that consists of integrating photovoltaics modules into the
building envelope, such as the roof or the facade. By simultaneously serving as building envelope material and power generator”. The definition is very self-explaining; however, we would like to add the advantages related with the increase in efficiency and reduction in costs related with usage of fewer materials for facades and roofs, the thermal advantages and the energy usage reduction.

Wind: As in the case of solar have a lot of similarities, related to the availability of natural resources (wind movements), infrastructure and financial analysis. However, there is space for some important differences. As a negative aspect, wind turbines can have impacts on aesthetics due to the height, and therefore, bothering the neighbors. As a positive impact, wind power production is highly cost-competitive with traditional energy production ways (Rezaie, 2011), thanks to the lower need of land compared with solar systems, and the higher efficiency, but it is important to mention that to achieve this competitiveness, very high investments are necessary, and they are not usually made by private players, rather by public ones.

Small wind turbines must have a certain number of considerations, first of all, they are a great option for isolated properties where the costs of grid energy are too elevated. In other areas, though, it is a great option to supply consumption of particular equipment, like electric cars, for example. Finally, it is of great importance to achieve a good height for the mast, in order to achieve an optimal production, that would be highly reduced when located close to the ground, however , the higher the turbine, the higher the chances to receive complains about neighbors and local government.

Hydroelectric: The use of river ricer for energy production Is not as common as any of the previous cases and that is because the availability of the resource is not so high as in the previous cases. For a facility to be able to implement a hydroelectric power plant, first, it has to be located next to the water body, and second, it should usually have to have a high energy consumption.

Being said that, when the facility already achieved these conditions, there are mainly a couple of options that can be used to produce energy. One, run-of-the-river, which intend to use the flux of the river to power a wheel or a turbine. This is a fantastic option thanks to the predictability and the low costs of maintenance. Two, impoundment, which is the most known
way, which is capturing water at a high point, and then releases it to a lower point to produce energy by the rotation of the turbine. This is actually not so used at the private level since it needs a huge number of requirements and investments, but in case of already existing damps, it has the advantage of working as potential energy battery that can be activated when needed.

Geothermal: This is a technology that is becoming more and more attractive in the last year's thanks to the huge amount of resources that can basically be located anywhere in the world. It also has very practical uses like the production of energy and the cooling and heating of buildings. To produce energy, it works pretty much like a coal power plant, where the steam coming from the underground, transform this energy into electricity. For cooling and heating purposes, it works with heat pumps that instead of using and realizing heat outside in the air, make the thermal transformation in the ground, generating excellent efficiencies. It is also possible to extract directly hot water from the ground for different uses, especially in hard winters when the ice covers some surfaces (Rezaie, 2011).

To conclude, this mechanism will tend to increase in use during the following years, pulled mainly by its solid financial returns, that is mainly supported by the long durability of the systems and the low maintenance costs of it. And importantly as well, it is a very clean and renewable energy.

Cogeneration: A very spread local power generation method, Combined Heat, and Power (CHP) what intend to do is to produce power when it is being used. That means that the system should use the heat generated in a process, recover it and make it useful for other processes in the factory that will use this heat to produce power itself.

The high spread of this technology can be attributed to the high increase in energy efficiency use in production facilities, by also generating reductions in CO2 production which has provided it with incentives around many countries. On the other hand, this has had a fast evolution during the last years thanks to the increased installation and implementation.

In conclusion, we see as renewable production suits totally smart buildings. The technology installed depends on the particular decision of each client and on the financial benefits that each of them can carry. Intelligent systems will make use of the energy production from these sources
as efficient as possible, making significant resources on the energy bill and reducing environmental impacts.

Water-Energy saving

Even if water savings are not the subject of interest of this project, by any means it is possible to leave it out of mention. That because, water consumption has an important impact on energy consumption (Energy Star, 2012) as well and in that sense, a double impact on the achieving of green buildings.

The reasons why water and energy used are so linked is because in many daily uses, like showers, cooking, heating, etc. The water is heated using electricity or gas, and therefore, the more the water use, the more heating devices will be working. It is also important to consider the energy usage by the water distribution company, they are using pumps and other devices for purification, distribution, generation, etc. meaning that the water bill at the end of the month is covering a lot of energy costs. The same principle can be applied in the same way with sewage treatment companies, the more you throw, the more expenses you cause afterward.

In that line, here some strategies that would also have an impact on energy consumption and general costs reduction: Identify and repair leaks on pipes, seals and fixtures; use green labeled toilets, taps, showers to reduce consumption; Install faucets with sensors that stop flux automatically; always consider the most water efficient boilers and heaters. Also consider acquiring tankless devices when the use is not so frequent; replace inefficient steam cookers, combination ovens, dishwashers and ice machines; get horizontal axis washing machines for higher water and energy efficiency; decorate the building with native plants that can get its water from the natural environment, instead of using huge amounts of water rinsing them; and, in high consumption facilities (water-intensive industries) hire experts on water management, the savings in water and energy consumption will exceed by far the expenses paid to him (Energy Star, 2012).
**Types of buildings**

Definitely, the implementation of smart will depend a lot on the kind of building and their energy consumption sometimes is worth to create complex projects because the financial paybacks will be faster, but some other times, some specific implementation will have more positive financial returns. And so, we would like to show in the following figure the factors that influence the most, the consumption of energy in a building and the kind of building that the factor could influence.

![Energy influencing factors and buildings affected by them (Energy Star, 2013)](image)

As expected, the heating and cooling requirements are the factors that influence the most amount of types of buildings. That is why, when searching for energy savings through smart implementations, intelligent HVAC systems receive so much attention. They can be
implemented as an interesting option, both as a stand-alone system or as an integrated system (depending on how much more systems are worth to implement).

Equally, we find that the size of the building also affects the most of types of buildings, but differently, to the previous case, there are many systems that interact with the energy consumption. Starting with the lighting system, which under usual conditions, must be spread along the totally of the building. The same happens with HVAC systems, that in most of the cases have to level temperatures across the total area of the building.

Other important factors to consider are operating hours per week since different smart implementations should be applied in cases with continuous or intermittent functioning. When continuous, the chances to recover big investments are increased since the constant functioning generates more savings. On the other side, intermittent functioning should search for smoother and more efficient transitions between working and non-working hours but also diminishing consumption to the most in non-working times.

Curiously, industrial refrigerator units are present on many kinds of buildings. However, the savings that can be achieved here are mostly related to energy efficiency measures related to the consumption and refrigeration liquids present in the equipment, rather than with smart implementations.

Now we would like to switch our attention to analyze how different types of buildings consume energy, meaning, see how their energy consumption is divided between different uses. This is also extremely important when defining energy saving implementations through smart systems in buildings since the attention will be focused in the areas with more impact on the bill and better financial benefits.

For the purposes of this project, Figures 11 to Figure 17 do not show many surprises. The most of consumption in both, electricity and thermal requirements come from cooling, ventilation, heating, and lighting, with just some exemptions, in the case of food service buildings, where there a lot of expenses due to refrigeration and cooking.

And so, we can still be coherent with the idea that the priority when implementing smart systems in buildings for saving energy, should be in the HVAC and lighting systems. With this kind of
implementations, the savings will be realized faster, producing better financial scenarios, and having also the best environmental impacts.
3. Green Buildings

Energy-inefficient buildings, without support on renewables for local consumption and made from toxic materials are not just harming the environment and the people that use them but are also not sustainable in the long term, both economically and technically. Therefore, green buildings are the right decision, they can consume fewer resources and produce more energy than what they need, by at the same time, benefiting the people using them and the environment around.

However, in order to get all the economic and operational benefits, it is necessary to carry on an integrated and well-coordinated project, especially when the building is created from zero. On the other hand, the benefits extend to aspects like the higher productivity of the users, better health and the huge impact on global energy consumption and waste production when adopted in large scale.

Following, we will go deeply showing the possible benefits that green buildings could have, especially trying to focus on the ones related to the energy consumption.

Drivers of Green Buildings

- Reduction in capital costs
- Reduction in operating costs
- Marketing benefits
- Premium valuation
- Policy benefits (permissions)
- Reduced risk (liabilities)
- Health and productivity improvements
- Attraction to new and current employees
- Staying ahead of regulations
• Business opportunities
• Doing the right thing

(Häkkinen, 2011)

Energy usage reduction

Around the 40% of the total energy consumption is made by buildings (Rodman, 1995), additional to the important consumption of water (16% of the total) and the huge impact on landfills (up to 40% of the trash). Reduction in energy consumptions has positive impacts on expenses and pollution at the building level, while it also has positive impacts at higher levels, like in the production plants, that can reduce production on-peak hours or eliminate the production that covers the losses in transmission for example.

The first point that is important to mention is that most of the potential in energy savings come from simple solutions in the design of buildings. For instance, the orientation of a building in a way that allows sun entering in winter months and blocking it in summer will allow savings in the HVAC energy consumption. The materials used around and inside the building, the natural ventilation systems and the insulation are other important examples of how to reduce consumption.

On the other hand, optimizing the orientation of the building with respect to the geographical location and to the existing vegetation and buildings, will also allow more natural illumination, reducing the usage of artificial lighting, having a double positive impact: the reduction on consumption from lamps and the reduction in the usage of coolers due to the reduced heat generated by artificial lamps (this light produces more heat than natural light).

Finally, the introduction of renewable energies on buildings is becoming more and more financially likely. This is providing savings in the short and long-term, in many cases, thanks to the incentives provided by governments but also due to the independence and the increase on security by stop depending on third parties like production plants that at the same time, stop depending on foreign fuels.
It is always important to keep in mind that the integration on design in these buildings plays a fundamental role, as an example using the previous strategies, there will not be saved if I reduce the heat load inside the working area if I over-install HVAC systems, causing the same energy consumption and over-cooling the areas.

**Environment importance**

As mentioned, the ultimate goal of green buildings is to improve the environment, so it is important to mention some important aspects that must be considered and observe how to have they related with the goal of this project, reduction in energy usage.

First, the revamping of already existing buildings should be highly considered, in one hand, it reduces the impacts of spreading the urban centers by reducing utilizing the empty land, and on the other hand, it can highly reduce waste, energy, and money for demolitions, and most importantly, construction (Kibert, 2016).

It is also important to learn and adapt the building to the local customs and solutions that in many cases can be very ancient and therefore, are very useful and sustainable for the specific area. To clarify this, an example is provided: the usage of green roofs and walls. By providing local flora, the project not just increase wildlife in the city, but also provides beauty, better air and from an energetic and economic point of view, it provides a great insulator, extends the lifetime of the surfaces, and facilitate the treatment and transport of storm waters.

**Goals**

Health: Considering that the average person spends around the 90% (Adler, 2011) of his time indoors, the impact that the building could have on his health is very high. Two aspects are the main causes of poor health in buildings, hazardous chemicals used in the construction, for instance, paint. And the lack of proper ventilation that would allow carbon dioxide flow and humidity dissipation. It is important to mention here that an adequate ventilation will reduce the
energy requirements due to the reduction in heat load and opens the opportunity to recover heat from certain areas.

Productivity and comfort: It is clear that factors that can help the users of a building having good health will also directly affect their productivity. Proper lighting, for example, will increase the comfort of people while also generating reductions in energy consumption by optimizing usage of natural light (Adler, 2011). In the other hand, controlling the ventilation almost individually of the areas used by different users will provide them with great comfort, by at the same time providing fresh air and lastly reducing the energy usage required for cooling.

Cost savings: Due to efficiencies in materials, labor and equipment

**Barriers**

Lack of knowledge: Even though is a growing business, the knowledge across the industry is not well spread yet and therefore constructors or buyers do not identify the advantages.

Simplicity: New trends often carry with it longer times in construction and this at the same time is translated into higher costs, therefore, developers aim to maintain things as simple and known as possible.

Maintaining trends: Since the market does not offer green buildings, the customers do not expect green buildings to be sold either. New green projects are seen as unnecessary investments since the classic market is already working well.

Lack of incentives: Many times the governments do provide incentives, the problem is that they are not directed to the actors who do the investments, meaning that who receive the incentives are users, rather than developers.

(Häkkinen, 2011)
Conclusion

In conclusion, it is clear that buildings could produce more energy than they consume if properly designed and implemented. On top of it, using low impact and comfort materials will reduce the impact on the environment and on the users. From the economic point of view, they make a lot of sense, especially in the long term thanks to the strong reduction in usage costs, maintenance costs and also in the increased productivity of the employees.
4. Smart Buildings

Smart buildings are part of green buildings and play an important role by achieving them for the purpose of our project we will focus deeper in this section and see how some specific smart implementations can help achieving green buildings, especially in the area of energy performance.

A smarting building is the one that includes in it the integrated installation of technology systems. Between these technologies and systems, we find, building automation, facility management, information and telecommunications, safety management, and facility management. It can also be seen as the integration between building systems and technological advancements (Buckman et al, 2014).

Additionally, the aim of a smart building is to provide the owner or manager of the building with information about the different spaces in order to allow him to manage the different scenarios around the building. For doing this, it is also necessary to design a cost-effective project where everything is integrated since the very beginning so the technologies around the building can interact smoothly with each other.

The role of the HVAC and lighting control, power management, and smart metering play the most important role in reducing the energy usage in the building, meaning that a better functioning in these systems will be translated in a bigger reduction in energy use. It is also important to mention that the smart grid will be also highly dependent on this kind of buildings, transforming it into a two-way collaboration.

Finally, it is important that the main players in smart buildings, developers, and owners, can see economic benefits coming from energy savings and at the same time, they require the constant help of new technologies.
Structure of a smart building

To provide an overview of how these technology systems are composed in a smart building, we will mention the three main layers of devices: end devices, control devices, and monitor and management devices as shown in Figure 7. The three of them must have a constant communication between each other, communication that can occur through cables or wireless, and that support the computers where the information is processed and reported with a fundamental role played by databases. In a subsequent section, we will provide more detailed examples of the specific devices that are located in each of these layers.

![Figure 6. Layers of devices that compose a Smart System in a Smart Building](image)

Integrated systems

The stand-alone systems are the ones that even though, share information with other systems, they work by themselves, instead, the integrated systems have unique databases where all the information from the sub-systems arrive and then is processed for a conjoint functioning. Because of this, we will focus the explanation on the integrated systems, considering that by explaining them, we will be explaining its sub-parts which end up being the stand-alone systems.
Structure

For a system to be integrated it must have integration at physical and functional levels, meaning that, cabling, spaces, and infrastructure, in general, have a smooth interoperability.

This explanation about the layers is not specific enough for the purpose of this work, and therefore we will use the model provided by the International Standard Organization (ISO) which provides an open system interconnection model, that has more specific layers where each of them play a role in the communication of the network that composes the system (International Standard Organization, 2016).

Physical layer: This is the layer where the electrical communication occurs with the help of cables.

Data layer: It receives bits and transforms them into logical data that can be transferred and able to communicate.

Network layer: It is on a charge of routing the information in the most efficient ways between devices.

Transport layer: Responsible for guaranteeing a reliable transport of the data in the network.

Presentation layer: Manage the format and dialogue to the end users of the applications.

Application layer: It is the layer that has direct interaction with the user.

Here we would like to make an important mention to the network of the building since this is the core of smart buildings. It allows for communication equipment, sensors, data, control rooms, systems, or even other networks. Nowadays, the networks have passed from just cabled ones to wireless where not just computers can be connected but also tablets and smartphones, increasing the efficiency and accessibility.
Levels

Much has been said about integrated systems but what is really an integrated system, how is it composed and how to achieve one? Those are the questions we would like to answer now since we have put so much attention on it.

As in systems mentioned previously, there are also levels of integration in a building, depending on the how well and deep is it made and how much of advantages will provide to the users (Sinopoli et al, 2010). Following we will show some of these different levels.

Single systems managed from a workstation

- Systems physically connected
- Systems produced by the same manufacturer
- Systems from different manufacturers that open their system to each other
- Systems integrated by industry’s standards

*Figure 7. Levels of systems’ integration*

Single systems managed from a workstation: This level of integration arguably has any kind of integration since what is actually happening is that all the systems work in a stand-alone manner, but all its results are sent to the same room, where a person is aware of all them and is able to make certain kind of integration based on his knowledge.

System physically connected: In this case two or probably more systems are wired between each other, allowing them to send signals to each other in specific and programmed situations like
emergencies, for instance. So actually, the systems are not working constantly in an integrated way, but in specific cases, they can send signals to change their behaviors.

Systems produced by the same manufacturer: In this case, the systems are perfectly compatible between each other and usually are bought and installed together from the beginning, even though, it also allows for future acquisition and following integration. However, it has as a negative point that, first, in many occasions, a single manufacturer does not produce all the needed systems and, second, the buyer is bound to the same manufacturer during all the life-cycle of the building.

Systems from different manufacturers that open their systems to each other: This case is similar to the one mentioned previously, but considering in this case, that the cooperation between different manufacturers can fill holes in production from one manufacturer or the other, and so, complying with all the requirements from the client.

Systems integrated by industry´s standards: As our last level, we have the full integration between manufacturers under the same standards. This will allow a total flexibility to the clients who will be able to get all the required equipment without limitations of sticking to the same manufacturer and also allowing a full integration and communication between the different systems.

Before finishing this section, we would like to make a couple more of comments related to important considerations. First, middleware software is broadly used to stick together different computer programs (, for our particular case, it can very useful bringing together systems that work under different standards, opening a world of possibilities and clearly improving the advantages of the users, like the ones they have in standardized integration. Second, an important attention as to be given to the integration of data as well, since every system comes with data in different formats and quantities and so it is fundamental to establish since the very beginning the number of systems that will be working together, the data produced by each of them in order to build the adequate capacity and finally, how can this data will be integrated efficiently.
Steps for an integrated system

Get to a good end a smart building or complex of smart buildings with well-functioning integrated systems is not an easy task and therefore, continuously there is suggested a number of steps (Sinopoli et al, 2010) that would definitively help to achieve this goal.

Understand building’s use: The kind of building that is under question will determine many factors when planning the smart systems to be used. Every kind of building has different necessities, depending on the number occupant, type, and quantity of equipment, business, size, different areas, location, etc. That will be reflected in investment costs, as well as in operational costs and therefore the economic model will be different in each case.

Early planning of smart systems: Contemplate and ensure the adoption of smart systems in the building will guarantee a smoother and cheaper integration. The later the decision is taken, the more disruptions on the building will have to be made and therefore, the costs will increase as well.
Establish expectations and goals: With new technologies, sometimes it is not clear what is going to be achieved in both, economic savings, and new functions. Therefore, it is important to not create over-expectations that could not be achievable and generate problems in the future.

Establish roles: It is clear that the people needed and the training for the already existing people is different to the one needed in classical projects. For this reason, it is important to define roles since the very beginning to avoid resistance to the new processes and the new technologies that will be applied.

Define the scope: This is probably the most determinant step. It is where the designers define how many systems will be installed, how many of them will be integrated between each other and until which level are they going to be integrated. Meaning that they will be either physically or functionally integrated.

Establish technical standards: It is important from the beginning, because of costs and facility of operation, that standards related to cabling, equipment, data, and software are clearly established. This will facilitate and optimize all the processes, since the installation, to the integration until the utilization.

Training the personnel in new practices: The main goal in these step is to guarantee that the people accept and interiorize the integrated functioning that the conception, construction, and operation of the building will have. Usually, the people were used to take care of independent things but with the new systems, they must understand that certain aspects in a system affect some other in a different system.

Generate costs of the smart systems: It is important to always consider that the new smart systems will have additional costs or at least, will have different costs structures that have to be refreshed. It is also important to keep a constant updating during the construction of new costs that the project incur on.

Include new activities into the schedule: Exactly as in the previous point, it is important to know that the new smart systems will have different implications on the scheduling and programming of the building when compared to classical projects. It is also highly important to consider that
to achieve an integrated building there will also be very new activities that will be strictly dependent on others.

Supervise the plan: After the plan is drafted, the most important activity leading to success is the constant supervision. Monitor that the installation of the new and complex system is made properly will play a fundamental role achieving the final goals of functionality and energy savings.

As a conclusion of this section, we see that as a new subject, the apparent complexity of smart buildings projects can increase significantly, carrying with it additional costs, not just in equipment but also in planning, labor, and materials. But it is important to always keep in mind that a project well carried, and always focus on integration will generate benefits that will exceed by far the effort and the costs that were taken. On the other hand, companies are acquiring more experience every time and also manufacturers are reducing costs, factors that promise that it will become easier and more attractive in the close future.

**Lighting systems**

When talking about energy, probably, lighting comes as the most obvious consumer of energy, this is not necessarily wrong since the lighting systems consume between the 30% and 40% (Nguyen et al, 2013) of the electricity consumed in a building. However, the light consumption depends on many factors like the programmed times of functioning, the utilization of sensors for people, utilization of daylight, and the filtering in the windows.

**Smart lighting**

First, it is important to mention that these systems are usually managed with the help of a server that can be interconnected to other functionalities in the building and that can be accessed through the web. Following, Figure 9 shows how is hierarchically organized a smart lighting system (Bhardwaj et al, 2010), followed by an explanation of each of its components.
Occupancy sensors: They simply detect whether space, determined by the range of recognition, is occupied or not. They are usually installed in spaces where the occupancy of people is not constant so important savings in energy can be accomplished. They can use technologies like infrared, ultrasound, or audible sound, depending on the type of space, there more suitable technologies than others.

Dimmers: They can identify factors like occupancy, natural lighting intensity or receive indications on the necessities of the moment, and then, they are able to optimize the level and configuration of light needed in a space.

Photoelectric controls: The measure the natural light in defined spaces and regulate the light to maintain an ideal level of light constantly during the whole day, in some case, it can reduce the intake of natural light when this is excessive.

Relay panels: For an easy understanding, they are like a light switch, that you turn to make the light work or stop working. The difference is that a relay panel can receive several inputs (information from sensors and dimmers for instance) and generate several outputs (determines which lamps to turn on) based on the inputs.
Ballasts are an instrument that is fundamental for the correct functioning of some of the objects mentioned previously since they regulate the amount of energy that the lamps receive, and so, regulate the light intensity in them and therefore the energy consumed by them.

For concluding and as mentioned in many occasions, the integration between the different systems is fundamental. The lighting itself plays a very important role since it plays relevant roles in other systems. Its interrelation with the HVAC system would play a fundamental role in the decrease of energy consumption, maintenance, and life-cycle costs. Also, the influence it has on the security system, by providing escape ways in emergencies or decreasing the insecurity in certain areas.

**HVAC systems**

These systems play a fundamental role in the energy consumption of the buildings and therefore, in the costs. The smart functioning of the HVAC system depends on factors like weather, occupancy, and distribution of the spaces inside the building, and the goal of it is to maintain a simultaneous and optimal functioning of it that allows an excellent air and temperature quality by reducing the energy consumption.

Depending on the kind of building, the necessities will be different, higher occupancy like in the case of office, commercial and institutional buildings will have a higher occupancy than residential buildings (Agarwal et al, 2010), for example, generating greater values of heat and CO2. Sometimes, and depending on the local climate there will be the need to focus the attention on the circulation of air rather than in the provision of heat, in the case of winter months, or in the summer months, sometimes there will be necessary more conditional air than planned.

It is also important to mention that there are different levels of complexity depending on the number of spaces a building count with, their uses, their level and so on. As a simple example is easy to think on an offices´ building with more than a couple of level that is interconnected, naturally the heat will go to the up, reducing the need for artificial heating in the last floors. And so, in big buildings, have a smart HVAC system means count with a centralized management application that monitor and send orders to the local controls of the individual spaces and offices.
in order to comply with the specific requirement of each one, avoiding under or extra use of energy.

Following, the classical components of the system are briefly mentioned.

Boilers: With the usage of a fuel, the boilers heat water, next, the water or steam is pumped around the building generating heat in it.

Chillers: They use heat exchangers that produce cool air from the warm air that enters the unit.

Air-handling units: Those are systems that are distributed around the whole building (usually metal boxes) and are simply on a charge of providing heat or cold depending on the necessities of the particular spaces.

Air thermal units: They are designed to attend the necessities of specific areas in the building, they can also be called thermal zones and refer to spaces with similar conditions.

**Improving energy efficiency**

Even though the efficiency of the HVAC systems has been constantly improving during the last years, both, because of regulations and the clients’ necessities, they still count as a big share of the total energy consumption in buildings. Of course, there are easy and fast solutions that can be implemented, for instance, to improve ventilation, like open windows or leaks in the walls, especially when the heat load is not so high inside. Next, we will explain some potential improvements for more complex cases.

Reducing heating and cooling loads: As mentioned in many occasions, the interconnection between the different systems in a smart building is fundamental. When the lighting system uses more efficient devices like fluorescent lamps, the generation of heat is also lower as inefficient lamps, and therefore, the heat load inside the building is reduced. This principle can be applied to basically any equipment used inside a building, from computers to heavy machines in a manufacturing location.

On the other hand, the cooling loads can be prevented with better insulation.
Reducing cooling and heating equipment’s size: There are two important aspects to mention here. The first, is that the HVAC systems are usually designed based merely on the area that the equipment will serve, totally omitting important factors related with the design and orientation of the building as mentioned in previous chapters, that could have an important impact on the cool and heat loads. Second, the HVAC systems are designed to maintain ideal temperature on the 100% of the time, meaning that they are designed considering the worst scenario, that could have a chance to occur once a year. If for example, the systems are designed to cover the 95% of the scenarios of the year, the size of them could be importantly reduced and consequently, their energy consumption.

Maintenance: The HVAC is sometimes over maintained and on other occasions is under maintained, especially when it is located in places not easy to reach. The installation of sensors supported by software that can promptly recognize failures will increase the efficiency of the systems in real time and will also increase the life of them.

Displacement ventilation: This methodology could strongly reduce the use and size of HVAC systems. By the slow provision of fresh-cool air in the lower part of the areas, the waste-warm air will be displaced to the upper section where it is collected for subsequent extraction.

**Smart HVAC**

The smart HVAC systems must control and adapt to many different variables like temperature, humidity, maintenance and state of the equipment and equally important but less obvious, the flow, speed and pressure of liquids and gases that run through the system.

To do so, the systems are composed of a number of devices and programs that allow gathering data, then analyze it and finally make decisions based on that, allowing to control the actuators. As shown in Figure 10.
To better explain the idea, we will provide an example: Thermostats can be programmed in a way that identify when the temperature of the room is out of the desired parameters, in a moment when the temperature is too high, it will communicate (by cable or wireless) that to the controller, who will identify which is the best action to take subsequently (turn on a conditional air unit). Finally, the controller will order the actuator to switch on, allowing the conditional air unit to start working until the temperature is inside the parameters again.

For a better understanding of the structure of the HVAC systems, it is important to mention that they are divided into three levels, each of one can count with its own controllers (Sinopoli et al, 2010), next we briefly explain each of these levels and its functions:

Field level: This is the lowest and most basic level. They serve single devices, rooms or areas, so its controllers are locally located and can work independently.

Building level: As the next level, they manage the field level units, and additionally, they manage the information coming from the lower levels to control the situations in a more holistic way.
Management level: At the highest level, it has many goals since it is responsible for the coordination and control of the lower levels. That means that it must administrate the HVAC system by displaying the system information, generate reports and storing data. It also identifies trends and then schedules the system based on that. The system is managed itself by an operator in a workstation where tools like software and a server facilitate the process.

Energy Management Systems

This is the last milestone necessary to have a complete and integral energy management system and it has the goal of ensuring the quality of the power in the building. To do so it monitors the electrical distribution system, generating data on consumption, quality, and possible failures (Snoonian, 2003).

When referring to smart buildings and energy reduction, this is the most important system since it is the one that uses the data to create strategies to reduce power consumption and power costs, depending on the time of the day, the price of energy, requirements of the building and so on. They also see the usage trends in the building, identify needed maintenance and generate alerts about higher than usual consumptions of energy. Conceptualization is presentet on Figure 11.

![Figure 11. Structure of Power and Energy system](image-url)
Following we will show the structure of these systems:

Monitoring: Its role is to monitor the consumption and loads of the most consuming equipment, it can be done through sensors or transformers that measure electric current and voltage. Sensors can have different levels of complexity, since they can go from simple devices that take measures every certain amount of time and then distribute it, to stand alone devices that can monitor constantly, and have their own display and response system.

Displaying: It is always connected with the monitoring. The devices can go from displays of a single equipment to displays that make compounds of consumption in many devices at the same time.

Central workstation: With the help of a specialized software, analyses the data collected previously to take the necessary actions in order to optimize the energy consumption in the building. To do so it generates reports with graphics of historical, real-time and trend data. It also has communication with the systems mentioned previously (lighting and HVAC) and makes compounds of consumption costs and possible reductions.

Between one of the main applications and functions of the workstation is the one of demand response. The goal of this is to increase the elasticity of the energy users when the price of energy increases (peak hours). This is made with two strategies: first, reduce the usage of systems that use energy or second, use locally produced energy during these periods.

**Tools**

Smart meter: As classical electrical meters, measure the electricity consumed in a location so the utility can generate a bill to that specific location based on the price of electricity at different hours during the day. However, the smart meters can evaluate many more things, that are also useful for the user. For instance: pricing in real time, identification of opportunities to cut energy usage, recommendations to implement energy efficiency measures and subsequent confirmation of improvements, power quality, communication with other meters in far locations, etc.
Smart power strips: It is calculated that worldwide that between the 7% and the 13% (Turner, 2010) of the energy consumed in the building is caused by devices in standby mode or turned off. Therefore, the power strips can play an important role reducing these percentages. Sometimes they sense the volume of current use and turn off after a while, they can be also programmed to turn off at certain hours or be synchronized with the computer, so it goes off when the computer does. They can also be on the charge of providing information on consumption to the users.

Power over Ethernet (POE) devices: Conventionally, devices like phones, cameras, security readers and so on, where powered by electricity lines with the simple goal of maintaining a constant energy flux. However, new devices can have access to POE, allowing the system to dime their energy intake depending on the necessities of the device. That means that they do not just receive energy, but they are also able to interchange information related to energy consumption and saving opportunities.

Internet of Thing

First, it is important to provide a small explanation of what the internet of things is. It is simply the idea of connecting devices to the internet network, and when we say devices we are referring to any kind of existing device. The first things that come to mind are devices that have a natural connection to the internet like cellphones or computers, but it can extend to many more things that are not classically connected. For the interest of this project, we can give examples like energy meters, HVAC devices, lighting systems, etc.

The goal or advantage of counting with constantly connected devices to the network is that there is also the chance to monitor and control them. It is a trend that has been growing during the last decade and that is expected to keep growing exponentially during the following years thanks to the bigger availability of wireless networks, technologies that transform devices into transmission, and finally, to the decrease in prices of data storage, that allow to store all the data received.
Passing to the called by many like Building Internet of Things (BIoT), which is the subject of most interest for us in this section. As mentioned before, there are many examples that can be easily imagined when thinking about buildings due to a large number of devices present. On top of it, the functioning of some of these devices has a direct impact on the functioning of some other devices. And so, BIoT arises as a fabulous option for implementation of smart buildings and energy efficiency measures (Gluhak et al, 2011).

It is also interesting to note that the communication of the monitored devices is not just headed to a controlling system that takes all the decisions of control, but the information can also be transmitted to other devices, taking immediate reactions that will optimize energy consumption or improve the security, for instance.

In conclusion, the BIoT is a really interesting option for implementing smart systems in buildings. And that can be reflected in some companies that are expert in networking and internet matters and are entering in the business. Also, many other companies who have had more expertise on energy efficiency, energy management, or devices (HVAC, lighting, etc.) production, are trying to increase their expertise on digital subjects, in many situations by promoting partnerships with other more experienced players.

**Building Information Modeling (BIM)**

According to the Autodesk (the most remarkable provider of BIM tools), BIM is “an intelligent 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure”.

There are not so many more things to say about that, apart from that it can also be linked with a database, meaning that it can be linked with basically any kind of information that the user would like to add. The other great advantage of BIM is the doors that it opens to better coordination between all the different players along with all the coordination process and after. Naturally, it also allows a better integration of different systems, which is our main concern when talking about smart buildings and the many systems inside it.
Finally, it is a great graphical tool that could also have huge commercial advantages when showing results to potential customers. It means that it does not just have technical uses, but it also has the possibility to be open to many more people that have different interests.

**Other systems**

It is important to mention other systems (Sinopoli et al, 2010) that are also part of smart buildings, but for the goal of this project, which is to focus on energy savings, these systems are not so relevant.

Access systems: They control the entrance of people to the building or to specific areas inside it. It is mainly related to the increase of security needed in the last years. On the other hand, it can play a role when integrated with HVAC and lighting systems thanks to the information that provides related to occupancy.

Surveillance systems: This is, again, related to the security of the building. The main component in these systems is the closed-circuit television systems which are basically composed of video, displaying and storage devices.

Alarm systems: Emergencies detection and communication are the goals of these systems and they play a fundamental role in the security and death-life situations for the people.

Video distribution systems: The goal of these systems is to transmit information to the users of the buildings, related to security, feeds, entertainment or more importantly, energy consumption.

Voice distribution systems: The voice networks are part of the buildings infrastructures for decades, but, nowadays their integration with other systems transform them into a fundamental part of the whole system.

Audiovisual systems: In building used life offices but mainly in universities and schools, these systems are of high importance. Well-functioning cabling and wireless networks will determine a good projection of the audio and video that wants to be shown. And therefore, a good
communication between the users of the building. When integrated with other systems, its efficiency and costs improve very much.

Facility management systems: Differently to the systems mentioned previously, this system is related directly to the operations of the building, especially industrial facilities, but also in other, less demanding, kind of buildings. Between its main functions, it has managing assets, inventories, and maintenance. On the other hand, it also focuses the attention on safety and automation of the building by providing maintenance recommendations, schedules for workers and so on. Finally, the energy management system, included here, do things like monitoring the electricity bills and compare them with the expectations, and compare the consumption of similar buildings, while always considering the comfort and satisfaction levels inside the building.

**Economics**

**Life-Cycle Costs**
Buildings have very long-life cycles, depending on their use it can range between 20 to 40 years (Adler et al, 2011) (at least for accountability purposes) but we can see, especially in Europe, that many of the buildings in use exceed these times by far. That, when not considering the revamping of old buildings.

Because of that, it is important to consider the life cycle costs, which are mainly represented by the construction costs, maintenance costs, and especially, by operational costs as shown in the following graphic and its explanation.
Construction costs

Since the goal of the project is to focus on smart buildings, we will only mention the construction costs that are related specifically to that. And so, the additional construction costs are the technology systems itself, that will transform a normal building into a smart building.

It is also necessary to consider if the installation of these technology systems will be installed in an integrated way for all the future systems or if they will be installed on stand-alone systems. It is clear that when installing in an integrated way the costs will be lower than if each system would be installed alone. That is caused because of the efficiencies generated due to the material, labor, engineering, project management and contractors’ costs in general.

As an easy example, we can mention the cabling and its pathways that could be highly reduced if managed by a single contractor with its own standards. On the other hand, if the problem is to standardize different contractors, the project management costs would also be highly increased.

As mentioned previously, the costs of project management can be significantly reduced. In a construction project, around 10% (Adler et al, 2011) of the total cost of the project and therefore
is something to put a huge amount of attention on. And so, reductions of 30% (Adler et al, 2011) as reported in some informs, will have a huge impact on the general economics of the building.

In terms of devices and equipment, it will be highly reduced, starting from cables that play a huge role in costs, followed by computers, software, sensors, displays and data points. The standardization, in general, is something to consider from the beginning, it is usual that independent systems count with different standards when is down to equipment and software, this implies high standardization costs as one option or increasing in training and space to achieve the ability to manage the different systems independently, as the second option.

The factors mentioned previously are related with construction costs, but as we are talking about life-cycle costs, in the following graphic, some of the most significant savings according to the Continental Automated Building Association are shown.

![Figure 13. Savings when comparing an integrated approach versus a stand-alone approach](image)

**Financial indicators**

In this section, the aim of the project is to carry on a model in order to establish the economic viability of projects on different types of buildings when implementing either, energy efficiency
measures, individual smart energy implementations, or integrated smart energy implementations.

Our first step is presented in Table 1. And what it represents is the energy consumption of seven different types of buildings. For each type, the total energy consumption is presented, divided into electrical and thermal consumption. Additional to this, the energy consumption is further divided by systems: HVAC (Space heating, Cooling, Ventilation, Water heating), Lighting, Cooking, Refrigeration, Office equipment, Computing, and others. The information is presented in energy intensities (KWh/m2), together with the percentage that it represents.
Table 1. Energy consumption in different types of buildings (U.S. Energy Information Administration, 2012)

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Education</th>
<th>Food sales</th>
<th>Health care</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yearly average Energy consumption intensity (KWH/m²)</td>
<td>Yearly average Thermal energy consumption intensity (KWH/m²)</td>
<td>Yearly average Energy consumption intensity (KWH/m²)</td>
</tr>
<tr>
<td>Total</td>
<td>118.4 100%</td>
<td>96.5 100%</td>
<td>524.2 100%</td>
</tr>
<tr>
<td>Space heating</td>
<td>5.4 2%</td>
<td>84.2 73%</td>
<td>6.5 2%</td>
</tr>
<tr>
<td>Cooling</td>
<td>26.9 19%</td>
<td>17.2 3%</td>
<td>54.9 19%</td>
</tr>
<tr>
<td>Ventilation</td>
<td>17.2 15%</td>
<td>30.1 5%</td>
<td>62.4 22%</td>
</tr>
<tr>
<td>Water heating</td>
<td>2.2 1%</td>
<td>22.1 19%</td>
<td>13.9 6%</td>
</tr>
<tr>
<td>Lighting</td>
<td>20.5 17%</td>
<td>38.8 8%</td>
<td>46.3 17%</td>
</tr>
<tr>
<td>Cooking</td>
<td>2.2 1%</td>
<td>5.7 3%</td>
<td>46.3 5%</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>10.8 9%</td>
<td>371.4 70%</td>
<td>15.1 6%</td>
</tr>
<tr>
<td>Office equipment</td>
<td>5.4 4%</td>
<td>5.4 2%</td>
<td>12.9 5%</td>
</tr>
<tr>
<td>Computing</td>
<td>20.5 17%</td>
<td>6.5 2%</td>
<td>25.8 9%</td>
</tr>
<tr>
<td>Other</td>
<td>17.2 14%</td>
<td>17.7 5%</td>
<td>29.1 5%</td>
</tr>
</tbody>
</table>
For a clearer understanding of the information presented in Table 1, charts are presented in a more summarized way. Showing how both the electric and thermal energy is consumed by different function and systems in the building.
There are many things that we would like to highlight from the previous table. Food sales (Figure 12), where we can consider mainly supermarkets, have high energy consumption, especially in terms of electricity, and the most of this electricity consumption comes from refrigeration purposes. Which is something easy to imagine since many products must be maintained under constant cold conditions. On the other hand, the heating and cooling systems mainly cover the thermal necessities. Easily to imagine since the big volumes in buildings like supermarkets require high amounts of heating to achieve a balanced temperature.
Healthcare (Figure 13) is also an interesting case since it has high energy consumption in both electrical and thermal intensities. This is due to the highly demanding requirements that must be present in hospitals in order to attend the necessities of patients and delicate materials. Cooling and Ventilation are the two systems that most consume electrical energy, the fact that is coherent with maintaining the air under a good temperature and quality. While most of the thermal energy is consumed by the Heating system, again, coherent with the necessities of maintaining the air at the correct temperature for the necessities of patients and users during winter.
Figure 16. Electric and thermal energy consumption in Healthcare buildings

- HVAC
- Lighting
- Cooking
- Refrigeration
- Office and computing equipment
- Other

Figure 17. Electric and thermal energy consumption in Lodging buildings

- HVAC
- Lighting
- Cooking
- Refrigeration
- Office and computing equipment
- Other
It is also important to mention the high electricity consumption in office buildings (Figure 14) pulled by the ventilation (maintaining good air quality for the high-density population), lighting and computing systems. Or lodging buildings, represented by hotels, which have a high thermal consumption, interestingly, mainly generated by the water heating system (needed for covering the need of the guests).

Figure 18. Electric and thermal energy consumption in Retail buildings
Figure 19. Electric and thermal energy consumption in Office buildings

Electric consumption - Office buildings

- HVAC: 41%
- Lighting: 24%
- Cooking: 23%
- Office and computing equipment: 16%
- Other: 1%

Thermal consumption - Office buildings

- HVAC: 76%
- Lighting: 0%
- Cooking: 4%
- Office and computing equipment: 1%
- Other: 1%

Figure 20. Electric and thermal energy consumption in Religious worship buildings

Electric consumption - Worship buildings

- HVAC: 39%
- Lighting: 32%
- Cooking: 11%
- Office and computing equipment: 5%
- Other: 4%

Thermal consumption - Worship buildings

- HVAC: 82%
- Lighting: 18%
- Cooking: 9%
- Office and computing equipment: 4%
- Other: 0%
Finally, in Figure 18, a comparison between the average consumption in the different types of building is presented in Figure 18. Food sales have by far the highest consumption in electricity, caused mostly by refrigeration as mentioned previously. Healthcare buildings have a balanced consumption of thermal and electric energy, which in both cases is considerably high. Retail and Office buildings have high electric consumption when compared with their thermal load, suggesting biggest investment on electric savings measures. Contrary to the worship case.

![Yearly energy consumption intensity](image)

*Figure 21. Energy consumption intensities in different types of buildings*

The second step of our analysis, showed on Table 2, was to establish the average energy savings that could be achieved by implementing energy efficiency measure in the building, by implementing smart energy measures in already existing buildings, and by implementing smart energy implementations in a new project, in which case, is usually translated into a more integrated system.
Table 2. Average savings in energy achieved with implementations on energy efficiency and smart energy technologies (Environmental Protection Agency, 2012)

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Yearly average Electricity consumption intensity (KWH/m²)</th>
<th>Yearly average Thermal energy consumption intensity (KWH/m²)</th>
<th>Average energy savings due to energy efficiency implementations (%)</th>
<th>Average energy savings due to smart systems implementations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Renovation</td>
<td>New construction</td>
<td>Renovation</td>
<td>New construction</td>
</tr>
<tr>
<td>Education</td>
<td>118</td>
<td>97</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Food sales</td>
<td>524</td>
<td>198</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Health care</td>
<td>278</td>
<td>254</td>
<td>2%</td>
<td>14%</td>
</tr>
<tr>
<td>Lodging</td>
<td>165</td>
<td>142</td>
<td>3%</td>
<td>8%</td>
</tr>
<tr>
<td>Retail (other than mall)</td>
<td>164</td>
<td>69</td>
<td>11%</td>
<td>14%</td>
</tr>
<tr>
<td>Office</td>
<td>171</td>
<td>86</td>
<td>10%</td>
<td>18%</td>
</tr>
<tr>
<td>Religious worship</td>
<td>56</td>
<td>91</td>
<td>13%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Here, it is interesting to highlight that the biggest savings due to energy efficiency can be achieved in buildings dedicated to Religious worship, Office, Retail, and Education. It is interesting to think that these are buildings that are not under constant use, meaning that is usually used just during a portion of the day, while the remaining types of buildings are the ones that require a constant functioning along the day. At the same time, we can see that the biggest savings due to energy efficiency implementations are achieved on the buildings that have lower energy intensity consumption, the fact that is not positive since the final impact is lower compared to if the buildings with the highest energy consumption would be able to save more energy.

Steeping to smart energy implementations, we see a pattern pretty similar to the one observed when implementing energy efficiency measures. However, there is one exception, since in this case, important savings can also be achieved in Healthcare buildings. This could be due to many reasons that we will explore deeper in a further section, but as a general explanation, Hospitals allow for automatization and optimization of many scenarios while still maintaining ideal conditions (which are controlled by a central operator), contrary to, for instance, hotels where most of the consumption is generated by guests that can manipulate the conditions of their space to their will.
In relation with the other three cases (Office, Retail and Education), the implementation of smart technologies is optimal since many of them can adapt themselves in a very efficient way to the behavior of the users, meaning that the building provides energy and services to the locations in the building that have the strict need of it and at the exact quantity. This provides a scenario similar to the previous one, where the technologies are higher in less intense consuming buildings, lowering the final energy savings. Nonetheless, the important savings that can be achieved in high consuming, Healthcare buildings, show a very interesting scenario, considering that in many cases the high costs in this industry block many people of good health service.

![Average energy savings](image)

*Figure 22. Savings due to energy efficiency implementations and due to smart technologies*

Our next step is not very different from the last one. However, we wanted to go deeper into energy savings generated by specific smart systems and by specific technologies implementations, as shown in Table 3. For this step, we took just four out of the seven types of buildings mentioned previously: Office, Retail, Lodging, and Healthcare buildings. And we consider the main smart systems that have an impact on energy consumption: HVAC, Lighting, Energy Management, and Plug Load.

We can observe that in terms of percentage, lighting systems are the ones that, on average, have a larger percentage of energy savings followed by plug loads and finally by HVAC systems. And so, starting with lighting systems, they have an average impact on energy savings of more
than 30% (on the lighting system), except in Lodging buildings where the savings are just around 15%, due to reasons that we already mentioned in the previous two steps. In this section we also find smart technologies that are very standardized for all the different types of buildings, like the very mentioned sensors for occupancy/vacancy and daylight sensors, retrofit kits (it can include new brackets, sockets, screws, reflectors, etc.), installation of gateways or hubs (control that allow to set timers, wakeup lights, alarms, dimming, etc.), and the similar to the already existing ones, exterior lighting controls.

In the HVAC systems, savings range between an average of 15% to 18% (on the HVAC system), having a specially high average of 28% in healthcare buildings. Here, the technologies that can be implemented are less broad used that in the previous case, meaning that different technologies are implemented depending on the necessities of different types of buildings. However, it is valid to mention the similarity to the previous case, occupancy-based thermostat and the learning thermostats which are already pretty widespread technologies. There are also the CO2 demand-controlled ventilation systems, which instead of functioning based on occupancy, are based on the amount of CO2 present in the ambient. Smart kitchens with exhaust controls (turning on and off exhausting fans when needed), when possible, can allow savings up to 60% on the cooling system which is something very impressive.

Talk about Energy Management systems is a bit redundant since the EMIS was born being smart or their main goal was to be smart. Therefore, in this section, we mention the very standardized, cloud-based EMIS, which incorporated cloud computing and the IoT as part of its software and hardware. In our research, we found that it can be applied to all kinds of buildings with savings that range from 5% to 15%, but more importantly, savings that are applied to the entire building, differently to the previous cases where the savings were directed to the specific systems of the technology.

Then we have the technologies related with plug load, which for this project we did not consider it as a system itself, even if its functioning represents important values on the final energy consumption of the building, and the implementation of smart technologies also could generate important energy savings. In average, the savings generated in Office and Retail buildings, are over the 25% (on plug loads), generated by the wide standardized two technologies: advanced
power strips that can reduce up to 65% the energy consumed by devices connected to them (thanks to features that reduce consumption when the equipment is not working), and the smart plugs (plugs that can be controlled remotely, allow for scheduling, and to monitor power usage).

Among other interesting technologies, we find the controls that could be implemented in vending machines (present almost everywhere) that could make them save up to 25% of energy consumption. Refrigeration system controls could also very important, considering that in a previous step, we mention how high is the electric consumption generated by refrigeration in supermarkets, which is not deeply considered here but could have an impact of up to 30%.

![Average energy savings due to smart systems](image)

Figure 23. Energy savings in different types of buildings thanks to smart systems (King et al, 2017)

To conclude this step, we would like to mention that even if the average savings generated by every intelligent system or technology is important, what is more important and relevant at the end, is to analyze which systems consume more energy in each type of building and see where the final energy savings would have more relevance. To clarify this point a bit better, we provide an example. In the case of the office building, the average savings due to smart HVAC systems are 18% while the savings due to smart Lighting systems are 33%, let us say, for practical purposes, that the lighting system could generate the double of the savings generated by an HVAC system when implemented. However, if we consider that the consumption of the HVAC system is of 154 KWh/m2 while the consumption of the lighting system is of 29 KWh/m2 (more
than 5 times!), the savings coming from the implementation of a smart HVAC system will be much higher and profitable (end goal) than any other system.

Table 3. Energy savings due to smart systems and smart technologies (Perry et al, 2017)

<table>
<thead>
<tr>
<th>Smart system</th>
<th>Technology</th>
<th>Office savings (%)</th>
<th>Retail savings (%)</th>
<th>Lodging savings (%)</th>
<th>Health care savings (%)</th>
<th>System where the savings happen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart HVAC</td>
<td>Occupancy-based wireless thermostat</td>
<td>5 -- 10</td>
<td>5 -- 10</td>
<td>10 -- 30</td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Learning thermostats</td>
<td>10 -- 30</td>
<td>5 -- 10</td>
<td>10 -- 30</td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Networked tenant submeters</td>
<td>2.5 -- 5</td>
<td>5 -- 10</td>
<td>10 -- 30</td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Advanced rooftop controller</td>
<td>20 -- 40</td>
<td>20 -- 40</td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>CO2 demand-controlled ventilation</td>
<td>10</td>
<td>10</td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Smart window solar film</td>
<td>10 -- 20</td>
<td>10 -- 20</td>
<td></td>
<td>Cooling</td>
<td>Cooling</td>
</tr>
<tr>
<td></td>
<td>Wireless windows and door contacts</td>
<td>3 -- 5</td>
<td>10 -- 30</td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Smart kitchen exhaust controls</td>
<td>5 -- 10</td>
<td>10 -- 30</td>
<td></td>
<td>Heating</td>
<td>Heating</td>
</tr>
<tr>
<td></td>
<td>Electronic solar film for windows</td>
<td>10 -- 20</td>
<td>10 -- 20</td>
<td></td>
<td>Cooling</td>
<td>Cooling</td>
</tr>
<tr>
<td></td>
<td>Automated shade system</td>
<td>10 -- 20</td>
<td>10 -- 20</td>
<td></td>
<td>Heating</td>
<td>Heating</td>
</tr>
<tr>
<td></td>
<td>Wireless steam trap monitoring</td>
<td>15 -- 25</td>
<td></td>
<td></td>
<td>Steam energy</td>
<td>Steam energy</td>
</tr>
<tr>
<td></td>
<td>Networked central plant submeters</td>
<td>5 -- 45</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Upgrade from pneumatic to electronic controls</td>
<td>10 -- 20</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Wireless pneumatic thermostats</td>
<td>5 -- 15</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td>Smart Lighting</td>
<td>Occupancy, vacancy and daylight sensors</td>
<td>20 -- 40</td>
<td>20 -- 40</td>
<td>20 -- 40</td>
<td>Lighting</td>
<td>Lighting</td>
</tr>
<tr>
<td></td>
<td>Retrofit kit</td>
<td>33</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>Exterior lighting</td>
</tr>
<tr>
<td></td>
<td>Wired or wireless gateway/hub</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exterior lighting controls</td>
<td>30 -- 50</td>
<td>30 -- 50</td>
<td>30 -- 50</td>
<td>30 -- 50</td>
<td>Exterior lighting</td>
</tr>
<tr>
<td></td>
<td>Cat-6A cabling (POE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC and lighting</td>
<td>Wireless infrared ceiling occupancy sensors</td>
<td>12 -- 24</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Cloud-based EMIS</td>
<td>5 -- 15</td>
<td>5 -- 15</td>
<td>5 -- 15</td>
<td>5 -- 15</td>
<td>Whole building</td>
</tr>
<tr>
<td></td>
<td>Tenant comfort feedback system</td>
<td>15 -- 25</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Networked guest room building automation system</td>
<td>15 -- 30</td>
<td></td>
<td></td>
<td>HVAC</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td>Advanced power strips</td>
<td>26 -- 65</td>
<td>26 -- 65</td>
<td>25</td>
<td>9</td>
<td>Plug load</td>
</tr>
<tr>
<td></td>
<td>Smart plugs</td>
<td>48 -- 53</td>
<td>50 -- 60</td>
<td>50 -- 60</td>
<td>50 -- 60</td>
<td>Plug load</td>
</tr>
<tr>
<td>Plug Load</td>
<td>Vending machine controls</td>
<td>20 -- 25</td>
<td>20 -- 25</td>
<td>20 -- 25</td>
<td>Vending machine</td>
<td>Vending machine</td>
</tr>
<tr>
<td></td>
<td>Distributed energy smart inverter</td>
<td>12</td>
<td>12</td>
<td></td>
<td>Whole building</td>
<td>Whole building</td>
</tr>
<tr>
<td></td>
<td>Refrigeration system controls</td>
<td>15 -- 30</td>
<td>15 -- 30</td>
<td></td>
<td>Refrigeration</td>
<td>Refrigeration</td>
</tr>
<tr>
<td></td>
<td>Smart pool pump controls</td>
<td>25 -- 40</td>
<td></td>
<td></td>
<td>Pump</td>
<td>Pump</td>
</tr>
</tbody>
</table>

Our next step is to establish data related with the area used in different types of buildings, with which we proceed to calculate the average energy expenditure for the building. For consistency with our model, we will use the average values provided by the U.S. Energy Information Administration, from where most of the previous numbers were obtained. As we can see in Table 4, we provide the average price paid by electricity and by thermal energy (represented
mainly by the price of natural gas) in different buildings. The energy expenditure for the building is calculated using the following formula:

\[ \text{Building area} \ (m^2) \times \text{Electricity price} \left( \$/KWh \right) \]
\[ \times \text{Electrical consumption} \left( KWh/m^2 \right) \]
\[ + \text{Building area} \ (m^2) \times \text{Thermal energy price} \left( \$/KWh \right) \]
\[ \times \text{Thermal consumption} \left( KWh/m^2 \right) \]

An example related to Retail buildings here to make it clear:

\[ 1200 \text{ m}^2 \times 0.099 \$/\text{KWh} \times 164 \text{ KWh/m}^2 + 1200 \text{ m}^2 \times 0.031 \$/\text{KWh} \times 69 \text{ KWh/m}^2 \]

It is also important to mention that from this point on, all the values related with prices are used based on the information obtained (in English, therefore in US dollars), but it could be easily replaced with the prices in Europe, Italy or Lombardy. The important aspect to rescue is the methodology.

*Table 4. Average energy expenditure in different types of buildings (U.S. Energy Information Administration, 2012)*

<table>
<thead>
<tr>
<th>Building type</th>
<th>Area (m2)</th>
<th>Electric energy price (dollars/KWh)</th>
<th>Thermal energy price (dollars/KWh)</th>
<th>Average energy expenditure (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>6400</td>
<td>0.096</td>
<td>0.022</td>
<td>$86.525</td>
</tr>
<tr>
<td>Food sales</td>
<td>1600</td>
<td>0.094</td>
<td>0.027</td>
<td>$87.451</td>
</tr>
<tr>
<td>Health care</td>
<td>2500</td>
<td>0.090</td>
<td>0.025</td>
<td>$78.630</td>
</tr>
<tr>
<td>Lodging</td>
<td>8400</td>
<td>0.095</td>
<td>0.023</td>
<td>$158.546</td>
</tr>
<tr>
<td>Retail (other than mall)</td>
<td>1200</td>
<td>0.099</td>
<td>0.031</td>
<td>$22.020</td>
</tr>
<tr>
<td>Office</td>
<td>1500</td>
<td>0.104</td>
<td>0.025</td>
<td>$29.928</td>
</tr>
<tr>
<td>Religious worship</td>
<td>1000</td>
<td>0.106</td>
<td>0.024</td>
<td>$8.086</td>
</tr>
</tbody>
</table>

Following, we searched information related to the prices related to the implementation of different technologies (the same technologies shown in Table 3). A range of prices is provided, depending on the brand, the characteristics or the availability. The price is provided together with the unit of measure. For instance, one occupancy-based wireless thermostat would cost
between US $ 150 and US $ 300. Or a CO2 demand-controlled ventilation system would cost between US $ 1 and US $ 3 for every cubic foot per minute required in the determined area. Another important mention to do is that in general, all the technologies consist of one-time investment, however, when installing Energy Management and Information Systems, monthly subscriptions are required in the most of the cases.

Table 5. Cost of some smart technologies (Perry et al, 2017)

<table>
<thead>
<tr>
<th>Smart system</th>
<th>Technology</th>
<th>Price (dollars)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart HVAC</td>
<td>Occupancy-based wireless thermostat</td>
<td>150 -- 300</td>
<td>thermostat</td>
</tr>
<tr>
<td></td>
<td>Learning thermostats</td>
<td>250 -- 300</td>
<td>thermostat</td>
</tr>
<tr>
<td></td>
<td>Networked tenant submeters</td>
<td>2000 -- 4000</td>
<td>tenant</td>
</tr>
<tr>
<td></td>
<td>Advanced rooftop controller</td>
<td>2000 -- 4000</td>
<td>roof top air handling unit</td>
</tr>
<tr>
<td></td>
<td>CO2 demand-controlled ventilation</td>
<td>1 -- 3</td>
<td>cfm</td>
</tr>
<tr>
<td></td>
<td>Smart window solar film</td>
<td>160 -- 215</td>
<td>square meter</td>
</tr>
<tr>
<td></td>
<td>Wireless windows and door contacts</td>
<td>25 -- 75</td>
<td>contact</td>
</tr>
<tr>
<td></td>
<td>Smart kitchen exhaust controls</td>
<td>1 -- 2,5</td>
<td>cfm</td>
</tr>
<tr>
<td></td>
<td>Electronic solar film for windows</td>
<td>160 -- 215</td>
<td>square meter</td>
</tr>
<tr>
<td></td>
<td>Automated shade system</td>
<td>375</td>
<td>motorized shades</td>
</tr>
<tr>
<td></td>
<td>Wireless steam trap monitoring</td>
<td>650</td>
<td>steam trap</td>
</tr>
<tr>
<td></td>
<td>Networked central plant submeters</td>
<td>400 -- 3000</td>
<td>meter</td>
</tr>
<tr>
<td></td>
<td>Upgrade from pneumatic to electronic controls</td>
<td>800 -- 3000</td>
<td>actuator</td>
</tr>
<tr>
<td></td>
<td>Wireless pneumatic thermostats</td>
<td>6 -- 12</td>
<td>square meter</td>
</tr>
<tr>
<td>Smart Lighting</td>
<td>Occupancy, vacancy and daylight sensors</td>
<td>20 -- 100</td>
<td>sensor</td>
</tr>
<tr>
<td></td>
<td>Retrofit kit</td>
<td>50 -- 200</td>
<td>fixture</td>
</tr>
<tr>
<td></td>
<td>Wired or wireless gateway/hub</td>
<td>300 -- 1000</td>
<td>gateway</td>
</tr>
<tr>
<td></td>
<td>Exterior lighting controls</td>
<td>200 -- 400</td>
<td>fixture</td>
</tr>
<tr>
<td>HVAC and lighting</td>
<td>Wireless infrared ceiling occupancy sensors</td>
<td>50 -- 150</td>
<td>room</td>
</tr>
<tr>
<td>Energy Management Systems</td>
<td>Cloud-based EMIS</td>
<td>0,11 -- 4,31</td>
<td>square meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,11 -- 1,08</td>
<td>square meter per month</td>
</tr>
<tr>
<td></td>
<td>Networked guest room building automation system</td>
<td>500 -- 1000</td>
<td>room</td>
</tr>
<tr>
<td>Plug Load</td>
<td>Advanced power strips</td>
<td>25 -- 100</td>
<td>strip</td>
</tr>
<tr>
<td></td>
<td>Smart plugs</td>
<td>100 -- 120</td>
<td>plug</td>
</tr>
<tr>
<td>Other</td>
<td>Vending machine controls</td>
<td>180</td>
<td>vending machine</td>
</tr>
<tr>
<td></td>
<td>Distributed energy smart inverter</td>
<td>0,16</td>
<td>watt</td>
</tr>
<tr>
<td></td>
<td>Refrigeration system controls</td>
<td>800 -- 900</td>
<td>unit</td>
</tr>
<tr>
<td></td>
<td>Smart pool pump controls</td>
<td>300 -- 500</td>
<td>pump</td>
</tr>
</tbody>
</table>

After gathering all the information mentioned previously, we can progress to start establishing how large would be the investment and which savings are going to be achieved with that level of investment.

First, we have the case of an office building. In this case, we decided to implement eight technologies, three on the HVAC system, three on the Lighting system, one on Plug loads and a Smart Energy Management System. We chose these options since they represent good
important savings on the energy consumption of this kind of building, however, it is important to mention that technologies could be added or removed from the model since all the necessary information is already provided.

Going deeper in the content of Table 6, the first new component we see is Quantity, which refers to the number of times of the product, based on the unit of measure, should be used on the entire building (areas taken from Table 4). For obtaining the 9 we consider a building of 3 floors, with the necessity of two thermostats per floor or 1 thermostat every 167 (Zoopla)square meters. One rooftop air handling unit for the entire building, for offices, the necessary value of cfm to achieve a good level of air quality is of 0,915 cfm/m2 (Katipamula et al, 2013). Sensors should be aligned with thermostats, one fixture of light for every 10 m2, one hub per floor or per every 500 square meters (making it 3 in total), and the EMIS, based on the area (1500m2), US $0,5 per square meter. Finally, it was considered that a power strip can be used by 4 workers, generating the acquisition of 55 power strips.

Then the costs presented in Table 5 are multiplied by the quantity, obtaining the value of the investment necessary to implement the technology mentioned.

The quantification of the savings percentage was done base in much of the information presented previously: Table 1 presents the percentage of energy consumed by every system in terms of both, electrical and thermal energy. Table 3. Shows the percentage of savings generated by a technology when implemented and it also mentions on which exact system the impact is done. Therefore:

\[
\text{% electrical energy savings on system } \beta \\
= \text{% electrical energy saved by technology } \alpha \text{ on system } \beta \\
\times \text{% electrical energy consumed by system } \beta \text{ on the building}
\]

\[
\text{% thermal energy savings on system } \beta \\
= \text{% thermal energy saved by technology } \alpha \text{ on system } \beta \\
\times \text{% thermal energy consumed by system } \beta \text{ on the building}
\]
Here an example: learning thermostats save an average of 20% of energy on the HVAC system, which represents the 40% of the total electrical energy consumption on office buildings, making it an 8% of energy savings on the total electric consumption of the building. Equally happens with the thermal consumption, learning thermostats save an average of 20% of energy on the HVAC system, which represents the 90% of the total thermal energy consumption on office buildings, making it an 18% of energy savings on the total thermal consumption of the building.

Finally, the costs and savings are added up for a further step.

*Table 6. Implementation costs and energy savings in an office building*

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost (dollars)</th>
<th>Savings percentage (electricity)</th>
<th>Savings percentage (thermal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>Learning thermostats</td>
<td>thermostat</td>
<td>9</td>
<td>2475</td>
<td>8%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Advanced rooftop controller</td>
<td>roof top air handling unit</td>
<td>1</td>
<td>3000</td>
<td>12%</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>CO2 demand-controlled ventilation</td>
<td>cfm</td>
<td>1373</td>
<td>2745</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>Occupancy, vacancy and daylight sensors</td>
<td>sensor</td>
<td>9</td>
<td>539</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retrofit kit</td>
<td>fixture</td>
<td>150</td>
<td>7500</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wired or wireless gateway/hub</td>
<td>gateway</td>
<td>3</td>
<td>1950</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>EMS</td>
<td>Cloud-based EMS</td>
<td>square meter</td>
<td>1500</td>
<td>3300</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>square meter per month</td>
<td>1500</td>
<td>750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug Load</td>
<td>Advanced power strips</td>
<td>strip</td>
<td>55</td>
<td>3465</td>
<td>11%</td>
<td></td>
</tr>
</tbody>
</table>

Similar to the previous case, the technologies proposed for this type of building are the same, as well as the number of technologies implemented, making it proportional to the size. However, there will not be many workers using computers, and then, the amount of power strips per m2 is lower than in the offices.

*Table 7. Implementation costs and energy savings in a retail building*

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost (dollars)</th>
<th>Savings percentage (electricity)</th>
<th>Savings percentage (thermal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>Learning thermostats</td>
<td>thermostat</td>
<td>7</td>
<td>1976</td>
<td>6%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>Advanced rooftop controller</td>
<td>roof top air handling unit</td>
<td>1</td>
<td>3000</td>
<td>10%</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>CO2 demand-controlled ventilation</td>
<td>cfm</td>
<td>1098</td>
<td>2196</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Lighting</td>
<td>Occupancy, vacancy and daylight sensors</td>
<td>sensor</td>
<td>7</td>
<td>420</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retrofit kit</td>
<td>fixture</td>
<td>120</td>
<td>6000</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wired or wireless gateway/hub</td>
<td>gateway</td>
<td>2</td>
<td>1300</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>EMS</td>
<td>Cloud-based EMS</td>
<td>square meter</td>
<td>1200</td>
<td>2640</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>square meter per month</td>
<td>1200</td>
<td>600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug Load</td>
<td>Advanced power strips</td>
<td>strip</td>
<td>30</td>
<td>1890</td>
<td>3%</td>
<td></td>
</tr>
</tbody>
</table>

24974 | 63% | 63% |
For the next building case, lodging, a much shorter selection was made, partly because it is complicated to achieve significant savings on the Lighting system and on plug loads. Learning thermostats and Energy Management systems remain, however, occupancy sensors specially designed for this use are recommended. It represents a high investment since the sensors must be installed in each of the rooms, which we assumed on 210. The other important consideration to highlight is that considering that the system implemented is simpler, the monthly subscription for the EMIS is not so expensive (US $ 0, 35 per square meter) and it can also be partly managed by the maintenance personnel of the hotel (which is considerable big).

Table 8. Implementation costs and energy savings in a lodging building

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost (dollars)</th>
<th>Savings percentage (electricity)</th>
<th>Savings percentage (thermal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>Learning thermostats</td>
<td>thermostat</td>
<td>5</td>
<td>1375</td>
<td>6%</td>
<td>10%</td>
</tr>
<tr>
<td>HVAC and Lighting</td>
<td>Wireless infrared ceiling occupancy sensors</td>
<td>room</td>
<td>210</td>
<td>10500</td>
<td>7%</td>
<td>12%</td>
</tr>
<tr>
<td>EMS</td>
<td>Cloud-based EMIS</td>
<td>square meter</td>
<td>8400</td>
<td>18480</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>square meter per month</td>
<td>8400</td>
<td>2940</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30355</td>
<td>27%</td>
</tr>
</tbody>
</table>

Finally, for the healthcare building, a completely different approach, in terms of smart technologies was used. This is due to the, already mentioned, particularity of this kind of building, which the industry has made sure to develop technologies that suit much better the necessities of it. As we can see, the implementations, apart from the EMS, are only applied to the HVAC system. We have one submeter (it should be enough for a hospital of 2500 square meters) for the auxiliary power plant the hospital count with. On the other hand, we have very technical implementation related to the steam traps monitoring, that ensures to detect any leakages of steam around the network (5 traps for every 500 square meters). Additionally, the upgrading to electronic controls in order to maintain ideal temperatures would provide more accurate results, helping saving energy.
Finally, in our last step, we generate some financial indicator to try and identify clearer how good and possible is to carry on with these investments. To do so we used the costs of the investment as initial negative cash flow, then we use the monthly costs generated by the EMS to generate de negative cash flows during the years, and finally, for the positive cash flows we used the following formula:

\[
\text{Electric energy expenditures} \times \% \text{ savings on electric energy} \\
+ \text{Thermal energy expenditures} \times \% \text{ savings on thermal energy}
\]

With these data available, we were able to find the Net Present Value in a scenario of 10 years with a discount rate of 5%. With the same discount rate, we found the Payback Time and finally we could also find the Internal Rate of Return.

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost (dollars)</th>
<th>Savings percentage (electricity)</th>
<th>Savings percentage (thermal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>Networked central plant submeters</td>
<td>meter</td>
<td>1</td>
<td>1700</td>
<td>11%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Wireless steam trap monitoring</td>
<td>trap</td>
<td>5</td>
<td>3250</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Upgrade from pneumatic to electronic controls</td>
<td>actuator</td>
<td>5</td>
<td>1900</td>
<td>6%</td>
<td>3%</td>
</tr>
<tr>
<td>EMS</td>
<td>Cloud-based EMIS</td>
<td>square meter</td>
<td>2500</td>
<td>5500</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>square meter per month</td>
<td>2500</td>
<td>1250</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Implementation costs and energy savings in a Healthcare building

Table 10. Financial indicators of smart system implementations

<table>
<thead>
<tr>
<th></th>
<th>Office Scenario</th>
<th>Retail Scenario</th>
<th>Lodging scenario</th>
<th>Health care Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment</td>
<td>24974</td>
<td>19422</td>
<td>30355</td>
<td>12350</td>
</tr>
<tr>
<td>Income cash flows</td>
<td>18872</td>
<td>12758</td>
<td>43626</td>
<td>21785</td>
</tr>
<tr>
<td>Monthly Expenditures</td>
<td>9000</td>
<td>7200</td>
<td>35280</td>
<td>15000</td>
</tr>
<tr>
<td>NPV (10 years)</td>
<td>51256</td>
<td>23493</td>
<td>34090</td>
<td>40039</td>
</tr>
<tr>
<td>Payback Time</td>
<td>3,8</td>
<td>4,9</td>
<td>5,1</td>
<td>3</td>
</tr>
<tr>
<td>IRR</td>
<td>38%</td>
<td>26%</td>
<td>24%</td>
<td>54%</td>
</tr>
</tbody>
</table>

The data presented in Table 10 contains all the relevant information that was necessary to carry on with the calculation of the indicators, as well as it contains the indicators. The healthcare scenario seems very positive since a low investment can carry with it very good returns and fast payback times. This is especially led by the installation of a smart submeter on the central plant...
of the hospital, which is cheap and can generate great savings on the HVAC system, which is the most consuming one.

Contrary, the lodging scenario is the one showing the less positive scenario showing payback times superior to the 5 years. This happens mainly led to the high costs that the hotel would incur when implementing a smart energy management system. Even if the maintenance personnel of the hotel can carry much of the activities that could not be done by tenants in other buildings, the high areas make it not optimal. Additionally, it important to consider that every room is independent of each other and therefore the conditions cannot be controlled as a whole, but separately and less optimally.

Office and Retail buildings carry the same technological implementations; however, the scenario is better in the first case due to the opportunities to have a more controlled and predictable scenario that allows controllers to optimize the systems in a better way. On the other hand, a bigger density of smart power strips leads to higher energy savings.

To finish this section, we would like to add some information related to the implementation of smart stand-alone technologies. Which as mentioned in a previous section, can also be very interesting options for existing buildings that would be open to carrying low investments or not disruptive ones.

Table 11. Payback time for stand-alone smart technologies (King et al, 2017)

<table>
<thead>
<tr>
<th>Smart system</th>
<th>Technology</th>
<th>Payback time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart HVAC</td>
<td>Smart thermostat</td>
<td>3 -- 5</td>
</tr>
<tr>
<td></td>
<td>Automated shade system</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Smart window solar film</td>
<td>2 -- 3</td>
</tr>
<tr>
<td>Smart Lighting</td>
<td>Occupancy, vacancy and daylight sensors</td>
<td>3 -- 6</td>
</tr>
<tr>
<td></td>
<td>Retrofit kit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wired or wireless gateway/hub</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Web-based management system (software and hardware)</td>
<td>1 -- 4</td>
</tr>
<tr>
<td>HVAC and lighting</td>
<td>Wireless infrared ceiling occupancy sensors</td>
<td>2,5 -- 3</td>
</tr>
<tr>
<td>Energy Management Systems</td>
<td>Cloud-based EMIS</td>
<td>3 -- 5</td>
</tr>
<tr>
<td>Plug Load</td>
<td>Advanced power strips</td>
<td>0,6 -- 1,5</td>
</tr>
<tr>
<td></td>
<td>Smart plugs</td>
<td>0,3 -- 1</td>
</tr>
</tbody>
</table>
The first observation is that just two technologies have payback times inferior to one year, and both are related to smart plugs. That opens a very interesting scenario for office buildings since it is something very simple to implement and applied in big densities, it would generate important energy savings. Smart window solar films also have interesting returning times, that together with the fact that they do not require maintenance and it can be applied for a big range of costumes make it as a very interesting one too. Cloud-based Energy Management and Information Systems as the core of the implementation of smart technologies and systems have a payback time very average when looking at other technologies, the fact that makes sense since are still in many cases developing technologies that would work better together.
5. Construction or renovation

A building is a very complex project where the necessities and interests come to a common, and therefore everybody will try to get most of the benefits for itself. Because of that, it is important to establish global goals since the beginning and maintain constant and clear communication between the players. All the teams included must achieve a great, integration in order to achieve the global and the personal goals. This is achieving an integrated building, under the adequate specifications, budget and time.

As usual, we will put our attention on smart buildings rather than classical buildings and to do so we will make clarifications in each of the steps taken in order to achieve to the smart building. Also, comments will be made on practices that have a direct impact on energy functioning.

Players

For the purpose of a clear assignation of roles and responsibilities, we would like to divide the people involved in the project in four different groups (Sinopoli et al, 2010) as shown in Figure 24.

![Diagram](image_url)

*Figure 24. Teams involved in the realization of the project*
Owner’s team: This team is the group composed usually of the economical providers. It is composed of, naturally the owner, the manager or future manager of the facility, the future operators, or users of the building.

Design team: It is composed by the classical players which are mainly the architect, designers, engineers, and consultants. However, it is important to consider that there are a set of new players that are covering the necessities of new buildings that aim to achieve high levels of automation and environment assurance. These are mainly consultants, that play with their knowledge and the technologies available in the market to advice the best possible solution.

Suppliers: For the purpose of smart buildings, the suppliers are fundamental. The new technologies and practices are announced or communicated by these players. The fast acquisition of the latest technologies is a source of strategic advantage from the distributors. The adaptation in the production to the necessities of the clients and the new directives will determine the most successful manufacturers. And, in general, the ability to communicate in a clear way the role and advantages of new technologies will determine their fast spreading in the market.

Construction team: In this case, the most usual model is that the owners hire contractors and they by themselves, hire subcontractors who have the tools and knowledge to take to a good end the project in an efficient manner. However, the influence that the owner and his supervisors around the project can vary depending on factors like the complexity and specificity needed for the project. In many occasions, the owner himself carry on with his team, with the construction.

**Process**

After being mentioned how complex is the project of a building, it is important to establish a recommended framework of steps to arrive at a good, especially in the case of smart buildings where particular integration in certain matters is of high importance (Sinopoli et al, 2010). To do so, Figure 25 is presented, followed by its proper explanation.
Conceptualization: Here is where everything starts. The owner identifies some new necessities. Necessities that can be related to spacing, comfort, costs, sustainability and so on. Based on that, the budget to cover those necessities through a building is defined. Followed by the identification of an area or terrain. The main players present in this stage of the process are the owner’s team and the users. There are also architects and engineers that provide ideas and very rough feasibilities. In relation to the smart systems, there are usually few discussions at this very early point.

Contracting: Here is where the owner decides who is going to be responsible to take the project to a good end. Meaning that the owner will start delivering the different steps of the project to third contractors that are best suited to carry on with the activities. The common way of doing this is by first contracting a company that makes the designs according to the necessities of the owner, followed by contracting the most suitable constructor based on the designs made. There are many different variations of that depending on the capabilities and vertical integration of the owner and the contractors. In relation with the smart systems, it is important to count in both of the main phases with contractors that have expertise doing smart buildings, and also to ensure
the coordination between contractors during each step since the ideas with respect to certain topics can differ depending on the novelty of the technology.

Design: At this step, the responsibilities pass to the contractor who will be in charge of transforming the clear specifications provided by the owner in the previous steps, into reality. This starts with the creation of schematic designs, that will evolve along the way depending on restrictions and allowances, finalizing with construction designs that will be the ones passing to the next contractor who will transform it into reality.

In this face, is where the designer of smart systems enters really into play and starts interacting with all the other designers in the project. In the case of the architect, for example, it should establish clearly spaces used by the systems and its networks. Electrical and mechanical engineers will be in charge of the design of lighting and HVAC systems respectively, and therefore a constant communication with the designer on a charge of automatizing and communicate them, is especially important. Civil engineers will be aware of communication ducts between areas and loads caused by equipment. Finally, the owner´s team will approve budgets, extra equipment, and complexity levels.

Procurement: Before entering in the construction phase, it is important to establish how much money is going to be used for going the construction of the process. Usually, the owner´s calculates how much would it cost to build all the necessary materials for the construction, plus overhead expenses and proposes a value. The interested company evaluates that and after and negotiation process, an agreement beneficial for both parties is achieved.

During this phase, the designer of smart systems has a counseling role, making sure that all the equipment, cabling, and software is correctly calculated and included in the budget.

Construction: The final and probably the most important phase, where all the players must have an important role again, so the project can be finished perfectly. There will even be external players supervising that the rules are followed and local community advocating for their own priorities.

The smart systems´ designer main role will be to ensure that the systems are installed as it was specified in the designs and ensure that they will function properly. His other role is to have a
constant communication with tenants and future IT users of the building, guaranteeing a good understanding on the technologies available and, of course, training on the administration of them.

After the construction of the building the work should not be considered over, there will operation and maintenance work in the future. Unfortunately, when the user of the building take possession of it, all the knowledge and data created during all the previous phases is lost and therefore, the tenants will have to start finding things by themselves. This is transformed into a huge lack of efficiency and therefore, in a loss of money. For example, the facility manager should count with data related with energy consumption, maintenance dates, integration with other systems availability and many other aspects that can be planned optimally by having the knowledge. We can say that many times, the smart buildings do not get to achieve their maximum potential due to the lack of data and knowledge.

To make a fast a summary, the final tenant should count with the following documents: the original design that was used to start the construction, specifying materials, mechanical footprints, structural requirements, etc. Then, the documents generated during the construction process by the contractors, showing information about product testing, design changes, coordination agreements, etc. Finally, the closeout documents, related to warranties, maintenance recommendations, contractors and final designs.

Finally, the documentation of new buildings, that are expected to be smart, should be coordinated since the beginning with the used software that will facilitate the gathering and storage of information, and so, we will talk in one of the following sections about this.

**Revamping**

Many times, when talking about smart building, the first association made is to the construction of those new smart buildings. But if we consider that almost the totality of the building stock in the world is already there, that there are areas that lack space for new constructions, that there are cities that are extremely big and therefore continuing building things around the perimeter of them will not improve the problems of its inhabitants, or that the heritage that exists in many
European cities must be conserved, make the renovation and adaptation of existing buildings, the best option.

The implementation of smart technologies in existing building usually has positive financial impacts related to first, expenses generated by the building itself like energy and maintenance costs. And second, the bigger attractiveness of the building compared with other old buildings without renovation, attractiveness that is translated into higher rents, higher selling costs, more liquidity and so on.

To achieve all the advantages mentioned previously, it is important to make some general clarifications before going deeper into the subject. First, the new systems will have to be integrated with the existed systems, and they usually use different communication and functioning standards, therefore, it is always important to consider that before deciding the new choices. Second, to avoid intrusion into the existing infrastructure, the implementation of wireless systems will be a great priority, even if the efficiency of the system is affected. And finally, the implementation of an integrated approach is not achieved easily since there are
systems already working, other systems will be almost impossible to implement, and the cultural barriers or financial barriers would not allow them, and so, a stand-alone system is common choices that can also bring important benefits.

When renovating a building, the financial considerations will be the most important factor, sometimes regulations or external pressures can play a role though, and therefore there will always be questions related to the potential savings in energy and operations or questions related to the potential incomes related to higher rents or sale of the spaces of the building. Being said that, we will present some of the most important steps taken when carrying the revamping of a building. Figure 26 shows some of the main considerations in this case.

Exploring systems: Since in most of the cases, the renovation is being carried on old buildings, the available information will be very scarce. For example, equipment’s specification will be information that stopped being relevant some time ago. Original designs are another example of data that very probably will be difficult to find.

And therefore, the necessity of gathering information through exploration becomes the prime method. It will be possible to gather information related to the energy consumption and its costs of the last years, there will be clear knowledge about expenses related to maintenance and focus of expenses related to that, capacity of production of the building, data gathered through surveys of the users and tenants or, even information of similar buildings that already did some smart implementations.

Follow standards? The decision about following already existing standards have advantages and disadvantages. On one hand, we have the disadvantages related with extract costs generated by paying extra consultants with expertise in certified projects, flexibility due to the rigid standards that have to follow, longer times in the case of discrepancies with the standards, etc.

On the other hand, we have the advantages, between which we found: efficiency due to the advantage of following standards instead of improvising, local and global recognition of the prizes achieved, increases in the price of the building, certainty of doing the things well, many projects to benchmark with, etc.
In the end, the decision will be made by weighting the importance of the advantages and disadvantages based on the necessities and priorities of the client. If, for instance, the goal is to make the building visible and marketable, a certification will make a great difference, instead, if the goal is just to reduce the energy costs until the desired point to cover regulations, then just the necessary implementations will be made.

Upgrade HVAC and lighting systems: Being these two, the system with the highest energy consumption, they should be the first systems that the owner should check for optimizing. These are systems that have also had a fast development in their technologies during the last decades and therefore, there is a second reason to make it a profitable solution. Before making any implementation in the hardware, and this applies to any system´s upgrade, there should be an upgrading of the software.

The monitoring systems are the cheapest implementation, and they will allow two things, first, optimize the functioning of the system in a more efficient way, and second, allow the tenants to collect information on functioning and consumption. Being done that, the physical implementations can be made with a higher certainty on the future impacts.

Upgrade power management and security systems: As mentioned previously, further improvements will be evaluated on the returns of the investment. The implementation or upgrading, of power management systems, will require of many modern devices and equipment likes sensors, data storage points, and specialized software. And so, its implementation will depend on the characteristics of the building and the advantages of implement this kind of system.

On the other hand, security systems as other technological implementations will also increase the intelligence of the building as a whole, and will also increase the attractiveness of the building, especially in cases when the flux of people is high, and the priority of the building is to provide comfort and healthiness.

Upgrade monitoring and management of the systems: When we talk about this, we are referring to two things in particular, first, the integration of existing systems with new systems in order
to have a global monitoring, and second, the training of people to take them to be familiar with the new system and exploit to the highest level the advantages of the system.

In relation to the first consideration and coming back to a comment presented at the beginning of this chapter. In the renovation, processes are common to make implementation of individual systems. And therefore, every time a new system is installed, there are chances that this new system will not be using the same standards as already existing ones. And so, it is very important to find solutions to this problem. It could be done through the integration of protocols as a first option, or through the centralized coordination by the operator in management room. Exploiting in both cases the integration of systems to its maximum and getting the economic benefits of them.

In relation to the second consideration, the tenants in a charge of maintenance of systems are usually, used to work with classic systems where the priorities are related to maintaining the systems running and in good shape. The inclusion of smarter systems that have as a function, not just to being functional, but also optimizing the process to reduce energy consumption, for instance, could be a bit intrusive. For this is important to create a shock plan to break cultural barriers in first hand, and then train the people to be able to interact and manage the smart system and treat them like they are and not as classical systems (generating investment without returns).
6. Global companies

**ABB**

As a massive conglomerate, the Swiss company offers a holistic solution for making the buildings furthermore intelligent than what is usually believed by not just implementing unique functions and devices. Rather implement a solution with hundreds of devices connected and working harmoniously, that could further connect with exterior grids or even cities. The company already offer services and products related to energy efficiency, and systems to improve comfort and energy consumption. It also guarantees the chance for implementation with future implementations and modifications.

**Cisco**

Between the offers focused on digital transformation, the digital building stands as one of the main solutions to improve the “workforce experience”. They offer a complete range of components that would compose a digital building a hole. This system is supported by the network which is based on the Internet of Things devices and sensors with Power over Ethernet (Cisco strength). Additionally, smart lighting, building automation equipment, controls and technology, cabling, and software are either offered by the company or some of their partners to achieve the final goal.

**Hitachi**

Between its range of Information and Communication Technologies services and solutions, the Japanese company prioritizes its intelligent building solution between smart solutions by focusing its offer on Smart Energy Management System,
supported by some of its strengths products like smart connections (Internet of Things), big data analytics, cloud-based solutions, and radio frequency identification (RFID).

**Honeywell**

Interestingly, the company does not offer a product or a solution itself. Instead, they offer a scoring system, which would measure how well or how much could improve a building based on three aspects: Green (energy usage), safe (safety and security), and Productive (productive working environments). This is a great tool to help to spread information about actual performance and potential improvements.

**IBM**

The company counts with a segment focused on energy and environment, inside which, the so-called “cognitive buildings are offered as one of the main alternatives to a better world through innovation. They offer tools that would allow to manage energy use and optimize space, operations, and real estate planning. To do so, “IBM Watson IoT”, one of the most developed systems in the area of cognitive computing, can work together intelligent building technologies to achieve the desired goal for occupants, staff, and owners. From design and construction to occupancy experience, focusing on operations and financial management, the system can attend many necessities.

**Johnson Controls**

Probably, the company with the most focus on designing and production of devices that would facilitate the implementation of smart buildings. The company recommends an early engagement of the company with the building in order to detect and achieve the best possible solutions. The company also offer solutions for a large range of kinds of buildings, ranging from residential and industrial, passing through governmental and educational, to sport and healthcare buildings. They
would be in charge of basically everything (design, implementation, commissioning, and ongoing operations of all converged technologies).

**Legrand**

As other companies, the French company is making its bet based on the number of connections to the network devices that exist and that will continue increasing in the close future. Currently, they are generating large revenues from connected products and they want to use this advantage through the so-called “Eliot program” to expand this into residential, commercial and industrial buildings. The company is focusing its attention in four aspects: smart and connected emergency lighting, home automation (supervision and control from personal devices), energy efficiency (smart meters) and sound distribution (receivers and diffuser) for better comfort.

**Panasonic**

They are one of the most important players worldwide when referring to the production of energy efficiency devices and technologies. They do not just have a strong position producing lighting system, HVAC systems, and renewable energy devices, but they also provide a range of smart meters that can be paired with any of the products mentioned previously. Additionally, they offer the tools necessary for storing the data coming from the meters, software to analyze it, communication gateways, and controllers that could be local and remote ones. The company is searching for allies to complement all this technical capacity into a more digital and internet-based one.

**Schneider Electric**

Probably one of the most influencing companies in all the matters related to energy management has also been very active in smart cities and smart buildings. The so-called, “EcoStruxure” is a very large project to implement smart cities. For purposes of the this project, we will explain
deeper the ones related with smart built environment, which is further divided in: smart building management (improve users productibility and optimize energy and operational efficiency, building services for optimize the life cycle, water network optimization, and enterprise asset performance improvement (centralized and IoT based administration systems). It is important to mention that this is just a small range of the whole ecosystem of products offered to achieve smart cities in an integrated way through analytics, connected products, and edge control.

**Siemens**

The German conglomerate counts with the “building technologies” division exists since a long time, and it is using the also extended experience in automatization, power distribution, lighting, HVAC systems from other divisions of the company to offer a total service of what a smart building is. The goal of the company is to be able to coordinate many solutions in order to allow a global answer that is more efficient and safe. Furthermore, the company has already done an agreement with companies focused on the internet and digitalization business to increase their credibility even more in what refers to these kinds of solutions.

**Verdigris**

The fast-growing company has focused its effort in identify energy usage in buildings and posterior savings of it. To do so it uses digital solutions starting by IoT hardware, on charge of record in a detailed way the energy consumption coming from all the place, followed by analytics that will optimize the use of energy and finally, artificial intelligence that will learn from patterns in order to predict future behaviors related with energy income and utilization.
7. Case studies

The Edge, Amsterdam, Netherlands

An office building with 40,000 square meters designed and built for the consultancy company, Deloitte. It is a smart building categorized as highly and environmentally friendly that is able to provide great comfort for its user and therefore, promoting satisfaction and productivity, while at the same time, saving energy and maintenance costs, which at the end is translated into better financial results. That without counting the savings in times and materials during the construction.

Starting with the orientation, the building is oriented in a way to receive sun from the north for general illumination, using thick glass to reduce noise. The south facades (where the offices are located) count with louvers and solar panels, the louvers can adapt themselves to the angle of the sun, providing shade and reducing heat gain, while the solar panels collect enough energy to charge electric cars, smartphones, and computers. Additionally, the south façade plus east and west count with smaller openings and openable panels for ventilation.

Ethernet-powered lighting system provided by Philips uses an array of 30,000 sensors and 6,000 luminaries across the building, and it is totally IP based (computationally controlled), measuring occupancy, lighting levels, temperature, and humidity, allowing the whole system to efficiently adapt to the necessities of the users by reducing energy use. The sensors also provide information related to traffic at lunchtimes, to reduce food waste, unused spaces saving in cleaning activities, and lights and equipment to be replaced.
In specific energy terms, the solar panels add up to 65,000 square feet, between facades, roof, and even close buildings. The big atrium work as a heat exchanger for the building, receiving excess air from the offices, moving the warm air to the upper part of the building where a heat exchanger uses the warmth. In the lower part of the atrium fresh and cold air is also provided to generate a balance in the area. It also counts with deep wells that work as thermal energy storage that uses the temperature differentials for air cooling and heating purposes.

In terms of connectivity, every employee has the chance to be connected to the building through the smartphone, which apart from providing information about the building (free parking spaces and desks, navigation, etc.), they can also customize their job place according to necessities and preferences but also receiving notifications about energy consumption. This combined with many of the applications mentioned previously generate a huge amount of data will provide a lot of information, both for the tenants (Deloitte) and for researchers in the future.

The BREEAM certified building is not just energy neutral, but energy positive, consuming 70% less energy than a traditional building with similar characteristics. To do so it has integrated the largest area of solar panels in a building in Europe, helped with heat pumps and other energy efficient measures. It has definitely created new standards for The Netherlands and for Europe in terms of green and smart buildings, giving a boost of competitive advantage to its tenants who expect to become a strong player in the digitalization industry.

**Foresterhill Energy Center, Aberdeen, UK**

This energy center with an area of 828 square meters was built to cope with the energy necessities of the Foresthill Health Center and to meet some of the following goals: improve the service from the old facilities which were old, expensive, and unreliable. Cover new energy requirements form the growing health center. Reduce energy costs. And, governmental promotion of the implementation of more sustainable energy production facilities.
After financial analysis, the old energy production system was decided to be replaced. This system was previously composed of boilers and it was replaced by a gas turbine CHP (5.3 MW of on-site power generation), a biomass steam boiler (1.5 MW sourced by local wood chip) and three fuel boilers (2 of 8.5 MW and 1 of 6.5 MW fueled by gas/fuel), able, all together, to provide heat, and the 90% of the electricity needs of the center.

The plant that is under the same roof, was designed to reduce CO2 production by 16% and a reduction in energy consumption of the 39%. It was also equipped with air dispersion modeling, in order to reduce the emission of other contaminants in the area.

As mentioned in one of the previous sections of the project, this project was achieved successfully thanks to the early coordination between all the interested players. Client, sustainability and energy assessors, design team and contractor all contributed and obtained the expected benefits.

**Carosello Shopping Centre, Milan, Italy**

This mall was one of the first Italian hypermarkets, built in 1972 with 54,000 square meters. It counts with 113 shops and 13 restaurants that generate a flow of more than 8 million visitors every year. During the last decade, the mall has been interviewed a few times by its own company (Eurocommercial Properties NV), including the one that began in 2015 with the goal of making it more sustainable and energy efficient, while reducing pollution and optimizing operational management. Bringing important costs reductions.

To do so, the focus was placed in three main areas: sustainability and environmental impact, building management, and occupier management (regulations and best practices). In terms
of environmental impact, important improvements were made on water consumption and waste management. Rainwater is collected in the green areas of the building, including the green roof, which at the same time, also works as a drainer. This collected rainwater is used for toilets, fire control system, and cooling systems. Additionally, dispensers of drinkable water will be installed to reduce the use of plastic bottles.

With the goal of improve comfort inside the building and to reduce energy consumptions, sensors were installed that had as a first parameter, to improve climate, lighting, and acoustics for the users. Ideal levels of light (also dimming exterior light) and ventilation are constantly measured, achieving important savings in energy. The previously mentioned green roof has also been of great help to reduce thermal loads in both summer and winter.

Finally, communication with the users of the mall, in relation with sustainability subjects, and surveys to operators and staff, asking about the shape of the asset help in keeping optimal maintenance practices. In conclusion, this is a good example of how old buildings can be revamped without the utilization of huge amounts of money and make relevant impacts that can generate a big competitive improvement due to the improved comfort a and image transmitted to the clients.

**Smart buildings at Microsoft, Redmond, USA**

In its aim to reduce the carbon footprint generated by the company, Microsoft did a pilot project in their headquarters (118 buildings with 14.9 million square meters, 30,000 mechanical equipment, 7 building management systems, daily consumption of 2 million kWh of energy) to implement some smart building solutions developed by some vendors and by themselves as well. The main point was to try and demonstrate that IT can help improve efficiency in energy and resources use.

The first pilot project started in 2011, focusing on 13 buildings with a total area of 240,000 square meters. The buildings had all different ages and therefore, different building management systems, making it an ever more complex situation. The program had three pillars:
- Fault detection and diagnosis: identify faults and inefficiencies through data analysis coming from the different building management systems, specifically, identifying and quantifying the economic cost of energy from every fault. The difference is that in the past, all this checking and revisions were made manually and randomly. The results so far, have shown a reduction in 4 million KWh every year, which is translated into US $ 250,000.

- Alarm management: this refers to the ability of the system of identifying and prioritize the most important events (power failures, for example) instead of checking manually all the reports produced by the alarm even if they have no real relevance.

- Energy management: the goal was to be able to manage the system in a more holistic way. With the help of the of smart systems and analytics, the base load and the power consumed by the main systems (HVAC and lighting) can be optimized, by knowing better the energy consumption and trend across the buildings.

  On the other hand, energy consumption can be tracked to individual departments or spaces and therefore inform these users about energy consumption with the goal of also reduce plug load.

The project started by Microsoft is expected to act like a living-lab that still has many results to show in the future. Until now it has not just produced great savings in energy and costs but has also worked for understanding better the functioning of the new systems and also the energetic behavior in the installations. More results are expected in the future.

**Craven Hill Gardens, London, UK**

The project that consisted of transforming a building with five entrances and seven floors, from the 19th century, into 18 apartments of different sizes, putting special attention on efficiency and sustainability. And so, the most superficial green strategies were: adding better
internal thermal insulation and replace windows with double glazing. Now, in terms of energy efficiency, a CHP engine was installed together with solar panels, that together with passive systems that allow solar gain and improved natural ventilation, reduce the energy consumption coming from the utilities. The results were impressive, when compared with the precious functioning, there was reduced energy consumption of the 78%.

Additionally, the comfort was prioritized by also adding noise insulation, and guaranteeing a high-quality air for the users. Also, important to mention that the waste produced by demolishing activities was reduced almost to the 100%. Efficient fixtures have also reduced water usage, being reflected in reduced water and energy costs.

This project not just show how old buildings can be renovated in very sustainable ways, passing from producing waste to create a space that provides extra energy and green spaces to the community. It also shows how the interest of new real estate investors with a high acquisition power is turning into greener options that will not just have a good environmental impact, but it will be also reflected in reduced energetic costs.

**Methodist Olive Branch Hospital, Olive Branch, USA**

This 5 floors hospital with 206,000 square feet counts with a capacity of 100 beds but designed keeping in mind future expansions allowing for more services offering. Being a hospital, a lot of attention was placed, first, in reducing water consumption from equipment, but also, in reducing toxic substances normally produced by mercury lamps, lead plumbing fixtures, cadmium paints, and volatile organic compounds in adhesives. More comfort was provided to the patients by reducing light pollution, greener spaces, and better thermal control.
In what concerns to energy, the lighting system was composed mainly by LED lamps, that achieved a lighting power in the building-average of 0.83 Watts per square feet (it is easy to find that the normal values are the double of that). In terms of HVAC, the hospital used ground source heat pumps for its cooling and heating purposes while ventilation was managed naturally through dedicated outside air systems. In conclusion, the hospital achieved energy savings of the 35% with respect to their baseline and 46% lower than the national average.

**CIFI Sustainable Demonstration Building, Beijing, China**

A building designed for the community with a library, leisure, and cafes, as a good example of what can be achieved applying a series of sustainable measures. The use of pre-fabricated and recycled materials for its construction generated a very few wastes and a very efficient construction process. Natural drainage measures integrated with the green landscape and roofs can also help storing rainwater for additional uses.

In terms of energy, which for the geographical locations become very important considering that the loads in summer and winter are pretty demanding. First, the building was designed to take as more advantages from the passive design as possible, such as a convex element and ducting on the roof that helps with ventilation, double glassing, and decking, also for better ventilation. In terms of renewable energy production, the building integrated film glass on the facades and solar panels on the roof, that also worked as a solar thermal system for cooling and heating purposes.

Finally, an intelligent energy management system monitors in the real time and generates control that has achieved savings in energy and pollution. The building has worked as a good
point on research and a base point for future development in what has to do with urban adaptability by saving energy and resources.
CONCLUSION

Financial feasibility in the implementation of smart technologies and systems in buildings are attached to many factors: long-term strategies of the tenants, resources availability, integration of the system, local scenario (prices of energy and available technologies), and knowledge and expertise. And therefore, the results can also be very variable. However, here we tried balanced implementations, obtaining positive results (Payback Times oscillating between three and five years). It is always important to also keep in mind the Life Cycle Costs of a building when considering the long-term, also the added value acquired thanks to image and productivity.

This project is enough to get a global understanding of what a smart building is and to its impact on energy consumption. See how they can have a positive impact on many other scenarios like the global energy consumption and sustainability for both the environment and people. Integration is a key term, since the real core of a smart building is the integration of its systems and the coordination between them, but it is also important in the sense that integration at bigger scales, with other buildings, can generate big smart communities and cities.

Most of the buildings are already built, and for this reason, energy efficiency measures are also another important factor to consider. Efficient implementations, helped by smart technologies like sensors, the Internet of Things, and data analysis software’s can end in great savings for already existing buildings.

It is always important to keep an eye on the type of building under question. Energy consumption profiles can change greatly from one to another. For instance, food sales buildings consume a lot of energy due to refrigeration purposes, while in an office building, this would not have a representation. Contrary to offices that have high computer and office equipment energy consumption compared to any other kind. We say this because of
technologies that better impact in some buildings at the same cost of investment, so it is always important to keep a flexible approach.

Being said that, HVAC, lighting, and energy management systems, together with power outlets are the most interesting aspects to analyze when thinking of reducing the energy consumption through smart technologies. We are talking that HVAC can consume up to 50% of the total energy of a building and with the implementation of smart technologies, it can be saved around the 40% of the energy in the system. The same happens for lighting system, that even if it represents a lower percentage of the total consumption, at the end add a lot of reductions.

On one hand, prices are expecting to continue decreasing while technologies are expected to continue improving. On the other hand, many companies coming from different industries, including traditional building technology providers, energy management companies, but also software companies are entering the business, generating an optimal business scenario open to new opportunities and players. All these situations give a promising situation where the necessities for a drastic change in the global energy consumption and sustainability of the world.
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