Buildings

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2. Buildings

Unsplash

Buildings are foundational items of urban development, as they sustain all the key functions of a city, from housing to services to communications (1). What is more, today's urban areas transform and distribute energy, sustain biodiversity, and provide well-being to city dwellers (2). As such, buildings have become, more than ever before, the lifeblood of the world's fast-growing urban fabric (3).

Nevertheless, buildings currently face a number of challenges. First, buildings are the single largest contributor to global greenhouse gas emissions (4), accounting for a third of all energy-related carbon dioxide emissions globally (5). Second, building construction accounts for the greatest share of natural resource use globally. Urbanisation drives the loss of productive land, which affects both managed systems, notably agriculture, and natural systems (6). Third, solid and liquid wastes discharged from buildings, particularly for cooling purposes, cause local pollution (7). Fourth, building materials can increase temperatures in urban areas, especially where green spaces are scarce, thus creating the so-called urban heat-island effect, which has negative impacts on human health (chapter 7). Fifth, in many buildings indoor air quality is poor as a result of indoor biomass combustion and deficient ventilation, which increases the risk of illnesses such as asthma, pneumonia, tuberculosis, and premature death (8). Sixth, buildings are vulnerable to the effects of climate change (9), as a growing share of the building stock experiences reduced lifetimes (or the increased risk of collapse) due to adverse weather conditions exacerbated by climate change, such as extreme heatwaves, droughts, fires, and flooding (10).

Solutions to these problems are to be found in the way buildings are planned, built and managed. Indeed, buildings afford the greatest opportunity for delivering long-term, cost-effective greenhouse-gas emission reductions: if implemented today, existing technologies would make it possible to reduce up to 60 percent of the energy buildings will use by 2050 (11). Similarly, indoor and outdoor building pollution can be substantially reduced through readily available efficient heating, ventilation, air conditioning, and cooling systems, thus avoiding millions of chronic diseases and premature deaths each year (12). Passive cooling interventions such as shading, natural ventilation and heat sinks can also alleviate the urban heat-island effect (Chapter 7). Automated design and prefabrication can help reduce natural resource use while increasing the efficiency of the building sector's value chain.

Upgrading the building stock can lead to additional benefits beyond those associated with human and environmental health. From a macro-economic point of view, investments in upgrades to existing buildings can contribute up to 15 percent of national gross domestic product and 10 percent of employment worldwide. Work productivity can also increase through effective building design and improving the indoor air quality of workspaces (8). In light of the above, efforts to reduce global warming greenhouse-gas emissions from buildings represent not only a necessity but also an opportunity to boost economic growth and social development. Against this background, the objective of this chapter is to describe buildings' technological potential in respect of climate change adaptation and mitigation in urban contexts. To this end, key approaches to climate-conscious buildings are described along with potential technology solutions, highlighting some of the synergies with other components of the urban system (i.e., health, waste, transport, droughts and floods).

2.1. Overview of technology options

Buildings are complex systems in the form of still structures (13). The “optimal” composition of the system can vary significantly across regions and building uses. Nonetheless, efforts to identify such optimal compositions should in all cases treat a building as a unity – and in turn as part of the larger urban system – rather than a set of technologies or components. In fact, to obtain the necessary impact, a holistic approach will be needed that considers a bundle of these solutions along the whole lifespan of the building, including master planning, life-cycle assessment and integrated building design. In keeping up with this principle, this chapter describes solutions that help manage building energy use in urban contexts. Although the focus is on options that are relevant to developing countries, deciding optimal technology bundles will of necessity be region- and need-specific.

Broadly, mitigation typologies for buildings can be clustered into the following groups:

- Passive design strategies
- Nature-based solutions
- Energy-efficient building systems
- Behavioural energy consumption patterns
- Onsite renewable energy generation

Passive design strategies. In buildings, passive design refers to the use of natural elements to reduce or even completely remove the need for mechanical cooling, heating, ventilation and lighting (14). One example of passive design is the optimisation of spatial planning and orientation to control solar gains and maximise daylight intake, or employing the building structure and fabric to facilitate natural ventilation strategies. A second example is the use of thermal mass to reduce internal peak temperatures (15). In traditional architecture practices, this involves using natural materials to improve the cooling and/or heating properties of the building. In Baja California, for instance, traditional houses are built of adobe, a heat-absorbing material that, due to its high heat capacity, stores heat during the day and releases it at night, thus regulating indoor temperatures (16). In the Philippines, thatched buildings enable abundant ventilation and protection from the heat (17). In cold countries like Sweden, traditional architecture uses an airtight building envelope that avoids infiltration, as well as few and small windows, except on the south side, to increase solar intake while reducing heat loss (18).

Nature-based solutions. The phrase ‘nature-based solutions’ refers to building design options that mimic nature and/or rely on natural materials to reduce building energy use. In the urban contexts, nature-based solutions help sequester carbon dioxide, balance local and global carbon cycles, and protect biodiversity (19). They can do this through so-called ‘green and blue infrastructure;, respectively, tree, parks and hedgerows, among other vegetable-based elements, and rivers, canals and wetlands, among other water-based elements (20). Nature-based solutions are also relevant in the context of drought, for example (chapter 5).

Nature-based solutions for buildings can include (but are not limited to) green walls and green roofs, street trees and other green urban infrastructure that can be applied in both residential and commercial buildings. Other examples of nature-based solutions in building construction are timber and wood framing structures, wood for building envelopes and flooring, straw or hempcrete walls, insulating wood fibre-based sheathing, and cellulose-fibre insulation.

Energy-efficient building systems. Globally, the energy consumed for space heating and cooling accounts for up to 40 and 61 percent of the total energy demand in commercial and residential buildings respectively (21,22). Compared to older buildings, newly constructed buildings typically use more energy per square meter due to their energy-intensive air-conditioning and/or heating systems (17). The building elements that are most relevant to increasing the efficiency with which energy is used in a building include, but are not limited, to (26) the building’s envelope (namely, its roof, outer and foundation walls, and its windows); heating, ventilation and air-conditioning systems (mainly, heat pumps, water heating and cooling systems, convectors and coils, and energy storage); appliances, such as those found in most households; and lighting (mainly through LED lamps and smart metering systems).

The proper sizing, installation and maintenance of efficient heating ventilation and air conditioning systems can reduce energy demand (23,24). For instance, in the United States recent studies have shown that best practices in building maintenance and operations reduce energy use by 10 to 20 percent across all climate zones. In contrast, poor maintenance practices can increase energy use by 30 to 60 percent (25).

Behavioural energy consumption patterns. Building energy use can be reduced by managing the building occupants’ active and passive use of space, systems and other amenities that influence, among others, the energy used for space and water heating (27). These patterns include window opening, the use of solar shading and blinds, adjusting heating ventilation and air conditioning set points, and the use of hot water. There is ample evidence that, if not managed, behavioural energy consumption patterns increase the demand for energy (28). Therefore, through educational programmes targeting the behavioural aspects of building energy consumption, building energy use can be reduced significantly.

On-site renewable energy-powered electricity generation. Renewable energy-powered electricity-generating technologies can be placed on buildings (consider, for example, a set of photovoltaic solar panels on a rooftop). By providing alternative sources of electricity and heat, potentially in combination with energy storage technologies, reliance on these so-called distributed electricity-generating options can complement electricity supplied from the main grid (29). These technologies are especially relevant in the context of efforts to provide electricity to rural areas in developing countries. Kenya, for instance, is the world leader in the number of solar power systems installed per capita (30).

2.2. Selected technologies

The following paragraphs describe three technologies: green walls and green roofs; efficient heating, ventilation and air-conditioning systems; and photovoltaic panels. The selection is based on three considerations. First, in relation to the required investment, these technologies have the potential to achieve large energy savings in buildings. Second, all three technologies are relevant to urban contexts in developing countries. Third, these three technologies have been identified as having the greatest impact.

2.2.1. Green walls and green roofs

Scope of the technology

In the context of buildings, green walls and roofs are among the most relevant nature-based solutions, mainly due to their ability to reduce building energy demand and the carbon sequestration capacity of the plants and substrates they uphold (31). Green walls and roofs are especially suitable for consolidated urban areas, where the space available for new green infrastructure is limited or non-existent (32).

Although their capabilities vary depending on the natural species selected, it is estimated that green surfaces can provide annual emissions reductions of the order of 0.5 kilograms of carbon dioxide per square metre (33). Likewise, a number of quantitative studies have demonstrated the impact of lowering urban temperatures and increasing humidity when the building envelope is covered with vegetation. This is particularly relevant in warm and dry regions, where green walls and roofs help reduce temperatures, thus limiting the use of ventilation and air-conditioning systems, preventing urban heat-island effects, and contributing to managing droughts (chapter 5). Similarly, humid climates can also benefit from green surfaces, especially when both walls and roofs are covered with vegetation (34).

Ancillary benefits of green roofs and walls

The benefits of a green envelope go way beyond reducing emissions and balancing urban temperatures. Indeed, green roofs and walls are reported to increase the well-being of urban residents, while contributing to ecological stewardship and safeguarding biodiversity. Further, they enhance the aesthetic value of the urban landscape, improve building performance, increase real estate values, and promote recreational building use (35–37).

The potential benefits of green roofs and walls in terms of quality of life and well-being can be achieved in a number of ways. One is through air purification, because a suitable choice of urban vegetation will be able to collect fine dust and improve air quality (38), thus helping prevent respiratory disorders (39). In addition, contact with nature has been shown to contribute to humans' physical well-being (for example, by reducing blood pressure, heart rate and muscle tension, and by producing stress hormones) (40). Finally, when they are accessible to the building's occupants, green roofs can create a space for physical activities, thus preventing sedentary lifestyles and related diseases, notably obesity (39).

In terms of costs, the installation and maintenance of green roofs and walls might incur higher initial costs than most conventional building cladding systems. However, when environmental and social benefits are monetized during the building's life-cycle, green roofs and walls become economically attractive (41,42).

Barriers to adoption

The uptake of green roofs and walls faces several barriers (Table 1), which are more prominent in developing countries. Across regions, the lack of finance is a pervasive barrier, which arises mainly as a result of the limited public awareness about the cost-benefit ratios of nature-based solutions (43). Limited coordination across institutions and a certain inertia in management approaches represent further barriers to the uptake of green roofs and walls (44), as different public departments and/or institutions operate on the basis of distinct visions, goals and legal structures (45). Arguably, identifying appropriate indicators and metrics to quantify the socio-economic and/or environmental effectiveness of green surfaces would help break down these barriers (20).

Table 1. Selected barriers to green roofs and walls

Category	Barrier
Economic and financial	(Perceived) high initial capital investment
	Lack of available financial resources
	Lack of knowledge of financial incentives
Market conditions	Property ownership, split incentives and bureaucracy
	Risk aversion and resistance to change
	Lack of public awareness and support
	Few local reference examples
	"Siloed" thinking and institutional arrangements
Legal and regulatory	Lack of support policy and legal frameworks
	Lack of political will and long-term commitment
Human capacity	Lack of skilled knowledge brokers and training programs
	Lack of design standards and guidance for maintenance and monitoring
Technical	Functionality and performance uncertainties

Source: Own elaboration. Clara Camarasa (UNEP DTU Partnership, Copenhagen, Denmark) adapted from Sarabi S, Han Q, Romme AGL, de Vries B, Valkenburg R, den Ouden E. (45)

Enablers to adoption

Due to the fragmented nature of the construction industry's value chain, no single stakeholder holds the key to the large-scale uptake of green roofs and walls. Rather, there is normally a whole cohort of such stakeholders, starting with architects. Architects are responsible for the conception of a building's envelope, and therefore for the integration of nature-based solutions in the building's design plans. An architect's local knowledge can help ensure that green roofs and walls suit the local context, increasing the likelihood that these nature-based solutions will be accepted and ultimately successful. Building owners, on the other hand, must create a demand and promote the appropriate use and maintenance of green roofs and walls to ensure continuity. To establish this demand, conducive regulatory frameworks are needed in the form of building codes, standards and/or guidelines. Furthermore, national and local governments should increase awareness of the benefits of green roofs and walls, as well as sharing know-how on their implementation. In some jurisdictions, financial instruments, such as tax incentives, may be needed to support the upscaling of these solutions.

Trade-offs

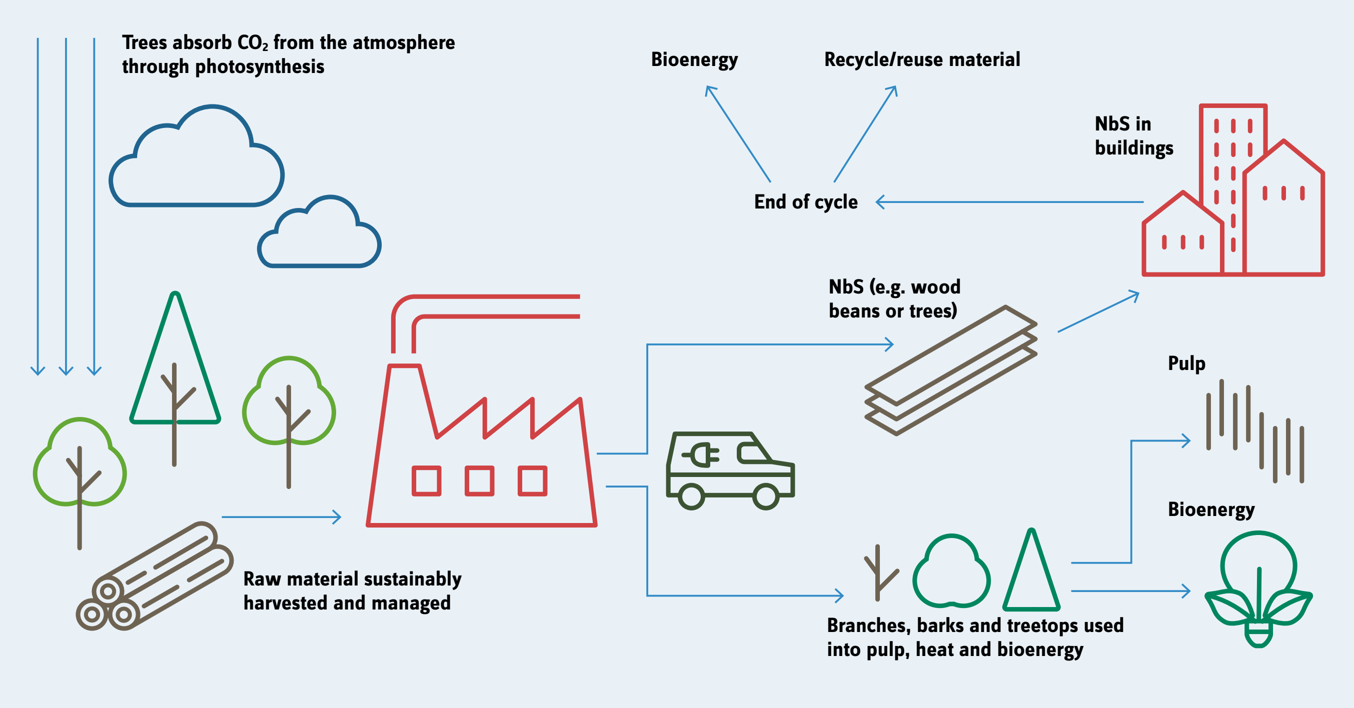
Unintended negative impacts can arise if species with low biodiversity values are promoted, as they can displace natural species, thus altering ecosystem balances (20). Likewise, it is important to avoid planting allergenic species. Otherwise, the respiratory benefits might become negative impacts. A further potential trade-off concerns the broader cradle-to-grave impacts of the products and processes involved in the manufacture and installation of green roofs and walls. As for any building material or construction practice, these products and processes result in environmental (and social) footprints in the form of the energy and materials used and recycling and disposal requirements, among other issues (46). If this footprint is not duly assessed (Figure 1), green roof system components (for example, the substrate and the water-proofing membrane) may cause more emissions during their life-cycle than they actually capture (33). Green roofs may also require additional maintenance compared to conventional or cool ones, as well as irrigation, which may be a problem in water-scarce contexts. Conversely, a positive impact can be achieved when the whole lifespan of the building solution is taken into consideration.

2.2.2. Efficient heating ventilation and air conditioning systems

Scope of the technology

Worldwide, building energy use represents a significant share of final energy demand. In developing countries, improved energy access and a greater use of energy-consuming devices has led to heightened energy use in buildings (4,47). Efficient heating, ventilation and air-conditioning systems for buildings have the potential to reduce carbon-dioxide emissions by up to two giga-tonnes globally and save 710 million tonnes of oil equivalent of energy by 2050 as compared to non-energy-efficient systems (48).

Figure 1. Life-cycle of carbon sequestration in buildings for nature-based solutions in buildings



Source: Own elaboration. Clara Camarasa (UNEP DTU Partnership, Copenhagen, Denmark), 2021.

Mitigation benefits

Beyond the decrease in energy demand and associated greenhouse-gas emissions, efficient heating, ventilation and air-conditioning systems offer a wide array of additional benefits. First, compared to traditional systems, efficient systems last much longer and require less maintenance. Second, levels of hazardous gases are reduced, notably carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides, ozone, radon and volatile organic compounds, for which efficient systems offer comparatively higher indoor-air quality. For instance, volatile organic compounds or unbalanced levels of carbon dioxide can cause headaches, dry coughs, dizziness, nausea, tiredness, and eye, nose, and throat irritations. Third, when combined with building automation and control systems, efficient heating, ventilation and air-conditioning systems can be used to detect potential threats associated with natural accidents, human error or terrorism, as well as chemical, biological, radiological, and explosive incidents that cause major structural damage to the building or its infrastructure.

Barriers to adoption

There are several barriers to the more wide-spread deployment of efficient heating, ventilation and air-conditioning systems. These barriers relate to economic and financial considerations, market conditions, legal, regulatory and institutional capacities, human capacities, and awareness and information (Table 2).

Enablers to adoption

A rising demand for technologically advanced heating, ventilation and air-conditioning systems is expected to drive the market growth of these technologies. Demand-side actors such as owners of private and public buildings are often identified as the main decision-makers in the adoption of this technology. However, recent studies demonstrate

Table 2. Selection of barriers to heating, ventilation and air-conditioning systems

Category	Barrier
Economic and financial	Perceived high initial capital investment
	Long payback times due to low energy prices
	Perceived financial disincentives: perception of investment as costly and risky, and split economic interests among stakeholders due to fragmented value chain
	Limited knowledge about investment horizons, risks, and life spans
Market conditions	Fragmented building-sector value chain
	Limited awareness of available technical capacity and potential ancillary benefits
	Technology lock-ins
	Lack of interest in future energy-sector issues
Legal and regulatory	Lack of regulation against rent-seeking behavior
	Inappropriate or lack of a regulatory framework (e.g., building codes and standards)
Institutional and organizational	Limited institutional capacity
	Limited management and organizational skills
	Lack of interconnection regulations and grid access limitations
Human capacity	Unskilled technical personnel
	Lack of inadequate technical capacity
Information and awareness	Fragmented or lack of information
	Lack of awareness of the technical capacity and benefits

Source: Own elaboration. Clara Camarasa (UNEP DTU Partnership, Copenhagen, Denmark)

that they are not the only decision-makers involved in the technology selection: engineers, installers and construction companies also have a high level of interest and influence in this process (49). Nonetheless, a conducive policy environment is needed for these groups to be able to promote efficient heating, ventilation and air-conditioning systems. Therefore, public authorities ought to reform regulatory frameworks, develop educational and awareness-raising programmes, and introduce appropriate financial incentives.

Trade-offs

The proper sizing of efficient heating, ventilation and air-conditioning equipment is one of the most important processes in terms of appropriate energy use in a building. An oversized unit can lead to energy waste, high costs over time and uncomfortable inner temperatures, all of which are the opposite of what these systems intend to achieve (50). To avoid these unintended negative impacts, it is important to conduct thorough assessments of the capacity required, given the needs and use of the building. Another important aspect to consider is the building's use. In order to be effective, heating, ventilation and air-conditioning systems require periodic maintenance to improve their lifespan and efficiency. Maintenance should be combined with adequate occupant behaviour practices on energy use to ensure sustained reductions in energy consumption (51,52).

2.2.3. Photovoltaic panels

Scope of the technology

Small-scale solar photovoltaic panels – typically placed on rooftops – are key components of net-zero energy-building strategies (53). Solar photovoltaic panels transform sunlight into direct-current energy. Through an inverter, direct-current energy is converted into alternate current energy.

Mitigation benefits

Rapid technological developments and related cost reductions have made solar photovoltaic systems, and therefore electricity, more accessible in places where they used to be absent. In developing countries, two features of these systems have helped increase their uptake. First, most developing countries are located at latitudes with high solar irradiance. Second, solar photovoltaic systems are relatively affordable and suitable for both homes and energy communities (54).

The advantages of solar photovoltaic panels extend far beyond the buildings' energy use. When placed on a grid-connected roof, they produce electricity at the site of consumption, thus avoiding losses during grid transmission and helping utilities meet broader demand by feeding surplus electricity into the grid. Selling excess electricity back to the grid provides revenues that should be taken into account in making financial decisions over whether or not to install solar photovoltaic systems on a building. Not least, the widespread development of solar panels that green buildings are favouring has helped the solar energy industry create jobs around the world: in Bangladesh, for instance, home solar systems have generated 115,000 direct jobs and 50,000 more downstream (2). Furthermore, the deployment of solar photovoltaic systems goes hand in hand with the growth of the electric vehicles industry (55,56). Thanks to the relentless advances in energy storage, energy-sharing between buildings and electric vehicles is becoming a reality. Indeed, in the near future, building designs are likely to include (private) charging stations for electric vehicles (chapter 3).

Barriers to adoption

At present, solar photovoltaic panels provide less than two percent of the world's electricity, but modelling shows that they could contribute 4.9 Gigatonnes of carbon dioxide emissions reductions in 2050, representing 21 percent of the overall energy-sector emissions reductions needed to meet the Paris Agreement's climate goals (57).

Despite the growth in solar photovoltaic system-powered electricity generation and emissions reduction potential, financial barriers, notably high capital costs, long payback times and risks, still hinder their adoption, particularly in developing countries

(58). Indeed, lacking policy inducements, solar photovoltaic systems are not profitable in some contexts.

Enablers to adoption

Empirical evidence across various regions reveals that government incentives to strengthen the solar photovoltaic market in frontrunner countries is having a positive impact on developing countries. Governments can be key enablers of this technology in a number of ways. To bridge the higher upfront costs compared to fossil-fuel based technologies, governments are relying on direct capital subsidies, tax incentives, storage incentives and/or incentives for electric vehicles. They can also leverage market barriers by creating synergies among enablers.

Trade-offs

The operation of solar photovoltaic systems presents few environmental shortcomings. Conversely, the manufacture of these systems produces hazardous substances (notably arsenic and cadmium), water pollution, and emissions of air pollutants (59,60). Counterbalancing these negative effects requires actions across the whole value chain. Technology developers are working to reduce or avoid the unintended negative impacts mentioned above. In parallel with this, solar photovoltaic system installations should be properly planned, notably with regard to their siting, and they should be maintained adequately so as to keep them in service for as long as technically possible. Finally, end-of-life recycling and disposal procedures should be in place locally.

2.3. Key policy-related issues

Regulations for energy efficiency in buildings in developing countries, especially in rapidly developing economies such as India and China, are designed to improve comfort and reduce the sharp increase in building energy use. However, the efficiency standards included in building codes rarely represent the optimum for efficiency, and builders and designers rarely have an incentive to exceed the standards set out in the codes or to come closer to that optimum because higher standards mean lower profits. For this reason, more stringent energy-efficiency requirements should be introduced for new buildings.

Another important policy consideration in relation to climate-mitigation policies in buildings is related to the fact that these typically cover the interest of specific stakeholder groups in the building value chain. Due to the fragmented nature of the construction industry’s value chain, so-called split incentives, where the party that has the power to introduce change has no incentive to do so, hinder the adoption of stringent climate change-mitigation technologies.

Green walls and green roofs. Building regulations can support increasing installations of green walls and green roofs by considering or representing them in building codes and standards. Currently, building codes across the world are largely anthropocentric, hence nature-based solutions such as green building elements are typically not featured (61). For building regulations to effectively support green walls and green roofs, natural species need first to be recognised as necessary within a shared urban habitat before being integrated into urban activities across all building-development processes. This will require both awareness-raising of the need for their preservation and a stronger understanding of local natural ecosystems and how these can be integrated into building design.

Efficient heating, ventilation and cooling systems. There are a number of policy-related aspects to consider in relation to energy-efficient heating, ventilation and cooling systems. First, there should be a policy of introducing energy consumption limits in large buildings. Second, with reference to indoor air quality, a reference indoor air renovation rate should be devised and pollutant concentrations inside buildings should be limited. Third, in terms of a system's units design, the system's installed power should be limited and a number of energy-efficiency requirements introduced for the design of new systems. Another important aspect concerns maintenance of the systems: periodic energy audits, including inspections of boilers and air conditioning systems, should be mandated. In addition to the foregoing, regulations on thermal the behaviour of buildings should define the requirements for buildings without heating ventilation and air conditioning systems (for example, wall and floor insulation, types of glass coverings and surfaces, limiting heat loss and controlling excessive solar gains). Furthermore, regulations should set limits for the energy requirements for air-conditioning and hot water production, making it compulsory to install solar energy systems and favouring the use of other sources of renewable energy (62).

Photovoltaic systems. In order to incentivise the adoption of photovoltaic systems, self-consumption schemes should be as comprehensive and as simple as possible. Consumers and "prosumers" (that is, electricity consumers that produce some of their electricity needs from their own power plants, use the distribution network to inject excess production, and withdraw electricity when self-production is not sufficient to meet their own needs) should be provided with all the necessary information to calculate the incomes and costs that are relevant to the distributed generation. Self-consumption schemes with or without decentralized storage should be permitted and enforced by renewable energy laws or other applicable legislation addressing all relevant stakeholders, from utilities to prosumers. In addition, tariff design should be flexible and adjusted in a timely fashion to allow additional customer classes and effective billing and reporting systems to be established (63). To enable this, policy instruments should create rate structures or incentive programs so that system owners can be compensated for the variety of benefits and services provided by energy storage associated with distributed solar energy.

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