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Review

Advanced Active and Passive Methods in Residential Energy Efficiency

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Abstract: Energy efficiency in buildings is very important since it contributes significantly to fossil fuel consumption and consequently climate change. Several approaches have been taken by researchers and the industry to address the issue. These approaches are classified as either passive or active approaches. The purpose of this review article is to summarize a number of the technologies that have been investigated and/or developed. In this technical review paper, the more commonly used active and passive building energy conservation techniques are described and discussed. The pros and cons of both the active and passive energy techniques are described with appropriate reference citations provided. This review article provides a description to give an understanding of building conservation approaches. In the active classification, several methods have been reviewed that include earth-to-air heat exchangers, ground-source and hybrid heat pumps, and the use of new refrigerants, among other methods. In the passive classification, methods such as vegetated roofs, solar chimneys, natural ventilation, and more are discussed. Often, in a building, multiple passive and active methods can be employed simultaneously.

Keywords: active building energy systems; passive building energy systems; Trombe wall; white roofs; vegetated roofs; ground-source heat pumps; new refrigerants

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1. Background

1.1. Decarbonization

Building operations are a critical step towards obtaining global carbon neutrality [1]. Commercial buildings are among the more energy-consuming sectors and they present the fastest growing demand worldwide. Building decarbonization is beyond the scope of this paper. However, in a recent paper addressing the decarbonization of commercial building operations, the results of Xiang et al. [1] showed: (1) the mean carbon intensity of commercial building operations in 16 countries declined approximately 1.94% throughout the period of 2000 to 2019; (2) energy intensity involving different end-uses contributed to decarbonizing commercial buildings with the largest contribution from space heating (-14.33 kg $CO_2/m^3/yr$) and service lighting (-5.29 kg $CO_2/m^3/yr$); and (3) the pace of decarbonization of global commercial buildings is slowing. In another decarbonization study, the results of Ma et al. [2] indicated that: (1) commercial buildings operational carbon emissions continue to increase by 17.7% with economic growth effects and energy use being the key drivers contributing to the increase; (2) since 2009, operational carbon emissions have decoupled from economic growth effects in most megalopolises; and (3) the operational decarbonization of megalopolises commercial buildings has been gradually accelerating. The National Governors Association [3] supports state decarbonization efforts to enhance energy reliability and resiliency, reduce air pollution, improve public health, and foster economic development. Energy efficiency plays an extremely important role in this effort. Benefits of increasing energy efficiency include: cost savings, increased reliability and resiliency, reduced emissions, increased health benefits, economic and workforce development, and energy affordability. Barriers to increased energy efficiency include: high up-front costs, utility regulatory disincentives, workforce gaps, valuing energy savings, and lack of consumer awareness.

1.2. Introduction

Residential and commercial buildings account for nearly 40% of energy use [4]. Space conditioning accounts for 40% to 60% of building end-use. In the U.S., heating, ventilation, and air conditioning (HVAC) make up about 50% of energy use in buildings, which is about 20% of their total energy consumption [5]. Sun et al. [6] and Ben Romdhane et al. [7] have shown that phase change materials can be used in a variety of ways to store and release energy by using their endothermic/exothermic properties, resulting in improved energy consumption, heat storage, and improved thermal comfort. Additionally, phase change materials provide assistance to energy shortages, and carbon emissions. Li et al. [5] provide an excellent discussion of active and passive energy methods. Active systems require the use of a fan and heat pumps/boilers to move the energy throughout the building. Passive energy techniques are more energy-efficient for application in buildings. Passive techniques reduce building energy consumption, abate the carbon footprint, and alleviate building energy bills [8], although not all strategies are cost-effective. Ponmurugan et al. [9] emphasize that reduction in heat gains into buildings through walls, ceilings, and roofing plays a vital role in passive energy techniques. Additionally, passive heating and cooling systems can reduce space-heating and space-cooling loads in buildings [10].

This paper addresses both active and passive energy conservation methods in buildings. This paper does not address every energy conservation method, but we address the major energy conservation methods. Development of effective and efficient energy techniques is critical to controlling room air temperatures and improving building energy consumption [11].

2. Active Building Energy Conservation Methods

Any heat exchange method for providing indoor comfort to buildings that does not employ a prime mover (pump, fan, etc.) to force the flow of heat from the source to the point of use is considered a passive approach. By that definition, for example, solar collectors can be considered active systems if they are a component in a forced flow system and otherwise passive systems. The presence of heat pumps or similar air conditioning devices brings the system to the active category. Active systems typically offer better overall efficiency, while passive systems are attributed to lower costs. Another major difference between an active and a passive system is that the latter typically requires less maintenance. In some buildings, a combination of active and passive systems can be applied.

2.1. Modifications to the Conventional Vapor-Compression Refrigeration Systems

Analyses of various modifications to the conventional vapor-compression refrigeration cycle have been reported in the literature that is reviewed below. A conventional vapor-compression refrigeration cycle uses a vapor compressor to increase the enthalpy (increased pressure and temperature) of an appropriate working fluid (refrigerant) before it is run through a heat exchanger (condenser) to reject heat to the surroundings. The refrigerant which is slightly subcooled (compressed liquid phase) is passed through a throttling device that causes a pressure drop and consequently a significant drop in the refrigerant's temperature. The cold, low-pressure vapor–liquid refrigerant mixture enters the evaporator where it receives heat from the indoor environment (cooling effect) while it turns into vapor prior to entering the suction side of the compressor. Conventional vapor-compression refrigeration systems offer a typical coefficient of performance (COP) of 2 to 3. It has been shown that by using the soil around the building both as a source of thermal energy and as a storage system by hooking up the heat pump system to a ground loop, the system's COP and consequently its energy efficiency improves significantly due to less electricity use.

The ground loop is usually either vertical (boreholes) or horizontal (shallow). Additional modifications have also proven to be effective. These additional modifications include the use of assistive equipment such as liquid dry coolers [12–14], solar collectors [15], and a combination of solar collectors and biomass generators shown in Figure 1 [16]. The mentioned modifications in most cases increase the system COP by 1 to 2.5. Adding a liquid dry cooler to the ground loop of a ground-source heat pump increases the system's thermal efficiency (reduces seasonal electricity use) when the outdoor temperature is favorable to bypass the ground loop. Bypassing the ground loop allows the soil to recover from continuous heat removal/rejection which otherwise would diminish its potential to supply the needed energy. The benefit of adding a solar thermal collector array to the ground loop is apparent because the thermal energy collected can assist with the performance of the heat pump. A solar-assisted heat pump system is evidently only effective during the heating season, and COP values of as high as 6 have been reported for these systems [17]. However, when photovoltaic/thermal (PV/T) collectors are employed, the benefits can be collected in both the heating and cooling seasons [18]. In PV/T systems, while the top layer of the collector is made of solar cells that generate electricity, the lower layer acts as a thermal collector that can heat a liquid or air for heating the building. The electricity generated by the PV cells is used to supplement the electricity use by the compressor and fans of the air conditioning equipment. Researchers in Canada reported using recovered waste heat from a data center as the heat source for activating an absorption chiller system for cooling [19].

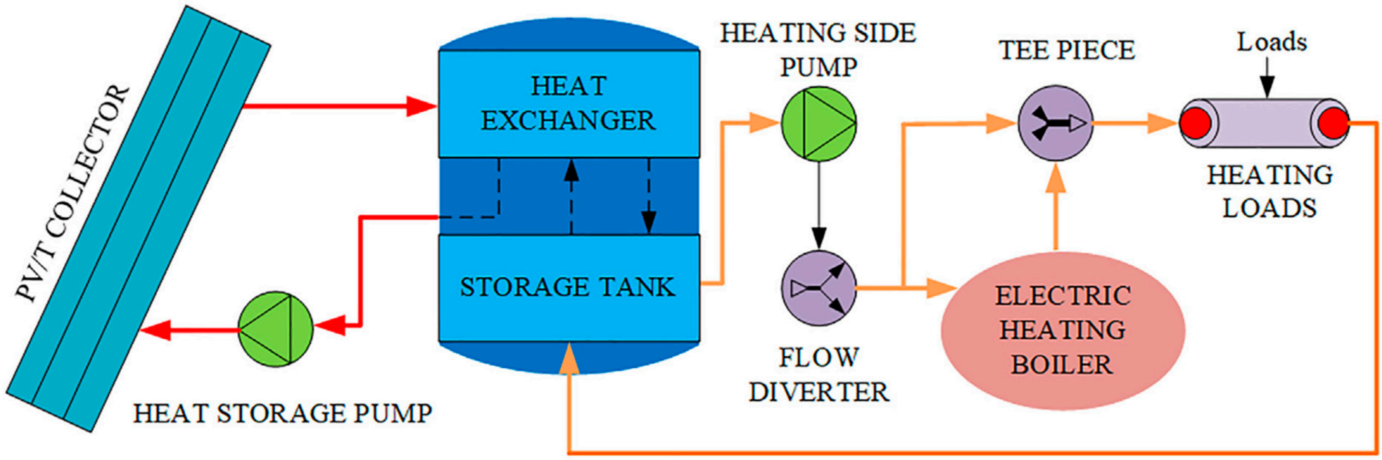

Figure 1. Schematic diagram of a combined solar collector and biomass boiler system [16].

2.2. Advances in Heat-Activated Cooling Systems

Absorption water chillers have been in use for many years. The principle of operation is similar to the vapor-compression refrigeration system with the difference that the process of increasing the pressure of the refrigerant occurs in a combination of an absorber-generator system in which one fluid has a considerable capacity for absorbing a second fluid. The pair of fluids that are used for this application is commonly, ammonia-water or lithium bromide-water. This category of refrigeration systems is called "thermally-activated cooling" [20]. A schematic diagram of a solar-assisted absorption cooling system is presented in Figure 2.

These systems use less electricity because they do not have to compress a gas in a compressor. Instead, they employ a pump to pump a liquid from the absorber to the generator. The pump uses significantly less electricity than a compressor. The required energy is supplied by a heat source. Various heat sources can be used to activate the process as long as the temperature of the source is at least 80 °C. The heat from the direct combustion of natural gas [21], exhaust heat from a microturbine system which is also used to generate electricity [22], the heat from an internal combustion engine's jacket coolant loop [23] and the heat generated by operating a phosphoric acid fuel cell [24] have been reported to have been used for this purpose. In comparison to vapor-compression refrigeration systems, absorption refrigeration systems do not achieve high COP values and are limited to COP values of less than 1.5 in practice.

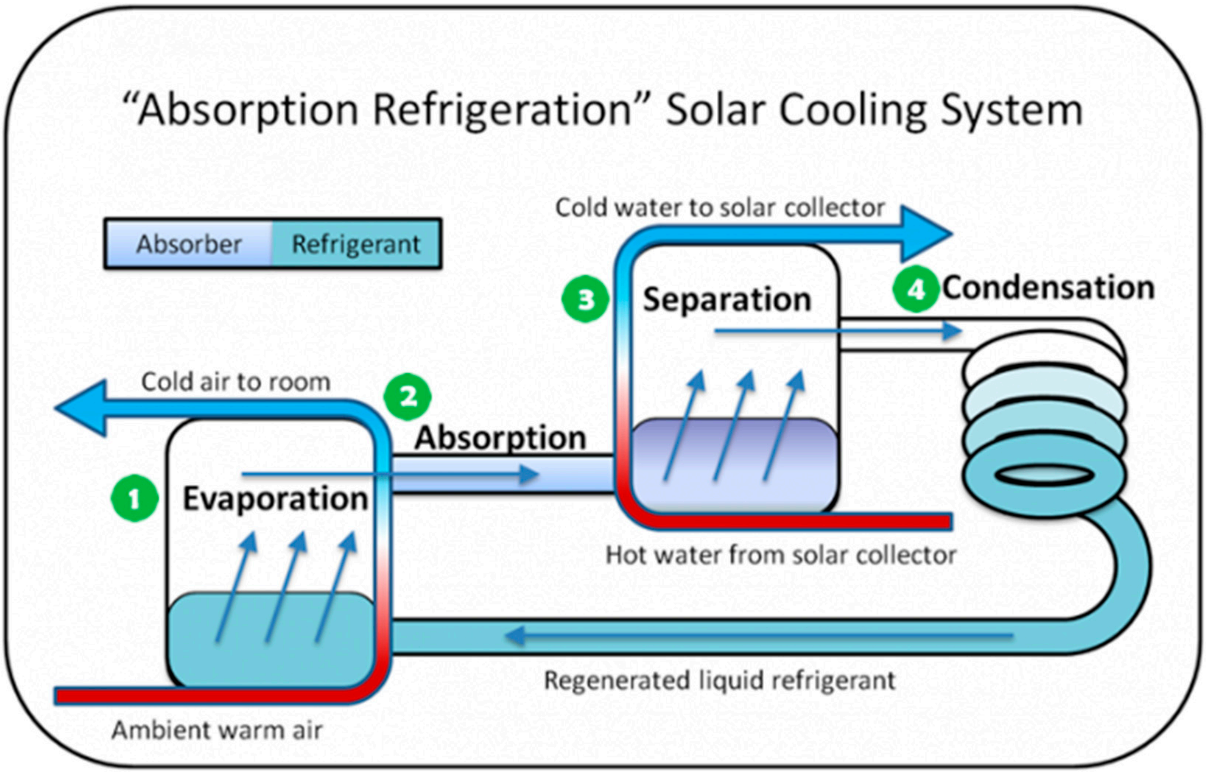

Figure 2. Schematic diagram of an absorption cooling system with heat supply by solar collectors.

2.3. Non-Conventional Systems

Besides the evaporative cooling method which is only feasible for dry climates, the vapor-compression and absorption refrigeration systems are considered conventional cooling systems. Several cooling techniques are outside the realm of conventional systems for which examples are given below. Adsorption cooling systems use a solid desiccant material to adsorb a liquid into the solid desiccant and then desorb the liquid as vapor in a generator in a somewhat similar manner to the process in an absorption refrigeration system. Shanghai Jiao Tong University researchers reported a COP of greater than 0.5 on a 9-kW adsorption refrigeration system [25]. Similar to absorption chillers, various heat sources have been used for the desorption process of the adsorption systems. Desiccant materials have also been used in modified evaporative cooling units for buildings. In desiccant evaporative cooling systems, the outdoor air is passed through a desiccant wheel or a liquid desiccant tower to reduce its humidity to near 0% relative humidity. The ultra-dry air then enters an evaporative cooler where it absorbs water vapor to the saturation point before it enters the interior conditioned area [26,27]. In liquid desiccant air conditioning systems, the desiccant material ($CaCl_2$) used is regenerated in a heat exchanger that uses a range of heat sources including solar energy [28] or a heat pump [29].

Proximity to large lakes offers the potential to use deep lake water's low temperatures (12–13 °C) for cooling of buildings as reported by Fung et al. [30] and Kuyuk et al. [31]. The proposed system requires a significant initial investment, however the return on investment is quick due to the utilization of a natural reservoir (sink) for the heat removed from the buildings.

Other methods exist that are considered assisting technologies to the conventional cooling systems. Earth-to-air heat exchangers (EAHE) [32], have gained popularity to reduce the energy use by air conditioning systems. Outdoor air flows underground through a pipe structure that optimizes heat gain/loss to the soil. The conditioned air is then used as the outdoor fresh air for the building's air handling unit. The COP of the system is expected to increase due to the pre-conditioning of the outdoor air [33].

Radiative sky cooling [34,35] is another assistive technology that is gaining popularity. The clear night sky has favorable conditions to cool down the liquid that flows in an unglazed radiator due to the very low apparent sky temperature. The apparent sky temperature can be as low as 4 °C when the ambient temperature is 30 °C according to some simplified models [36].

2.4. New Refrigerants

In conventional vapor-compression refrigeration systems, the search for less harmful refrigerants is a continuous battle. Many thermodynamically near-perfect refrigerants have been ruled out as potentially harmful to the environment. In searching for or developing new refrigerants, researchers must balance the global warming potential and the thermodynamic properties that improve the efficiency (COP) of the refrigeration system. Carbon dioxide and propane are some of the natural refrigerants that have been the subject of some studies. Using CO_2 as a refrigerant has some inherent issues to be considered. The system needs a cascade transcritical compressor because the typical condensing pressure of CO_2 is 71 bar [37,38]. Nonetheless, in comparison to traditional refrigerants, carbon dioxide is considered less harmful to the ozone layer.

The other front on which scientists are focusing their attention is developing new refrigerants that have new formulations or creating new ones that are made of blending two or more existing refrigerants. An extremely crucial point that is to be considered is that any new refrigerant must be compatible with the refrigeration systems that are in operation around the world. Any attempt at introducing a new refrigerant that requires major modifications to the existing refrigeration systems to the market will fail due to the overwhelming cost associated with it. Among the new refrigerants that researchers are studying are R-454b and R-1234yf. R-454b is an environmentally sustainable replacement for the popular R-410A refrigerant [39]. Similarly, R-1234yf is a replacement for the popular refrigerant R-134a [40]. The importance of introducing new drop-in refrigerants is in their ability to replace older refrigerants that are usually more harmful to the environment when released into the atmosphere during the repair.

2.5. Summary of Active Heating and Cooling Systems for Buildings

The vapor compression refrigeration cycle is still the most widely used method for cooling despite its heavy dependency on grid electricity. Moreover, since it is prone to refrigerant leaks, new refrigerants that are generally less harmful to the environment must be developed. On another front, the development of technologies that can reduce electricity use is imperative. Thermally activated cooling technologies if supplied by waste heat or by renewable sources are a solution. Non-conventional cooling and heating systems are also being developed that require less electricity to operate, use less harmful refrigerants (or none), or are better compatible with renewable energy sources.

2.6. Pros and Cons of Active Energy Conservation Methods

The advantages and limitations of active energy conservation methods are listed in Table 1.

Table 1. Pros and Cons of Various Active Energy Conservation Techniques.

Technology	Estimated Payback Period	Pros	Cons
Ground-source heat pumps–vertical ground loop [12–14]	5–10 years	• High energy storage in the soil • Higher deep soil temperatures	• High initial cost • Longer construction time • Requires special equipment to dig the boreholes
Ground-source heat pumps–horizontal ground loop [12–14]	4–9 years	• Less additional initial cost • Simpler equipment to maintain • Less overall energy use compared to an air-source heat pump	• Moderate additional initial cost • Requires large open area to bury the pipes • Lower heat storage capacity • Lower soil temperature due to the shallow depth
Ground-source heat pumps–hybrid [14]	4–8 years	• Better energy efficiency compared to all other heat pump types • Increase the energy storage capacity of soil	• Additional equipment to maintain • Need a complex control strategy to optimize
Solar-assisted heat pumps [15–18]	2–5 years	• Renewable source of assisted heat • High overall energy efficiency • Less adverse environmental effects	• Require large area for collector installation • Additional equipment to maintain • Higher initial cost • Not applicable to cooling
Absorption refrigeration systems with renewable heat source [19–22]	2–3 years	• Can use various heat sources including renewables • Requires less electricity	• Contain harmful chemicals • Not available in small capacities • Low efficiency compared to vapor-compression refrigeration cycle
Desiccant cooling–solid desiccant [25–27]	3 years	• Less maintenance compared to liquid desiccant • High efficiency	• More equipment to maintain compared to conventional methods • Reactivation requires a heat source
Desiccant cooling–liquid desiccant [28,29]	3–4 years	• High efficiency • Reactivation can be done by renewable sources of heat • Can be used to precisely control the humidity	• High maintenance and more equipment • Higher initial cost and maintenance cost • Usually contain corrosive material • Reactivation requires a heat source

Table 1. *Cont.*

Technology	Estimated Payback Period	Pros	Cons
Deep lake water cooling [30,31]	5–9 years	• High energy efficiency • Free source of cold • No harm to environment	• Only applicable where the building is near a deep lake • Additional piping and equipment
Earth-to-air heat exchangers [32,33]	1.5–2 years	• Low maintenance • Long life • Applicable for heating and cooling • Can be easily bypassed	• Additional initial cost of burial • Use of land • Small temperature differences
Radiative sky cooling [34,35]	1.5–4.5 years	• Low maintenance • Long life • Can be bypassed	• Require unobstructed view of sky • Require a relatively large surface area • Not applicable to heating

3. Passive Building Energy Conservation Methods

3.1. Shading

Global warming and heat island effects have caused increased cooling energy consumption in buildings [41,42]. Probably the most effective way to cool a building in summer is to keep the heat energy from building up in the first place [43]. Kamal [43] and Abdel-Aziz et al. [44] state that the most important passive cooling strategy is shading. Shading involves blocking the sun before its energy can get into the building. The primary source of heat buildup (heat gain) is sunlight absorbed by the building through the roof, windows, and walls, while secondary sources include heat-generating appliances in the building and air leakage. Shading can reduce the peak-cooling load in buildings, thereby reducing the size of the heating, ventilation, and air conditioning (HVAC) equipment. Shading minimizes solar radiation incidence [43–45]. Trees and vegetation are effective ways to shade and reduce heat gain. Energy savings are reported to range from 10% to 40% [43]. Tree-shading has resulted in up to 2.7 °C reduction and up to 3.0 °C temperature difference compared to unshaded areas; and trees affect ambient air temperature from 0.5 °C to 1.0 °C average overnight and day and up to 2.0 °C lower than the outside temperature [42]. Abdel-Aziz et al. [44] reported that shading can help to reduce peak summer temperatures by 1 °C to 5 °C. Homeowners in older neighborhoods with established trees were observed to use less energy for air conditioning than homeowners in a recently developed site [46].

Shading the effects of direct solar radiation can be achieved by Kamal [43]: (a) shade provided by the effect of recesses in the building envelope; (b) shading provided by static or movable blinds or louvers; (c) transient shading provided by orientation of the building; (d) permanent or transient shading provided by surrounding buildings, screens, or vegetation; and (e) shading of roofs by rolling reflective canvas, earthen pots, vegetation, etc. Several shading overhang configurations are available for shading devices, including movable opaques (curtains, awnings, etc.), louvers, and fixed overhangs [43,45].

Trees have many benefits for urban environments, including carbon sequestration, removal of air pollutants, noise reduction, and reduced energy consumption [41]. Akamphon and Akamphon [41], as well as other researchers [47,48] noted that trees can reduce a building's energy cost by 25% to 50%. Abdel-Aziz et al. [44] noted that a medium-sized deciduous tree (with leaves on it) can reduce solar irradiance by 80% and 40% if leafless. Trees reduce the amount of radiant energy absorbed and stored by a building, use evapotranspiration converting liquid water in plants to vapor thereby cooling the air, and reduce wind speed which reduces infiltration of outside air and causes effective ventilation and convective cooling of building surfaces [42,49]. Shading performance is affected by building surface, tree location, tree size, canopy density, season, solar angle (time of day), and microclimate conditions [44,45,49]. Trees are capable of lowering air temperature, improving air quality, and reducing building energy consumption [42]. Hwang et al. [50] noted that trees can reduce residential cooling and heating energy consumption by: (1) casting shade onto building surfaces and manmade ground covers, (2) modifying airflow around buildings, and (3) allowing ambient air temperature through evapotranspiration.

Balogun et al. [42] investigated the effect of tree-shading on energy demand for two similar buildings in Akure, Nigeria, one that was shaded and the other unshaded. The two buildings were of the same architectural design, built at the same time with the same materials, had the same orientation, and were located 60 m apart from each other. The unshaded building warmed earlier and faster than the tree-shaded building. Their results indicated that tree-shading can save up to USD 218 on energy costs on a monthly basis.

Trees facing west produce the largest energy savings. Trees with high shading coefficients and moderate crown size (such as jackfruit, mango, mahogany, and Indian cork trees) maximize shading [41].

3.2. Natural Ventilation

Natural ventilation is a common passive technology, but it is dependent on the ambient environment, such as air temperature and wind speed. (Figure 3). If the air contains too much moisture, ventilation can bring additional moisture into the building causing discomfort to the building inhabitants. Mushtaha et al. [51] addressed three passive energy techniques: shading devices, natural ventilation, and thermal insulation. Implementation of such techniques can reduce 59% of the building's total energy consumption.

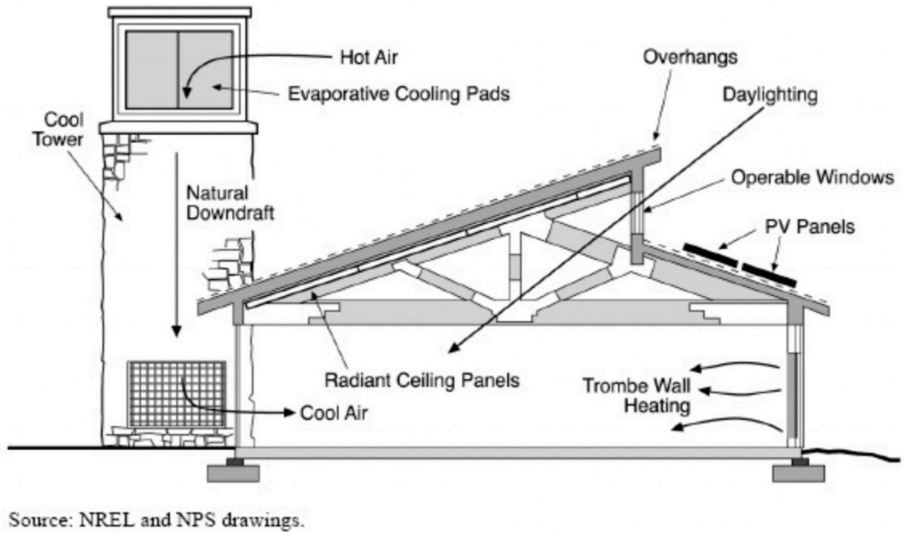

Figure 3. A proposed natural ventilation system for homes.

3.3. Windcatcher

A windcatcher is a building's architectural feature used for natural ventilation. Windcatchers are passive systems that require no energy for their operation. They generally take the form of small towers installed on the top of buildings. The tower draws air from the outside into the building, providing natural ventilation in hot arid, and humid climates. They are generally built facing away from the wind direction to minimize ingress of blown dust and sand. They can significantly influence to reduce cooling loads and supply the necessary ventilation rate of buildings [52].

3.4. Solar Chimneys

Solar chimneys are inexpensive and easy passive solar heating and cooling systems in a building. Solar chimneys are hollow containers that connect the inside part of a building with the outside environment. They are tall structures constructed facing the sun, typically with a dark-colored surface to absorb solar radiation. As the chimney heats up and rises, it draws additional air in at the bottom of the chimney. They are very effective in climates that are hot and humid. There may be multiple solar chimneys to increase surface area. Low emissivity coatings and glazings help reduce heat losses to the outside environment. The solar chimneys should be insulated from the building so as to not transmit heat gains into occupied spaces. In cooler conditions, solar chimneys can be used to direct absorbed heat back into the building.

Among renewable technologies, a solar chimney is an efficient renewable energy system that has been frequently adopted in buildings to reduce the energy consumption by HVAC systems through enhanced natural ventilation [53]. Solar chimneys can be adopted for both energy savings and fire safety.

3.5. Window Glazing

Insulated glazing on windows reduces heat conduction through the windows. Double-paned windows offer significant energy savings compared to single-paned windows. Glass panes have poor insulation properties. Single-paned windows have an *R*-value (insulation) of about 0.9. Double-paned windows (two panes with a gap between the panes) have an *R*-value of about 2.1; a triple-paned window has an *R*-value of about 3.2. Higher *R*-vales can be obtained when a less conductive gas (such as argon) replaces air as the gas in the gap; *R*-values as high as 10 have been reported. While these *R*-values are less than those of walls (*R*~12 to 15), significant reductions in heat transfer can be realized. In a separate study, Choi et al. [54] investigated *U*-values of walls, roof, and floor elements.

3.6. Trombe Walls

A Trombe wall is an equator-facing wall painted a dark color to absorb thermal energy from incident sunlight and is covered with glass on the outside with an insulating air gap between the wall and the glaze. Trombe walls are representative of passive solar building design. During cold winter months when leaves are off trees and the sun's path is low, heat will travel to colder spaces; the brick wall will absorb heat and will release the heat into the space through radiation. As heat enters the room, it will rise as the colder air within the room drops. As the cold air drops, the Trombe wall heats it, creating a convection cycle thereby creating an even heat distribution. Trombe walls also function during the summer months. Trombe walls generally have roof overhangs built at their eaves. Because the sun is higher in the summer, the overhang blocks most of the sun's rays. National Renewable Energy Laboratory [55] provides a good discussion regarding Trombe walls. Liu et al. [56] noted that higher Trombe wall-to-wall ratio limits and more significant potential for energy savings than office buildings.

Advantages of a Trombe wall include:

- Trombe walls can significantly reduce heating costs (due to Trombe walls ability to capture energy and radiate it for longer periods of time, releasing heat during evening hours).
- Trombe walls provide comfortable heat, radiating heat into the building space and creating a convection cycle).
- The system is a passive energy technique, containing no moving parts and requires no maintenance.
- Trombe walls are based on simple and inexpensive construction.
- Convection heats the room from top to bottom, allowing the entire building source to heat evenly.
- Trombe walls significantly reduce heating bills.
- Even in spaces too large to heat entirely by Trombe walls, Trombe walls cans help supplement oil, gas, or electric heating systems, thereby reducing energy costs and resource consumption.

Limitations of Trombe walls include:

- Spaces that are not well insulated may not realize the benefits of solar radiation.
- Trombe walls are not very attractive.
- Trombe walls can be a source of heat loss during extended overcast days.
- Trombe walls do not work everywhere, particularly if the sun's path is blocked by trees, mountains, or other buildings.

3.7. High-Albedo Roofs

White roofs (high-albedo roof coatings) can provide cooling energy savings of 10% to 79%, as reported in residential buildings in Florida and California [57]. White roofs involve reflective materials to reduce the transmittance of energy through the roof. Roofs can reach temperatures exceeding 150 °F. White roofs can commonly reduce the energy demand by 10% to 30%. Figure 4 is a graphical presentation of the difference in heat absorption between a "Dark roof" and a "Cool roof". Insulation thickness was noted to play a significant role in preventing heat loss from buildings [58]. Insulation thickness also delays the transfer of heat due to thermal inertia of the insulation layer. Applying a high-albedo coating to building rooftops results in significant energy reductions [59]. Passive design and landscape variables (rooftop albedo and shading vegetation) are considered important green building techniques [60].

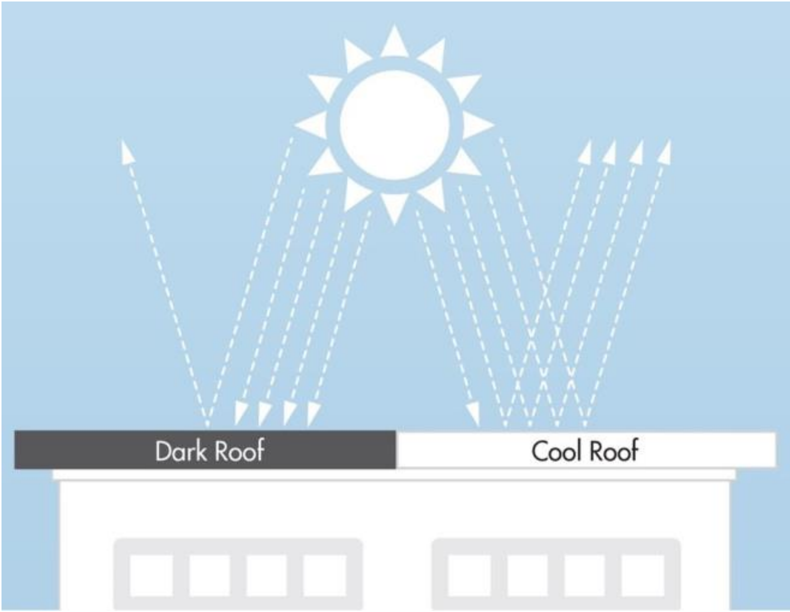

Figure 4. A cool roof compared to a dark roof. Source: EPA, 2022.

Dirt can accumulate on the high-albedo roofing surfaces to alter the performance of the roofing system. Bretz and Akbari [57] note that most of the albedo degradation occurs in the first year of application, with a 70% decrease in performance with the first two months of exposure; after the first year, the degradation slowed, with data showing small losses in albedo after the second year. Cleaning the roofs with soap is effective for restoring the original albedo, but it is not cost-effective. Reflective coatings have also been used on the University of California, Davis exterior walls, resulting in significant energy reductions [61].

3.8. Vegetated Roofs

Getter and Rowe [62] provide a good review of the role of extensive green roofs in sustainable development. Green roofs are classified as being either intensive or extensive systems. Intensive roofs employ a variety of plant species (that may include trees and shrubs) that require deep substrate layers and they require intensive maintenance. Intensive roofs generally are limited to flat roofs. Extensive roofs generally require minimal maintenance. They are generally not accessible to the general public. Due to their shallower substrates, plant species are generally limited to herbs, grasses, mosses, and drought-tolerant species such as sedum. Extensive green roofs can be installed on sloped roof surfaces.

Green roofs have a roof barrier installed on top of a roofing membrane. Above this barrier is a drainage layer that allows excess water to flow away from the roof. On top of the drainage layer is a fabric filter to prevent silt and particulates from clogging the drainage layer. An optional water retention fabric can be placed on top of the fabric filter to allow extra water to be retained for the benefit of the plant species. On top of that is a growing substrate to support plant growth. The depth, density, and humidity of the growing medium are three components of the growing medium contributing to its efficiency and performance.

There are four main components of vegetated roofs: (a) waterproofing membrane and filter membranes; (b) drainage films; (c) growing medium; and (d) vegetation. Saadatian et al. [63] note that some vegetated roofs need water for irrigation, increasing water consumption.

Green roofs (vegetated roofs) help mitigate the urban heat island effect, provide thermal comfort for the building occupants, add aesthetic environmental values, and most importantly reduce the energy consumption of buildings [63]. In a pilot study involving a vegetated roof of area 1388.0 m^2 and containing approximately 20,000 sedum plants conducted on a campus building at the University of Alabama at TBirmingham, Peters et al. [64] gathered utility bill information both prior to and after implementation of the green roof, involving electricity, natural gas, and chilled water. After the implementation of the pilot green roof, utility bill (energy) savings of ~20% to 25% were achieved (compared to the case prior to the implementation of the vegetated roof system). Saadatian et al. [63] also note that green roofs can reduce the roof temperature to 27 °C (compared to a temperature of 80 °C on a conventional black roof). Further, in terms of air quality, plants produce more oxygen and sequester carbon dioxide. Further, Tsoka et al. [65] noted that a continuous shading canopy of trees offers significant energy savings of about 54%.

In a study conducted in Iran, the reduction in energy consumption associated with green roofs ranged from 6.6% to 9.2%, resulting in a payback period of 25 to 57 years [61]. Significant results obtained from their study include: proper selection of green roof type depends on the climate; using green roofs causes a significant decrease in energy consumption and its associated energy costs; increasing the soil layer thickness increases the required energy for cooling and decreases the required energy for heating; the desired and positive effects of green roofs on energy consumption are better for buildings with fewer floors; and decreasing energy consumption should not be the only factor used to justify the use of green roofs.

Benefits associated with vegetated roofs include [62,63,66,67]:

- reduced volume of stormwater runoff;
- delayed stormwater runoff;
- increased stormwater runoff water quality;
- increased life span of roofing membranes;
- energy conservation and reduced urban heat island effect;
- increased biodiversity and providing habitats for wildlife;
- improved aesthetic value;
- mitigation of air pollution;
- noise reduction;
- insulation benefits; and
- application of LEED (Leadership in Energy and Environmental Design) credits.

Roofs represent 21% to 26% of urban areas [62,68]; therefore, vegetated roof systems provide an excellent opportunity to counteract the destruction of natural habitats in cities.

3.9. Summary of Passive Energy Methods

By incorporating passive energy design options in air-conditioned residential buildings, Abdul Mujeebu and Bano [69] showed a 34% reduction in the energy performance index could be achieved, compared to a 32% reduction for a green roof. Latent heat storage units can effectively reduce building energy consumption, reduce indoor temperature fluctuations, and improve indoor thermal comfort [6]. Furthermore, careful attention to building envelope design focusing on passive energy options can improve the indoor thermal environment by 5.82 °C, reduce thermal discomfort by 80.75%, and save up to 77% on energy requirements [70]. Passive cooling techniques can maintain the indoor temperature within a comfortable range while reducing the building energy load [71]. Passive building strategies that favor building energy conservation also have a positive impact on the building's resilience [72]. Passive energy systems can be incorporated into retrofitting buildings [73].

3.10. Pros and Cons of Passive Energy Conservation Methods

The advantages and limitations of passive energy conservation methods are listed in Table 2.

Table 2. Pros and cons of various passive energy conservation techniques.

Technology	Estimated Payback Period	Pros	Cons
Shading [42–45,74,75]	2.0 years	• Can provide a significant re-duction in summertime energy consumption • Provides evaporative cooling • In the summertime, trees block unwanted solar radiation entering the building, reducing the cooling load • Can improve building aesthetics • Trees can act as windbreaks to lower ambient wind speed	• High maintenance cost • May be difficult to clean windows • May attract birds and associated droppings
Natural Ventilation [5,51]	2.5 years	• Access to continuous airflow providing good humidity control • Delivers fresh air to the building interior • Reduces risk of condensation, residue, and mold • Lower operating and maintenance costs • Better health and wellness • Expels air impurities and odors • Easier access to better day-light • Eco-friendly	• Variable conditions • Dependent on natural forces • Addition to existing buildings can be expensive • Possibility of intrusions • Potentially adverse noise levels, air pollution, insect vectors, and security
Windcatcher [52,76]	6 months–1 year	• Windcatchers are an efficient cooling passive system that can help reduce the cooling loads in buildings • Adding evaporative cooling to windcatchers improves their function and indoor conditions • Windcatchers can decrease temperature down to 14 °C • Is a sustainable method of ventilation in buildings • Reduces electrical power consumption • Particularly useful in hot, arid, and humid climates • Effective for small rooms in buildings	• Windcatchers do not operate well for low air flow rates • Tall windcatchers operate more efficiently than smaller wind-catchers • Insects can go through wind-catchers resulting in uncomfortable living conditions
Solar Chimneys [77–80]	4.29 years	• Do not rely on direct sunlight • Can store heat and generate solar power around the clock • Versatile potential for commercial use • Do not require complex water cooling system • Cost-effective and energy efficient • Reliable • Low maintenance • Environmentally friendly • No electricity or gas is needed to power the chimney	• High construction costs • Efficiency concerns limits application to large systems • Technology is not widely known or used • While photovoltaic systems con-vert ~8% to 15% of energy collected into electricity, solar chimneys only convert ~1% to 2% into electricity

Table 2. *Cont.*

Technology	Estimated Payback Period	Pros	Cons
Window Glazing [81–83]	6.0 years	• Glazed windows reduce the amount of energy escaping due to two or more panes of glass • Improved noise insulation/soundproofing • Improved security/safety • Reduces interior fading • Increases property values	• Glazed windows trap heat • Difficult to repair if condensation occurs (necessitating replacement) • High initial costs • May not be a good match for buildings with older architectural styles
Trombe Walls [84–86]	2.56–2.85 years	• Are a very flexible solar option • Can be used to both cool and heat a building • Provides improved energy savings • Eliminates sun-drenching • Reduces glare on furnishings • Effective for nighttime heating • Provides reduced condensation • Provides thermal mass in a concentrated area without taking up much space • Provides comfortable, quiet rooms with stable temperatures • Are an attractive option	• Adds to construction costs primarily due to the increased foundations weight • Can become serios heat sinks (losing heat at night unless well-insulated • Operating louvres or dampers to close the vents is an operational hassle • Reduce daylighting and access to panoramic views • Covering them at night can be a hassle
Cool Roofs [58,87–89]	5.7 years	• Light colored (white) reflect sunlight reducing the need for air conditioning (reductions of 10% to 30% in electricity demand) • Lowers air conditioning bills • Results in better indoor comfort • Eco-friendly • Reduced roofing wastes in landfills • Decreased heat island effect	• White roofs may contribute to global warming (limiting the trans-port of moisture to the atmosphere which limits cloud formation resulting in less rainfall and increased drought conditions) • High installation costs • Dirt accumulation decreases system performance • Causes higher heating costs • May not be suitable for colder climates
Green Roofs [62–64,66,67,90–93]	6.2–18 years	• Helps insulate buildings, absorb rainfall, and reduce urban air temperatures • Provides biodiversity and habitat for animals • Reduces building energy consumption • Delayed stormwater runoff • Increased stormwater runoff water quality • Improves roof longevity • Adds beauty and value to building (aesthetics) • Mitigation of air pollution • Noise reduction	• High installation costs • Require more maintenance than traditional roofs

4. Summary and Conclusions

This paper does not address all the active and passive energy techniques being used today; rather, this paper describes and summarizes the more commonly used techniques applied in the field today. The paper presents a review of new and advanced technologies for heating and cooling of buildings that can reduce energy use while providing the required comfort for the occupants. As stated in the disclaimer, this paper does not center its attention on building decarbonization approaches. The paper has two sections for active and passive methods, respectively. A table at the end of each major section provides the advantages and disadvantages of each of the described technologies.

On the topic of active methods, several variations of and modifications to a conventional heat pump system have been discussed. There are various levels of initial investment associated with each of the variations, and the associated energy savings have been identified. Ground-source heat pumps (also called geothermal heat pumps) have shown promise and are being widely considered by HVAC designers and contractors for installation on small- to medium-sized buildings. The other methods that were discussed in the paper are still in the development stage and are not as common as ground-source heat pumps yet. Some of the techniques are limited in their application depending on the size of the HVAC load. A section was dedicated to the development of new refrigerants because they are under constant development to make them more environmentally friendly.

When it comes to passive techniques, there are multiple approaches that can be adopted by the designers. Among the methods discussed, shading and natural ventilation require the least amount of additional initial investment. Nonetheless, they can offer a significant reduction in the HVAC load and consequently contribute to lower energy bills. Some of the methods are still in the development phase to make them economically and technologically feasible when it comes to their relation to the building structure. Architectural and esthetic considerations are important when a technology is to be adopted. Trombe walls and solar chimneys fall into this category. Trombe walls can be used with smaller buildings, while a solar chimney installation only makes sense in larger buildings. The windcatcher concept has been around for more than a thousand years and perhaps it is time to adapt it to modern-day buildings to save energy. Its effective implementation requires a careful balance between architecture and zone layout, and it might be limited to use in low-rise buildings. Low-emissivity and multiple-glazing windows have documented proof that they work. The extra cost is a factor to be considered. Modifications to the roof of a building, such as green roofs and high-albedo roofs, can also provide energy savings. While high-albedo roofs are easier to implement, green roofs are more effective and at the same time require quite high maintenance.

As pointed out by Ma et al. [2] and the National Governors Association [3], attention on integrated decarbonation and building energy conservation approaches is accelerating.

Energy conservation of existing buildings plays a major role in reducing global carbon emissions and building energy consumption [94]. This is extremely important because building energy consumption accounts for nearly 40% of the global energy consumption [93,94], and the U.S. accounts for 20% of the world's CO_2 emissions [93]; it is key to the world's energy conservation and low-carbon development [94]. Energy use is currently driven by a number of factors, such as: population growth, economic changes, building size, service demands, and efficiency of energy use [93]. The main energy-consuming components in buildings are lighting and HVAC systems [93]. The retrofitting of existing buildings to reduce energy consumption provides an excellent opportunity for reducing global energy consumption. Building maintenance structure retrofits include transforming roofing systems and windows. Active measures relate to heating, ventilation, and air conditioning (HVAC) systems and lighting systems. Renewable energy measures refer to solar photovoltaic systems and ground source heat pump systems. Huang et al. [94] indicated that building energy conservation focuses on three aspects: energy conservation influencing factors and energy conservation barriers, energy conservation measures, and energy conservation optimization methods. As noted by DOE [93], 34 states and more than 253 municipalities have now instituted green building policies. The international Energy Agency [95] noted that without concerted efforts to bolster efficiency, energy intensity in industry may increase.

From the discussion provided, it is apparent that no single building active or passive energy conservation technique will maximize energy conservation in a building, rather an integrated approach involving a combination of building active or passive energy conservation techniques must be employed to maximize energy conservation efficiency for buildings.

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References

1. Xiang, X.; Mam, M.; Ma, X.; Chen, L.; Cai, W.; Feng, W.; Ma, Z. Historical Decarbonization of Global Commercial Building Operations in the 21st Century. *Appl. Energy* **2022**, *322*, 119401. [CrossRef]
2. Ma, M.; Feng, W.; Huo, J.; Xiang, X. Operational Carbon Transition in the Megalopolises' Commercial Buildings. *Build. Environ.* **2022**, *226*, 109705. [CrossRef]
3. National Governors Association. *State Energy Efficiency Policy in a New Era: A Toolkit for Governors*; National Governors Association (nga.org): Washington, DC, USA, 2021.
4. Ibem, E.O.; Udezi, B.E.; Oti, O.M.; Fakorede, O.A. Assessment of Architects' Knowledge of Passive Design Strategies in Terminal Buildings among Architectural Firms in Lagos State. In Proceedings of the 1st International Conference on Sustainable Infrastructural Development, IOP Conference Series: Materials Science and Engineering, Ota, Nigeria, 24–28 June 2019; Volume 640. [CrossRef]
5. Li, X.; Shen, C.; Yu, C.W.F. Building Energy Efficiency: Passive Technology or Active Technology? *Indoor Built Environ.* **2017**, *26*, 729–732. [CrossRef]
6. Sun, W.; Feng, J.; Zhang, Z.; Fang, X. Research Progress of Phase Change Heat Storage Technology for Passive Energy Conservation in Buildings. *Huagong Jinzhan/Chem. Ind. Energy Prog.* **2020**, *38*, 1824–1834. [CrossRef]
7. Ben Romdhane, S.; Amamou, A.; Ben Khalifa, R.; Said, N.M.; Younsi, Z.; Jemni, A. A Review on Thermal Energy Storage Using Phase Change Materials in Passive Building Applications. *J. Build. Eng.* **2020**, *32*, 101563. [CrossRef]
8. Elaouzy, Y.; El Fadar, A. Energy, Economic and Environmental Benefits of Integrating Passive Design Strategies into Buildings: A Review. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112828. [CrossRef]
9. Ponmurugan, M.; Ravikumar, M.; Selvendran, R.; Merlin Medona, C.; Arunraja, K.M. A Review of Energy Conserving Materials for Passive Cooling in Buildings. *Mater. Today Proc.* **2022**, *64*, 1689–1693. [CrossRef]
10. Rempel, A.R.; Lim, S. Numerical Optimization of Integrated Passive Heating and Cooling Systems Yields Simple Protocols for Building Energy Decarbonization. *Sci. Technol. Built Environ.* **2019**, *25*, 1226–1236. [CrossRef]
11. Kumar, V.V. Energy consumption of Residential Buildings in Extreme Climates with Phase Change Material-Aluminum Radiation Reflector Cool Roof. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 9703–9715. [CrossRef]
12. Hou, G.; Taherian, H.; Li, L. A Predictive TRNSYS Model for Long-Term Operation of a Hybrid Ground Source Heat Pump System with Innovative Horizontal Buried Pipe Type. *Renew. Energy* **2020**, *151*, 1046–1054. [CrossRef]
13. Hou, G.; Taherian, H.; Li, L.; Fuse, J.; Moradi, L. System Performance Analysis of a Hybrid Ground Source Heat Pump with Optimal Control Strategies Based on Numerical Simulations. *Geothermics* **2020**, *86*, 101849. [CrossRef]
14. Hou, G.; Taherian, H. Performance Analysis of a Hybrid Ground Source Heat Pump System Integrated with Liquid Dry Cooler. *Appl. Therm. Eng.* **2019**, *159*, 113830. [CrossRef]
15. Al-Yasiri, Q.; Szabó, M.; Arıcı, M. A Review on Solar-Powered Cooling and Air Conditioning Systems for Building Applications. *Energy Rep.* **2022**, *8*, 2888–2907. [CrossRef]
16. Xu, L.; Hou, G.; Taherian, H.; Song, Y.; Wang, Y.; Moradi, L. Modeling and Assessment of a Novel Solar-Biomass Based Distributed Multi-Generation System. *J. Renew. Sustain. Energy* **2022**, *14*, 036301. [CrossRef]
17. Tehranian, M.; Taherian, H. Solar-Assisted Heat Pump Combined with Seasonal Storage Tank to Meet Multi-Family Buildings Heat Demand. In Proceedings of the Solar Conference, Denver, CO, USA, 9–12 October 2017; American Solar Energy Society: Denver, CO, USA, 2017.

18. Herrando, M.; Ramos, A. Photovoltaic-Thermal (PV-T) Systems for Combined Cooling, Heating and Power in Buildings: A Review. *Energies* **2022**, *15*, 3021. [CrossRef]
19. Amiri, L.; Madadian, E.; Bahrani, N.; Ghoreishi-Madiseh, A. Techno-Economic Analysis of Waste Heat Utilization in Data Centers: Application of Absorption Chiller Systems. *Energies* **2021**, *14*, 2433. [CrossRef]
20. Deng, J.; Wang, R.; Han, G. A Review of Thermally Activated Cooling Technologies for Combined Cooling, Heating and Power Systems. *Prog. Energy Combust. Sci.* **2011**, *37*, 172–203. [CrossRef]
21. Torrella, E.; Sánchez, D.; Cabello, R.; Larumbe, J.; Llopis, R. On-Site Real-Time Evaluation of an Air-Conditioning Direct-Fired Double-Effect Absorption Chiller. *Appl. Energy* **2009**, *86*, 968–975. [CrossRef]
22. Ochoa, G.; Acevedo-Peñaloza, C.; Forero, J. Thermo-Economic Assessment of a Gas Microturbine-Absorption Chiller Trigeneration System under Different Compressor Inlet Air Temperatures. *Energies* **2019**, *12*, 4643. [CrossRef]
23. Han, X.; Li, J.; Xiangqiang Kong, X.; Sun, T.; Zhang, C.; Yin, L. Thermodynamic Performance Study on a Novel Absorption Compression Cascade Refrigeration Activated by an Internal Combustion Engine. *Int. J. Energy Res.* **2021**, *45*, 9595–9612. [CrossRef]
24. Darwish, M. Building Air Conditioning System Using Fuel Cell: Case Study for Kuwait. *Appl. Therm. Eng.* **2007**, *27*, 2869–2876. [CrossRef]
25. Liu, Y.; Wang, R.; Xia, Z. Experimental Study on a Continuous Adsorption Water Chiller with Novel Design. *Int. J. Refrig.* **2005**, *28*, 218–230. [CrossRef]
26. Taherian, H.; Salarian, H.; Ghadamian, H.; Khalaji Assadi, M. A Study of Liquid Desiccant System Performance. In Proceedings of the 6th International Symposium on Heating, Ventilating and Air Conditioning, Nanjing, China, 6–9 November 2009. Available online: https://www.researchgate.net/publication/255961670_A_Study_of_Liquid_Desiccant_System_Performance?enrichId=rgreq-65aada6b-bb94-4d5d-89c2-2687553c78d8&enrichSource=Y292ZXJQYWdlOzI1NTk2MTY3MDtBUzoxOTM1NDExMjI2NTAxMTlAMTQyMzE1NTIwNzMxMg%3D%3D&el=1_x_2 (accessed on 6 April 2023).
27. Lee, Y.; Park, S.; Kang, S. Operational Optimization of a Hybrid Desiccant Cooling System for Building Air Conditioning System. *Heat Mass Transf.* **2022**, *59*, 39–54. [CrossRef]
28. Sharma, A.; Kaushal, R. Performance Evaluation of a Solar-Powered Flat-Plate Multichannel Liquid Desiccant Air Conditioning System. *Heat Transf.* **2021**, *50*, 4103–4121. [CrossRef]
29. Lee, J.; Jeong, J. Hybrid Heat-Pump-Driven Liquid-Desiccant System: Experimental Performance Analysis for Residential Air-Conditioning Applications. *Appl. Therm. Eng.* **2021**, *195*, 117236. [CrossRef]
30. Fung, A.; Taherian, H.; Rahman, M.Z.; Selim, M. Feasibility Study of Deep-Lake Water-Cooling System at Ryerson University. *ASHRAE Trans.* **2015**, *121*, 393–401.
31. Kuyuk, A.; Ghoreishi-Madiseh, S.; Hassani, F.; Saspito, A.; Amiri, L.; Templeton, J. Performance and Economic Assessment of Large-Scale Deep-Lake Cooling Systems: A Canadian Example. *Energy Procedia* **2019**, *158*, 43–48. [CrossRef]
32. Fatahian, H.; Taherian, H.; Salarian, H.; Fatahian, E. Thermal Performance of a Ground Heat Echanger in a Cold Climate: A CFD Study. *Eur. Phys. J. Plus* **2021**, *136*, 265. Available online: https://ui.adsabs.harvard.edu/link_gateway/2021EPJP..136..265F/doi:10.1140/epjp/s13360-021-01265-7 (accessed on 6 April 2023). [CrossRef]
33. Peretti, C.; Zarrella, A.; De Carli, M.; Zecchin, R. The Design and Environmental Evaluation of Earth-to-Air Heat Exchangers (EAHE). A Literature Review. *Renew. Sustain. Energy Rev.* **2013**, *28*, 107–116. [CrossRef]
34. Hosseinzadeh, E.; Taherian, H. An Experimental and Analytical Study of a Radiative Cooling System with Unglazed Flat Plate Collectors. *Int. J. Green Energy* **2012**, *9*, 766–779. [CrossRef]
35. Sun, X.; Sun, Y.; Zhou, Z.; Alam, M.; Bermel, P. Radiative Sky Cooling: Fundamental Physics, Materials, Structures, and Applications. *Nanophotonics* **2017**, *6*, 997–1015. [CrossRef]
36. Evangelisti, L.; Guattari, C.; Asdrubali, F. On the Sky Temperature Models and their Influence on Buildings Energy Performance: A Critical Review. *Energy Build.* **2019**, *183*, 607–625. [CrossRef]
37. Dilshad, S.; Kalair, A.; Khan, N. Review of Carbon Dioxide (CO_2) Based Heating and Cooling Technologies: Past, Present, and Future Outlook. *Int. J. Energy Res.* **2020**, *44*, 1408–1463. [CrossRef]
38. Hussman Corporation. *CO2 Transcritical Systems Training Manual*; Hussman Corporation: Bridgeton, MO, USA, 2018.
39. The CHEMOURS Company. Opteon™ XL41 (R-454b) Refrigerant. 2022. Available online: https://www.opteon.com/en/products/refrigerants/xl41 (accessed on 6 April 2023).
40. Honeywell International Inc. Solstice® yf (R-1234yf). 2022. Available online: https://www.honeywell-refrigerants.com/europe/product/solstice-yf-refrigerant/ (accessed on 6 April 2023).
41. Akamphon, S.; Akamphon, K. Cost and Benefit Tradeoffs in Using a Shade Tree for Residential Building Energy Saving. *Environ. Asia* **2014**, *7*, 19–24. [CrossRef]
42. Balogun, A.A.; Morakinyo, T.E.; Adegun, O.B. Effect of Tree-Shading on Energy Demand of Two Similar Buildings. *Energy Build.* **2014**, *81*, 305–315. [CrossRef]
43. Kamal, M.A. Shading: A Simple Technique for Passive Cooling and Energy Conservation in Buildings. *Archit.–Time, Space and People, Monthly Magazine*, January 2011; pp. 18–23.
44. Abdel-Aziz, D.M.; Shboul, A.A.; Al-Kurdi, N.Y. Effects of Tree Shading on Building's Energy Consumption—The Case of Residential Buildings in a Mediterranean Climate. *Am. J. Environ. Eng.* **2015**, *5*, 131–140.

45. Maleki, B.A. Shading: Passive Cooling and Energy Conservation in Buildings. *Int. J. Tech. Phys. Probl. Eng.* **2011**, *3*, 72–79. Available online: https://www.coa.gov.in/show_img.php?fid=100 (accessed on 6 April 2023).
46. Carver, A.D.; Unger, D.R.; Parks, C.L. Modeling Energy Savings from Urban Shade Trees: An Assessment of the CITYgreen® Energy Conservation Module. *Energy Manag.* **2004**, *34*, 650–655. [CrossRef]
47. Huang, Y.; Akbari, H.; Hara, T.; Rosenfeld, A. The Potential of Vegetation in Reducing Summer Cooling Loads in Residential Buildings. *J. Appl. Meteorol.* **1987**, *26*, 1103–1116. [CrossRef]
48. Meier, A.K. Strategic Landscaping and Air-Conditioning Savings: A Literature Review. *Energy Build.* **1991**, *15*, 479–486. [CrossRef]
49. Simpson, J.R. Improved Estimates of Tree-Shade Effects on Residential Energy Use. *Energy Build.* **2002**, *34*, 1067–1076. [CrossRef]
50. Hwang, W.H.; Wiseman, P.E.; Thomas, V.A. Enhancing the Energy Conservation Benefits of Shade Trees in Dense Residential Developments Using an Alternative Tree Placement Strategy. *Landsc. Urban Plan.* **2017**, *158*, 62–74. [CrossRef]
51. Mushtaha, E.; Salameh, T.; Kharrufa, S.; Mori, T.; Aldawoud, A.; Hamad, R.; Nemer, T. The Impact of Passive Design Strategies on Cooling Loads of Buildings in Temperate Climate. *Case Stud. Therm. Eng.* **2021**, *28*, 101588. [CrossRef]
52. Sangdeh, P.K.; Nasrollahi, N. Windcatchers and their Applications in Contemporary Architecture. *Energy Built Environ.* **2022**, *3*, 56–72. [CrossRef]
53. Shi, L.; Zhang, G. An Empirical Model to Predict the Performance of Typical Solar Chimneys Considering Both Room and Cavity Configurations. *Build. Environ.* **2016**, *103*, 250–261. [CrossRef]
54. Choi, B.-E.; Shin, J.-H.; Lee, J.-H.; Kim, S.-S.; Cho, Y.-J. Establishment of Passive Energy Conservation Measure of Fenestration System in Nonresidential Building of Korea. *Int. J. Polym. Sci.* **2017**, *2017*, 8681737. [CrossRef]
55. National Renewable Energy Laboratory. Building Research: Building a Better Trombe Wall. In *NREL Facts*; Undated; National Renewable Energy Laboratory: Golden, CO, USA. Available online: https://www.nrel.gov/docs/legosti/fy98/22834.pdf (accessed on 6 April 2023).
56. Liu, Y.; Yu, Z.; Song, C.; Wang, D. Heating Load Reduction Characteristics of Passive Solar Buildings in Tibet, China. *Build. Simul.* **2022**, *15*, 975–994. [CrossRef]
57. Bretz, S.E.; Akbari, H. Long-Term Performance of High-Albedo Roof Coatings. *Energy Build.* **1997**, *25*, 159–167. [CrossRef]
58. Ramamurthy, P.; Sun, T.; Rule, K.; Bou-Zeid, E. The Joint Influence of Albedo and Insulation on Roof Performance: An Observational Study. *Energy Build.* **2015**, *93*, 249–258. [CrossRef]
59. Akbari, H.; Bretz, S.; Kurn, D.M.; Hanford, J. Peak Power and Cooling Energy Savings of High-Albedo Roofs. *Energy Build.* **1997**, *25*, 117–126. [CrossRef]
60. Douthat, T.; Morgan, J.D.; Alibašić, H.; Grant, A. Passive Building Characteristics, and Summertime Residential Energy Use: A Spatial Analysis of Energy Efficiency in Gainesville, FL. *Build. Environ.* **2020**, *169*, 106542. [CrossRef]
61. Celniker, C.; Chen, S.; Meier, A.; Levinson, R. Targeting Buildings for Energy-Saving Cool-Wall Retrofits: A Case Study at the University of California, Davis. *Energy Build.* **2021**, *249*, 111014. [CrossRef]
62. Getter, K.L.; Rowe, D.B. The Role of Extensive Green Roofs in Sustainable Development. *HortScience* **2006**, *41*, 1276–1285. [CrossRef]
63. Saadatian, O.; Spian, K.; Salleh, E.; Lim, C.H.; Riffat, S.; Saadatian, E.; Toudeshki, A.; Sulaiman, M.Y. A Review of Energy Aspects of Green Roofs. *Renew. Sustain. Energy Rev.* **2013**, *23*, 155–168. [CrossRef]
64. Peters, R.W.; Sherrod, R.D.; Winslett, M. Chapter 2: Energy Savings Resulting from Installation of an Extensive Vegetated Roof System on a Campus Building in the Southeastern United States. In *New Developments in Renewable Energy*; Arman, H., Yuksel, I., Eds.; Intech Publishers: London, UK, 2013; pp. 21–49. [CrossRef]
65. Tsoka, S.; Leduc, T.; Rodler, A. Assessing the Effect of Urban Street Trees on Building Cooling Energy Needs: The Role of Foliage Density and Planting Pattern. *Sustain. Cities Soc.* **2021**, *65*, 102633. [CrossRef]
66. Refahi, A.H.; Talkhabi, H. Investigating the Effective Factors on the Reduction of Energy Consumption in Residential Buildings with Green Roofs. *Renew. Energy* **2015**, *80*, 595–603. [CrossRef]
67. Kirby, J.T.; Peters, R.W.; Watts, S.; Winslett, M. *Completion Report: Experimental Investigation of Runoff Mitigation from Vegetated Roofs*; Alabama Water Resources Research Institute: Auburn, AL, USA, 2011.
68. Wong, E. Green Roofs and the Environmental Protection Agency's Heat Island Reduction Initiative. In Proceedings of the 3rd North American Greed Roof Conference: Greening Rooftops Sustainable Communities, Washington, DC, USA, 4–6 May 2005; pp. 32–44.
69. Abdul Mujeebu, M.; Bano, F. Integration of Passive Energy Conservation Measures in a Detached Residential Building Design in Warm Humid Climate. *Energy* **2022**, *255*, 124587. [CrossRef]
70. Kini, P.G.; Garg, N.R.; Kamath, K. An Assessment of the Impact of Passive Design Variations of the Building Envelope Using Thermal Discomfort Index and Energy Savings in Warm and Humid Climate. *Energy Rep.* **2022**, *8*, 616–624. [CrossRef]
71. Bhamare, D.K.; Rathod, M.K.; Banerjee, J. Passive Cooling Techniques for Building and their Applicability in Different Climate Zones—The State of Art. *Energy Build.* **2019**, *198*, 467–490. [CrossRef]
72. White, L.; Wright, G. Assessing Resiliency and Passive Survivability in Multifamily Buildings. In Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings, Clearwater Beach, FL, USA, 9–12 December 2019. Available online: https://www.ashrae.org/file%20library/conferences/specialty%20conferences/2020%20building%20performance/papers/d-bsc20-c018.pdf (accessed on 6 April 2023).

73. Coelho, G.B.A.; Henriques, F.M.A. Performance of Passive Retrofit Measures for Historic Buildings that House Artefacts Viable for Future Conditions. *Sustain. Cities Soc.* **2021**, *71*, 102982. [CrossRef]
74. Kamal, M.A. A Study on Shading of Buildings as a Preventive Measure for Passive Cooling and Energy Conservation in Buildings. *Int. J. Civ. Environ. Eng.* **2010**, *10*, 19–22.
75. Abdel-Aziz, D.M. Effects of Tree Shading on Building's Energy Consumption. *Archit. Eng. Technol.* **2014**, *3*, 135. [CrossRef]
76. Jomehzadeh, F.; Nejat, P.; Calautit, J.K.; Yusof, M.B.M.; Zaki, S.A.; Hughes, B.R.; Yazid, M.N.A.W.M. A Review on Windcatcher for Passive Cooling and Natural Ventilation in Buildings, Part 1: Indoor Air Quality and Thermal Comfort Assessment. *Renew. Sustain. Energy Rev.* **2017**, *70*, 736–756. [CrossRef]
77. Klimes, L.; Charvát, P.; Hejčík, J. Comparison of the Energy Conversion Efficiency of a Solar Chimney and a Solar PV-Powered Fan for Ventilation Applications. *Energies* **2018**, *11*, 912. [CrossRef]
78. Clean Power Professionals Group. How Solar Chimneys Can Help Renewables Grow. 2022. Available online: https://energycentral.com (accessed on 6 April 2023).
79. Tiondi, E. 5 Advantages to Using a Solar Chimney. 2010. Available online: https://www.doityourself.com/ (accessed on 6 April 2023).
80. Shi, L.; Ziem, A.; Zhang, G.; Li, J.; Setunge, S. Solar Chimney for a Real Building Considering Both Energy-Saving and Fire Safety—A Case Study. *Energy Build.* **2020**, *221*, 110016. [CrossRef]
81. U.S. Department of Energy, Energy Efficiency & Renewable Energy. *Guide to Energy-Efficient Windows 2010 (October)*; U.S. Department of Energy: Washington, DC, USA, 2010.
82. Gorantla, K.; Shaik, S.; Kontoleon, K.J.; Mazzeo, D.; Maduru, V.R.; Shaik, S.V. Sustainable Reflective Triple Glazing Design Strategies: Spectral Characteristics, Air Conditioning Cost Savings, Daylight Factors, and Payback Periods. *J. Build. Eng.* **2021**, *42*, 103089. [CrossRef]
83. ConnectUS. 9 Advantages and Disadvantages of Double Glazed Windows. 26 September 2016. Available online: https://connectusfund.org/ (accessed on 6 April 2023).
84. Kostikov, S.; Grinkrug, M.; Yiqiang, J. Comparative Technical and Economic Analysis of the Trombe Wall Use in the Heat Supply System at Different Climatic Conditions. *J. Phys. Conf. Ser.* **2020**, *1614*, 012064. [CrossRef]
85. Gromicko, N.; Trombe Walls. International Association of Certified Home Inspectors, Boulder, CO, USA. Undated. Available online: https://www.nachi.org/trombe-walls.htm (accessed on 6 April 2023).
86. National Renewable Energy Laboratory. *Building a Better Trombe Wall*; U.S. Department of Energy: Golden, CO, USA, 1998.
87. Al Fayad, F.; Maref, W.; Awad, M.M. Review of White Roofing Materials and Emerging Economies with Focus on Energy Performance Cost-Benefit, Maintenance, and Consumer Indifference. *Sustainability* **2021**, *13*, 9967. [CrossRef]
88. Energy Roofing. Cool Roof Advantages and Disadvantages. Undated. Available online: https://energy-roofing.com (accessed on 6 April 2023).
89. Homes.com. The Pros and Cons of Cool Roofs. 2016. Available online: https://www.homes.com (accessed on 6 April 2023).
90. Florida Independent. The Pros and Cons of Having a Green Roof. 2022. Available online: https://floridaindependent.com (accessed on 6 April 2023).
91. General Services Administration. Green Roofs. Washington, DC, USA. Undated. Available online: https://www.gsa.gov (accessed on 6 April 2023).
92. American Society of Landscape Architects. Professional Practice—Increasing Energy Efficiency: Residential Green Roofs. Undated. Available online: https://www.asla.org (accessed on 6 April 2023).
93. U.S. Department of Energy, Energy Efficiency & Renewable Energy. *Energy Efficiency Trends in Residential and Commercial Buildings 2010 (August)*; U.S. Department of Energy: Washington, DC, USA, 2010.
94. Huang, H.; Wang, H.; Hu, Y.-J.; Li, C.; Wang, X. The Development Trends of Existing Building Energy Conservation and Emission Reduction—A Comprehensive Review. *Energy Rep.* **2022**, *8*, 13170–13188. [CrossRef]
95. International Energy Agency. *Buildings—Energy Efficiency 2020—Analysis—IEA*; International Energy Agency: Paris, France, 2020.