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Tips for Buildings Energy Saving: Results of Some Research

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Abstract: Increasing global warming is largely attributable to human activities. International strategies have already been implemented to reduce emissions to zero, thus reducing energy consumption. Given the current world situation and the rising costs of raw materials (gas and oil), it is incumbent on us to find savings solutions that can also be implemented in our own small way; there are many solutions, especially in the domestic sphere. In this paper, the focus is on building energy savings that can be achieved using modern technologies and starting with the simplest solutions. In particular, this paper shows how the conscious use of natural lighting can lead to significant electricity savings. Moreover, it describes the effect of innovative building insulation materials and the effect due to the installation of a local photovoltaic power generation system; at the end, it illustrates the new horizons that are opening with the introduction of new building control techniques. Some studies are also reported where the extent of achievable savings can be understood.

Keywords: building automation; natural lighting; thermal insulation; domotics; energy savings; renewable energy

1. Introduction

The increasing population, estimated to reach 10 billion in the 2050s, followed by higher globalization and industrialization leads to the rising of global energy demand: according to the International Energy Agency (IEA), the global energy demand will increase by 50% by 2030. Today most of the energy demand is met using fossil fuels (coal, oil and natural gas) that are geographically restricted and limited in resources: in the whole world, fossil fuels cover about 80% of the total energy supply and about 64% of electricity generation [1]. The excessive use of these sources contributes to generate pollution and to global warming.

In Figure 1, it is possible to appreciate the increase in energy consumption measured in tera joules (TJ) in the last 30 years followed, with the identical shape in Figure 2, by the carbon emissions in megatonnes of CO_2 (Mt CO_2) during the same period: it can be noticed that both are almost doubled from the 1990s to today with a constantly growing trend (mostly in industry, transport and electricity producers).

Investigating the total final consumption outlook, Figure 3, it has increased in all sectors led by electricity and natural gas. It has been estimated that final energy consumption will grow on average by 1% per year between 2020 and 2050, with electricity and natural gas meeting most of this increase [2].

Furthermore, in the outlook for emissions of different economies, Figure 4, there is a strong divergence between the advanced economies on the one hand and the emerging market and developing economies on the other, as said in [2]. In advanced economies, despite a small rebound in the early 2020s, CO_2 emissions will decrease between 2020 and 2050, thanks to the impact of policies and technological progress in reducing energy demand and switching to cleaner fuels. In emerging markets and developing economies, energy demand continues to grow strongly because of increasing population, brisk economic growth, urbanization, and the expansion of infrastructure; these effects outweigh

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improvements in energy efficiency and the deployment of clean technologies, causing CO_2 emissions to grow by almost 20% by the mid 2040s, before declining marginally by 2050 [2].

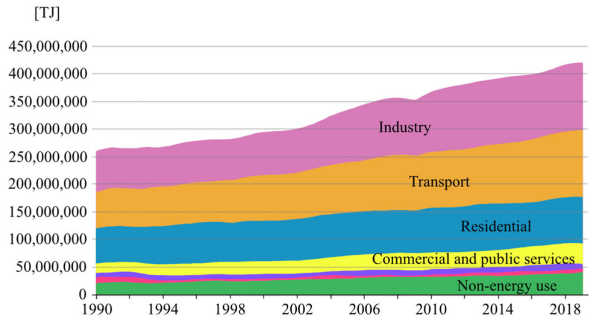

Figure 1. Total final consumption per sector, world [1].

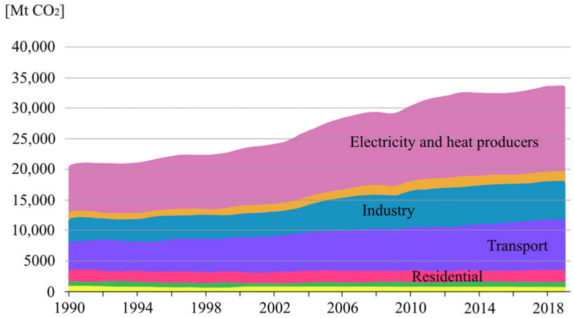

Figure 2. CO_2 emissions by sector, world [1].

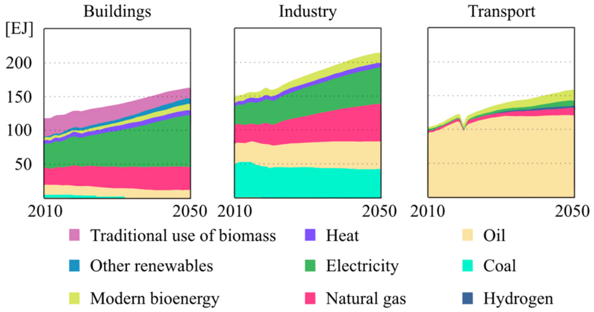

Figure 3. Total final consumption by sector and fuel [2].

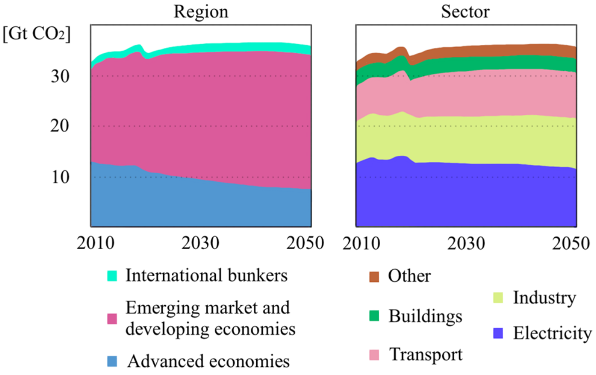

Figure 4. Energy-related and industrial process CO_2 emissions by region and sector [2].

Increased energy consumption and CO_2 emissions are elements that appear to have an influence on temperature rise. Over the last 50 years, the temperature has risen by up to 1.5 °C compared to the pre-industrial period, leading to the significant melting of glaciers and significant sea level rise [3]. To mitigate the temperature increasing due to pollution and to alleviate the environmental issue, it is necessary to develop clean and reliable energy systems.

Nowadays renewable and low carbon energy sources are used mostly by developed countries to reduce the consumption of fossil fuels, but the transition to "green" energy is slow and difficult mostly due to the reliability and cost of these technologies. Solar, hydro, wind are some examples of renewable sources, as their reserves are restored more rapidly with respect to their consumption rate. While hydropower is almost a saturated market with a stable technology, in the last 20 years solar and wind have spread widely, thanks to the development of new materials and configurations, and with the help of incentives from governments. The amount of electricity produced globally by wind increased from 31,348 GWh in 2000 to 1,273,409 GWh in 2018 (about 40 times more) and by solar from 800 GWh to 554,382 GWh (about 600 times more) [1].

Furthermore, the underestimation of the problems of insulation in temperate climate countries has led countries such as Italy and Spain to be among the biggest contributors to this waste. Retrofitting buildings under renovation and constructing new ones with advanced energy efficiency standards can save up to 20% of the energy currently consumed, the equivalent to 400 million tonnes of CO_2, only in Europe, and this is the reason why the Italian government has made available national incentives in recent years [1].

The national and global energy situation is going through a very peculiar time due to both the post-COVID-19 situation and the current war in Ukraine, when oil and gas costs have skyrocketed. The consumption of oil and gas is three times higher than the discovery of new deposits and this gap is constantly widening. The real risk of energy supply shortages is therefore very high.

In view of the skyrocketing costs of gas and oil and their possible shortages, it is considered attractive for the buildings of the future to improve and implement the following aspects to achieve energy, and in particular electricity, savings:

- Lighting installations and daylighting;
- Heat transfer through external buildings surfaces;
- Local electricity production plants;
- Home automation.

2. Lighting Installations and Daylighting

Lighting is the first and most widespread of the electrical applications introduced into the home. Since the distant 1880s, when the first private home was artificially lit, light sources have come a long way, illuminating our nights and even our days, changing the face of our cities, and radically altering our habits and needs.

The domestic lighting sector has had a considerable impact on national energy consumption [4]. The 13.5% of Italy's total electricity consumption, approximately seven billion kilowatt hours, is the annual share of electricity used for lighting. Going into even more detail and talking about the consumption for lighting of a "typical family" of four persons, it is possible to estimate an average consumption from 8% to 10% of the absorbed electrical energy.

It is obvious that the reduction in electricity consumption for lighting must not, however, be at the expense of the visual conditions of the environment. First of all, it is therefore important to carry out a proper lighting design that takes the following aspects into account [5]:

- Visual tasks to be performed (illuminance levels to be guaranteed);
- Quality and gradation of the light (colour rendering index and colour temperature of the source);

- Energy efficiency of the luminaire given by the ratio between light emitted (lumens) and electrical power absorbed by the equipment.

To better understand how to save money, it is therefore important to analyze the different light sources as it has been conducted in [6]. All lamps currently on the market can be classified, according to the way in which light is generated, into three main categories:

- Halogen/incandescent; they consist of a tungsten filament which, when crossed by an electric current, becomes incandescent, emitting a certain amount of visible radiation (light);
- Electric discharge in gases; they emit light through a discharge generated inside a gas. In particular, among others, traditional fluorescent tubular lamps (familiarly but erroneously called neon) and compact lamps belong to the family of discharge light sources;
- LED exploits the optical properties of certain semiconductor materials to produce photons from the recombination of electron lacuna pairs. When subjected to a direct voltage, the electrons in the conduction band of the semiconductor recombine with the gaps in the valence band, releasing enough energy to produce photons. Due to the reduced thickness of the LED chip, a reasonable number of these photons can leave it and be emitted as light.

Nowadays, LEDs have almost completely replaced the other lamps' topologies due to their considerable advantages:

- Service life: The life of a lamp is equal to the time interval between start up and the instant when the luminous flux produced is equal to 70% of the initial value. The LED has a longer service life (≈100,000 h) than both the halogen/incandescent lamp (≈2000 h) and the fluorescent lamp (≈10,000 h);
- Luminous efficiency: the luminous efficiency value of the white LED (150 lm/W) is close to the fluorescent lamp and higher than that of the normal incandescent lamp and halogen lamp (≈13 lm/W and ≈25 lm/W, respectively);
- Physical dimensions: LED sources occupy less space than all other light sources. This aspect is important because it allows the designer freedom of choice in order to realize lighting installations that perform their task in the best possible way;
- Ignition and start-up circuits: Even if LEDs require a particular auxiliary circuit for supplying (and it could take some milliseconds to turn on), the ignition is instantaneous as for halogen/incandescent lamps. Discharge lamps generally need an auxiliary circuit for supplying and a certain amount of time to reach their nominal operating conditions. This aspect must be considered in relation to the required use of the lighting installation.

Therefore, LEDs lead to energy savings and a reduction in CO_2 emissions with respect to other lamps and different studies which analyze this topic [7–9]. For example, in [7] an analysis has been developed of the energy savings obtainable by 2050 in Finland by substituting traditional lamps with LEDs. Therefore, energy use reduction in this country for lighting should be more than 70% by 2050. As a consequence, a reduction in CO_2 emissions should also be envisaged even if it should be remembered that renewable generation is widespread in Europe and emissions are already low, as is the case especially in the Nordic countries.

Natural lighting is another energy saving parameter that often is given little weight but allows for considerable energy savings. In fact, if the full potential of solar lighting was exploited, the use of artificial lighting during the day could be ruled out, resulting in a considerable decrease in energy consumption. At the same time, daylight provides people with conditions conducive to their wellbeing and work performance as sunlight is more pleasant than artificial light [10].

Often, however, the need to save energy clashes with users' habits. A typical situation is in workplaces where the start of activity takes place in the morning, when the availability of natural light is minimal, with the consequence that all artificial lights are switched on and are no longer switched off for the rest of the day, even when there is enough external light to correctly illuminate the entire room. This occurs with the probability shown in Figure 5, from which it can be seen that if the natural illuminance when the working activity starts is in the region of 100 lux, the probability of the lights being switched on is under 50% [5].

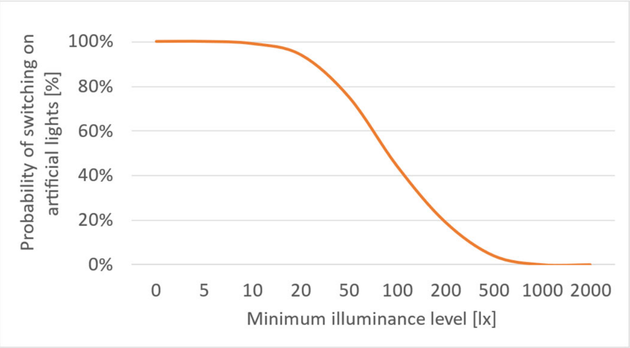

Figure 5. Probability of switching on artificial lights as a function of illuminance level [11].

Therefore, when the working activities start in the early morning, it is very important to optimize the use of natural lighting to avoid unnecessary waste.

It is also important to use light colors for internal surfaces to increase the contribution of illumination due to internal reflection and to avoid glare. In the case of rooms that cannot have vertical window surfaces to the outside, in addition to roof skylights, there are innovative light conduction systems (light chimneys, light guides) that allow light to be conducted, with high efficiency, from outside into the room to be illuminated [11].

A study carried out for an office on the third floor of a building site in the north of Italy, with a southern window orientation, showed that with a more conscious use of natural lighting, it is possible to save 51%, calculated on an annual basis, of the electrical energy from not using artificial lighting. Figure 6 shows the monthly trend of electricity consumption for lighting [12]. In orange, the energy consumption considering a continuous operation of artificial lighting in the working period is shown, and in green, this resulting from a coordinated use of artificial and solar lighting is shown.

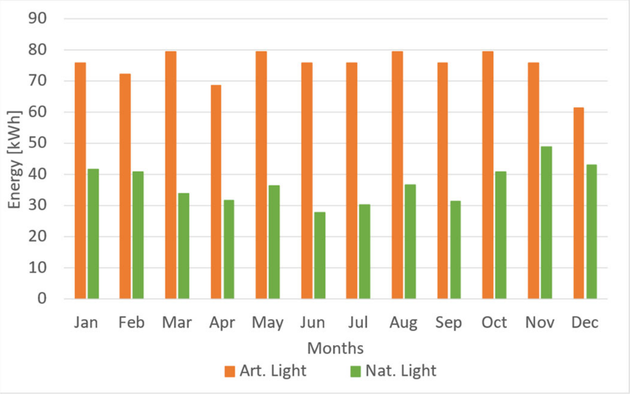

Figure 6. Monthly electric power consumption tendency for window facing south [12].

The use of shading on windows provides additional electricity savings [13–15]. There are different strategies that can be used, as outlined below:

- A reflecting horizontal shelf or light shelf (as reported in Figure 7);
- A thin sheet sun breaker;

- A grills sun breaker;
- Curtains;
- Venetian blinds or a horizontal thin sheet.

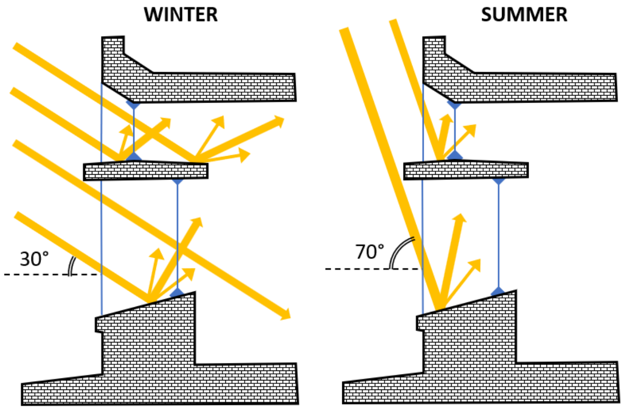

Figure 7. Sun's rays' orientation (winter and summer) through the use of a light shelf.

As the most efficient strategy for this type of exposure, only the light shelf has been discussed in detail below.

The use of a light shelf, as shown in Figure 7, allows light to be diffused within a room, ensuring better illuminance uniformity, and reducing overheating and glare problems. The light shelf is a matte horizontal console exposed outside and/or inside the window that reflects natural light onto the ceiling and walls of an interior room. This means that the window is separated into two parts, whereby the lower part is a traditional window and, as a result, the light shelf cannot obstruct the view outside of the occupants of the interior.

In addition, light shelves allow direct sunlight to be shielded in the summer period, thus reducing the consumption of electricity for air conditioning, while, in the winter period, they allow the sun's rays to enter into the room ensuring good illuminance distribution.

Figure 8 shows the performance in the case of the presence (outdoor only or indoor/outdoor) or the absence of a light shelf. The best solution is when the best illumination uniformity is guaranteed. From Figure 8, this is reached when the light penetrates deeper into the room, and therefore it can be achieved using an indoor/outdoor light shelf solution.

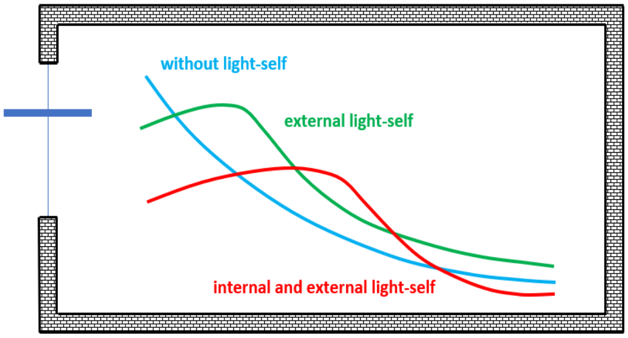

Figure 8. Illuminance qualitative tendency without and with (outdoor only or indoor/outdoor) the use of light shelf [16].

According to the study [12] already introduced above, the use of an indoor/outdoor light-shelf solution, with a mounting height of 2.2 m, allows, in this case, an energy savings of approximately 58%. Figure 9 shows the monthly results with and without the light shelf.

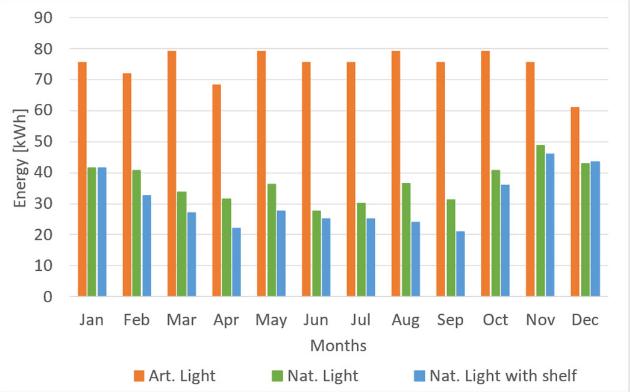

Figure 9. Monthly electrical energy consumption tendency: (orange) without regulation, (green) using natural light without a light shelf, (blue) using natural light with a light shelf (south-facing window) [12].

As previously described, the light shelf installation ensures both better illuminance and luminance uniformity. The latter parameter is very important for the visual comfort and health of the users [17,18].

When the window is north-facing there will be no particular problems like glare from directed sun rays, therefore these energy savings cannot be obtained.

3. Heat Transfer through External Building Surfaces

The use of large glass surfaces allows high levels of natural lighting throughout the year. However, applying light shelves as considered in the previous section introduces the issue of heat transfer through the external surfaces, so, attention must be paid to the summer season in which overheating problems can occur.

A possible solution is to equip the windows with infrared screens, as reported in some studies in the literature such as [19,20]. There are different types of films, depending on their use, i.e., when glare, sunlight or heat loads need to be reduced. In addition, they can be found in reflective or diffusing versions and in many different shades.

The use of these films reduces infrared radiation (and thus heat) by up to 80%, reducing air conditioning costs by up to 50% (proportional to the dimensions of the window), and eliminates 92% of glare [21]. It is thus possible to achieve energy savings from not using artificial light sources, because no blinds are used to solve the glare problem. In addition, considerable thermal energy savings can be achieved in summer from reduced energy consumption due to less cooling and in winter from lower heat dissipation.

Obviously, when these films are applied, as in the case reported in Figure 10, light transmission into the room can worsen; as a result, the electricity savings from the light component alone are normally lower than the energy savings (for light) that can be achieved by adopting these films.

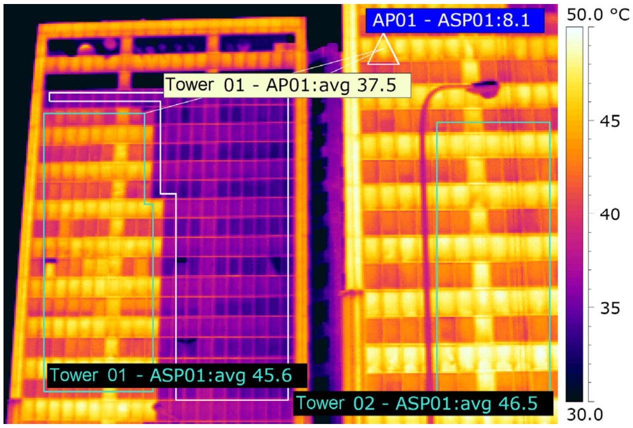

Figure 10. Thermal image of the facade of two buildings [5].

Figure 10 shows a thermal image of two buildings Tower 01 and Tower 02. Films are applied on half of Tower 01 only, so the other half of Tower 01 and all Tower 02 are without films. The thermal analysis on the front of Tower 01 revealed a skin temperature difference between the covered area (AP01) and the area without film (ASP01) of approximately 8 °C.

Thanks to these films a significant total energy savings is obtained because of a reduced cooling energy consumption. Only a small percentage of infrared (heat) can enter the room in which the cooling system is installed. A possible disadvantage of these films is the poor outward view, as shown in Figure 11.

Figure 11. View of the external environment without applied film (left window) and with applied film (right window) [5].

Furthermore, the heat transfer through external building surfaces includes not only the windows, but also the walls, so the materials employed to produce them should be the best in terms of energy savings.

The building's insulation can be realized with different materials which can be classified as conventional, state-of-the-art and sustainable as outlined in [22]. Conventional insulation materials include mineral wool, polystyrene, cellulose, cork, etc.; state-of-the-art insulation can be aerogel, vacuum insulation panels, etc.; and the natural insulators are the ones that are derived from agro and forest residues and sheep wools [23]. The thermal conductivity of state-of-the-art insulators is the lowest among the three insulation types, which means a thinner layer of the insulator is sufficient to maintain the same level of thermal resistance, but from an economic point of view, this insulator has higher costs compared to the other two.

To highlight the differences between the three types of cited insulators, Table 1 shows some examples of thermal conductivity.

Table 1. Ranges of thermal conductivity for different insulators material [24].

Material	Thermal Conductivity [W/mK]
Mineral Wool	0.030–0.040
Polystyrene	0.030–0.080
Cellulose	0.040–0.050
Cork	0.040–0.050
Aerogel	0.017–0.040
Vacuum Insulation Panels	As low as 0.004
Nature and Textile Waste	0.030–0.205
Leather and Other Waste	0.030–0.100

For example, using an innovative material such as aerogel, in terms of the percentage of energy saved, it can reach values in the order of 30% [25].

Then, to efficiently control the heat transfer through the external walls of buildings and save energy, the choice of the insulator material is a key point and depends on a balance between different elements: innovation, technical parameters such as thermal conductivity and economic aspects.

4. Local PV Production Plant

Private users can install a local photovoltaic (PV) production plant on their house roof with the goal of producing and self-consuming energy to save money. In function of the selected renumeration process (in Italy there are *scambio sul posto* and *ritiro dedicato*, here named *on-site exchange service* and *dedicated withdrawal service*, respectively), the produced energy or the surplus of electricity produced is sold to the grid operator at a predefined rate. Essentially, it is sold to the grid operator at a tariff that, unlike in the past, is lower than the tariff at which the "producer user" (prosumer) himself buys energy for his own needs. In the past, therefore, it was very convenient to use the *on-site exchange service* to sell energy to the grid operator (since the sales rate was much higher than the purchase rate), whereas now the convenience comes from using self-produced energy, thus avoiding absorbing energy from the grid (at a higher cost), so the *dedicated withdrawal service* seems to become more interesting.

Today, a successful photovoltaic investment depends on two main factors:

- How much self-consumption can be obtained;
- How much is the energy produced "in-house".

Considering that with the *on-site exchange service* the GSE (*Gestore del Sistema Elettrico* is the Energy Services Manager of Italian Grid) pays for the energy produced by the PV generators of the user, the payback time of the investment and the economic feasibility of the entire operation is strongly influenced by the amount that the user self-consumption energy reduces the electrical bill. For this reason, it is essential to have a clear idea not only of how much is paid for the energy produced by photovoltaics, but also of how much the self-consumption is expected to be.

As an example, considering a photovoltaic power plant of a 6 kWp installed on the roof of a house in northern Italy, the graph in Figure 12 shows the monthly values (kWh) of:

- Energy feeding into the grid (blue);
- Self-consumed energy (green);
- Absorbed energy from the grid (orange).

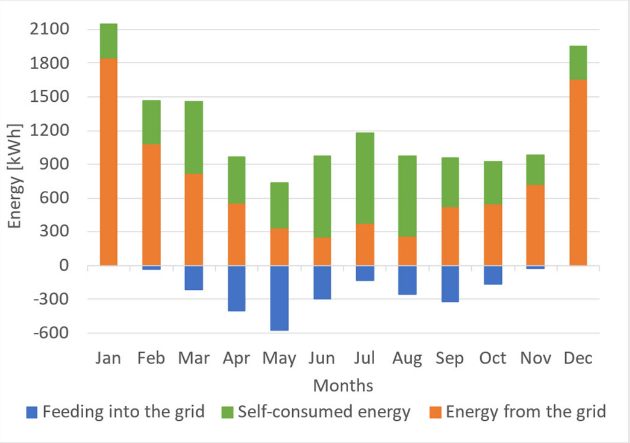

Figure 12. Monthly energy consumption 2021−Plant (6 kWp) in northern Italy.

The total energy production in 2021 has been 8.20 MWh, while the total energy consumption for all the necessary services of the house (no gas is installed) was 14.72 MWh, composed of 5.76 MWh of self-consumed energy and 8.96 MWh of energy from the grid.

It is clear that the contribution of photovoltaics in winter is marginal, while, in the other part of the year, its contribution is very important to reduce the value of the energy required from the grid.

The total cost for the energy (due to the sum of the orange bars in Figure 12) paid in 2021 by the user has been about EUR 1710.

According to the rules for the *on-site exchange service* [26], the refund of photovoltaic energy production (due to the sum of blue and green bars in Figure 12) from the GSE has been EUR 854.

This means that the net cost for energy consumed in 2021 for all services in the house (gas not installed) has been EUR 856.

If the user did not have the PV power plant, the estimate of his annual electrical bill (due to the sum of the orange and green bars in Figure 12) should be about EUR 2809.

So, the user who has the PV power plant and receives incentives for the energy produced has a cost saving of 70% on their annual electrical bill. If the regulatory authority decides to stop the incentives the user has in any case a cost saving around 40% on their annual electrical bill.

It is true that the EUR/kWh was not the same as today, but in any case, the bill cost reduction can be considered significant. Moreover, taking into account the achievable savings due to the incentives, the pay back of this PV power plant is estimated to be 3.5–4 years.

With the *on-site exchange service*, the energy that is paid by the GSE to the user is the generated one. The kWh paid by the grid operator is calculated on the basis of the measurements taken by the “production” meter, i.e., the one that counts the kilowatt-hours generated by the PV plant.

Differently, if the user had chosen the *dedicated withdrawal service*, the remuneration should follow the rules of [27], and the kWh paid by the grid operator is calculated on the basis of the measurements of the injected energy taken by the “exchange” meter, i.e., the one that connects the plant to the public grid and counts the kilowatt hours fed into the grid and withdrawn from the grid at different times. Just to give an approximate idea with the *dedicated withdrawal service,* the price of the electric kWh produced by the photovoltaic source stands around four cents per kWh [28]. So, in this case, the energy exchanged is remunerated less than 50 percent of what is paid on the bill [29].

In the end, a local PV power plant allows a saving from an economic point of view and from an energetic one.

5. Building Automation

Building automation is the discipline that deals with the study of technologies to improve the quality of life of living beings, in man-made environments. In detail, it studies particular systems to automate home or work environment and facilitate the performance of many actions that usually take place in these environments. It also plays an important role in making equipment, installations and intelligent systems. The use of this discipline changes the concept of a building, which, when automated in this way, takes the name of automated building or, more narrowly, automated home or smart home. In particular, the term intelligent home is used to indicate a domestic environment that has been suitably designed and technologically equipped to facilitate activities inside the home (such as switching on lights, activating and controlling electrical appliances, managing air conditioning, opening doors and windows, etc.), to increase security (anti intrusion control, gas leaks, fires, flooding, etc.) and to allow remote connection with tele-help, tele-assistance, tele-monitoring services, etc.

The purpose of a home automation system is therefore the total control of all services, enabling even complex new operations, which are only possible if several simple systems are connected and intelligently managed. Possible areas of automation are:

- Environment management (microclimate and energy requirements);
- Appliance management;
- Communication and information [30];
- Security.

However, it is important to emphasize that the greatest social benefit to be gained from the use of ambient automation is energy saving and the levelling of electricity consumption, applying load shedding and load shifting techniques.

Moreover, a fully automated system can avoid the costs generated by energy wastage due to forgetfulness or other particular situations, by continuously monitoring the environment, with sensors and actuators with low electricity consumption, and ensuring, for example, the thermoregulation of individual rooms according to environmental changes (habits, outside temperature, time of day, occupancy, etc.) or the correct lighting of the environment using presence sensors, twilight sensors, flow regulators, etc. [31,32].

A study carried out in a multi-storey residential building consisting of 27 flats has estimated the energy savings achievable with the application of these systems; the results are summarized in Table 2 [31,33].

Table 2. Estimating energy savings with the application of home automation in residential buildings [31,33].

Plant	Estimating Energy Savings %
Heating system management	5%
Cooling system management	3%
Air-conditioning system management	15%
DHW system management	6–12%
Lighting system management	15–28%

In addition, by managing the switching priorities of household appliances, it is possible to even out electricity consumption and use energy when it costs less, such as during the night. Using certain appliances (dishwasher, washing machine, etc.) during these hours leads to significant cost savings [31,33].

Furthermore, to ignite management, it is possible to supervise the operation of the heaviest loads (oven, water heater, washing machine, boiler, etc.) by managing their controlled disconnection to avoid overloads and consequent blackouts [34]. The loads are managed through the combined action of a central unit, which can also be the flat’s electronic meter, with a remote interface. Load shedding can take place when the total consumption forecasted or measured goes beyond the programmed limit (contracted committed power). This method allows maximum utilization of the available power by penalizing to a minimum the loads enabled to be disconnected, which are generally the interruptible loads. In fact, load disconnection is controlled by the system, taking into account the amount of power that can be recovered by switching it off, based on the weight (expressed in kW) of the load itself. Moreover, to avoid dangerous current absorption spikes, due to the simultaneous switching on of several loads, the system can also provide for the gradual reactivation of these loads.

6. Conclusions

The possibilities for energy savings in the residential sector are many and must be considered simultaneously.

As seen in this paper, great benefits can be achieved either by managing and installing electrically efficient loads or by considering efficiency measures in terms of building surface heat transfer; but sometimes one solution can work against the others.

As shown in the studies reported in this paper, there can be considerable economic and energy benefits from new technologies. For example, replacing traditional light sources with high-efficiency sources (high-efficiency fluorescents and LEDs) is a simple measure to improve the efficiency of the system that can be conducted by anyone at an affordable cost.

The conscious use of natural lighting leads to electrical energy savings in the order of 50%; the choice of innovative insulation materials can lead to a thermal and electrical energy saving of around 30%.

The installation of a local PV power production plant leads to a not negligible cost saving, as the reduction of the annual bill stands between 40% and 70% depending on the self-consumption amount and the presence and entity of incentives established by the regulatory authority.

The use of intelligent load management systems, and thus home automation in a general sense, can also be of extreme interest for the public grid, which could, in a highly automated system, exploit the disconnection of interruptible loads in the event of grid emergencies as a strategy to avoid unconditional load shifting and load shedding and thus possible network blackouts.

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