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Net-zero building designs in hot and humid climates: A state-of-art

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ABSTRACT

Net Zero building is becoming a global trend as a strategy to reduce the carbon footprint. In order to achieve Net-Zero building design in hot and humid climates, efforts must be put to reduce the overall energy use to the maximum extent by integrating appropriate building technologies into the architectural designs. In this paper, the latest ideas dealing with building performances and net-zero building design projects, are reviewed and an outlook is given including new concepts of combined systems in hot and humid climate regions. The paper is structured in the following manner which includes basic guidelines, natural ventilation systems, cooling and dehumidification, insulation and construction materials, reviews of several net-zero energy building projects. The paper also proposes novel wind tower dehumidification design and ventilated attic building design for the hot and humid region. Thus the state of art review is presented for net-zero buildings in a hot and humid climate.

1. Introduction

A report published by the World Bank India in 2008 [1] as shown in Fig. 1 states that heating and cooling requirement is about 35% of the energy used in Indian households back in 2008. As the economy grows and more people get used to a higher standard of living, the (domestic) energy consumption increases (See Fig. 1). Considering that there are 1267 billion (July 2016 est.) Indians [2] there is a drastic need for new technologies and investments. This is an example of a developing country, which has a growing economy thus causing higher pollution rates and endangering the environment.

By applying new building designs and modern technologies the cooling loads in hot and humid climates can be dramatically reduced. A basic reference system which contributes as a guideline for architects and engineers must be established, equivalent to the EU building directive. This is the main requirement for every country to reach the goals, stated in the Paris agreement.

In tropical/subtropical climates a lot of energy is consumed for cooling and conventional air conditioners are widely used. Commercial cooling systems are inefficient, require a lot of energy and cause pollution. New technologies need to be efficient, profitable and environmentally friendly. They also have to make sure that habitats feel comfortable and healthy conditions need to be provided. Due to humidity in those areas, it is very hard to design a net zero energy building that fulfills the comfort requirements.

Humans cool down their body temperature mostly through transpiration (latent heat loss) when it comes to higher temperature. In humid climate areas that process is limited due to the water proportion in the air. If the air is almost saturated it will not absorb any more water. Because of that the human body cannot transpire and it gets uncomfortably warm.

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Nomenclature

VOC	Volatile Organic Compound
NZEB	Net Zero Energy Building
HVAC	Heating Ventilation and Air-Conditioning
SAPO	Silico Amino Phosphate
CVD	Chemical Vapor Deposition
MSVD	Magnetron Sputtering Vacuum Deposition
VT	Visual Transmittance
PCM	Phase Change Material
SPD	Suspended Particle Device
PV	Photo Voltaic
PVC	Poly Vinyl Chloride
LEED	Leadership in Energy and Environmental Design
U value	Overall heat transfer coefficient value

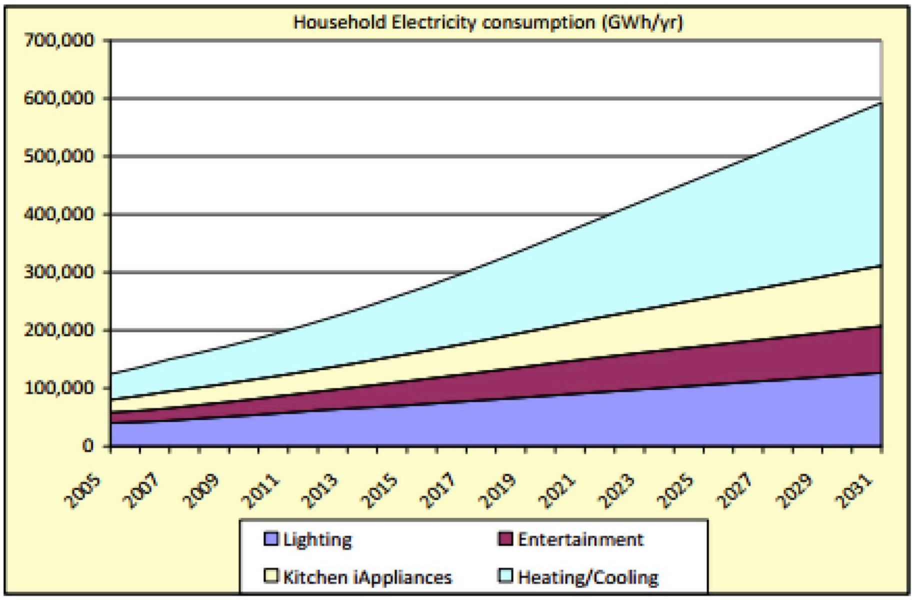

Fig. 1. Total power consumed by appliances in India.

Jørn Toftum [3] researched how humidity affected comfort and concluded that high humidity combined with high air temperatures lead to stuffy air and discomfort. (Table 1).

L.G. Berglund and W. Cain [4] also stated, that a relative humidity above 65% lead to discomfort and pollutants are more likely sensed as unpleasant.

Mold development starts at a relative humidity of 80%–95% depending on the material, temperature and exposure time [5]. Growing mold causes serious risks for health and for the stability of buildings in humid climates. Consequently, cooling systems in humid areas have to dehumidify the air in order to give the body a chance to transpire and to prevent condensation.

Beside of the relative humidity, the air flow makes a difference in how temperatures are sensed. The higher the velocity of the air

Table 1
Air temperature, water vapor pressure and the percentage of dissatisfied with the thermal perception of the inhaled air at this condition.

Air temperature [°C]	Water vapor pressure [kPa]	Percentage of dissatisfied [%]
20	1053	11
20	1638	11
20	2106	21
23	1406	26
23	1968	18
23	2530	50
26	1177	18
26	1850	45
26	2355	55
26	3027	82
29	1002	19
29	1603	42
29	2204	68
29	2806	76

the warmer the air temperature can be without feeling uncomfortable. Moreover, the quality of the air and how it is sensed depends on VOCs, which are for example emitted by the concrete of the walls and furniture and on the quality of the outside air.

Furthermore, indoor long-wave radiation causes a different sensation on your skin, depending on the temperatures of the surrounding walls. When the walls are warmer than the air temperature, a slightly higher temperature is sensed on the skin.

2. Requirements/basic guidelines of NZEB

2.1. Basic guidelines

In climates where solar radiation is high and heavy rainfalls and humidity cause mold problems, some basic measures have big effects on the state of the building. Cooling and ventilation are most important and cause the biggest part of energy consumption. NZEB (net zero energy building) require passive and active actions in order to provide a net zero energy performance. It is most important to concentrate on all possible passive energy saving actions before adopting active measures.

Every part and aspect of the building has to be planned and simulation programs can help to estimate the energy performance. Shady Attia [6] developed a system simulation tool which can be used to change the parameter of a designed building in Egypt. Tools like this will be necessary to establish and work with zero energy guidelines.

Solar control: In hot climate areas, the shading coefficient of the windows must be kept low, because solar radiation causes the greatest part of the cooling load. Due to the greenhouse effect, the sun can be a natural heater. Short-wave radiation comes through the window, is transferred into long-wave radiation and the energy remains in the room, in the form of heat. Therefore, solar covers are needed to prevent direct solar radiation from entering the building. Special attention has to be paid to the windows orientated towards the sun most of the day. Trees and greeneries can be used as shading devices, too.

K·K.W. Wan et al. [7] found that in subtropical climates of China the solar energy was the main part of the cooling load but in severely cold climates the radiation caused a decrease in energy consumption. The angle between the sun and the external walls plays a significant role, apart from the shading coefficient. In Hong Kong the heat gain due to solar radiation was much lower than in Dunhuang because the shading coefficient was lower and the altitude of the sun overall was Solar radiation can either be reflected, higher in Hong Kong. Those results were based on GSR measures.

P.K. Latha et al. [8] reviewed natural and synthetic building construction materials, which can help to reduce emissions and lead to more sustainable building design in tropical climates:

The energy performance of a building not only depends on the solar radiation but also on the material and color of the surfaces. There are several types of research about the correlation between cooling/heating loads and the colors and pigment size of surfaces. Light-colored external surfaces are recommended to ensure a good energy performance.

The higher the ratio of the reflected light, the better the energy performance of the building. White color has the highest reflection rate thus preventing heat gain but also causes dazzling of the human eye. Furthermore, white rooftops easily get dirty, which makes them economically less attractive.

Mehdi Baneshi et al. [9]. compared different pigments on white and black substrates, used for rooftops in different climate areas, to conventional paints. The best results were made using CuO pigment coatings. A decreased annual cooling load demand and an increased annual heating load were measured, depending on the climate region. In cold mountain areas the enhanced heating load causes no improvement in the energy performance of the building. However, in desert climates the maximum annual savings for air conditioning came up to 1442 kWh, while in Mediterranean climates the maximum amount of savings was 1148 kWh.

The higher the U-value of the rooftop the higher the impact of the color and pigments of the rooftop, regarding the energy performance of the building.

Heat recovery systems are necessary to build NZEB's, as Zhiyong Tian et al. [10] proved. For their net-zero project in Beijing, several saving measures were applied. The heat recovery system had the greatest influence on the energy performance of the building, followed by wall insulation, Low-E glass, rooftop insulation and inside shade. In this case, the ratio of the roof to walls was proportionally small, which needs to be considered.

The higher the surface - volume ratio of the building the higher the heat flow. A detached house for example has more surface area than a high-rise building. Therefore, the basic geometry of the building has to be adjusted accordingly by the architect.

Olgyay V. and Olgyay A [11]. carried out studies on ratios in different climate zones. The optimum ratio length to width was found to be 1:1.7 in hot and humid climates. The acceptable ratio range is between 1:1.7 and 1:3.

Moreover, rain covers, which prevent rain from entering, must be used to protect the walls. Drainage systems have to ensure that the water does not remain on surfaces and the rain cover has to protect the walls. Solar covers and rain covers are recommended to be built as one item.

Special attention has to be paid to buildings getting heavy rainfalls. Capillary action can lead to destabilization and flooded parts of the building. Either drainage layers have to be used or the building itself must be built on columns.

Before discussing measures, it needs to be stated that actions may be redundant when the habitants of the building use more energy due to increasing living standards. Therefore, baseload is significant for the success of net-zero energy buildings. Simple actions, such as exchanging the type of lightning bulbs being used, can have major effects on energy performance. By scheduling cooling systems, fans, etc. huge amounts of energy can be saved. Besides, sensors can improve the performances of HVAC (heating, ventilation and air conditioning) and the indoor comfort level by measuring and adjusting the temperature, humidity and air flow.

2.2. Natural ventilation

can help to solve the problem of too much moisture A natural ventilation system can help to solve the problem of too much moisture and it can play a major part of NZEBs. A high velocity of the air is required in hot and humid climates to ensure a comfortable living situation due to the humidity. Also, good outside air quality is a basic requirement to make sure the inside air quality fulfills comfort standards.

To ensure air exchange, wide openings for the wind to enter are essential. Natural ventilation systems can either use the stack effect or wind. It is suggested to use both to have a redundant system that ensures ventilation at all time. N. Khan et al. [12] and Ben Richard Hughes et al. [13] worked on a review of wind-driven ventilation systems, which sums up most of the natural ventilation methods.

The wind direction and wind speed are primarily responsible for the efficiency of natural ventilation systems. Wind-driven forces are responsible for 76% more indoor air flow than buoyancy driven forces [14]. The obstacles indoors, which block the air flow, play a big role too.

The dimension of the building can lead to reduced air flow. St. Clair et al. [15] proved that a building with a dimension of 15m decreases the effect of natural ventilation.

There is also a difference in laminar and turbulent winds. Turbulent winds cannot be predicted and can lead to a lack or increased ventilation whereas laminar winds create rather steady ventilation. On the coast, sea and land breezes can be used to ventilate a building effectively.

In hot and arid climates wind towers in combination with evaporative cooling and solar chimneys in order to increase stack effects are used to not only create air flow but also cooling.

The height of the tower is linearly correlated to the airflow volume and the efficiency also depends on the width of the tower. The tower must be tall enough not to be in contact with turbulent air streams around the rooftop and the wind velocity increases with the height. Specifically in urban areas, a minimum height it necessary to catch enough wind for the natural ventilation system. Furthermore, the air quality usually improves with the height due to less influence by urban pollution.

The right type and orientation have to be chosen according to the wind direction and variation.

In case the wind tends to come from one direction, a four-sided wind tower is most efficient when oriented 45° to the wind direction. The more openings the tower has the lower the air flow. On the other side, the influence of the angle also decreases the more openings the tower has. At a zero angle wind flow a two-sided tower provides the highest amount of air [13].

A rectangular wind tower is more effective than a circular wind tower due to the shape of the rectangular tower. The square surface causes a greater drift of the wind thus a higher pressure difference between windward and leeward side [16].

Wetted pads, column clay conduits or cloth curtains and misters can be used for the evaporative cooling process inside the wind tower. Wetted pads work best on high air velocity whereas wetted columns need the low speed of air to be more effective. The highest temperature reduction has been carried out by the cooling pads [17].

The pads are located at the top of the wind tower where water gets pumped up and sprayed on the device to keep the pads continuously wet. The length of the wetted columns is limited by the height of the tower which also limits the efficiency rate of the tower.

However, evaporative cooling leads to decreased air velocity. The temperature variation influences the cooling effect more than

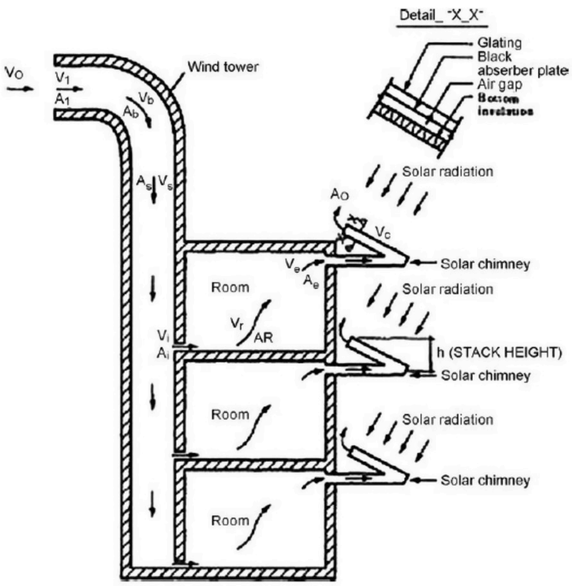

Fig. 2. A combination of wind tower and solar chimneys [12].

the change of relative humidity [18].

Another way of improving the effect of the wind tower is by including a storage device to use night cooling in order to keep the walls of the tower cooler than the air temperature during the day. In that way, the air stream is precooled before it enters the evaporative cooling device.

In hot and humid climates desiccant dehumidification has to be applied first. The problem is that conventional desiccant wheels will cause a high drop of pressure and a rise of temperature.

Mario Grosso et al. [19] introduced a hybrid wall system, which combines a desiccant adsorption device regenerated through solar water collectors on the roof, a low-pressure heat exchanger system and a passive evaporative cooling device. As the ventilation system the stack effect is used by installing solar collectors. They tested silica gel and zeolite modules for the humidity adsorption. The tests results showed that a temperature above 75 °C is needed to ensure sufficient desorption. The zeolite that was used is SAPO 34. While the silica gel needed mechanical ventilation the zeolite-coated coil can work on natural ventilation because of increased air flow in the fin area.

Dominic O'Connor et al. [20] developed a novel desiccant wheel, which can be used for natural ventilation, i.e. for wind towers. This device has a high potential for passive ventilation techniques, as it reduced the humidity of the airstream up to 55%, decreased regeneration temperature to 48.5 °C and resulted in a pressure drop of only 2 Pa. However, the novel wheel design has to be tested and simulated on real buildings first.

Sriraj Gokarakonda and Georgios Kokogiannakis [21] connected an earth tube ventilation, a rotary wheel desiccant dehumidifier and a passive downdraught evaporative cooling tower. The earth tube precools the air before it is dehumidified, which makes the desiccant wheel work more efficiently.

Wind towers can be connected to solar chimneys, which combines wind driven ventilation and the stack effect. In case there is no wind, the solar chimneys still make sure that air is exchanged by extracting the indoor air.

In connection to a wind tower Bansal et al. [22] found an enhanced wind flow double as high in respective to a single wind tower. Fig. 2 shows such a combination including solar chimneys for every room.

Wind catchers are more compact and modern versions of wind towers, which also use wind effects and the stack effect. To cover more than one wind direction, usually several devices are put on top of the roof, all pointing in different directions. The wind speed internally almost equals the speed the wind has before it runs through the wind catcher. Wind catchers work more efficiently when connected to windows. Dampers control the volume of the air flow and can be completely opened during the night to let fresh air enter the building and to provide cooling for the next day.

The latest products of the company Monodraught [24] also include solar power (as shown in Fig. 3). By using a solar driven fan the air flow can be increased. Once the solar panel reaches 6 V the fan is activated and if 14 V is reached, the power is transmitted to 25 V which causes 250% the higher speed of the fan. This makes it a self-controlled system, which is most effective when the fan sits on top of the system below the solar collector. The "suncatcher" combines the natural ventilation system with "sun pipes" thus preventing airflow and daylight.

Omidreza Saadatian et al. [25] reviewed several windcatcher technologies. Wind tower louvers are used in modern ventilation systems to absorb sound, prevent precipitation from entering and to protect from solar radiation. Liu Li et al. [23] evaluated different systems with a varying amount of louver layers and found that the more louvers the better the air flow at a maximum of 6 layers.

Turbine ventilators are designed to spin, driven by wind power, which causes low pressure inside the device and extraction of the warmer indoor air. According to Omidreza Saadatian et al.[[25], straight curved turbine ventilators create the greatest air flow rate. Long volume turbines, which have longer vanes, improve the ventilation effect, as S. Wests' work concluded [26].

Fig. 3. Sola-Boost Classi [24].

A solar driven fan can support the turbine ventilator in order to extract more air. Improvement was found when the wind velocity was below 5 m/s. At higher speeds the fan does not help to increase the air flow rate [27]. An engine can also be integrated thus creating a redundant system. Fig. 4 shows the turbine ventilator incorporating a PV fan design.

Lien and Ahmed [28] found that a turbine ventilation system works as louver when the wind speed is not high enough. Accordingly, the ventilation rate must be increased by at least 2.22 m/s. Li and Ward [29] carried out a simulation project, which results were that the wind direction change has a greater effect on the air exchange than the rooftop angle.

The attic space is the main factor when it comes to heat gains. The sun heats up the rooftop which causes the high temperature in the attic. As a prevention a hybrid system ensuring ventilation and extraction of heat can be used effectively in tropical places. Karam M. Al-Obaidi et al. [30], reviewed attic wind ventilation systems and concluded that the higher angle of the rooftop the lower the rotation speed of the turbine ventilator. Also, the wind velocity is linearly correlated to the rotation speed according to him.

Tropical weather can change rapidly and prediction of wind speed is difficult. Therefore, Karam M. Al-Obaidi et al. [30]. suggests a hybrid system including an inlet opening at the gable and a turbine ventilator with curved vanes of 450 mm–500 mm diameter. A solar panel on top of the opening cap is highly recommended [18].

Atria and courtyards are effective ways of cooling and ventilating. Courtyards are more efficient when applied in hot climates [31]. Vegetation and open water surfaces in the courtyard improve the energy performance of the building due to shading and evaporative cooling [32]. Also, the cooling effect increases when grass or soil is used instead of concrete pavements [33]. By covering the courtyard during the nighttime a study in Saudi Arabia found a decrease of 4 °C [34]. On the other side, vegetation can harm the ventilation effect by blocking the wind.

Muhaisen and Gadi et al. [35]. proved the importance of the geometry and proportion of courtyards. It is suggested that the warmer the climate the deeper the courtyard should be in order to protect the area from sunlight. Taleghani et al. [36] found that the higher the albedo of the facades of the courtyard the higher the mean radiant temperature.

In humid areas, the ventilation effect is a big part of the overall performance of courtyards. By using greeneries and water ponds, the humidity increases and the surfaces of the courtyard are in danger of condensate. Furthermore, the wind flow is blocked and the stack effect weakened. Consequently, the ratio of greeneries should not be too high in humid areas.

Yixing Chen [37] carried out a study on personal ventilation systems for workspaces. By using a personal ventilation system the ambient indoor temperature can be higher than suggested 23 °C. The best results were made when personal ventilation air temperature was at 20 °C and ambient temperature was at 26 °C, which lowered the cooling load by 14% and energy consumption by 10.8%, in respective to an ambient temperature of 23 °C.

The outcome was even better when the air was re-circulated. The energy consumption was 15% higher for an ambient temperature of 23 °C than it was for a temperature of 26 °C.

Wind direction is the main parameter of the performance of natural ventilation systems. By applying architectural urban building designs, wind can be channeled through cities in order to ensure sufficient wind speed. Moreover, vegetation can be useful to channel wind and as a shading device.

2.3. Construction materials and insulation

Buildings in hot and humid climates traditionally use a lightweight construction with low thermal mass, in order to reduce heat storage, which can have negative effects on indoor temperatures at night. Thermal mass construction is usually only applied in climates with high diurnal temperature ranges and low relative humidity.

Nishita Baderia et al. [38]. tested another approach using heavyweight construction in combination with night ventilation. The

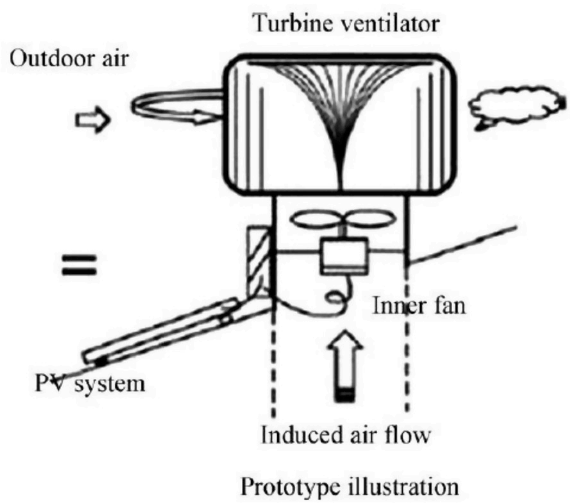

Fig. 4. Turbine ventilator incorporating a PV-fan system [12].

tested building was located in Ningbo, China, which is classified as humid subtropical climate region. Even though the diurnal range was only 10 K the results showed that heavyweight construction performed better than lightweight construction regarding energy consumption and comfort. However, this was only one example. More studies have to be carried out on this subject. Furthermore, condensation can occur and cause serious problems in regions where relative humidity is higher than 80%.

The U-value has to be kept respectively low by installing insulation layers. This is essential in air-conditioned buildings to keep the cooling load low. Especially the rooftop needs insulation due to the solar radiation impact. It is suggested to use a continuous layer of insulation wrapping the whole house thus solving the problem of thermal bridging.

On the other hand, condensation can be increased by adding insulation layers. Three ways of insulation are to be considered: exterior insulation, interior insulation or core insulation.

As said before, thermal mass is not predominantly used in hot and humid climates due to small diurnal temperature ranges and high relative humidity.

By insulating the wall interiorly, the building can be cooled very quickly because the thermal mass does not need to be cooled first. The construction process is much cheaper when applied after the construction of the building and can be done by the inhabitants themselves.

However, problems such as thermal bridging and acoustical issues occur. Furthermore, the boundary layer between insulation and the concrete is in danger of condensate. Therefore, a vapor barrier must be added in front of the insulation layer.

An exterior insulation layer protects the wall from solar heat gain and in order to that avoids destabilization. Besides, thermal bridges are averted and the indoor side of the wall operates as heat storage. Light weighted construction diminishes this effect. Especially in monsoon areas, the insulation layer must be protected from heavy rain to avoid a higher thermal conductivity and the decay of the wall.

Core insulation leads to good insulation both thermally and acoustically. The construction is expensive and difficult though and it has to be ensured that no moisture can reach the insulation layer. Moreover, it is not possible to apply core insulation after the construction of the building.

J.C. Lam et al. [39] stated that a higher U-value does not necessarily go along with higher energy consumptions in warmer climates. Some days the indoor temperature can be higher than the outdoor temperature. However, the cooling mode can be still on due to the baseload of the building, which heats it up. In that case, a higher U-value might lead to lower energy consumption.

Furthermore, insulation costs linearly rise with the thickness of the insulation layer. To make insulation affordable it is necessary to find the most effective ratio of energy savings to insulation costs. A study has been carried out comparing insulation thickness of the case Cameroon to recent studies of Malaysia, Turkey, China and Tunisia [40]. It concludes, that for the evaluation of insulation layers orientation, insulation material and outdoor climate must be considered. For the hot and humid climate of Cameroon the optimum thickness for an extruded polystyrene insulation layer was from 0.092 to 0.102 m. Hence, the overall life cycle savings are kept as low as possible.

Depending on location and occurrence different materials can be used to replace conventional substances and improve sustainable building designs. Expanded cork, wood and timber, straw, Rockwool, different kind of bricks, stone rocks and even sheep or cotton wool can be effective insulation materials [8].

Innovative synthetics can be alternatives to improve energy performance and lifecycle emissions. Aerated autoclaved concrete is known to be a material having a lot of advantages which make it highly suitable for hot and humid climates. It is lightweight, easily workable, environmentally friendly, long-lasting and does not degrade under normal conditions. Apart from that, it is an insulation material itself, fire- and sound-resistant and due to its lightweight it is safer in earthquake regions than regular concrete [41].

According to Yanli Qi et al. [47] other promising materials are i.e. vermiculite concrete, aerogels, vacuum insulation panels and shape memory polymers. It has to be noted that these need a lot of energy for their production but compensates it during their lifespan.

Another way of insulation are phase-change materials. A study for Singapore proved the effectiveness of PCM. The results showed that the heat gains were reduced significantly when PCM insulation was used. The layer should preferably be attached to the external surface in order to reduce heat gains at night [42].

2.4. Windows

The window size and orientation have to be chosen according to the climate and wind direction.

In hot and humid regions, the window-floor ratio is recommended to be 15–20% [43].

Windows are the main source of heat gain and need to be properly insulated and covered in order to lower the U-value and to prevent solar radiation from entering.

Allen Khin Kiet Lau et al. [44]. carried out a study on shading devices in Malaysia and found out that in hot and humid climates an egg-crate shading device reduces the annual cooling demand more than a horizontal or vertical shading device. Another result was that when applied to west and east facades the shading devices showed a greater impact than those applied south and north.

Also, windows have to make sure that sufficient daylight is available for the inhabitants. Different heat gain effects can occur in a window, which has to be considered, including: radiation, conduction, convection and infiltration. The latest widely used technologies on the market at the moment are low–emissivity (low–e), spectrally selective, tinted heat absorbing and gas-filled windows which are combined to create optimum results [45].

Low-e glasses have a metal or metallic oxide coating to increase their reflectance thus decreasing the absorbance and lowering the U-value. According to the U.S. Department of Energy Low-E glasses cost about 10–15% more in the USA but reduce energy consumption by 30–50% in comparison to regular windows. However, this can cause a reduced daylight coefficient if spectrally selective coatings are not used [46]. There are two manufacturing technologies to produce low-e class which results in either hard-coated glass CVD (Chemical Vapor Deposition), also known as pyrolytic or soft-coated glass MSVD (Magnetron Sputtering Vacuum Deposition), known as sputtered. The soft-coated glass is less durable than hard-coated and requires special storage and handling.

As a consequence of low-e coatings, the visual transmittance (VT) is reduced. To solve this problem, spectrally selective coatings can be applied, which only transmit visible light and still work as insulation. Yanli Qi et al. [47]. tested a new plasticized polyvinyl chloride coating with promising results. The applied coating can protect the inhabitants from UV radiation, it blocks near-infrared light and blue light whereas visible light is transmitted.

Another effective way of protecting houses from heat gains are tinted windows, which absorb solar heat. However, the absorbed heat can still lead to heat gain caused by conduction and radiation of the glass. Therefore, insulation must go along with a tinted window.

Double- and triple-paned windows are predominantly used to lower the U-value [48]. They leave a gap in between the glass layers, which is either vacuumed or filled with air, argon, krypton and occasionally xenon. Argon is applied most because of economic aspects but krypton is performed better. These noble gases are denser than air thus reducing air movement and convectional heat gains. Besides, the R-values are higher so that heat conduction is diminished. The larger the gap between the layers the better the insulation effect. Because the use krypton is more effective, the gap does not need to be as big as for argon. Therefore, it is used to save space which is needed when many layers are built.

Research Frontiers is the first company, which established smart glass technology on the market. Switchable glazing helps the user to control the optical and thermal properties of windows according to the environment and needs [49]. Materials can change their reflectivity and absorptivity. There are thermochromic materials, which change their properties when the temperature is changing, electrochromic materials, which react to an electrical pulse and photochromic materials, whose optical properties depend on light changes.

Aritra Ghosh et al. [50] measured the U-value for single pane windows using switchable glazing, double pane windows and the combination of them. Adding suspended particle device (SPD) to the double pane windows resulted in a drop of 0.99 W/m^2K. They also researched on PV powered SPD switchable device, which showed promising results according to the paper [51].

Areas which have heating and the cooling season can also make use of flipping the windows in order to transfer the windows into a heating device in the cold season. For that a double pane window is needed, which has a low-e pane and a clear pane. Additionally, the window should be insulated to keep the absorbed heat inside in winter and to make sure that heat is not transferred from the outer pane to the inside in summer [43].

All insulation and shading can be useless in case the frame shows a weak thermal performance or leaks air. Commonly used materials are wood, metal, aluminum and polyvinyl chloride. Wood is a good insulator but must be protected from weather influence, which makes it hardly usable for regions having heavy rainfalls. Metal frames cause heat gains but are durable. Aluminum is predominantly used even though the U-value is 205 W/m^2K. To reduce heat gains a thermal break is added to the construction. However, aluminum frames should not be used in beach homes due to corrosion, which can result from salt water and salty air [52].

PVC frames differ from company to company depending on the additives they use for the composite. Milgard offers a vinyl frame, which is extremely durable, non-corroding, energy-efficient and does not need any maintenance. A recently developed technology lets UV radiation transmitted through the colors thus causing the window to look new for years. Another option this company recently offers is fiberglass frames, which is based on the traditional wood profile. It is extremely strong, does not need much maintenance and can be painted. The physical advantage of fiberglass is the fact that it barely expands and contracts with weather changes [57].

3. Net zero energy buildings design

3.1. Net-zero building projects

Simi Hoque and Nabila Iqbal et al. [53].developed an NZEB in the hot-humid region of Panama, as an example of net-zero building designs in developing countries. The building is well-insulated using sustainable light-colored materials for the envelope, such as teak pressure-treated wood for the walls, glass countertops and clay tiling. As insulation layer straw, coated by a mix of plasterboard and clay, was used. Volatile organic compounds were kept low and a highly durable white-painted reflective metal roof was used. To reduce heat gain the roof was ventilated from below.

The results were U-values of 0.15 W/m^2K for the walls, 0.3 W/m^2K for the floor, 0.25 W/m^2K for the roof and 1.4 W/m^2K for the windows.

To support the passive cooling of the building a thermal mass element was installed in the form of a 30 mm stone slab, which absorbs heat during the day in the shaded space in order to decrease air temperature. To mitigate heat gain from solar radiation overhanging solar and rain cover were attached to the house. By using a plunge pool, which is orientated to the direction where the wind comes from, the relative humidity was lowered from 70-90% to 50–70%. The pool is shaded and remains at a temperature below 20 °C thus causing condensation of the air, which is led towards the house afterward.

The cool sea breeze was used as natural ventilation. Large openings face towards the wind and smaller openings are on the other side of the building to create a cross ventilation. Besides, slit windows also face south-east towards the wind and can be controlled according to the comfort needs of the inhabitants. Electricity and hot water supply are based on solar power and to ensure power throughout the year a battery subsystem was built.

Table 2
Summary of net zero energy projects.

Reference	Cooling	Dehumidification	Power supply	U-value	Ventilation	Additional measures
Simi Hoque and Nabila Iqbal [53]	Passive cooling (sea breeze) supported by heat absorption element	Shaded plunge pool	PV	Walls 0.15 Floor 0.3 Roof 0.25 Windows 1.4 (local wood)	Slit windows; cross ventilation	Length to width ratio 1:2; solar panels for hot water supply
Trevor S.K. Ng [54]	Radiant cooling and underfloor air supply based on absorption chiller and electric chiller	Desiccant dehumidification	PV	Walls < 0.6 Roof < 0.2	Ventilated attic; wind orientation optimization	Use of bio-diesel; window-wall ratio 0.4
Tim Selke and Moritz Schubert [55]	air-soil heat exchanger; concrete core activation based on a solar absorption chiller	Negligible	PV	Wall 0.261 Roof 0.175–0.224	No ventilation	Heat recovery; thermally massive building envelope

This project shows how a NZEB can be designed, using local resources and natural effects.

Trevor S.K. Ng [54] reviews a zero-carbon emission building located in Hong Kong, which saves 45% energy compared to the local standard. As active measures, they included a photovoltaic system and a combined cooling and heating power system based on bio-diesel. For the inhabitant's comfort, an energy-efficient AC system which consists of desiccant dehumidification, underfloor air supply and radiant cooling has been established.

Insulation layers were added to lower the U-value to < 0.6 W/m^2K for the walls and below 0.2 W/m^2K for the roof. The window-wall ratio was decreased in order to avoid heat gains. Additionally, an active skylight and light pipes were used to have sufficient daylight thus saving energy for lightning. An enhanced natural ventilation system was installed and the building was orientated towards the wind. However, natural ventilation could only be used for 30–40% of the year when external temperatures were below 20 °C due to heat gains diminution. Also, the system was supported by fans. By exporting 99 MWh/year produced by the photovoltaic system the carbon, which was emitted in other lifecycle states, is equated.

Another opportunity is the use of geothermal cooling, as in an air-soil heat exchanger. This can be primarily effective in hot climates, where the temperature between earth surface and 5m depth differs a lot.

Tim Selke and Moritz Schubert et al. [55]. report about a LEED™ Platinum standard certified building in Saudi Arabia, where an air-soil heat exchanger is used to precool the fresh air for the ventilation system. This causes a temperature drop of 12.8 K–18 K.

Apart from that, concrete core activation extracts heat from the walls. Pipes inside of the walls, ceilings and floors were integrated. Water, which is cooled down by a solar absorption chilled water system, runs through the pipes. The summary of various net Zero energy projects are listed in Table 2.

3.2. Green building

Green roof concepts can help to improve the energy performance of a building and a whole city. By adding vegetation to the rooftop the building benefits from several advantages. Heating demand is decreased in winter because of the additional thermal mass, which offers thermal resistance. In summer the cooling load is reduced due to evapotranspiration effects. Other benefits are the water storage effect in case of storms decreasing the danger of floods, the creation of a natural habit and the sound insulation. Moreover, plants and soil can filter the rainwater and reduce the ratio of heavy metals and pollutants. Urban effects can occur, such as decreased average temperature in the city, improved air quality and sequestration of carbon dioxide. There are two types of green roofs: intensive and extensive roofs. Intensive green roofs have thicker layers, which can hold smaller trees, bushes and shrubs. Extensive roofs are based on thin substrates, where predominantly sedum species are planted. Even though intensive green roofs are more effective, extensive roofs need much less maintenance work.

A study shows that cooling effects of the green roof have the greatest impact on sunny days. Green roofs have a reversed effect in relation to common roofs. During the night they work as heater whereas they have a cooling effect during the day. At night, the indoor air temperature under the green roof was 2.5 °C higher than under the common roof. Because most heat is emitted through evapotranspiration (and longwave radiation) the soil always needs sufficient water supply [56].

Green walls on high-rise buildings have a significant impact on the energy performance in sub-tropical regions. Irene Wong and Andrew N. Baldwin et al. [57]. found a reduction of $2651*10^6$ kWh in electricity use and $2200*10^6$ kg of carbon dioxide emission.

A lot of strategies have been reviewed in the present paper. The difficulty for the architects and engineers now is to combine these in the most efficient and affordable way to establish a normed guideline. Since the main energy is consumed by HVAC, new technologies, such as evaporative cooling etc., have to play their role in enhancing the overall energy performance of buildings.

As we know tropical and subtropical regions have high solar radiation rates. This makes solar driven technologies highly feasible and reliable. If natural ventilation systems and solar power are used in combination, there will be a good chance to reach zero energy consumption. Investment costs must be reduced so that these technologies become affordable and a standard norm.

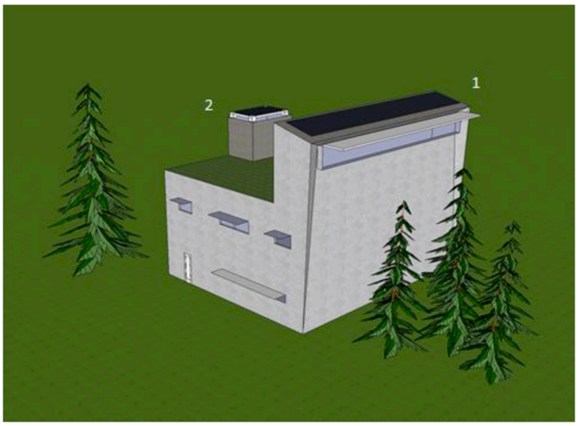

Fig. 5. Novel wind tower dehumidification design.

4. . Novel building design aspects

A new suggested design, which needs to be tested and evaluated, is shown in Fig. 5. A wind tower (1) is used which holds the novel desiccant wheel by Dominic O'Connor et al. [20]. Louvers must be installed in the wind tower hence preventing insects etc. from entering. A solar chimney (2) on the other side of the building is combined with the natural ventilation system to increase air flow during times of low wind speeds. A green roof helps to reduce solar heat gains and to cool down the house [58]. The vegetation in front of the house channels the wind into the wind tower. In case the wind regularly comes from more than one direction more openings must be established. A solar absorption chiller can be used to provide cooling water for radiant cooling of the rooms. Solar and PV panels can be added to the wind tower and solar chimney. Besides, the solar/rain covers orientated to the sun can be equipped with PV technology.

Another approach is shown in Fig. 6. The attic in this building is ventilated through an opening at the end of the roof, a solar chimney (1) and two turbine ventilators (2) at the top. A solar absorption chiller is used for radiant cooling. Cooled water runs through pipes in the ceiling of every room. A heat recovery system must be established. For that the whole house has to be sealed properly. The hot air inside of the building rises to the top where it is dragged through pipes to the solar chimneys that are integrated in the solar cover of the windows (3). This is the method is shown in Fig. 4. Vegetation in the back of the house (4) channels the wind towards the louvers at the bottom of the house [59]. Before wind enters the building, it gets precooled by an air-soil heat exchanger. Condensation occurs inside of the pipes. A filter system and a water tank collect the water, which can be used for domestic purposes. Eventually, the less humid air enter the rooms and gets dragged towards the solar chimneys (3). A pool such as the one used by Simi Hoque[53] can be added to the house if the indoor humidity is still too high. PV panels on the roof provide power.

5. The case study of NZEBs in India

With a modest beginning of 9565 m^2 project area in the country (as on August 2016) more than 7 NZEB projects with a footprint of over 33,777 m^2 projected area are certified and fully functional in India (see Table 2). They are listed in Table 3 and Fig. 7.

5.1. Sun carrier omega project overview

Sun carrier omega office is located in Bhopal, central India with a built-up area of about 9888 sq. Ft. Sun Carrier Omega is the first company to bring to India the Sun Tracking Intelligent Solar PV System, which generates about 40% more energy than fixed systems. It also provides large capacity vanadium redox flow energy storage and management system, the Cellcube series etc. The building has been designed to promote green awareness to all the visitors and occupants to spearhead the green movement in the state and the country. The key parameters of the Project are listed in Table 4.

The innovative deployment of an integrated on-site solar photovoltaic generator and energy storage system makes it a building fully powered by renewable energy.

- Net Zero Energy Building located in Central part of India, in the City Bhopal
- Uses two ground-mounted single axis sun tracking PV units of 67 KWp with 140 MWh energy generated per annum
- Uses Vanadium redox flow battery: 3 Units of Cellcube FB 10–100 @ 15 KW/100 KWh
- Demonstration project by Suncarrier Omega; incorporated as a Joint Venture Company between Omega Renk Pvt. Ltd. and a + f GmbH, a GILDEMEISTER group company.
- The project was the winner for Inter Solar Awards 2012

Fig. 6. Ventilated attic building design including an air-soil heat exchanger unit.

Table 3
Comparison of NZEB in India.

S.No	Name of the Premises	Location	Climate type	Project area	Occupancy type	Typology	Grid connectivity	EPI
1	Indira Paryavaran Bhawan	New Delhi	Composite	9565m^2	Office &Educational	New	Connected	44 kWh/m^2/yr
2	CEPT	Ahmadabad	Hot & dry	498m^2	Office &Educational	New	Connected	58 kWh/m^2/yr
3	Akshay urja bhawan	Haryana	Hot &Dry	5100m^2	Office	New	Connected	30 Wh/m^2/yr
4	ECB	Noida,UP	Composite	891m^2	Lab	New	Connected	71 Wh/m^2/yr
5	Sun Carrier Omega	Bhopal	Hot &Humid	918m^2	Office-Private	New	Off grid	–
6	GRIDCO	Bhubaneswar	Warm & Humid	15,793 m^2	Office	New	Connected	90 Wh/m^2/yr
7	Malankara Tea Plantation	Kerala	Warm &humid	–	Office-Private	Old	Connected	–

Fig. 7. NZEB in India.

Table 4
Key parameters [60].

1	Location	Bhopal, M.P, India
2	Geographical coordinates	23° N, 77° E
3	Occupancy Type	Office – Private
4	Typology	New Construction
5	Climate Type	Hot and Dry
6	Project Area	9888 ft2
7	Grid Connectivity	Off Grid
8	Rating	LEED Platinum
9	Specific energy consumption	108 kWh/sq.m/Year

The Technical feature of the system is shown in Fig. 8.

5.2. Sun carrier omega NZEB strategies

The commercial building of Sun Carrier Omega has adopted the below-mentioned demand side green technologies and strategies to be one of India's net-zero energy buildings [62].

a. Site Sustainability:

- The project is located close to public transport to reduce vehicular pollution
- 100% of non – roof impervious areas are installed with high SRI paver blocks
- 14% of the total car parking area is provisioned for carpoolers to promote share ride to minimize the transportation strain on the environment.
- 51% of the site area – exclusive of the building footprint, is covered with native or adaptive landscape species.

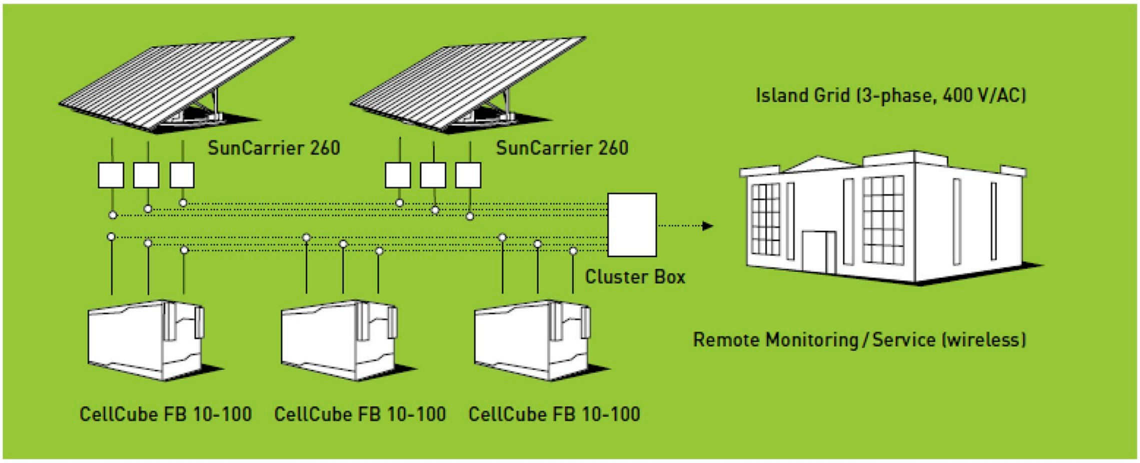

Fig. 8. Technical schematic of renewable energy generation and storage [61].

Fig. 9. Features of sun omega NZEB at Bhopal, India.

- 81% of the roof area is covered with a highly reflective material to reduce heat islands and reduce the impact on microclimate.

b. Water Efficiency:

- Every effort has been taken to reduce the water consumption by installing efficient water fixtures, low flow dual-flush toilets, sensor-based auto-flush urinals and low flow fixtures.
- 100% of onsite wastewater is treated and reused for landscaping/other purposes.
- A rainwater recharge pit of 180 cu m per day is installed capable of removing 80% TSS.
- The building has achieved a 40.9% reduction in potable water use

c. Energy Efficiency:

- 100% annual energy consumption of the building is sourced by the onsite PV modules generating 140 kWh. This facility does not draw any power from the grid.
- The project achieved a 43.8% energy cost reduction
- The building is fed by two Sun Carrier Solar Panels installed at the site. Cell Cube vanadium redox battery system is used to store the excess power generation.
- Energy efficient measures like High Albedo paint on the roof, Efficient daylighting System, Energy efficient LED lighting, insulation, occupancy monitoring, Efficient HVAC and VRV systems are installed for saving more energy than conventional systems.
- Selection of CFC free and HCFC free refrigerants which avoid global warming and ozone depletion

d. Resource management:

- Approx 96% of total construction waste of debris has been recycled or reused cutting down the debris disposal to landfills.
- Reducing virgin material exploitation through recycling the material.
- 99.1% of the wood-based products used are certified by following FSC principles.
- The project achieved a recyclable content value of 10.6% of the total material by cost thereby reducing virgin material exploitation.
- About 24% of the project's material and products by cost were derived within 800 km of the project site thereby reducing transportation pollution.
- 5.95% of the total materials cost used on the project were from rapidly renewable sources.

e. Indoor Air Quality:

- Smoking is prohibited in the building thus ensuring the health and safety of all its occupants.
  • 77% of the occupants can control the air speed and temperature of the A/C units.
- More than 81% of the regularly occupied areas have daylight.
- 92% of the buildings regularly occupied spaces have direct lines of sight to the perimeter glazing.
- Low emitting paints, carpets and composite wood products have been used to enhance the indoor environment and provide a superior workplace for all employees.
- CO_2 sensors are provided to measure the CO_2 level in a densely occupied area/breathing zone.

The building is carved with various green features poising the technology and environmental sustainability. It's has achieved the LEED Platinum certification under LEED India (Fig. 10).

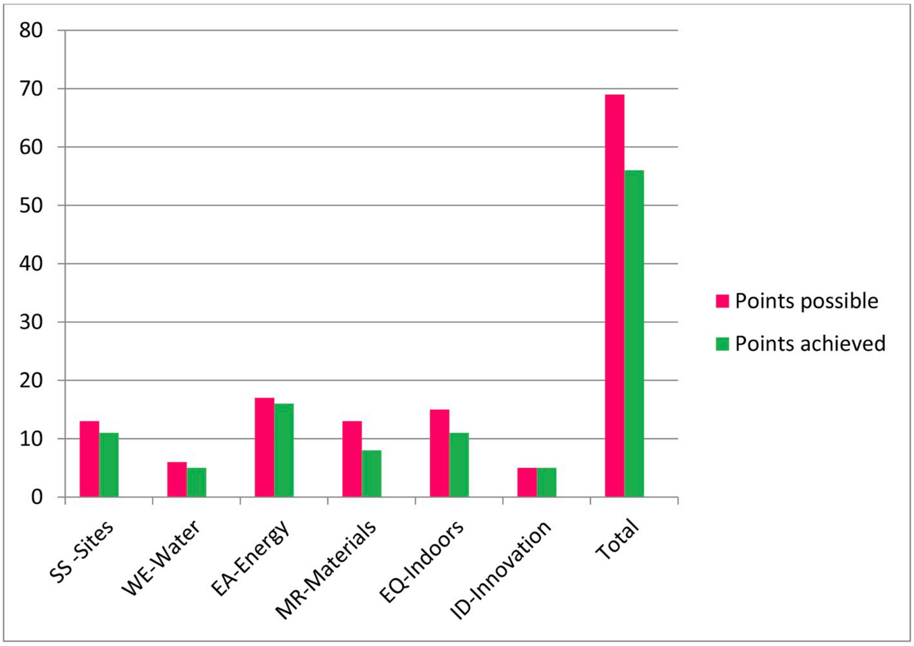

Fig. 10. LEED Performance metric of Sun Omega NZEB.

6. Conclusion

The basic scheme of a Netzero building design is to provide thermal comfort with less energy consumption. Various building designs in hot and humid climates have been reviewed. The biggest problem in these areas has been found to be humidity, which makes it difficult to establish strategies that are used in other climates. Cooling only is not enough to ensure comfort for the inhabitants but is already responsible for the biggest part of energy consumption. By applying new designs, it has been shown that net-zero energy performances can be already reached. These regions get enormously high solar radiation rates, which has to be used to deal with the unfortunate climate conditions. At locations, where wind velocity is high enough, natural ventilation systems have to be established. Achieving energy independent buildings requires different design solutions and strategies to provide seasonal comfort performance.

Conflicts of interest

All authors declare no conflict of interest to this manuscript.

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Appendix A. Supplementary data

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References

[1] The World Bank, Residential consumption of electricity in India documentation of data and methodology, Background Paper India: Strategies for Low Carbon Growth, 1 2008, pp. 1–73 http://www.moef.nic.in/downloads/public-information/Residentialpowerconsumption.pdf.
[2] CIA, The world fact book https://www.cia.gov/library/publications/resources/the-world-factbook/geos/in.html; issue date: 29.09.2016.
[3] Jørn Toftum, Anette S. Jørgensen, P.O. Fanger, Upper limits of air humidity for preventing warm respiratory discomfort, Energy Build. 28 (1998) 15–23.
[4] L.G. Berglund, W. Cain, Perceived air quality, thermal comfort, and SBS symptoms at low air temperature and increased radiant temperature, Proc. Indoor Air, LAQ, San Diego, 2002, pp. 267–272.
[5] Hannu Viitanen, et al., Moisture conditions and bio-deterioration risk of building materials and structure, J. Build. Phys. 33 (2010) 201–224.
[6] Shady Attia, Elisabeth Gratia, Andre De Herde, L.M. Jan, Hensen, Tool for design decision making: zero energy residential buildings in hot humid climate, 13th Conference of International Building Performance Simulation Association, 2013 Chambéry, France, August 26-28.
[7] Kevin K.W. Wan, K.L. Cheung, Dalong Liu, Joseph C. Lam, Impact of modelled global solar radiation on simulated building heating and cooling loads, Energy Convers. Manag. 50 (2009) 662–667.
[8] P.K. Latha, Y. Darshana, Vidhya Venugopal, Role of building material in thermal comfort in tropical climates, A Rev. J. Build. Eng. 3 (2015) 104–113.
[9] Mehdi Baneshi, Hiroki Gonome, Shigenao Maruyama, Cool black roof impacts into the cooling and heating load demand of a residential building in various climates, Sol. Energy Mater. Sol. Cells 152 (2016) 21–33.
[10] Zhiyong Tian, et al., Investigations of nearly (net) zero energy residential buildings in Beijing, Procedia Eng. 121 (2015) 1051–1057.
[11] V. Olgyay, A. Olgyay, Design with Climate: Bioclimatic Approach to Architectural Regionalism, (1963).
[12] Naghman Khan, Yuehong Su, Saffa B. Riffat, A review on wind driven ventilation techniques, Energy Build. 40 (2008) 1586–1604.
[13] Ben Richard Hughes, John Kaiser Calautit, Saud Abdul Ghani, The development of commercial wind towers for natural ventilation, A review Applied Energy 92 (2012) 606–627.
[14] B.R. Hughes, M. Cheuk-Ming, A study of wind and buoyancy driven flows through commercial wind towers, Build. Environ. 43 (2011) 1784–1791.
[15] P. St Clair, R. Hyde, Towards a new model for climate responsive design at the university of the sunshine coast chancellery, J Green Build. 4 (3) (2009) 3–20.
[16] A.A. Elmualim, H.B. Awbi, Wind tunnel and CFD investigation of the performance of "wind catcher" ventilation systems, Int. J. Vent. 1 (2002) 53–64.
[17] M. Bahadori, Viability of wind towers in achieving summer comfort in the hot arid regions of the Middle East, Renew. Energy 5 (1994) 879–892.
[18] H. Saffari, S.M. Hosseinnia, Two-phase Euler–Lagrange CFD simulation of evaporative cooling in a wind tower, Energy Build. 41 (2009) 991–1000.
[19] Mario Grosso, Gianvincenzo Fracastoro, Marco Simonettib, Giacomo Chiesa, A hybrid passive cooling wall system: concept and laboratory testing results, Energy Procedia 78 (2015) 79–84.
[20] Dominic O'Connor, John Kaiser Calautit, Ben Richard Hughes, A novel design of a desiccant rotary wheel for passive ventilation applications, Appl. Energy 179 (2016) 99–109.
[21] S. Gokarakonda, G. Kokogiannakis, Integrated dehumidification and downdraft evaporative cooling system for a hot-humid climate, 30th International PLEA Conference (PLEA 2014), 2014, pp. 1–8.
[22] N.K. Bansal, R. Mathur, Solar chimney for enhanced stack ventilation, Build. Environ. 28 (1989) 373–377.
[23] Li Liu, C.M. Mak, The assessment of the performance of a windcatcher system using computational fluid dynamics, Build. Environ. 42 (2007) 1135–1141.
[24] Monodraught www.monodraught.com/; rec. date: 12.10.2016.
[25] Omidreza Saadatian, Chin Haw Lim, K. Sopian, M.Y. Sulaiman Revel, Air changes and extraction flow rate analysis of wind-induced natural ventilation tower under hot and humid climatic conditions, Int. J. Energy Environ. 6 (5) (2012) 2012.
[26] S. West, Improving the sustainable development of building stock by the implementation of energy efficient, climate control technologies, Build. Environ. 36 (1999) 281–289.
[27] C. Lai, Prototype development of the rooftop turbine ventilator powered by hybrid wind and photo-voltaic energy, Energy Build. 38 (2005) 174–180.
[28] J. Lien, N.A. Ahmed, Effect of inclined roof on the airflow associated with a wind driven turbine ventilator, Energy Build. 43 (2–3) (2011) 358–365.
[29] J.Q. Li, I.C. Ward, Investigation of roof pitch and wind induced ventilation by computational fluid dynamics, PLEA2006 – the 23rd Conference on Passive and Low Energy Architecture, 2006 (Geneva, Switzerland).
[30] Karam M. Al-Obaidi, Mazran Ismail, Abdul Malek Abdul Rahman, A review of the potential of attic ventilation by passive and active turbine ventilators in tropical Malaysia, Sustainable Cities Soc. 10 (2014) 232–240.
[31] A. Aldawoud, Thermal performance of courtyard buildings, Energy Build. 40 (5) (2008) 906–910.
[32] R. Ernest, The Role of Multiple Courtyards in the Promotion of Convective Cooling UK, University of Nottingham, 2011.

[33] A. Chatzidimitriou, S. Yannas, Microclimatic Studies of Urban Open Spaces in Northern Greece, (2004).
[34] In: Proc. PLEA Eindhoven, Vol.1, P. 83-88.
[35] N.A. Al-Hemiddi, K.A.M. Al-Saud, The effect of a ventilated interior courtyard on the thermal performance of a house in hot-arid region, Renew. Energy 24 (2001) 581-995.
[36] A.S. Muhaisen, M.B. Gadi, Shading performance of polygonal courtyard forms, Build. Environ. 41 (8) (2006) 1050–1059.
[37] M. Taleghani, M. Tenpierik, A. van den Dobbelsteen, D.J. Sailor, Heat in courtyards: a validated and calibrated parametric study of heat mitigation strategies for urban courtyards in The Netherlands, Sol. Energy 103 (2014) 108–124.
[38] Yixing Chen, Benny Raphael, S.C. Sekhar, Experimental and simulated energy performance of a personalized ventilation system with individual airflow control in a hot and humid climate, Build. Environ. 96 (2016) 283–292.
[39] Nishita BaderiaM Arch Environmental Design, The Role of Thermal Mass in Humid Subtropical Climate: Thermal Performance and Energy Demand of CSET Building, Ningbo, The University of Nottingham, UK, 2014 (PLEA 2014).
[40] Joseph C. Lam, K.W. Wan Kevin, Dalong Liu, C.L. Tsang, Multiple regression models for energy use in air-conditioned office buildings in different climates, Energy Convers. Manag. 51 (2010) 2692–2697.
[41] Modeste Kameni Nematchoua, et al., Study of the economical and optimum thermal insulation thickness for buildings in a wet and hot tropical climate: case of Cameroon, Renew. Sustain. Energy Rev. 50 (2015) 1192–1202.
[42] AAC India http://www.aac-india.com/advantages-of-aac-blocks/11.07.2016.
[43] Jiawei Lei, Jinglei Yang, En-Hua Yang, Energy performance of building envelopes integrated with phase change materials for cooling load reduction in tropical Singapore, Appl. Energy 162 (2016) 207–217.
[44] HPCB http://high-performancebuildings.org/pdf/ECM2/ECM2_Technical_Information_Warm-Humid.pdf ; receiving date: 14/11/2016.
[45] Allen Khin Kiet Lau, Elias Salleh, Chin Haw Lim, Mohamad Yusof Sulaiman, Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: the case of Malaysia, Int. J. Sustain. Built. Environ. 5 (2016) 387–399.
[46] U.S. Department, of Energy http://energy.gov/energysaver/window-types.
[47] Brooke House http://www.brookehouse.net/www.brookehouse/low_emissivity.htm.
[48] Yanli Qi, Xiuping Yin, Jun Zhang, Transparent and heat-insulation plasticized polyvinyl chloride (PVC) thin film with solar spectrally selective property, Sol. Energy Mater. Sol. Cells 151 (2016) 30–35.
[49] Ecoline Windows https://www.ecolinewindows.ca/gas-fill-important-feature-in-modern-windows/rec. date: 17.11.2016.
[50] Research Frontiers http://www.smartglass.com/.
[51] Aritra Ghosh, Brian Norton, Aidan Duffy, Measured overall heat transfer coefficient of a suspended particle device switchable glazing, Appl. Energy 159 (2015) 362–369.
[52] Aritra Ghosh, Brian Norton, Aidan Duffy, First outdoor characterization of a PV powered suspended particle device switchable glazing, Sol. Energy Mater. Sol. Cells 157 (2016) 1–9.
[53] Milgard https://www.milgard.com/materials/aluminum.
[54] Simi Hoque, Nabila Iqbal, Building to net zero in the developing World, Buildings 5 (1) (2015) 56–68.
[55] S.K. Ng Trevor, M.H. Yau Raymond, N.T. Lam Tony, S.Y. Cheng Vincent, Design and commission a zero-carbon building for hot and humid climate, Int. J. Low Carbon Technol. 11 (2) (2013) 222–234.
[56] Tim Selke, Moritz Schubert, LEED™ Platinum awarded Arabian Green Building with solar heat driven cooling technology, Energy Procedia 91 (2016) 824–831.
[57] He Yang, Hang Yu, Nannan Dong, Hai Ye, Thermal and energy performance assessment of extensive green roof in summer: a case study of a lightweight building in Shanghai, Energy Build. 127 (2016) 762–773.
[58] Irene Wong, N. Andrew, Baldwin, Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region, Build. Environ. 97 (2016) 34–39.
[59] http://energyinformative.org/where-is-solar-power-used-the-most/; 28.09.2016.
[60] En3online,Sun Carrier Omega Case Study, (2015) Avaliable from: http://www.en3online.com/wp-content/uploads/2012/10/Sun_Carrier_Omega_Case_Study.pdf.
[61] Inhabitat, Sun Carrier Omega Building Is Indias First Net Zero Energy Commercial Building, (2016) Available from: http://inhabitat.com/the-suncarrier-omega-building-is-indias-first-net-zero-energy-commercial-building/.
[62] PV-Tech, Zero Energy Buildings: Decarbonising India by Tapping the Sun, (2018) Available from: https://www.pv-tech.org/guest-blog/zero-energy-buildings-decarbonising-india-by-tapping-the-sun.