Chapter

Some Aspects of HVAC Design in Energy Renovation of Buildings

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Abstract

It is well-known fact that air conditioning systems are responsible for a significant part of all energy systems in building energy usage. In EU buildings, the building HVAC systems account for ca 50% of the energy consumed. In the U.S., air-conditioning accounts on average about 12% of residential energy expenditures. The proper choice of air distribution systems and sustainable energy sources to drive the electrical components have a vital impact to achieve the best requirements for indoor climate including, hygienical, thermal, and reasonable energy-saving goals. The building energy system components that have a considerable impact on the demand for final energy in the building are design, outdoor environment conditions, HVAC systems, water consumption, electrical appliances, indoor thermal comfort, and indoor human activities. For calculation of the energy balance in a building, we need to consider the total energy flows in and out from the building including ventilation heat losses, the perimeters transmission heat loses, solar radiation, internal heat from occupants and appliances, space and domestic water heating, air leakage, and sewage heat losses. However, it is a difficult task to handle the above time-dependent parameters therefore an energy simulation program will always be used. This chapter aims to assess the role of ventilation and air-conditioning of buildings through the sustainability approaches and some of the existing renewable energy-based methods of HVAC systems are presented. This comprehensive review has been shown that using the new air distribution systems in combination with renewable energy sources are key factors to improve the HVAC performance and move toward Nearly Zero Carbon Buildings (NZCB).

Keywords: Sustainable HVAC systems, building energy systems, thermal comfort, indoor human activities, Energy balance, Energy saving potential, Nearly Zero Carbon Buildings (NZCB)

1. Introduction

The generation and use of energy is the largest contributor to anthropogenic CO_2 emissions and therefore the most important factor to tackle greenhouse gases and climate change issues. According to the International Energy Agency (IEA), World Energy Outlook 2010, the worldwide contribution of the building sector to the final energy demand has steadily increased to about a third of the world's final energy demand. Therefore it makes the building the most energy-intensive sector which contributes almost 30% of the anthropogenic greenhouse gas emissions. More unfortunate is that the energy use in buildings will increase to 67% by 2030. A major cause for high energy use in buildings is the demand for better thermal comfort and air quality in indoor environments. It is estimated that heating, ventilation, and air conditioning systems are responsible for almost 50% of the total energy use in buildings which is about 10-20% of the national energy use in most developed countries. To reduce global CO_2 emissions, the economic use of energy resources is of outstanding significance. The buildings sector is a significant contributor to energy-related sustainability challenges. That is why buildings should be considered as a key element to a sustainable future because of their processes of design, and construction including their operation, and all human indoor activities. Therefore, reducing energy demand in buildings can play one of the most important roles in solving these challenges. A sustainable and efficient energy supply in buildings needs the use of more energy-efficient manufacturing materials which are a part of the futures critical is to tackle the sustainability-related challenges.

It is indicated that the air conditioning systems as a considerable part of building energy systems and account for about 12% of residential energy expenditures in the U.S., and the building HVAC systems are responsible for ca 50% of the energy usage in EU buildings [1].

The air distribution systems in buildings are of vital importance to achieving the best requirements for indoor climate including, hygienical, thermal, and reasonable energy-saving goals. Yang et al. [2] in a comprehensive review article tried to describe all existed air distribution methods in which the benefits and shortcomings are treated. The air distribution systems are the main element for good ventilation systems which play a key role in creating an acceptable microclimate in the indoor environment. Thus, the development and adoption of sustainable ventilation and air conditioning systems are a viable solution to mitigate climate change and curtail carbon emissions [3].

It is worth mentioning that globalization, economic development, and population growth will be among the factors that will increase energy use worldwide in the future.

According to Gustafsson [4], solar systems, including both thermal and solar cells, can be applied to reduce the environmental impact of buildings. He also pointed out that without an input tariff for surplus electricity and government subsidies for the Central and Northern European buildings, it is still not economically feasible.

However, in the renovation of multi-family houses, the solar energy systems can reduce the total lifecycle costs (LCC) both in Southern as well in Northern European climates.

In cold climates, air heat recovery and low-temperature heating were both found to have a larger impact in colder climates. To improve the performance factor of heat pumps, low-temperature heating systems can be used, particularly when the space heating demand is relatively high concerning the hot water demand. It is worth mentioning that this chapter is based on a comprehensive review of existing literature in the research area. We tried to show that using the new air distribution systems in combination with renewable energy sources are key factors to improve the HVAC performance and move toward the EU's directives for Nearly Zero Carbon Buildings (NZCB).

2. Energy flow in buildings

Maintaining the indoor climate has a direct impact on energy usage, that is to say, the energy is used to clarify and control the indoor air quality. Danielski [5] described the main energy balance in buildings as all the energy flows to and from the building which includes:

- Transmission or conduction heat losses from building surfaces
- all internal heats from the building occupants, lightings, and appliances
- solar radiation especially from windows
- space heating and domestic water heating
- ventilation heat losses, infiltration and exfiltration air leakages
- heat losses by sewage system.

The building's components which their interaction have an impact on the demand for final energy in the building and henceforth on the whole energy system are [5]:

1. Design process
2. Outdoor environment conditions as a significant factor
3. HVAC systems
4. Total water consumption
5. electrical appliances
6. thermal comfort in the indoor environment
7. indoor human activities in the indoor environment.

However, each of the energy flows includes many variables that can vary with time, therefore an energy simulation program will always be used (see, later on about energy simulation).

2.1 Energy renovation of buildings

Gustafsson [4] stated that the building sector accounts for around 40% of the total final energy use in the EU. Therefore, the energy renovation of buildings, or increased energy efficiency through renovation, can be considered vital in the work toward the EU climate and energy goals for the year 2030. It is noted that comparing the building renovation without energy efficiency measures, the energy renovation can often reduce life-cycle costs as well as the environmental impact.

When making renovation of old apartment buildings, the improvement of ventilation is unavoidable. By using a modern and energy-saving ventilation strategy one can provide a healthy indoor environment for the occupants [6].

Randazzo et al. [7] stated that: using data for 8 industrial countries shows that when households adapt to the increasing temperature of global warming and climate change, then the electricity demand increases yearly between 35–42%. They pointed out that this is because of adapting new air condition systems and consequently the rate of poverty for the lowest-income increases as well. They also show that CDDs (the colling degree days) affect electricity expenditures and forced households to purchase and then use air conditioners. They also pointed out that households on average spend 35–42% more on electricity when they adopt air conditioning. Therefore, by recognizing the role of space cooling in energy consumption to drive up emissions, the national policy agendas should thus prioritize increasing the supply of electricity from renewable sources [7].

2.2 Energy saving potential in the building sector

The building sector is an important candidate for energy usage and presents a lot of potentials for energy saving. The population growth and desire for a better living standard are responsible for increasing energy demand. But researchers predict that there are a lot of potentials for energy saving in old and new buildings. Thus, the implementation of energy efficiency measures is calculated to result in up to 30% savings in the building sector by 2020 [8].

Many measures and methods are implemented to reduce energy use in the construction sector:

- implementation of energy-efficient renovation strategies for buildings
- stricter building regulations by taking into account modern technology,
- green building systems.

In the European Union, policies for demands on energy efficiency in buildings have been stricter according to the EU2030 goals to meet the EU's long-term 2050 greenhouse gas reduction target [9].

The above report pointed out that, the European Parliament approved the "*Directive on the Energy Performance of Buildings in 2010*" as a measure to realize this long-term potential. Thereby, all newly constructed buildings in the EU should be *nearly zero-energy buildings* (NZEB) as the directive demanded by the end of 2020. This means that all EU member states could convert existing buildings under renovation into almost energy-efficient buildings.

We may explore many energy-saving measures for this sector such as improving the building energy management, incorporating energy-efficient technology, and the awareness of energy efficiency for building occupants [10].

Residential energy consumption can be determined in two different ways, namely [11]:

1. Top-down approach: which is concerning with the building industry as an energy reduction and which does not differentiate energy consumption due to individual end uses. Top-down models determine the effect on energy consumption due to ongoing long-term changes or transitions in the housing sector, primarily to determine the need for delivery. Variables commonly used by top-down models include macroeconomic indicators (gross domestic product (GDP), employment rate, and price index), climatic conditions, housing construction/demolition levels, and estimates of appliance ownership and number of units in the housing sector.

2. Bottom-up approach: The bottom-up method covers all models that use input data from a hierarchical level that is smaller than that for the sector as a whole. Models can account for the energy consumption of individual end uses, individual houses, or groups of houses and then extrapolate to represent the region or nation based on the representative weight of the modeled sample.

The ventilation and air conditioning systems in operation are a potential energy-saving area in the building sector. This can be done by achieving thermal comfort and good health of the building occupants with minimized use of energy is the essence of HVAC systems [12].

2.3 Sustainable and well-designed air distribution systems and energy saving

Ventilation is a major player in air-conditioning and HVAC systems; therefore, it should effectively and properly be designed to save a reasonable amount of energy. The main goal of a ventilation system is to remove excess heat from the space, contaminant removal, and provide and distribute fresh air to the space.

There are two ways to ventilate occupied spaces, namely: natural ventilation and mechanical ventilation.

- Natural ventilation: The buildings are naturally ventilated via *air infiltration* and *airing*. *Air infiltration* is the airflow through adventitious leakages in the building envelope, while *airing* is the intentional air exchange through large openings like windows and doors, see Hayati [13].

- Mechanical ventilation: mechanical ventilation has also two main types, see Hesaraki and Holmberg [14]:

    - Constant air volume system (CAV): Concerning the CAV systems, supply or exhaust fans generate steady airflow to room space, the fan keeps the same power all the time. But temperature for the heating unit changes with the heating demand. For these systems, the operation cost is high because when the space is empty it is still on and uses its full capacity.

    - Variable air volume systems (VAV): The VAV systems mainly installed in school and office and the system has a relatively high initial cost and consist of more mechanical components. But its operation cost is lower than the CAV system. In a VAV system, the temperature will maintain at a certain level. Airflow is controlled by a damper and changes with heating or cooling demand. To the last, the indoor air temperature will be kept at the desired level. Therefore, the VAV system has the potential to save energy by reducing the airflow rate. Related to the variable air volume method (VAV), *Demand control ventilation* (*DCV*) is used and has the function to adjust the airflow rate with demand. Supply or exhaust airflow can vary with factors such as temperature, occupants, indoor polluting concentration, time, and relative humidity (RH). The research shows that ca 5-60% of energy can be saved with demand control [14].

The traditional air distribution and supply devices in ventilated rooms are not always able to effectively remove excess heat from the space. Therefore, chilled beams, especially the active systems, are used to achieve the desired cooling demand [15].

Yang et al. [2] explained that there are many different types of air distribution and ventilation systems which can briefly be defined as:

1. Mixing ventilation system (MV): A mixing ventilation system aims to dilute indoor pollutants by mixing. The researchers and building operators found that the effectiveness of MV is low, while energy consumption is high.

2. Diffuse ceiling ventilation system (DCV): Here, the outdoor air is supplied into the occupied zone from perforations in the suspended ceiling panels.

Because of the large opening area of the supply inlet and its low mentum, the air enters the occupied zone with very low velocity and no fixed direction then the room airflow is driven by the buoyancy force generated by heat sources.

3. Displacement ventilation system (DV): The displacement ventilation has a stratification system of two-layer. One cleaner layer in the occupied zone at low velocity and the other is the upper contaminated layer close to the ceiling. The contaminants and the excess heat are displaced upwards due to the plumes rising above heat sources in the room. Its ventilation effectiveness is usually >>100%. Wall displacement units are suitable for small cooling loads (<40 W/m^2) and desired higher cooling loads are compensated by the chilled ceiling panels or chilled beams.

4. Underfloor air distribution system (UFAD): UFAD uses an underfloor supply plenum located between the structural slab and the underside of a raised floor system to deliver conditioned air to floor supply outlets.

5. Stratum ventilation system (SV): SV is an effective method that supplies air to head (breathing) level and generated sandwich airflow fields in indoor environments. SV is most suitable for small to medium-sized or zonal rooms.

6. Impinging jet ventilation system (IJV): Here the supply device is a pipe that creates a jet of air down onto the floor level with quite a high momentum (That is to say it is resembling mixing ventilation) but because of a tin layer with relatively high velocity on the floor and then the velocity decays very rapidly away from the point of impact on the floor, it will behave like a displacement system. Instead of a displacement system that works with cooling only, this method is suitable for cooling and heating. Two new research articles that describe the heating and cooling usage of the impinging jet ventilation system are shown in [16, 17].

7. Confluent jets ventilation system (CJV): Like IJV, this is also a relatively new air distribution method developed in Sweden by the author and colleagues. Confluent jets define a system of multiple round jets issue from different nozzles that after a certain distance from the supply device, the combined jets behave as a single jet. Colliding with each other, after traveling a certain distance after their exit, to form a single jet that will converge to the exit of the ventilation system.

8. Wall attached ventilation system (WAV): WAV is based on the combination of MV, DV, and impinging jet flow. The concept is the predecessor of air curtain (jet) ventilation (ACV). The air jet with high momentum is directed downward and then reaches the floor level, impinges to corner, and then separates from the vertical wall surface and re-attaches to the floor to generate a clean air layer ("air reservoir").

9. Intermittent air-jet strategy (IAJS): This is a ventilation strategy with a rapid variation of ventilation flow rate. It works with a sinusoidal function and the flow rate is controlled within a specified range by repeatedly switching on and off the HVAC supply fan for stipulated periods. The purpose of IAJS is to create variations is to change the conditions within the room for the airflow pattern and the velocity field.

10. Protected occupied zone ventilation system (POV): This system is used to separate an indoor environment into several subzones by using low turbulent plane jets. The POV method is suitable for indoors with a protected occupied zone (POZ) like an open plan office and an isolation room. A POZ is defined as an occupied zone as a sub-zone consisting of the office personal working zone, where occupants spend most of their time indoors.

11. Personalized ventilation system (PV): The PV system is used to provide clean and cool air to the breathing zone or at least close to each occupant. It improves the inhaled air quality by delegating the occupants to optimize and control temperature, flow rate (local air velocity), and direction of the locally supplied personalized air according to their preference, and consequently to improve their thermal comfort conditions.

12. Local exhaust ventilation system (LEV): Here, the air is supplied directly to the occupants from a desk or seat unit. The occupant has access to the controls.

13. Laminar airflow (LAF)/Piston ventilation system (PiV): Here, the air is supplied vertically or horizontally across the whole room at low velocity (typically 0.2 to 0.3 m/s) and turbulence to create a piston-type flow. This is a very effective but expensive ventilation system with an extraordinarily high airflow rate (200 to 600 air changes per hour) and is only used for clean rooms and hospital operating theaters.

14. Demand-oriented ventilation system (DVO): According to Li et al. [18], when the occupants are not close to the located air terminals even for personalized ventilation (PV) the ventilation efficiency is not high. They raised a question that: can we realize the demand-oriented ventilation (DOV) for occupants wherever occupants are located? They answered that it is necessary for the operation stage that the DOV system should have the ability to know the various positions of occupants and switch the ventilation mode into the most efficient one for the scenario. An integrated theory for non-uniform indoor thermal environments should be established, based on which the design method.

It is well known that traditional HVAC systems are predesigned and operated using a fixed airflow pattern. The research conducted by Wang et al. [19] - using Adjustable Fan Network (AFN) for improving airflow pattern maneuverability - indicates that great progress has been achieved in the fundamental theory of nonuniform environment, based on which the multi-mode ventilation (MMV) system and the online identification method were proposed and shows energy-saving potential. The MMV system is generally based on the solid foundation of DOV. It is believed that with further development of this system, the DOV system can come up soon and play an important role in high-efficiency ventilation and energy saving in the future [19].

However, in real life operations of the conventional design and operation of the ventilation systems are based on the non-uniform indoor environment assumption but many calculation methods are based on a uniform airflow pattern. Thus, based on the design method, theoretical model, and control strategy of DOV an integrated theory for non-uniform indoor thermal environments should be established and developed.

As we know the ventilation is a major player in air-conditioning and HVAC systems as a whole, therefore it should effectively and properly be designed to save a reasonable amount of energy. The main goal of a ventilation system is to remove excess heat from the space, contaminant removal, and provide and distribute fresh air into space. Liang et al. [20] postulate that: ventilation which is a significant part of the HVAC system needs to be designed properly to save energy. The proper treatment of the space cooling load in the indoor environment relies on the effective use of different ventilation systems.

The ventilation energy can be reduced by the following parameters:

- Reducing room air temperature in winter and increasing it in summer. Occupants can adapt to small changes in room temperature
- Ventilation system balancing and minimizing air leakage from ducts, fans, etc.
- Heat recovery
- Demand control ventilation, e.g. using CO_2 controllers for dampers, etc.
- User control ventilation to cater to individual requirements.

It has been demonstrated by Fong et al. [21] that the use of advanced and sustainable ventilation methods like stratum ventilation (SV) and displacement ventilation (DV) systems in specific configurations can reduce the carbon emissions up to 31.7% and 23.3%, respectively. It has been concluded that with a properly designed supply air velocity and volume, location of diffusers and exhausts, the SV system has the potential to maintain better thermal comfort with a smaller vertical temperature difference, lower energy use, and better IAQ in the breathing zone [22].

Comparison of the mean air temperatures in the occupied zone confirmed that Stratum (SV) systems offered the highest cooling efficiency, followed by displacement ventilation (DV) and then mixing ventilation (MV) systems [23].

Studies involving Impinging Jet ventilation (IJ) and Confluent Jets ventilation (CJ) systems have shown that these methods of room air distribution methods are capable of providing considerably better air quality performance and at the same time require less energy than the MV system and a higher cooling capacity than DV systems, see [24–26]. In this part, the performance of systems based on the hybrid (Impinging Jet and Confluent Jets ventilation systems) method is compared with the mixing and displacement methods of air distribution, which are the most commonly used for room air distribution presently. **Figure 1** shows an impinging jet supply device and confluent jets system that is called a hybrid air distribution system (HAD) [27].

Comparing with the mixing ventilation system, it is known that a displacement system is a more efficient method of air supply, but it suffers from two main problems, namely:

1. it is not capable to be used for heating mode,
2. and it has a limited penetration depth into the room which hinders that the supply airflow covers the whole floor surface.

Therefore, hybrid air distribution systems (HAD) have been developed. HAD systems combine the benefits of both MV and DV systems to use the stratification effect of the DV, the entrainment effect of MV, and to overcome the shortcomings of the DV system. Two HAD systems have recently been developed by the author of

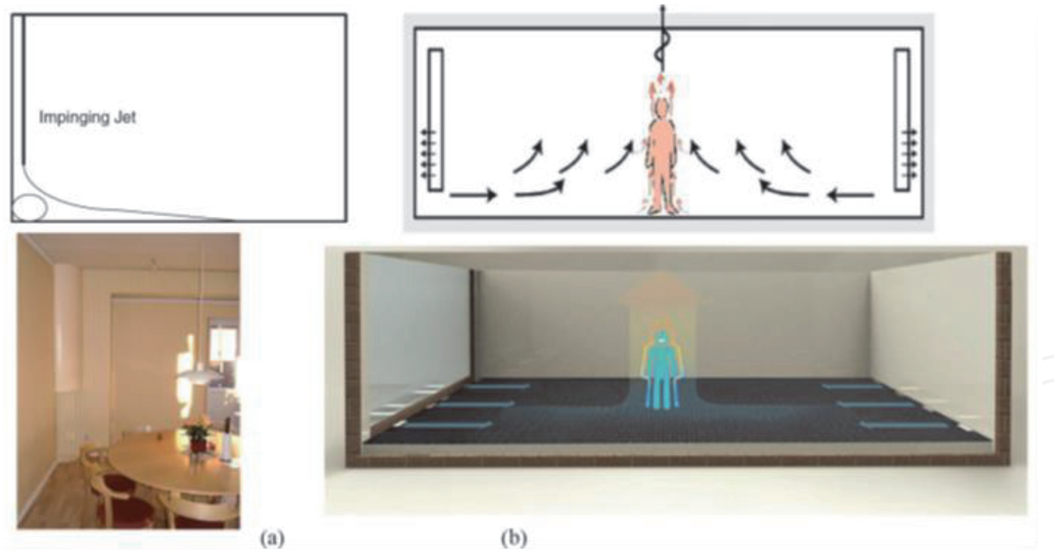

Figure 1.
Hybrid air distribution systems (HAD); (a) impinging jet; (b) confluent jets. Based on Awbi [27].

this chapter and colleagues in Sweden and the UK, that is the impinging jet ventilation (IJ) system and the confluent jets ventilation (CJ) system, see **Figure 1**. The contaminant distribution is very similar to that in a (DV) system because of the fresh air supply to the breathing zone in both the (IJ) and (CJ) methods of air distribution.

There is a need for assessing current methods of building ventilation and developing ventilation systems that are capable of providing good IAQ and energy performance to satisfy building occupants and, at the same time, meet new building energy regulations [28].

As we consider late on, the performance comparisons between the HAD air distribution systems, i.e. the imping jet and the confluent jets system, with the common mixing system show much better indoor air quality with lower ventilation energy requirement can be achieved by using the (HAD) systems of (IJ) and (CJ). One can see that the (DV) system generally performed well in cooling cases too. As we mentioned before, the (DV) system has limitations on the delivered cooling load, has less penetration depth of the DV jet in the occupied zone, and cannot be used for heating. Anyway, because of the higher supply air jet momentum, the other two systems of (IJ) and (CJ) were also shown to be used for both cooling and heating purposes, maintain good performance, providing higher cooling loads, and penetrating deeper into the room [28].

Cho et al. [29] and Karimipanah et al. [24], conducted some studies on the energy consumption of air supply processes for a ventilated rooms involving one MV (high-level) and three a wall displacement ventilation (DV), impinging jet ventilation (IJ), and confluent jets ventilation (C) which all later three were low-level supplies.

To achieve the same environmental performance for each case, the measures of energy usage were distinguished in terms of the fan power consumption and at the same time to the related airflow rate. The performance of the above-mentioned air distribution systems was compared using data from measurements in an environmental test chamber and computational fluid dynamics (CFD) simulations, see **Figure 2**.

The Air Distribution Index (ADI) concept was developed by Awbi [30], to obtain, simultaneously, the evaluation of the thermal comfort and air quality:

$$\mathrm{ADI} = \sqrt{\mathrm{N_{TC}} \times \mathrm{N_{AQ}}} \tag{1}$$

where N_{TC} is the Thermal Comfort Number, and N_{AQ} is the Air Quality Number.

Applying the Air Distribution Index (ADI) in a CFD study, compared the airflow rates for four different types of air distribution systems that are required to achieve an equal indoor environment.

The fan power (E) equation $E \propto q^3$ was used to compare the four systems. When the required air supply rate was changed to obtain an $ADI \sim 16$, as shown in **Table 1**. It was distinguished that the lowest required airflow rate (i.e. 0.025 m^3/s) was found to belong to the (CJ) system. Instead of the (IJ) system, the flow rate was slightly higher (1.4 times higher than that of CJ) which required 2.74 times more fan power compared to that of the (CJ) system. But the research showed that impinging jet (IJ) system used the fan power of ca half of that consumed by the mixing (MV) system. It was demonstrated that in comparison with the confluent jets (CJ) systems, the displacement system (DV) required a 1.1 times greater flow rate and 1.33 times higher power consumption. The results obtained for IJ and DV systems were almost similar.

The results reveal that mixing ventilation requires the highest fan power and the confluent jets ventilation needs the lowest fan power to achieve nearly the same value of ADI. The following results were obtained:

- The confluent jets (CJ) air supply system performance in terms of flow rate and fan energy (power) usage was considerably higher than those of the displacement DV), the impinging jet (IJ), and the mixing ventilation systems (MV) systems.

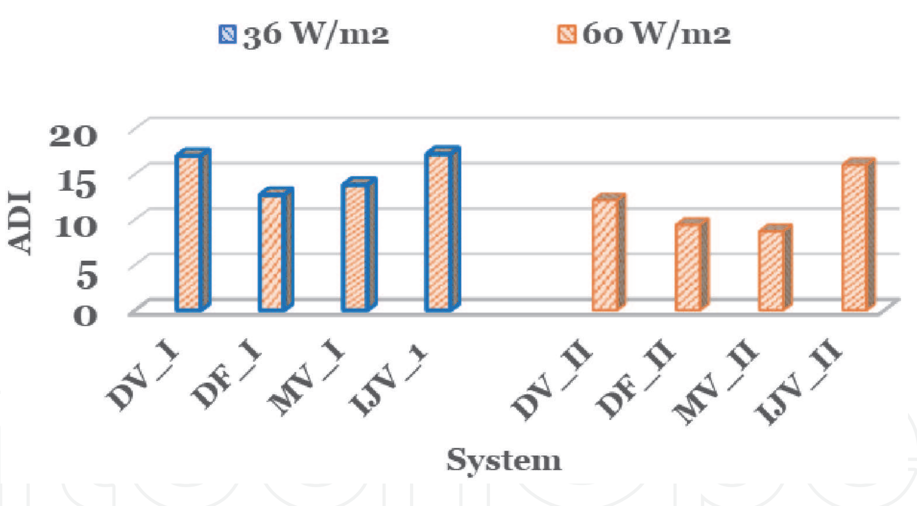

Figure 2.
The air distribution index from tests on four air distribution systems. (DV = wall displacement ventilation; DF = floor displacement ventilation; MX = mixing ventilation; IJV = impinging jet ventilation. Cases I and II refer to cooling loads of 36 and 60 W/m² respectively).

Ventilation system	ADI	Total flow-rate [m^3/s]	Fan energy usage compared to CJ
Mixing ventilation (MV)	15.5	0.045	5.83
Impinging jet ventilation (IJ)	15.7	0.035	2.74
Displacement ventilation (DV)	15.9	0.0275	1.33
Confluent jets ventilation (CJ)	16.1	0.025	1.0

Table 1.
Comparison between the fan power consumption of the ventilation systems for the same ADI (air distribution index) [24].

- Compared with the confluent jets (CJ) system, it is shown that to achieve the same ADI (Air Distribution Index) a mixing system (MV) needs at least 1.8 times more flow rate and consequently, consumes 5.83 times more fan energy.

- The displacement ventilation (DV) system needs 1.33 times and an impinging jet ventilation (IJ) system uses 2.74 times the energy consumed by the confluent jets ventilation (CJ) system. As one can see in **Table 1**, both IJ and CJ systems still perform much better and need less energy than the conventional high-level supply mixing ventilation (MV) system.

- Finally, the research shows that the choice of air supply system has a major impact on energy consumption.

Figure 2 shows that the total ventilation performance of a system in terms of combined heat removal effectiveness and ventilation efficiency can be interpreted by the value of the air distribution index (ADI) it achieves. It is also shown that with the higher value of ADI (e.g. ADI > 10) the compared systems archive better performance. At the same time demonstrating that the adverse comfort conditions (no cause of draughts) were presented.

As shown on the right-hand side of **Figure 2**, the mixing ventilation (MV) can perform quite well at higher cooling loads and it is surpassed by the DV and IJ systems for both cooling loads (36 and 60 W/m^2).

The results show that although mixing ventilation can perform reasonably well at the higher cooling load, it is outperformed by the DV and IJ systems for the higher cooling loads (60 W/m^2).

In a displacement ventilation system (DV) the thermal forces are more dominant than the flow forces but in impinging ventilation systems (IJ) the flow forces are more dominant therefore the IJ system performs better (higher ADI) than the DV system [24].

As one can see from studies of Karimipanah et al. [24], see **Table 1**, the energy performance of a ventilation system is directly related to the choice of room air supply system. When choosing a proper air distribution method as a major part of the total HVAC systems, will cause large differences in the thermal and air quality effectiveness and finally the requirements of energy usage. The research also shows that the overall performance of the confluent jets air supply system is somewhat better than the displacement and impinging jets systems (both low-level supply) but superior to the mixing system (high-level supply). The confluent jets behave like the displacement and the impinging jet ventilation systems combined. The energy consumption was presented in **Table 1**.

The above-mentioned air distribution index (*ADI*) is suitable for a *uniform* thermal environment in the occupied zone, but may not be suited for cases, as in the displacement ventilation, in which a major part of thermal stratification in ventilated spaces is present. Therefore, a modified Air Distribution Index (ADI_{New}) Has been developed for a *non-uniform* environment by Awbi [27] that will be described in the following section.

The new index $(ADI)_{New}$ for non-uniform (and some unform cases as can be described late on), combines the thermal comfort and air quality numbers as follows: The proposed air distribution index ($(ADI)_{New}$) combines the thermal comfort and air quality numbers as follows [31, 32]:

$$(ADI)_{New} = \underbrace{\left[\left(1 - \frac{|S|}{3}\right) * \varepsilon_t\right]}_{N_{T.C.}} + \underbrace{\left[\left(\frac{\tau_n}{\overline{\tau}_p}\right) * \varepsilon_c\right]}_{N_{A.Q.}} \quad (2)$$

where $N_{T.C.}$ is the thermal comfort number, $N_{A.Q.}$ is the air quality number, $|S|$ is the absolute value of the average overall thermal sensation over the exposure time, ε_t is the ventilation effectiveness for heat removal, τ_n is the room time constant, $\overline{\tau_p}$ is the local mean age of air and ε_c is the ventilation effectiveness for contaminant removal. These parameters are calculated as follows:

$$\varepsilon_t = \frac{T_o - T_i}{T_m - T_i}, \varepsilon_c = \frac{C_o - C_i}{C_m - C_i}, \tau_n = \frac{1}{ACH} \tag{3}$$

the used parameters in Eq. (3) are: T_o, T_i and T_m representing the outlet temperature, the inlet temperature, and the mean temperature value in the occupied zone respectively. C_o, C_i and C_m are the concentrations of contaminants (here CO_2) at the same locations as above and ACH is the air change rate per hour for the ventilated enclosure.

The local mean age of air ($\overline{\tau_p}$) can be calculated as follows:

$$\overline{\tau_p} = \frac{1}{C(0)} \int_0^\infty C_p(t)dt \tag{4}$$

there $C(0)$ is the input of tracer gas at the beginning of the measurements which is called for the initial concentration and C_p is the gas concentration at a certain point in the room (for this case in the breathing zone).

In Eq. (2), the $(ADI)_{New}$ development follows a logic that when the thermal sensation of the occupant is neutral (i.e. $|S| = 0$). The is an ideal thermal condition, in which the thermal comfort number $N_{T.C.}$ reaches its maximum value. When $|S|$ reaches its extreme values (i.e. -3 or +3), $N_{T.C.}$ reaches its minimum value (zero). In Eq. (2) the high value of the heat removal effectiveness (ε_t) gives rise to a higher thermal comfort number ($N_{T.C.}$) which implies that the ventilation system is efficient to remove excess heat from the occupied zone. In the same equation, both ε_c and ACH are connected to the air quality number ($N_{A.Q.}$) in $(ADI)_{New}$ which involving the contaminant removal effectiveness and consequently assessing the air distribution performance in the ventilated enclosure. Obtaining a low value for both $\overline{\tau_p}$ and ACH and a high value for the ε_c means that the ventilation system is performing well in removing contaminants and at the same time is capable of providing fresh air to the occupied zone. Consequently, the new air distribution index $(\mathrm{ADI})_{\mathrm{New}}$ presented in Eq. (2) is a unique and useful tool for the evaluation of air quality in both *uniform* or *non-uniform* thermal environments. The index is also useful for thermal comfort (based on the local comfort concept), see [32, 33].

As one can observe in Eq. (2) the calculation of $(ADI)_{New}$ the index needs both thermal comfort and air quality numbers. Almesri et al. [26], obtained the index for both mixing and displacement ventilation systems from tests in an environmental test chamber (2.78 m x 2.78 m x 2.3 m high). They used 4 males and 4 females for providing the thermal sensation data and for each test one subject was used [26]. All the tests were carried out with a supply temperature of 18°C and a total room cooling load of 21.2 W/m^2 (ventilation load of 9 W/m^2) of the floor area. The supply airflow rate was also 15 l/s which is equivalent to 3.64 l/s/m^2 floor area.

By using Eq. (3), they measured air temperature distribution in the occupied zone of the chamber to calculate ε_t. But for the calculation of ε_c and local the mean age of air ($\overline{\tau_p}$) at the breathing zone, the measured CO_2 concentrations were used. They also used the CBE thermal comfort model [34], which was also checked for accuracy with the subjects' votes, the occupants' overall thermal sensation $|S|$ was calculated. Finally, from Eq. (2) the $(ADI)_{New}$ index was obtained.

Ventilation system	$\|S\|$	e_t	$N_{T.C.}$	t_n (hr)	$\overline{\tau_p}$ (hr)	e_c	$N_{A.Q.}$	$(ADI)_{New}$
DV	|10.17|	1.10	1.04	0.33	0.23	1.35	1.98	3.02
IJ	|0.34|	1.08	0.95	0.33	0.25	1.28	1.68	2.83
MV	|0.49|	0.97	0.81	0.33	0.40	0.93	0.76	1.57

Table 2.
Parameters for the index based on CFD simulations (airflow rate = 15 l/s and air supply temperature = 18 °C in each case), based on [26, 27].

Table 2 summarized the results for the three ventilation systems. The results show that by using the above air supply conditions, the displacement ventilation system (DV) achieves higher, $(ADI)_{New}$ index, thermal comfort, and air quality numbers (NTC and NAQ) than those for the IJ and MV. The IJ system was a close second and far behind was the MV system. These simulation results and others have been given in Almesri [33] which confirmed the findings from experimental measurements in an environmental chamber using human subjects as given in Karimipanah et al. [24] and the above **Table 1**.

3. Parameters affecting the indoor environment and its energy

There are at least seven main parameters that affect the indoor environment and its energy usage are:

1. Building type

    a. Type of construction (i.e. heavy-weight, light-weight, low cost, prestigious building)

    b. Energy efficiency (degree of thermal insulation, air leakage, fabric thermal storage, night cooling, etc.)

    c. Sound insulation

    d. Level of services (very basic → highly automated).

2. Building location

    a. Urban, suburban, rural

    b. Quality of local environment (air pollution, noise pollution, etc.)

    c. External view (window sizes, glazing type, e.g. clear, tinted, number of panes, etc.).

3. Building Usage

    a. Type of activity (office work, retail business, leisure, etc.)

    b. Type of furnishing, floor covering, etc.

    c. Equipment used in the building.

4. Environmental systems

    a. Mechanical/Natural ventilation

    b. Type of air conditioning system

    c. Type of heating system

    d. Air distribution method

    e. Natural/Electrical lighting.

5. Thermal Environment

    a. Air temperature

    b. Radiant temperature

    c. Airspeed and turbulence

    d. Relative humidity.

6. Air quality

    a. Outdoor air pollution

    b. Indoor air pollution

    c. Ventilation rates

7. Degree of Control

    a. Building management system

    b. Personal environmental control (lighting, temperature, humidity, etc.)

With the renovation of the old apartment and other types of buildings, the improvement of ventilation is unavoidable to provide a healthy indoor environment for the building occupants, see Noris et al. [6].

3.1 The ways of assessing energy use in buildings

When assessing the energy use in all types of buildings, the energy-saving policies are affected by the fear of extreme climate change and consequently, the occupant's health may sometimes set aside. Wargocki and Wyon [35]. stated that: poor ventilation in buildings has negative effects on occupants' health. Sufficient ventilation for indoor climate comfort has important, especially in school buildings. They also concluded that:

- To have a better connection to real-life situations like normally functioning offices and schools, the laboratory experimental results using paid subjects should be validated by the field intervention experiments and the performance of real work should be monitored over time [35]

As stated by Bluyssen et al. [36], for the energy-efficient and well-performed building it is of vital importance that:

- It should not cause any illness for its occupants.
- It should have a high level of thermal comfort and indoor air quality for the occupants in their different activity levels.
- By taking into account available technology including life cycle energy costs, the engineers and designer should minimize the use of non-renewable energy.
- The high-quality (HQ) buildings should be designed, built, and maintained taking into account environmental, economical, and social stakes to ensure sustainable development.

The energy is used to control the indoor climate therefore large amounts of energy will be consumed to ensure a comfortable indoor climate in terms of heating or cooling demands.

Roulet [37] based on the recent European standard CEN 2006 [38] discussed two principal options for the energy rating of buildings. Firstly it is being calculated and secondly, it is measured. He called the above options as the *asset rating* and the *operational rating* which can be explained as follows:

- The asset rating: This will be based on the calculations of the energy balance of the building which was described in the former sections. This provides an assessment of the energy efficiency and performance of the building under standardized conditions which makes it possible to be compared with the retrofit process of other identical or nearly identical buildings. In this part, the energy simulation tools can be used.
- The operational rating: This will be based on the measurement of energy use and is dealing with the in-use performance of a building or in other words the practical issues. The operational rating measures can be compared with the theoretical calculations or asset rating and at the same time, they provide useful feedback to all involved partners of the building including owners, occupiers, and designers of new buildings.

4. Applications of renewable energy for HVAC systems

Historically, the severe entrance of renewable energy sources to the research area began during the oil crises in the 70:s which caused difficulties for the supply of oil products all over the world. The first UN conference about renewable energy and a sustainable global energy supply was held in Kenya's Nairobi in 1980 [39]. In the beginning, there were not any common definitions for all countries. To have a clear understanding of the above subject, in 2003, the International Energy Agency (IEA) defined renewable energy as follows: "*Renewable Energy is energy that is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower, and ocean energy and biofuels and hydrogen derived from renewable resources*" [40].

Nowadays, the high energy demand and at the same time struggle to mitigate the energy's environmental impact led to the following strategies [41]:

- The energy efficiency standard is one of the most popular strategies for building energy saving, which is dynamic and renewed based on the currently available technologies.

- In different countries, the "Feed-in-tariff" has successfully been applied to encourage the application of renewable energy.

However, renewable energy considers the primary energy from recurring and non-depleting indigenous resources.

It is also noted by Gungah et al. [42] that for the development of renewable energy policy and to judge whether it is successful or not, the following common criteria will be identified:

a. The institutional feasibility and extent of political support for the policy.

b. The effectiveness of renewable energy policy and the extent to which the objectives are achieved.

c. The efficiency regarding innovation with reduced costs

d. The equity and fair distribution of rents between the renewable energy developers and the state

e. The replicability and extent to which the policy can be adopted in other countries.

They also concluded that when modeling the energy policies, there should be a systemwide analysis of the new technologies being incorporated into the system and their complexities.

4.1 The environmental impact of renewable-powered HVAC

In the last decays knowing more about the renewable energy sources benefits the house owners will change to the technology that reduces the greenhouse gases and carbon footprint. However, by spending the major part of our life in confined spaces of homes and offices, it is evident that using modern HVAC systems has a significant environmental impact.

That is why the HVAC manufacturers are tackling the environmental impact and struggling to create more sustainable products for end-users. That is why energy consumption reduction for air conditioning has become an extremely urgent task.

It is reported by IPCC (Intergovernmental Panel on Climate Change) that elevating indoor temperature in summer and decreasing indoor temperature in winter are necessary means in reducing the energy consumption of air conditioners. Hence, 195 countries agreed to enhance the indoor temperature by 1.5°C for the HVAC energy reduction in the Paris Agreement. Instead of the formerly estimated 2°C, this is done to minimize devastating climate change impacts on human health and their wellbeing [43].

By switching to renewable energy sources for HVAC systems will significantly lower or even eliminate greenhouse gas emissions.

As the development of new techniques going on, the way HVAC systems operate and the impacts they have on our lives and environment are changing. For instance, the use of R-22 or Freon is not allowed for newly manufactured HVAC equipment, and the industry has largely switched to R-410A or Puron which does not damage the ozone layer.

Some examples of the new renewable technologies which are becoming more prevalent in the HVAC industry are as follows:

1. Solar-powered HVAC system: With this system the electricity obtained from solar panels is used to power heating and air conditioning units. In other words, Photovoltaic cells capture the sun's rays and convert them into electricity through solar panels, and the energy is used directly or through the grid to supply power to a building's HVAC system. In case the solar power disappears at night-time, the HVAC systems can use both powers from the grid. Customers may then be able to use excess energy to run other electrical components of their building or even sell extra energy back to the grid.

2. Ice-powered air conditioner: By creating a clean and renewable thermal battery, ice can be produced and stored during off-peak hours - which the electricity is cheap - and then will be used to cool the building envelope.

3. Thermally-driven chillers: Instead of driving the system by electricity, these types of HVAC systems will thermally be driven by solar panels that generate heat. Then the generated heat will be converted into chilled water for cooling purposes using a double-effect absorption. In case solar power disappears at night-time, these systems can supplement with natural gas.

4. Geothermal heat pumps: The geothermal technology systems have been sophisticated over the past few decades and used in some form for more than 60 years. Even if these geothermal heat pumps are not a new technology but are also frequently used in HVAC systems. It is worth mentioning that the geothermal systems only need a small amount of electricity to run and rely on natural power resources from the earth and sun to heat and cool the buildings. Finally, the geothermal heat pump technology eliminates combustion from fossil fuels and emits no carbon dioxide. Using these types of renewables, it is now even possible to heat and cool a building Without having a bad conscience about emissions. As a renewable future of HVAC, the used technologies for heating and cooling of the buildings are changing. Consequently, with the use of renewable HVAC technologies with their increased efficiency, environmental, and health impact improvements will be achieved.

4.1.1 Renewable-powered HVAC with thermal storage

Instead of using fossil fuels-powered, the available renewable-powered energy systems for heating and cooling of residential, office, and industrial buildings are an attractive alternative to overcome the considerable effects of global warming.

Hawxhurst et al. [44] integrated onsite renewable energy and thermal storage by coupling wind and solar power generation with a control strategy that matched load demand to power generation. They used renewable energy (alone) to charge building heating and cooling thermal storage systems using an isolated microgrid. As they pointed out, the control system will be designed to charge the thermal storage systems by matching their load to the available renewable supply and these thermal stores could then be used by the building control system at a later stage to offset energy consumption from either the grid or in the case of isolated systems, batteries or generators.

Thermal energy storage devices are more reliable compared with batteries because of their long life of spans, low cost, and robust nature. There are two types of thermal storage: Cold thermal storage and hot thermal storage. The cold thermal storage is achieved by using ice and the hot thermal storage is provided by ceramic bricks. It is worth mentioning that the significant part of the end-use energy is thermal thus these storage systems account for the majority of the energy storage capability.

The first advantage of the system proposed by Hawxhurst et al. [44] is a novel control strategy that matches load demand to power generation. The system stores excess energy in robust and low-cost thermal storage devices to ultimately reduce the demand for paired, grid-connected HVAC systems. The other advantage of their strategy is that the system does have batteries to store electrical energy for the control electronics.

4.2 Strategies to eliminate the shortfalls of renewable energy sources

Due to the intermittency of renewable energy resources which cause a shortfall of these technologies, various strategies to overcome this intermittency will be used. As Anthony et al. [45] pointed out, there is a lack of sufficient energy density to serve as a practical primary energy source for the industrial sector in its current clustered form. Unless factories were built adjoining custom renewable energy farms the current energy generation density is not sufficient.

They presented a methodology to investigate the generation, transport, and storage of energy based on a "*multi-physics approach*", tied to the end-use application [45].

4.2.1 Multi-physics approach to energy generation, transport, and storage

Instead of associating energy with electricity or hydrocarbons by default, the multi-physics approach simply requires consideration of different energy generation, storage, or transfer methods, based on all available physical phenomena, and considers the end-use of the energy form.

By employing such an approach the engineers will be free from the electricity and hydrocarbon-centric, default attitude toward energy to find efficiency gains in the margins. A particular application requires an approach modification for the design of an energy system to utilize multi-physics energy storage.

It is considered that different buildings have different energy needs. Therefore, different systems would be suited to each building application. The following structured approach to tackling this problem will be summarized as, see Anthony et al. [45]:

a. Energy demands: First the lists of major energy demands of the system should be handled.

b. Reduce demand: consider the possible new technologies which are available to reduce the energy demand you listed before and modify if possible.

c. Classification: Try to classify the physical mechanism used for each process, e.g. heating, cooling, gas compression, and so on.

d. Power and Energy: Consider the sizing of the system by quantifying the power demands in Watts and the energy demands in Joules.

e. Generation: Identify appropriate energy sources, preferably to include renewable energy sources for each energy need.

f. Transport: Identify appropriate energy transport methods for this important sector.

g. Storage: Identify appropriate energy storage methods to be applied to the system.

h. Safety and Practicality: Think of a safe and practical implementation of each delivery, transport, or storage method.

i. Lifecycle Costs: Finally, calculate the cycle life const (LCC) of the system.

Generally, there are two types of air conditioning (AC) systems namely [46]:

- Centralized AC systems and

- Decentralized/Zoned AC systems.

In their study Zhou et al. [46] show that in residential buildings, at the point where the centralized feature of the system meets the decentralized feature of users' load, the problems of high energy consumption and low energy efficiency could easily occur. They also pointed out that centralized AC systems are effective and should be promoted for the urban landscape. Also for the centralized AC in residential buildings, the adjustability in each segment (users' terminal, refrigeration equipment, and distribution system) would greatly influence the energy consumption and system efficiency.

In case the spaces do not have central HVAC systems or with inefficient heating and cooling options, ductless heat pumps provide efficient and easy-to-install HVAC systems. There are some advantages for the decentralized AC systems:

- users have greater flexibility controlling the AC terminals and as a consequence, the supplied cooling energy would be reduced effectively.

- no distribution system exists in decentralized AC systems which means that the total energy consumption would not include the consumption of fans or pumps.

Zoned AC systems rely on thermostats installed in every room to provide climate control information to a central HVAC control panel and are ideal for multi-story houses with the following characteristics:

- For those living in bigger homes with multiple people

- Homes with finished attics and basements

- Homes high ceilings

- Homes large windows and,

- Homes with extra rooms that aren't often used and the days of arguing about which rooms to heat and cool.

The Zoned AC systems minimize allergen transfer better than non-zoned HVAC systems, providing relief to those sensitive to airborne allergens.

4.2.2 Liquid desiccant air conditioning system (LDAC)

Liquid desiccant air conditioning systems (LDAC) belong to existing energy-efficient and environmentally friendly air conditioning technologies [47]. LDAC systems can be driven by low-grade heat sources such as solar energy and industrial waste heat. As a potential universal scheme in practical Si solar cell applications, the self-cleaning omnidirectional nano-based light-harvesting design with hierarchically structured packaging glass can be used. Since solar power has been considered as one of the most expensive sources of renewable energy, these renewable energy sources are still covering and assisting in merely a small portion of global energy demands. For instance, Photovoltaic (PV) power generates less than 1% of total electricity supplies.

4.2.3 Solar-biomass hybrid for air conditioning system (SBAC)

Another interesting system is a solar-biomass hybrid for air conditioning (SBAC) and cooling systems which is a completely renewable energy-based system as is illustrated in **Figure 3** [48]. It is demonstrated that the first part of **Figure 3**, the control volume on the left-hand side, is a solar water heating system.

The solar water system consists of a field of solar collectors, a hot water storage tank, and a circulating pump. The second part with a three-ways motor valve (in the middle of the Figure) is a biomass gasifier-boiler. The biomass gasifier-boiler consists of an automatic up-draft gasifier and gas-fired boiler. The control volume showed on the right-hand side of the figure is an absorption air-conditioner. The absorption air-conditioner consists of an absorption chiller, fan coil unit (FCU), cooling tower, and three pumps (cooling, hot, and chilled water pumps) [48]. It will be noted that the model-based design of a renewable energy-based solar-biomass hybrid air-conditioning system uses LiBr–H_2O absorption chiller.

There are also other interesting renewable energy-based methods for HVAC systems. For instance, Wang et al. [49] presented a tri-generation system which is the combined process of heating, cooling, and power generation, see **Figure 4**. The system is using sewage treatment digestion biogas according to the principle of energy gradient utilization technology. The tri-generation system uses Lithium Bromide (LiBr) absorption cooling technology for office air conditioning, a biogas power generator and, a heating system for digestion tanks.

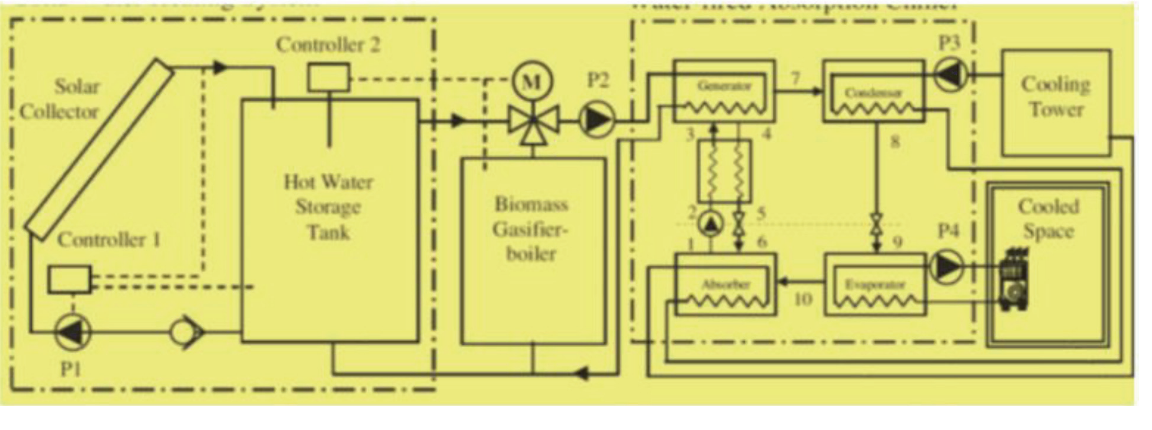

Figure 3.
Schematic diagram of the solar-biomass hybrid cooling system [48].

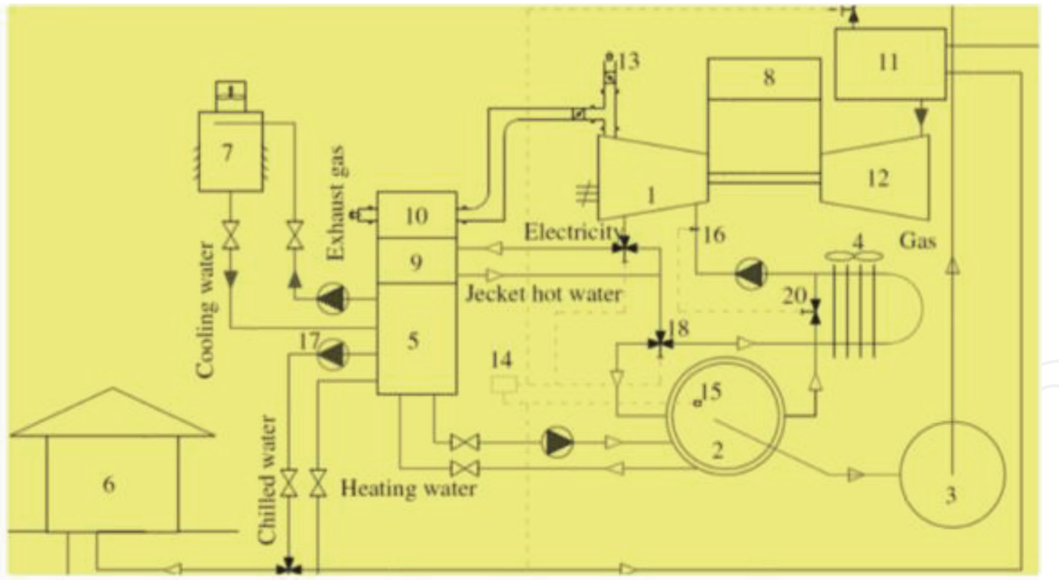

Figure 4.
*Schematic diagram of the proposed tri-generation system [49]. The numbers in **Figure 4** are: 1) biogas generator, 2) sludge digestion tank, 3) gasholder, 4) radiator, 5) Lithium bromide absorption chiller, 6) office building, 7) cooling tower, 8) combustor, 9) hot water generator, 10) flue gas generator, 11) inner air cooler, 12) compressor, 13) chimney damper, 14) controller, 15) temperature sensor, 16) thermometer, 17) pump, 18) three-port regulation valve, 19) valve and number 2, and 20) two-port regulation valve.*

They developed an innovative and more efficient utilization way for using the digestion biogas from sewage treatment works. The main findings can be concluded as follows:

1. When replacing the boiler with Lithium Bromide absorption chillers, the cooling capacity produced by the chillers can be used for space air conditioning. The chiller will also be used for cooling the inlet air of the biogas generator to improve its power generation efficiency.

2. It is shown that the tri-generation cycle system is very cost-effective.

3. The inconsistency of heating and cooling loads can be solved by the system and the extensive energy efficiency is much higher.

A schematic diagram of the tri-generation system is shown in **Figure 4**, which provides multi services by using a single energy source, including electricity supply, space air conditioning, and heating of sludge digestion tank or hot water supply to other users [49].

Finally, about the future of cooling and air condition systems *Fatih Birol, IEA Executive Director* indicates that: *"Growing demand for air conditioners is one of the most critical blind spots in today's energy debate. Setting higher efficiency standards for cooling is one of the easiest steps governments can take to reduce the need for new power plants, cut emissions and reduce costs at the same time"* [50].

5. Conclusions

In comparison with the total energy use in a building, the proportion of ventilation and air conditioning energy is expected to increase as the building's fabric energy performance improves. These lead to ventilation standards that recommend higher ventilation rates for improving indoor air quality (IAQ). However, there is a great global emphasis on reducing the reliance of buildings on fossil fuel energy and a move toward Nearly Zero Carbon Buildings (NZCB), the researchers are determined to develop more sustainable ways of HVAC systems. At the same time, many promising energy-efficient solutions for air distribution systems are available.

Some existed methods of sustainable HVAC systems using renewable energy resources and at the same time, some methods for overcoming the renewable energy sources intermittency and fall-down are presented. The Solar-biomass hybrid for air conditioning (SBAC) and the Liquid desiccant air conditioning systems (LDAC) belong to existing energy-efficient and environmentally friendly air conditioning technologies.

Some other examples of the new renewable technologies which are becoming more prevalent in the HVAC industry are also described:

- Solar-powered HVAC system

- Ice-powered air conditioner

- Thermally-driven chillers

- Geothermal heat pumps:

It was also described that a method, New Air Distribution Index (ADI_{New}), for evaluating the performance of air distribution systems is to introduce ventilation efficiency and energy effectiveness.

It was pointed out that reducing energy demand for heating and cooling is essential for improving the energy efficiency of a building but not at the expense of deteriorating air quality and the health of the people. The energy flows in buildings can be assessed in two ways: by calculation or by measurements. Estimation of various energy flows brings the necessary knowledge for improving energy performance. [37].

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Conflict of interest

The author declares no conflict of interest.

Nomenclature

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
ACH	room air change rate per hour
ADI	Air Distribution Index
$(ADI)_{New}$	New Air Distribution Index
BEM	Building Energy Simulation
CAV	Constant air volume

CEN	Comité Européen de Normalization
CJV	Confluent jets ventilation
CO_2	carbon dioxide
CDDs	the colling degree days
C_i	contaminant concentration at the inlet (CO_2)
C_m	the mean value of contaminant concentration (CO_2)
C_o	the contaminant concentration at the outlet (CO_2)
$C(0)$	the initial concentration of a tracer gas
C_p	the gas concentration at a certain point in the room (e.g. breathing zone)
DCV	demand-controlled ventilation
DV	displacement ventilation
HVAC	Heating, ventilation, and air conditioning
HQ	high quality
IEA	International Energy Agency
IAJS	Intermittent air-jet strategy
IAQ	Indoor air quality
IJV	Impinge jet ventilation
LDAC	Liquid desiccant air conditioning systems
LAF	Laminar airflow
LEV	Local exhaust ventilation
LCC	lifecycle costs
LiBr	Lithium Bromide - the cooling medium used in absorption cooling
MV	mixing ventilation
$N_{A.Q.}$	the air quality number
$N_{T.C.}$	the thermal comfort number
NZEB	Nearly zero-energy buildings
PiV	Piston ventilation
POV	Protected occupied zone ventilation
POZ	protected occupied zone
PV	Personalized ventilation
PV	Photovoltaic
RH	relative humidity
$\|S\|$	the absolute value of the average overall thermal sensation over the exposure time
SBAC	solar-biomass hybrid for air conditioning
SV	Stratum ventilation
T_o	temperature at the outlet, °C
T_i	the temperature at the inlet, °C
T_m	the mean temperature value in the occupied zone, °C
UFAD	Underfloor air distribution
VAV	Variable air volume
WAV	Wall attached ventilation
ε_c	the ventilation effectiveness for contaminant removal
ε_t	the ventilation effectiveness for heat removal
τ_n	the room time constant
$\overline{\tau_p}$	the local mean age of air at the breathing zone

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