NOVEL INTEGRATED DESIGN STRATEGIES FOR NET-ZERO-ENERGY SOLAR BUILDINGS (NZESBS) IN NANJING, CHINA

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ABSTRACT
The connotations and denotations of the term net-zero-energy solar buildings (NZESBs) have been in constant flux because of continuous developments in solar heating technology, solar photovoltaic (PV) technology, building energy-storage technology, regional energy-storage technology, and energy-management systems. This paper focuses on innovative strategies for implementing NZESBs in Nanjing, China. These strategies include integrated architectural design, including passive solar design (respecting climatic characteristics and conducting integrated planning based on the environment, building orientation, distance between buildings, building shape, ratio of window area to wall area, and building envelope) and active solar design (integration of the solar-energy-collecting end of the system – collectors and PV panels – with the building surface – roof, wall surfaces, balconies, and sun-shading devices – and the integration of solar-energy transfer and storage equipment with the building). Some Nanjing-specific recommendations and findings on NZESBs are proposed. The results illustrate that NZESBs can be realized in Nanjing if solar energy technologies are appropriately integrated with the characteristics of Nanjing's geography, climate and buildings.

KEYWORDS
novel; integrated design; strategies; net-zero-energy solar buildings; Nanjing

1. INTRODUCTION AND HYPOTHESIS
The building energy consumption in Nanjing mainly consists of heating, air conditioning, a hot water supply, lighting, cooking, household appliances, and elevators. In 2014, the overall energy consumed by buildings accounted for 33% of the energy consumption for all end uses (NMBS, 2015). When this percentage of energy consumption is combined with the energy consumption used to produce building materials and any other energy consumption that is related to buildings, this value accounts for more than 40% of the total energy consumption

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in Nanjing (NMBS, 2015). Moreover, heating and air conditioning always comprise a major portion (60-70%) of an entire building's energy consumption (Yunna and Ruhang, 2013). Therefore, measures and changes in the building modus operandi can yield substantial energy savings. Currently, buildings are increasingly expected to meet higher and potentially more complex levels of performance (Kolokotsa et al., 2011; Voss et al., 2011). Net zero energy solar buildings (NZESBs) have the potential to meet this higher requirement, help save energy and alleviate the impact on the environment because they adopt more energy-efficient measures and renewable energies than conventional buildings (EPC, 2002, 2010; Fong and Lee, 2012; Annunziata et al., 2013).

A NZESB means a building that has a very high energy performance, as determined in accordance with the Annex I of the Directive on the energy performance of buildings 2010/31 (EPC, 2010). The net zero amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby; The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building and domestic hot water needs (EPC, 2002, 2010).

2. BACKGROUND

In general, NZESBs involve two integrated design strategies: passive and active solar design (PSD and ASD). PSD includes landscape design, building siting, building envelopes, daylighting design, and ecology. ASD includes HVAC (heating, ventilation, and air conditioning), solar water heating (solar thermal) system design, BIPV (building-integrated photovoltaic) system design, BIPV/T (building-integrated photovoltaic/thermal) system design, other renewable energy systems, building energy management system, security and information technologies.

2.1 Passive Solar Design (PSD)

Passive energy is more sustainable than active energy systems because passive systems use far fewer natural resources to build and maintain. They do not rely so heavily upon gas for heating or coolants for air conditioning. Passive systems are designed so that they can take natural energy from the sun to heat a building and use specific design principles to cool a building. Passive energy systems are also cheaper than active systems because they are less susceptible to malfunction since they rely completely upon nature, rather than using mechanical equipment to produce energy (ESLARP, 2011).

Shape, size, orientation, climate, materials, construction techniques, equipment, occupancy behavior, and energy production systems are all part of the range of decisions that must be considered for NZESBs (Hoque, 2010). Building size is one of the most significant contributing factors to the resource efficiency and the environmental impact of a home (Wilson and Boehland, 2005). In conjunction with building size, decisions that capitalize on orientation, geometry, massing, and layout can effectively minimize building energy use (Lechner, 2008). Optimization strategies to reduce building energy demands by considering these measures exist and have been widely used by the building community (Xia et al., 2008). Additionally, the building envelope must be explicitly detailed—in terms of its construction, materials, insulation, and air and moisture barriers—to ensure reduced energy use, durability, as well as improved comfort for the building's users. Poor barrier performance and less than best-practice construction have resulted in significant energy losses in buildings. Thought should also be given to the specifications of the windows for maximum solar gains and heat loss. The general approach is to lower the WWR (window-to-wall ratio) (i.e. smaller window area), and use double/triple glazing systems with low-emissivity glass and inert gas filled cavity to minimize the amount of heat gain/loss (Weir and Muneer, 1998). By using the right building materials such as masonry or concrete and combining them with effective insulation, solar energy can be contained in the house allowing it to be comfortable year round (Desbarats, 1980; Jentsch et al., 2008); Artmann et al., 2007). It has been demonstrated that reflective roofs could result in substantial energy savings (Akbari et al., 1999; Tsang and Jim, 2011). In the context of NZESBs, however, these energy-efficient measures might not be suitable because of the limited roof space for installing renewable energy systems such as PVs and wind turbines. A compromise needs to be made between these two conflicting requirements (Li et al., 2013). PSD techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted" (Kruzner et al. 2013).

2.2 Active Solar Design (ASD)

ASD includes all of the features of PSD; i.e., in principle, the rules that apply to PSD also apply to ASD, such as the need to account for climate characteristics, integration with the environment, overall planning, layout and spacing, shape, ratio of wall area to window area, and building envelope. ASD uses solar-energy equipment such as HVAC, solar water heaters, and electricity generation, and it is sometimes even integrated with a ground-source or water-source heat pump system and energy-management system. Therefore, ASD is more efficient than PSD in solar-energy collection, storage, and transfer; systems based on ASD are easier to use, more flexible, and more controllable. In addition, ASD also solves the problem of the interruption of the solar-energy supply at night and on cloudy days. Hence, only ASD can truly realize NZESBs.

Major HVAC energy-efficient measures are variable air volume (VAV) air conditioning systems (Ardehali and Smith, 1996), variable speed drives for fans and pumps (Zhu and Jiang, 2003; Teitel et al., 2004) and high COP (coefficient of performance) chiller plants with optimal control (Ahmed, 1994; Hartman, 2001). Even adopting the best energy-efficient measures available, energy will still be required to power the day-to-day running of a building. For NZESBs, this is achieved through the use of renewable energy and other technologies. Major integrated technologies (Hemsath et al., 2011; Marszal et al., 2011; Lund et al., 2011; Nielsen and Moller, 2012) commonly adopted are BIPV, solar water heating (SWH) and heat pumps (HP). A BIPV system consists of integrating photovoltaics modules into the building envelope, such as the roof or the façade. The BIPV modules serve the dual function of building skin—replacing conventional building envelope materials—and power generator. Therefore, BIPV systems can provide savings in materials and electricity costs, reduce use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building (Ordenes et al., 2007; Wang et al., 2009; Heinze and Voss, 2009; Bambrook et al., 2011). In an integrated SWH system, the storage tank is ground- or floor-mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors. SWH systems are designed to deliver hot water for most of the year. However, in winter there sometimes may not be sufficient solar heat gain to deliver sufficient hot water. In this case a gas or electric booster is used to heat the water (Roonprasang et al., 2008; Chien et al., 2011; Chong et al., 2012; Bornatico et al., 2012). A HP is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the heat sink (Pulat et al., 2009; Chua et al., 2010; Kong et al., 2011; Bojic´ et al., 2011).

2.3 Design optimization

The integrated design of a NZESB is not a straightforward task; there are many elements that need to be solved and some of them conflict with others. In the literature, there are many studies that deal with the parametric optimization of the solar building design, analyzing one or more variables (Koc et al., 2003; Su, 2008; Mechri et al., 2010). In his review of computational optimization methods for sustainable buildings, Evins (2013) organized these studies into three: generic optimization, multi-objective optimization and algorithms. Brownlee and Wright (2012) focus their reviews on the existing approaches based on the analysis of multi-objective or multi-criteria optimization, using the Pareto approach. Recently, Attia et al. (2013) raise the possibility of using automated mathematical building performance optimization paired with simulation of buildings performance.

3. DESIGN METHODS FOR GENERAL NZESBS

In PSD, the architectural elements of a building are designed to collect, store, and distribute solar energy as light and heat. Some examples of PSD strategies include: extending the building dimension along the east/west axis to maximize solar light gain on the elongated south wall; sizing and shading windows to face the midday sun in the winter and be shaded in the summer; using shading elements (e.g. shrubbery, trees, trellises) to protect against solar heat gain in the summer while promoting it in the winter; and using insulation to reduce heat gain or loss (Kruzner et al., 2013; Rodriguez-Ubinas et al., 2014; Li et al., 2013). The key to designing a passive solar building is to best take advantage of the local climate (Yang et al., 2008). Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading (Pacheco and Lamberts, 2013; Norton, 2014; Koc et al., 2003; Aksoya and Inalli, 2006). In other words, two major ideas crucial to creating effective passive solar housing are orientation and materials. The orientation determines the potential use, or protection, of solar radiation and winds. The orientation can be analyzed in three levels: whole building, building's zones and glazed areas (Rodriguez-Ubinas et al., 2014). Passive solar buildings should be oriented to receive as much southern sun as possible. In the summer, the hot sun can be blocked by using overhangs or through landscaping like large foliated trees. In the winter, the sun should help heat the house because the sun angle is lower in the sky allowing more sunlight to hit the glazing more directly (Chiras, 2002).

Strictly speaking, integration with ASD is more difficult than integration with PSD. In addition to complying with the rules that apply to PSD, the following challenges must also be addressed. 1) Integration with the building. This problem exists throughout the entire life cycle of the building, i.e., from planning, design, construction, decoration, operation, management, reconstruction, and recycling up through demolition. The integrated design of the system must be compatible with the building. Designers and managers care most about the solar-energy product's shape, color, and compatibility with the building. Therefore, multi-color flat-plate solar-energy collectors and PV panels that can be integrated with a building are more popular. 2) The need for solar-energy equipment that fulfills the standard requirements for building materials, such as safety, durability, and ease of replacement. 3) Ventilation, cooling, and blockage problems of the PV/T equipment.

Generally, the integration of solar-energy equipment with a building includes the following aspects:

- The integration of the solar-energy-collecting end of the system with the building surface, such as the integration of the collector or PV panels with the roof, wall surfaces, balconies, and sun-shading equipment. This integration affects not only the aesthetics of the building but also the efficiency of the PV/T equipment.
- The integration of the solar-energy-transfer components, such as the pipes and wires, with the building. If not properly addressed, this element will not only affect the functionality and aesthetics of the building but will also waste collected solar energy.
- The integration of the solar-energy storage, such as the water storage tank and batteries, with the building. The storage component must also be carefully designed to prevent effects on the functionality of the building and the storage of the solar energy.

Therefore, novel general integrated design strategies for NZESBs include:

A. Passive solar design (PSD)

(1) Respect for climatic characteristics and implementation of integrated planning based on the environment.
(2) Building orientation.
(3) Distance between buildings.
(4) Building shape.
(5) Window to wall ratio.
(6) Building envelope.

B. Active solar design (ASD)

(1) Integration of the solar-energy-collecting end with the building surface, including integration with the roof and wall surface.
(2) Integration of the solar-energy transfer and storage equipment with the building.

4. DESIGN METHODS IMPLEMENTED IN NZESB PROJECTS IN THE NANJING CONTEXT

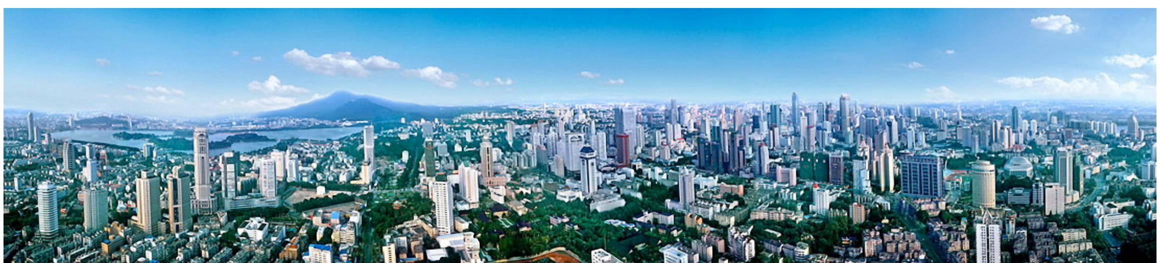
4.1 Nanjing context

4.1.1 Geography

Nanjing has a latitude of 32°N, a longitude of 119°E, and an average elevation of 30 m. With a total land area of 6,598 km^2, Nanjing is situated in one of the largest economic zones of China, the Yangtze River Delta, which is part of the downstream Yangtze River drainage basin (Wikipedia, 2015). The Yangtze River flows past the west side of Nanjing City, whereas the Ningzheng Ridge surrounds the north, east and south sides of the city. The dragon-like Zhong Mountain curls in the east of the city, whereas the tiger-like Stone Mountain crouches in the west of the city, leading to the popular saying “the Zhong Mountain, a dragon curling, and the Stone Mountain, a tiger crouching”. Figure 1 shows the geography of Nanjing, and Figure 2 shows a panoramic view of Nanjing.

Figure 1: Nanjing Area—Lower Yangtze Valley and Eastern China.

Figure 2: Panoramic view of Nanjing.



4.1.2 Climate

Nanjing has a humid subtropical climate and is under the influence of the East Asian monsoon. Nanjing experiences four distinct seasons, with damp conditions seen throughout the year: hot and muggy summers, cold, damp winters, and a reasonably long spring and autumn. Table 1 presents the climate data for Nanjing (1981–2010) (MBJP, 2015). The monthly mean temperatures range from 2.4°C in January to 27.8°C in July; the annual mean temperature is 15.46°C. The amount of incident solar radiation in Nanjing is generally high throughout March–October. The annual total solar radiation in Nanjing is 91.1 kWh/m^2, with approximately 1,982.8 h of sunshine. The mean monthly wind speed ranges from 2.45 to 3.08 m/s, and the annual mean wind speed is 2.69 m/s. The main wind direction in Nanjing is northeast in the winter and southeast in the summer.

4.2. PSD

4.2.1. Respect for climatic characteristics and the implementation of integrated planning based on the environment

(1) Integration with terrain topography

The topographical conditions are the most basic factor in determining the quality of BIPV design. It is typically not ideal to construct buildings in concave regions, such as valleys, lowlands, and the bottoms of ditches, because during the winter, the airflow will have a “frost cave” effect on such a building that may increase the building’s operational energy consumption. In

Table 1. Climate data for Nanjing (1981−2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average temperature (°C)	2.7	5.0	9.3	15.6	21.1	24.8	28.1	27.6	23.3	17.6	10.9	4.9	15.9
Average high (°C)	7.2	9.5	14.2	20.7	26.2	29.1	32.2	31.7	27.7	22.5	16.2	9.9	20.6
Average low (°C)	-0.7	1.4	5.3	11.0	16.5	21.0	24.9	24.4	19.9	13.6	6.8	1.1	12.1
Precipitation (mm)	37.4	47.1	81.8	73.4	102.1	193.4	185.5	129.2	72.1	65.1	50.8	24.4	1062.3
Relative humidity (%)	76	74	73	73	74	79	81	81	79	77	77	74	76.6
Mean sunshine (hours)	129.1	123.3	136.1	168.1	194.0	171.9	205.6	214.7	167.2	169.1	153.5	150.2	1982.8
Percent possible sunshine (%)	41	40	37	44	46	41	47	52	45	48	49	48	44.8
Mean solar radiation (kWh /m^2)	51.3	64.6	95.0	112.1	129.2	127.4	123.6	114.1	95.0	79.8	57.0	43.7	91.1
Mean wind speed (m/s)	2.6	2.8	3.08	2.95	2.85	2.8	2.7	2.72	2.62	2.45	2.6	2.6	2.69

Nanjing, it is preferable to construct buildings in areas close to water, as evaporation from the surface of the water can assist in carrying away heat. In addition, occupants of such a building will feel cooler and more comfortable when the cool air that has passed over the water enters the building. Therefore, designers should first carefully analyze and study the baseline conditions and understand the topographical characteristics of the construction site to facilitate the fabrication of an integrated design. The designers should also analyze and understand the ecological composition and distribution of the construction site, based on its topography, to protect and utilize the existing vegetation resources; the ability to do so is critical for microclimate optimization, soil and water conservation, and dust and noise prevention.

(2) Integration with climate conditions

Climate conditions are an essential component of the baseline conditions of a construction site. The climate conditions include the temperature of the region (cold or hot), the humidity conditions, the sunshine conditions, the perennial prevailing wind direction, the prevailing wind directions in the winter and summer, and the rain and snow conditions in the winter and summer. BIPV design utilizes such natural resources as sunshine and wind. Therefore, climate conditions have a decisive impact on BIPV design. It is imperative to analyze the climate conditions, such as the solar elevation angle and prevailing wind direction, when designing BIPV systems. In addition to the macroclimate conditions, the microclimate conditions at the construction site may also be relevant. A given region will exhibit different characteristics under different baseline conditions. For example, the ventilation paths within the construction site can be altered by such factors as the topography, vegetation, and height, density, location, and relative orientation of the surrounding buildings. The relief of the terrain and the blockage caused by high-rise buildings has a relatively large impact on the sunshine conditions. In short, designers should also analyze and study the effects of microclimate conditions (Lu and Xia, 2009).

(3) Integration with the surrounding building field

The surrounding building field is a baseline condition that cannot be ignored. The main energy source of BIPV technology is solar energy. Therefore, the spacing between each building and its surrounding buildings must provide sufficient sunshine access. When building blockage is considered, the optimum sunshine collection for a given building field may require various layout methods, such as staggering, enclosing, and setting back. When a wind-resisting or ventilating design is necessary because of certain climate conditions, it is vital to carefully analyze the distribution of the surrounding building groups to ensure the formation of a favorable wind environment within the building field.

4.2.2. Building orientation

The local climate conditions, geographical environment, and building area will affect the selection of the building orientation. Three aspects – daytime lighting, heat collection, and ventilation – typically collectively determine the optimum orientation of a building (Jin, 2011). The optimum building orientation differs in different regions. The maximum daily solar radiation is received by east-west vertical surfaces during the summer. Therefore, it is essential to circumvent east-west sunshine during the summer in regions with hot summers and cold winters. The building orientation should also be selected in such a way that it forms an angle with the prevailing wind direction during the summer and lies parallel to the prevailing wind direction during the winter (Jin, 2011; Zou, 2005). In practice, designers should consider every aspect, adjust the design approach to the local conditions, and select a building orientation that satisfies the requirements defined by production-related and domestic concerns. Solar-energy buildings are restricted by the PV system to a large degree. Solar-energy buildings should face in a direction with good solar radiation. Conditions permitting, solar-energy buildings should face south for optimum electricity-generation efficiency and output (Li and Hao, 2012) (Figure 3).

In Nanjing, daytime lighting is related to the sunshine duration and the external surface area of the building. Heat collection is determined by the amount of solar radiation, and ventilation strongly affects the indoor heat loss during the winter and the indoor natural ventilation during the summer and also affects the heat dissipation of the PV panels. Therefore, we determine the optimum building orientation based on these three aspects – daytime lighting, heat collection, and ventilation.

(1) Daytime lighting. When there is no blockage, there is over 9 h of sunshine in the range from 15° south by east to due south on the winter solstice. In the range from 20° south by east to due south, there is a long sunshine duration and large sunshine area during the summer. The sunshine duration on the summer solstice is more than 1.5 times the sunshine duration on the winter solstice. Thus, from the perspective of sunshine duration and area, the optimum building orientation in Nanjing is in the range from 15° south by east to due south.

(2) Heat collection. Solar-energy buildings should be oriented to ensure that the buildings receive as much solar radiant heat as possible and as rapidly as possible. During the winter, the solar radiant heat from 09:00 h to 15:00 h represents approximately 90% of the total daily solar radiant heat. Therefore, it is critical to ensure sufficient sunshine duration during

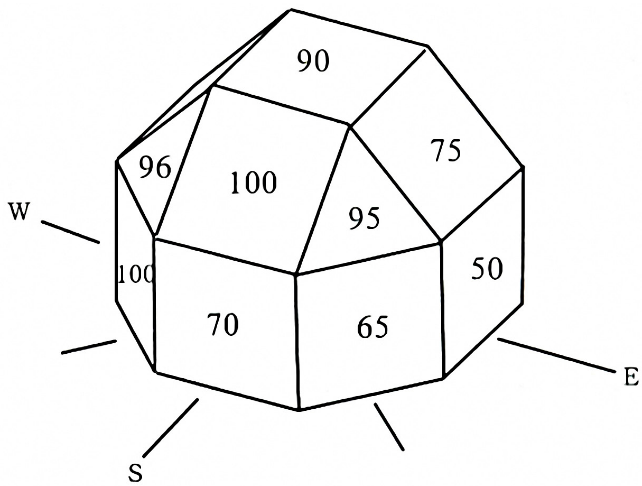


Figure 3: Relative electricity-generation outputs of a solar-energy battery in Nanjing with various orientations.

this period of time. To fully utilize the solar radiant heat, the building orientation should be adjusted depending on the characteristics of the solar-energy building. For example, in a school building, it is preferable to heat the classrooms as quickly as possible in the morning; however, these rooms are not used at night; thus, the orientation angle can be adjusted to 5-15° south by east. For residential buildings that are normally occupied at night, it is preferable for the solar radiant heat to enter indoors during later hours; thus, the orientation angle can be adjusted to 5-15° south by west (Wang and Zhao, 2002). The amount of direct solar radiation received by wall surfaces of every orientation has been obtained based on multi-year measurements in Nanjing. Wall surfaces that face south receive the maximum amount of solar radiation, and there is no radiation in the range from 30° north by east to 30° north by west during the winter. During the summer, wall surfaces that face south receive the maximum amount of direct solar radiation, whereas wall surfaces that face north receive the minimum amount of direct solar radiation. Solar irradiance is typically high in the morning and low in the afternoon. Therefore, the amount of solar radiation received by walls of given orientations in Nanjing can be ranked as follows (from highest to lowest): south > west > east > north.

(3) Prevailing wind direction. Nanjing is located in the northern sub-tropical monsoon climate zone. The prevailing winds during the summer are the southeast and east winds, whereas the prevailing winds during the winter are the northeast and east winds. The overall layout of residential building groups should be designed such that natural ventilation is optimized and buildings do not block the natural movement of the wind. The layout of residential buildings should be designed to face the prevailing wind direction in the summer. Sufficient ventilation spacing should be provided for different wind directions. Natural ventilation should be utilized to carry away excessive heat and create a comfortable thermal environment, thereby reducing energy consumption. Considering the prevailing wind direction in Nanjing, the optimum building orientation is southeast.

To summarize, three factors – daytime lighting, heat collection, and ventilation – should be considered simultaneously. For solar-energy buildings, the amount of solar radiation received by the building should be considered first. For this purpose, the optimum orientation in Nanjing should be in the range from 15° south by east to due south. The analysis presented above is based on vertical wall surfaces. Non-vertical wall surfaces and sloping roofs should also be analyzed to obtain a comprehensive understanding of the optimum building orientation.

4.2.3. Distance between buildings

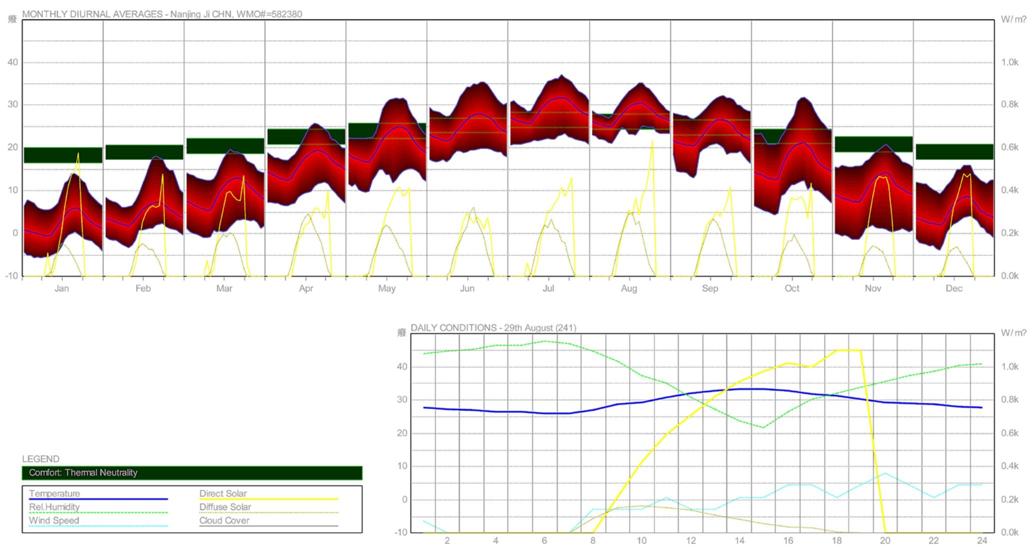
According to NMGF (2009), the distance between two buildings should be greater than 1.35 times the height of the southern building. However, the sunshine-spacing constraints of solar-energy buildings differ from those of traditional buildings. The amount of solar radiation received at a particular location differs immensely depending on the time of day. Therefore, even if the sunshine duration is the same, the amount of solar radiation received by the exterior surface of a building can be quite different at different times (Jin, 2011). In the diagram in the lower right-hand corner of Figure 4, the solid yellow line represents the hourly mean amount of horizontal direct solar radiation on a clear day (August 29) in Nanjing. The figure indicates that for the same sunshine duration (2 h), the amount of solar radiation received from 08:00 am to 10:00 am is nearly half the amount received from 10:00 am to 12:00 am. Therefore, sunshine duration is not the only factor that affects the performance of a solar-energy building; the amount of solar radiation received also plays a large role. Thus, in the design of a building layout, the spacing between the buildings should not be determined by sunshine duration alone; instead, sunshine quality should also be considered.

Because of the complexity of computing the amount of solar radiation, it saves time to use computer software for the analysis and determination of a suitable amount of solar radiation. The software is simple to master, and the data it generates is intuitive. In practice, for simple city environments, it is unnecessary to analyze the solar radiation in great detail to determine the building spacing; instead, only suitable time periods need be considered. In the diagram in the lower right-hand corner of Figure 4, the solid yellow line indicates that on August 24, the solar radiation quality was high and stable from 11:00 am to 06:00 pm in Nanjing. When seasonal variation is considered, the quality of the solar radiation is generally high from 10:00 am to 04:00 pm. For complex city environments, computer-aided software can be used to solve problems of this type.

4.2.4. Building shape

From the perspective of solar-energy utilization, a southward-facing wall surface should be designed to be able to absorb more solar energy than its heat loss; the absorbed heat can then be used to offset the net load of the building. If the thermal quality of all wall surfaces except the southward-facing one is the same, then the net load of the building is directly proportional to its area. Therefore, from the perspective of building energy conservation, we cannot simply assume that a smaller total area of the building envelope is better; instead, we should assess the issue of building energy conservation based on the criterion that the southward-facing wall surface should be as large as possible, whereas other surfaces should be as small as possible, i.e., the surface-area coefficient (the ratio of the area of all other surfaces to the area of the southward-facing wall surface) should be as small as possible for a passive solar-energy building. In addition, the surface-area coefficient of the building should also be used to study the effect of the building shape on energy conservation. In Nanjing, to obtain more solar radiant heat and reduce energy consumption, a cuboid shape with a long east-west axis is the optimum building shape, followed by a square shape. A cuboid shape with a long south-north axis is the worst building shape for energy conservation. Sunshine conditions are the most important concern for the design of solar-energy buildings. It is preferable to select a building shape that is beneficial for PV electricity generation and installation. In regions with hot summers and cold winters, such as Nanjing, the building shape should be designed to not only block windows from sunlight but also to avoid blockage from the shades on the

Figure 4: Analysis of the annual meteorological data of Nanjing.



PV panels. From the perspective of building energy conservation, it is also essential to reduce unnecessary small-scale roughness, control the shape coefficient, and reduce heat loss.

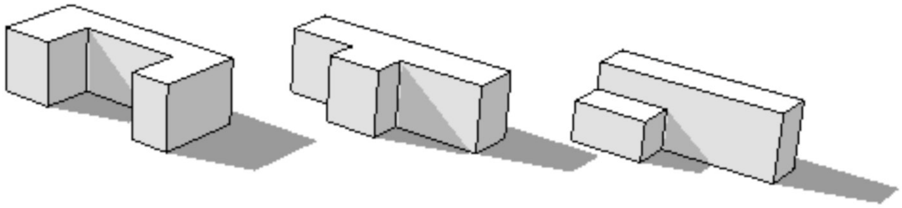
(1) Shape coefficient (SC)

A proper SC should be selected for each building to reduce energy loss. The SC refers to the ratio of the exterior surface area of the building that is in contact with the outdoor atmosphere, F, to the building's volume, V. The physical meaning of the SC is the exterior surface area of the building envelope that is required to enclose an indoor unit volume of the building. A larger SC indicates that more of the area of the unit building space is in contact with the outdoor atmosphere, and thus, the heat-loss area and the energy consumption are greater. In Nanjing, the SCs of traditional single-family houses, multi-story residential buildings, and high-rise buildings are 0.55, 0.40, and 0.35, respectively (MOHURD, 2010). However, solar-energy buildings rely on sunshine for energy. Therefore, to maintain a relatively low SC, it is ideal to increase the areas of the southward-facing wall surface and roof to capture the maximum amount of solar radiation. For instance, dot-style buildings can be connected in a row to reduce the total exterior surface area while increasing the southward-facing area exposed to solar radiation.

(2) Plane form

The plane layout of a building should not be a severely self-blocking shape, such as a U-, T-, or L-shape (Figure 5). However, the integration of different shapes is a common approach to building design. Concave and raised surfaces on the façade can also enrich the building shape. Because it is impossible to entirely avoid these common self-blocking layouts, computer-aided analysis can be used to reduce the area blocked by the shade cast by the building as much as possible and to properly arrange the location and angle of the PV panels. Additionally, the plane layout can be designed such that the protruding volume faces north, ensuring that there is no blockage on the southward-facing façade so that as many PV components as possible can be installed on this face.

Figure 5: Analysis of self-blocking U-, T-, and L-shaped buildings.



4.2.5. Window-to-wall ratio (WWR)

The requirements of the WWR for solar-energy buildings are complex. First, the effect of the window size on direct heat collection must be considered. Second, windows are heat-gain components, but they also consume a large amount of energy. Third, the effects of the size and location of the wall between the windows on the heat collected and stored by the wall must be considered. In Nanjing, the WWRs of north, west and east, and south sides of building envelopes are 0.40, 0.35, and 0.45, respectively (MOHURD, 2010). In passive solar-energy buildings, however, the south WWR of a residential building is approximately 50%, which is slightly higher than the standard requirement for building energy conservation. For school buildings, it is ideal to heat the rooms as quickly as possible in the morning; therefore, the south WWR is approximately 55%. For windows that face in other directions, the window area should be reduced, provided that the requirements for the indoor light environment can still be met. Measures should be taken to decrease the heat-transfer coefficient of the windows, reduce air infiltration, and increase heat preservation at night to reduce energy consumption.

4.2.6. Building envelope

The building envelope is the physical boundary between the indoor and outdoor environments, and it serves multiple functions. Even primitive building coverings were designed to protect occupants from wind and rain, preserve heat, and provide insulation, protection against sunlight, and ventilation. The design of building envelopes is constantly developing and changing over time. The functions of the building envelope have been drastically expanded and improved to provide a comfortable indoor thermal environment for the building's occupants. With the rapid development of modern technologies in particular, the impact of the building envelope on energy conservation has been continually growing. The concept of the building envelope has been revolutionized with the development of energy-saving modifications to the traditional building envelope and the emergence of new energy-saving structural joints. Improvements in materials and structural technologies have enhanced the heat preservation, insulation, and sealing performances of the traditional building envelope. Newly developed heat-preserving roofs and wall bodies as well as heat-preserving doors and windows offer superior comfort while simultaneously satisfying the requirements of energy conservation. Furthermore, the building envelope itself has been revolutionized to offer additional functions. The modern building envelope not only satisfies the traditional requirements of functionality but also provides a platform for the collection of natural, renewable resources. For example, to satisfy the requirements of solar-energy collection, storage, and distribution, interlayers are formed in the building envelope, and pipes are laid inside the roof, wall bodies, doors, windows, and floors to transfer, store, redistribute, and utilize energy. Both the wall bodies and floors can be used as storage for solar energy. Floor heating, which has been adopted for the purpose of energy conservation, imbues the floor, which is generally in direct contact with the human body, with additional functions that are beneficial to comfort and health. All of these developments have diversified the functions of the building envelope. The structure of the building envelope has become increasingly complex as technology has advanced. The use of novel materials, structures, and technologies in building envelopes is becoming increasingly important for the reduction of building energy consumption. The objectives and demands of building-envelope design have become increasingly clear and thus have become an aspect that cannot be ignored (Liu and Qin, 2005).

The heat transfer coefficient U of the building envelope is regulated by the new energy-conservation standards of Nanjing (see Tables 2 and 3), with which the design of solar-energy buildings must comply to ensure the effective use of solar energy. The requirements for solar-energy buildings with respect to materials and structure include the method of insulating the exterior walls and roof, the material selection, and the methods of structure fabrication, which must satisfy certain thermal-performance indices and guarantee good insulation and heat-storage properties. The sum of the heat consumption attributable to the windows and to air infiltration constitutes over 50% of the heat consumption of the entire house and thus represents a vulnerability in terms of energy conservation. Therefore, research efforts should be directed toward energy-conservation possibilities for doors and windows. It would be ideal to design doors and windows in such a way that they could serve as heat-gain components.

4.3. ASD

4.3.1 Determination of the PV plate inclination angle

Selecting a suitable angle for the installation of a PV system plays a key role in the amount of power that can be generated from the PV panels. The optimal angle of a PV installation depends on the geographic location and local climate conditions, such as the latitude, mean monthly sunshine (hours), and mean monthly solar radiation (kWh/m2). Nanjing is selected as the simulation site in an EnergyPlus V7.2.0 computation model (EnergyPlus, 2014). The capacity of the installed photovoltaic system is assumed to be 11.0 kWp according to the parameters of typical traditional single-family houses and the climate conditions of Nanjing City (see Table 1), and the different angles selected for the PV power generation system are listed in Figure 6. The PV modules are assumed to always run when the total incident solar power is greater than 0.3 W. If the incident solar radiation is less than 0.3 W, then the modules produce no power (EnergyPlus, 2014). As seen in Figure 6, no significant difference is found in the total annual electricity generation capacity of the PV system when positioned at angles

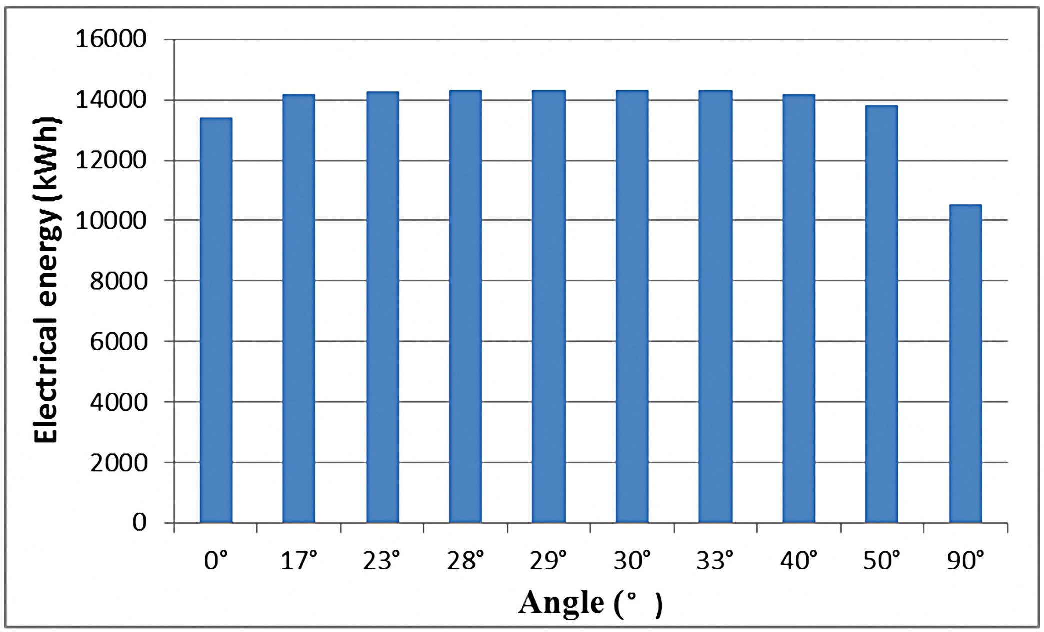
Table 2. Heat transfer coefficient U limits for roofs, walls, and doors (MOHURD, 2010).

	location	$U[W/(m^2K)]$
SC≤0.4	Roofs	0.8
	External walls	1.0
	External doors	2.0
SC>0.4	Roofs	0.5
	External walls	0.8
	Doors	2.0

Table 3. Heat transfer coefficient U limits for external windows (MOHURD, 2010).

	WWR	U[W/(m²K)]
SC≤0.4	WWR≤0.2	4.7
	0.2<WWR≤0.3	4.0
	0.3<WWR≤0.4	3.2
	0.4<WWR≤0.45	2.8
	0.45<WWR≤0.60	2.5
SC>0.4	WWR≤0.2	4.0
	0.2<WWR≤0.3	3.2
	0.3<WWR≤0.4	2.8
	0.4<WWR≤0.45	2.5
	0.45<WWR≤0.60	2.3

Figure 6: Annual electrical energy production using different inclination angles.



ranging from 17 to 40°. Combined with considerations such as architectural design style and construction difficulty, 17° is the ideal installation angle in Nanjing.

4.3.2. Integration of the solar-energy-collecting end with the building surface

4.3.2.1 Integration with the roof

The integration of the solar-energy-collecting end of an ASD system with the roof has certain unique advantages. The sunshine conditions are excellent; they are not affected by the building orientation and are not easily blocked. Thus, solar radiation can be abundantly received. Additionally, the adverse effects of the wind will be reduced when the solar-energy structure is installed close to the roof. Solar-energy collectors, such as PV/T panels, have a certain insulation effect. The primary feature of a solar-energy collector that is integrated with a sloping roof is the seepage-prevention insulation layer that is laid on top of the waterproofing-treated roof. Solar-energy-collecting components are installed on top of this insulation layer. The proper use of materials allows the cost of this type of roof to be lowered. In addition, the cost per unit area of the solar-energy conversion equipment can also be dramatically reduced when the complex functionality of the roof is utilized effectively. Figure 7 presents several methods of integrating solar-energy collectors with the roof that are suitable for the climate conditions of Nanjing. The solar-energy collection system, domestic hot-water system, and radiant floor-heating system can be integrated into one system; these three components are connected via heat exchangers, pumps, pipes, sensors, and controllers (Figure 8). The solar-energy collection system can also be integrated with the HVAC system (Figure 9). In Figure 9, when there is sunshine during the winter and the air temperature at the back of the BIPV/T system reaches a certain value, the air is exhausted via the exhaust fan into the HVAC system for heating. During the spring and summer, when there is a need for heating, the BIPV/T pre-heated air can also be exhausted into the HVAC system. When there is no need for heating (e.g., in the summer), the hot air can be exhausted to the outdoors via the exhaust fan. In regions where there is a large day-night temperature difference, the air at the back of the BIPV/T system may decrease to a value suitable for cooling because of the cooling effect of the nighttime radiation; in this case, the cooled air can be exhausted into the indoors via the HVAC system.

Figure 7: Several methods for integrating solar-energy collectors with the roof.

(a) Residential house

(b) Public building

(c) Integration with tiles

(d) Direct replacement of tiles

Figure 8: Schematic diagram of a solar hot-water system.

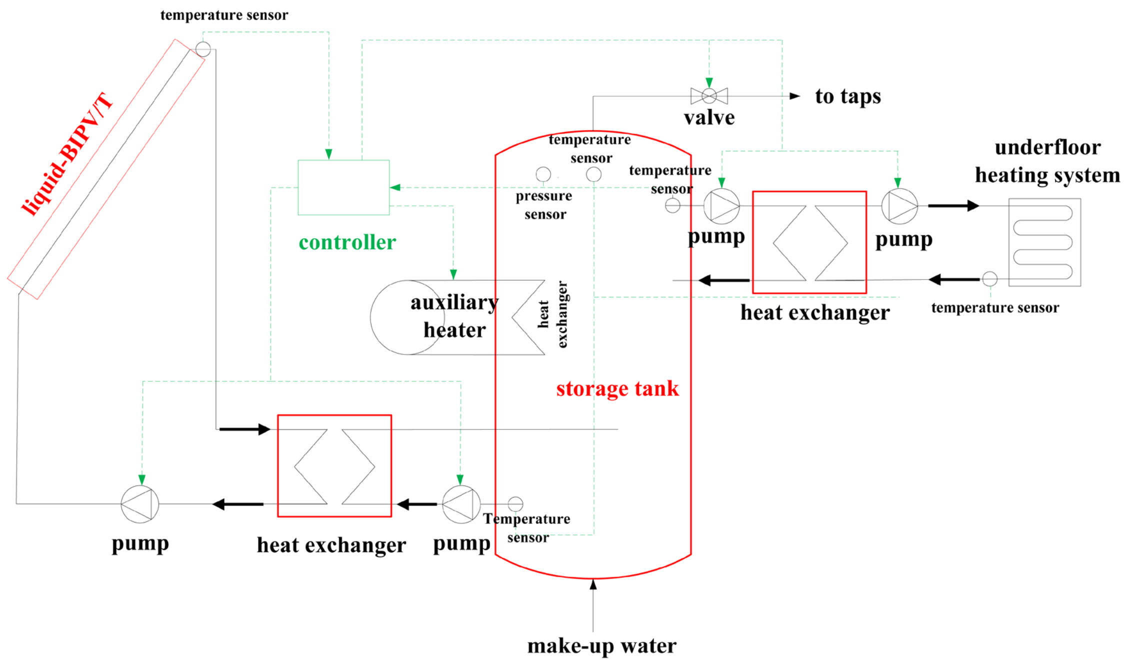
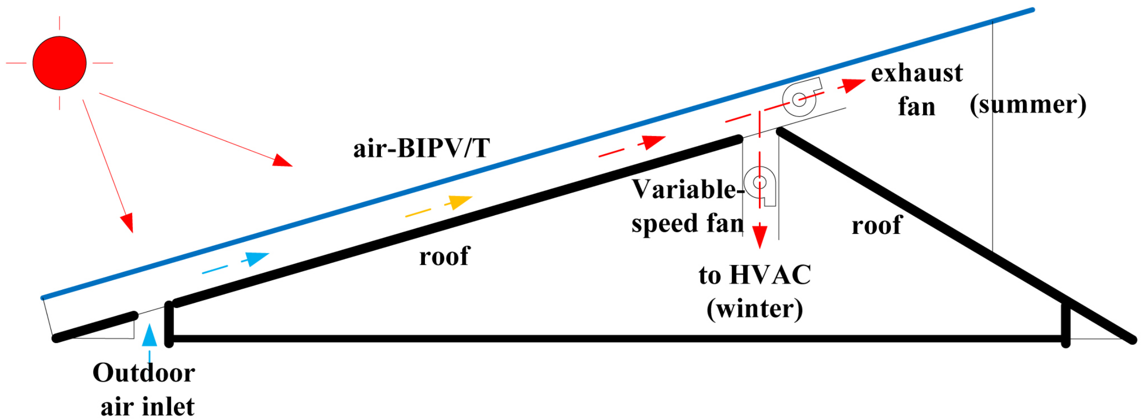


Figure 9: Working principle diagram of the air-BIPV/T roof system (winter conditions)



4.3.2.2 Integration with the wall surface

In Nanjing city, the population is large, but the land is limited. Therefore, buildings, including both residential and public buildings, are generally multi-story high-rises. For such buildings, the wall surface is the largest exterior surface that is in contact with solar radiation. Therefore, the integration of solar-energy collectors with the wall surface is an important approach to designing NZESBs.

(1) Integration principle

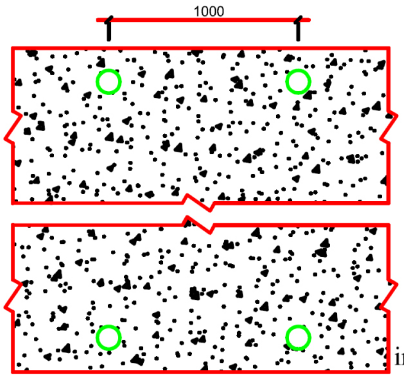
From the perspective of solar-energy utilization, a solar-energy collector can be combined with a heat-collecting wall design so that the entire wall body can serve as the collector, or the solar-energy collector can be integrated with the exterior wall surface as an attachment.

The latter integration method is typically used for the façades of residential buildings. Currently, the typical story height of multi-story high-rise heated residential buildings is between 2,800 and 3,000 mm, and the fence height of the balcony is between 900 and 1,200 mm. To achieve and standardize the integration of collectors with multi-story high-rise heated residential buildings, the collectors must first become a structural component of the buildings and be integrated into the building module. Therefore, it is recommended to use heat-collection units that consist of two types of collectors – one with a width of 900 mm and a height of 600 mm and the other with a width of 900 mm and a height of 800 mm. The collector installation area in a multi-story high-rise heated residential building is determined by the usable wall area of the southward-facing wall. For multi-story high-rise heated residential buildings with a depth of 12-15 m, the ratio of the building area to the entire southward-facing wall area is between 7.9:1 and 5.3:1. However, the entirety of the southward-facing wall cannot be used for collector installation in multi-story high-rise heated residential buildings. If it is, the entire system will be in disorder, and the overall appearance of the building will also be adversely affected. When the two aforementioned types of collectors – one with a width of 900 mm and a height of 600 mm and the other with a width of 900 mm and a height of 800 mm – are used, the ratio of the building area to the collector area ranges from 16:1 to 20:1 for those multi-story high-rise heated residential buildings with an emphasis on a transverse appearance, whereas the ratio of the building area to the collector area ranges from 14:1 to 16:1 for those multi-story high-rise heated residential buildings with an emphasis on a vertical appearance. These types of solar-energy collectors can be installed on the exterior wall surface as attachments, and they form a certain pattern on the façade that can be designed to serve as a pleasant aesthetic element. Color is an important factor that influences a person's disposition toward the appearance of the building. The use of unique color designs is one method of creating an identifiable façade and is also the premise on which the territorial sentiment of the residential area is based. The outer surface of a traditional collector is typically coated in black to increase the absorption of solar energy, but black collectors may affect the aesthetics of a building and may also have an oppressive effect on the residents when used on a large scale. These concerns are detrimental to the popularization of solar-energy buildings. Therefore, other colors that complement the color of the major structure of the building may be used in combination with black or other dark colors to enrich the appearance of the building façade. Although the use of mixed colors may incur a certain degree of sacrifice in the absorption of solar energy, it can break up the monotony of the landscape, alleviating the adverse effects thereof and creating an amenable building environment (Zhu, 2013).

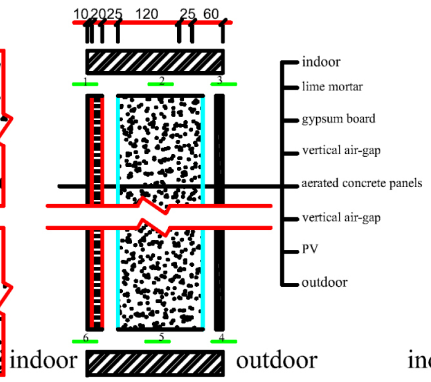
(2) Double-channel solar wall (or improved opaque ventilated
PV double-skin façade (DSF))

Double-channel solar wall meant that two air layers existed between the interior and exterior walls. At locations near the floor and ceiling, the air layers were connected with a 60-mm-diameter circular channel. The horizontal spacing between circular channels was 100 mm (see Figure 10 (a)). Switches were set on the circular channel (labeled #1 to #7 on the circular channels in Figure 10). These switches can be either manual or electric and can be used to guide air flow. The materials, structure, and dimensions of the wall are shown in Figure 10 (b). The current invention had positive effects such as regulating the effect of heavy thermal wall bodies for indoor thermal environments. As is known, a heavy thermal wall body is beneficial to maintaining a stable indoor thermal environment and is favorable in buildings that need sustained heating and cooling. A heavy thermal wall body also can protect a building's indoor

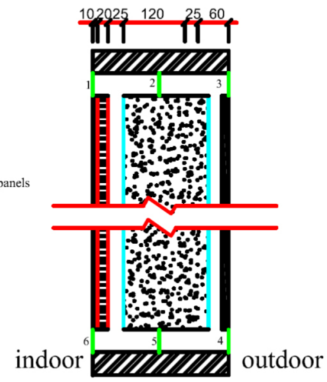
Figure 10: Double-channel solar wall.



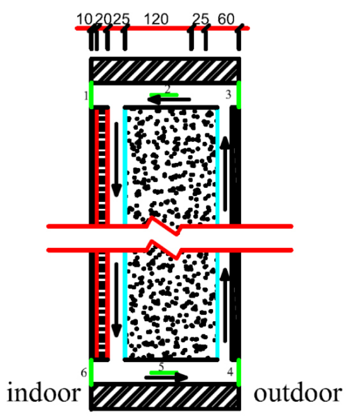
(a) Position of circular channel on the façade wall.



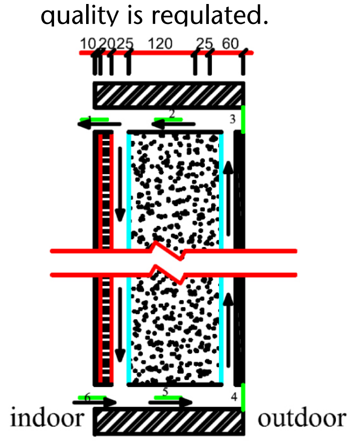
(b) During spring and autumn season, the impact from walls is reduced and air quality is regulated.



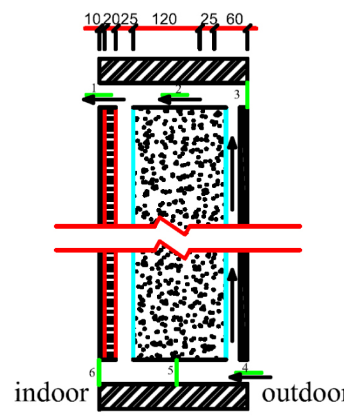
(c) Two-layer air insulation structure.



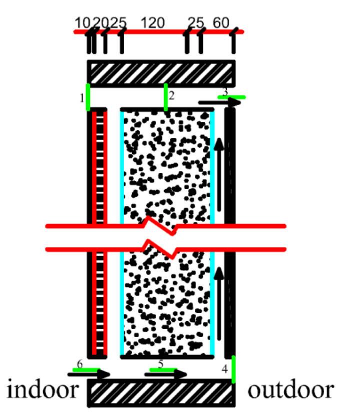
(d) During the winter season, when there is good daytime sunshine, solar energy can be connected from the external to internal walls with no air exchange.



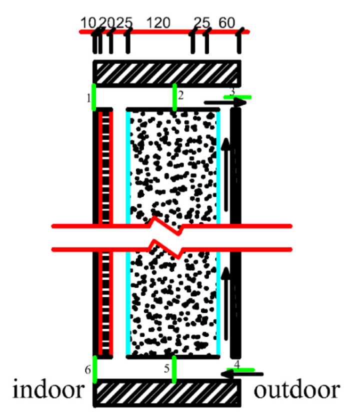
(e) During the winter season, when there is daytime sunshine, solar energy can be connected from the exterior to indoors and interior walls with no air exchange.



(f) During the winter season, when there is daytime sunshine, solar energy can be connected from the exterior walls to indoors with simultaneous fresh air introduction.



(g) During the summer season and daytime, indoor waste, indoor waster heat and air can be vented to the outdoors.



(h) During the summer season and daytime, a good heat insulation effet can be observed.

environment against the effects of drastic changes in the outdoor air temperature caused by harsh climates. However, when the outdoor temperature is mild, the above design elements can be used to adjust the indoor physical environment and therefore save energy. For example, it is already warm outdoors during the spring (especially during the day), but people still feel cold indoors, partly because the wall still stores a great deal of cold air. This phenomenon is very common in areas without winter heating. In autumn, it may be very cool outdoors (especially at night), but people still feel hot indoors, partly because the wall body still stores heat. This phenomenon is very common in buildings without summer cooling. If the exterior wall uses a Double-channel air layer structure and all the switches are turned on as, shown in Figure 10 (b), it can reduce the thermal mass effects of the walls. Therefore, it is easier for the wall to get warmer in spring and cool off in autumn. Because this is a passive technique, it does not consume energy. Of course, if all the switches are turned off, the two air layers will become good-quality insulation layers. As shown in Figure 10 (c), the average overall heat transfer coefficient U is approximately 0.34 W / (m2 • K). Because both the interior and exterior walls can have heat insulation, it is helpful for the buildings to maintain (especially intermittent) heating and cooling. Another positive effect of the Double-channel air layer structure is its solar energy utilization. PV components convert solar energy into electricity, whereas T components convert solar energy into heat. The storage and use of electricity is relatively simple. The use of heat is elucidated as follows: When there is bright sunshine during the daytime in winter, solar energy can be connected to the inner wall (Figure 10 (d)), indoors and to the inner walls (Figure 10 (e)), or to the indoors and simultaneously introduce fresh air (Figure 10 (f)). During the daytime in summer, solar energy can be used to extract indoor waste gas and heat to the outdoors (Figure 10 (g)) or emit heat from the outer air layer to the outdoors (Figure 10 (h)). Finally, this system can improve indoor air quality. Because the air layer and circular channels are connected both indoors and outdoors, by using switch regulation, the air pressure differential can be used to introduce fresh air or expel indoor gas waste, as shown in Figure 10 (b) (f) (g).

(3) See-through PV double-skin façade (DSF)

The large amount of air-conditioning energy consumption can be partially attributed to the extensive use of glass curtain walls currently used in modern buildings. The solar heat gains and heat losses via glass curtain walls share a large portion of office building air conditioning loads. Hence the need to develop new types of glass curtain walls is apparent. Although an air-tight DSF reduces heat losses in winter, the ventilated DSF is even more suitable for buildings in subtropical climates found in locations such as Nanjing. The airflow in the DSF significantly reduces the heat gain and therefore building cooling loads for most of the year. Additionally, a ventilated DSF integrated with PV glazing not only can reduce the energy use of air-conditioning and artificial lighting, but also generate electricity in situ. Chow et al. (2010) reviewed the energy performance of various advanced window technologies, including a series of single-glazed windows and double-glazed windows. For single-glazed windows, the simulation results showed that PV laminated glass provided the best solar heat gain coefficient (SHGC) compared with clear glass and the low-e coating glass. However, the low-e glass had a lower U-value than that of the PV laminated glass because of its lower infrared emissivity properties. Similar results were found for corresponding double-glazed windows. Compared with double-glazed clear glass and low-e glass windows, the double-glazed PV glass window reduced room heat gain by 200% and 53%, respectively. The SHGCs of the single-glazed and double-glazed PV laminated windows were 0.28 and 0.177, respectively, which are far less than those found for the clear glass windows. Based on the above findings, it can be concluded that PV laminated windows are more suitable for use in subtropical climate conditions and the low-e glass windows in cold climate conditions (Peng and Yang, 2013).

The overall energy performance of a ventilated PV window to be used in office buildings was evaluated (Chow et al., 2007). It was found that see-through a-Si glazing was more aesthetically and optically pleasing in the working environment than opaque crystalline silicon (c-Si) glazing. A comprehensive model including the energy balance, heat transfer as well as the optical performance of the ventilated PV window was developed by the authors. The simulation results based on the net energy provision by the PV modules and energy saving in artificial lighting and air conditioning, indicated that an optimum ventilated PV window of 2 m (W) x 1.5 m (L) could save up to an annual total of 885 kWh electricity in Nanjing. The impact of naturally-ventilated PV glazing on air-conditioning load reduction has been reported by Chow et al., (2009a). The annual simulation results, based on the weather data of a typical meteorological year (TMY) in Nanjing, showed that when compared to a common absorptive glazing, the use of naturally-ventilated PV glazing could reduce the air-conditioning energy use by 31%. Generally, the PV-DSF system consists of a double-glazed see-through a-Si PV module, an inward opening window as well as an air-flow duct between the two layers (Peng and Yang, 2013), as demonstrated in Figure 11.

(4) Integration with balconies

Figure 11: The scheme of the see-through ventilated PV-DSF system.

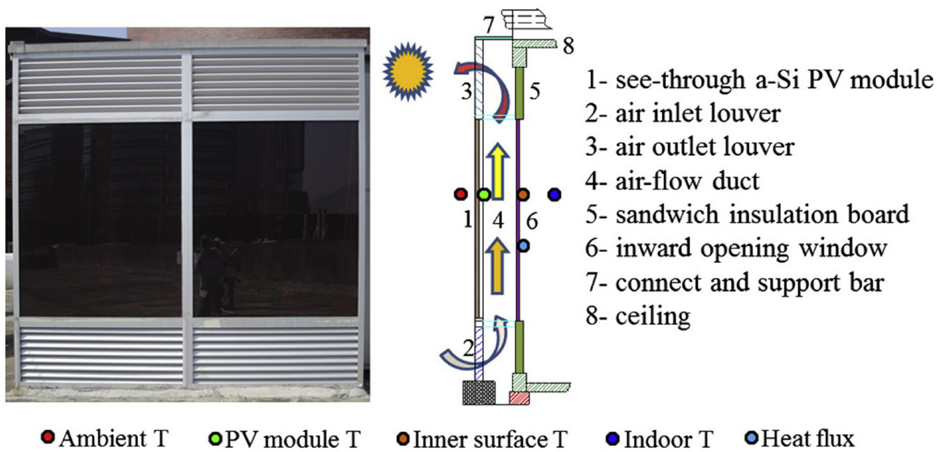


Figure 12: Solar hot water heaters and PV panels on buildings.

(a) Solar hot-water heaters integrated with balconies.

(b) PV panels integrated with balconies.

For a residential building, a collector that is located on the roof also has some inherent defects. For residents that live on the lower levels, there is a relatively large heat loss because of the long connection pipelines required. It is also difficult for residents to gain access to the roof to examine and maintain the collector. In addition, the pipelines from the residential units are exposed to the exterior and arranged in a disorderly fashion, which detracts from the original appearance of the building. By contrast, heat-collection equipment that is installed on the balconies is easier to examine, has shorter connection pipelines, and requires less civil engineering effort. Figure 12a shows the integration of solar hot-water heaters with balconies. The water tank is located on the balcony, and the collector is attached to the exterior of the fence, forming an element of a lively façade. Figure 12b provides a view of PV panels that are integrated with balconies, producing electricity and simultaneously enriching the façade of the building.

However, hot-water heaters that are integrated with balconies on southward-facing walls in regions at relatively low latitudes have certain shortcomings, namely, low heat collection during the summer season and low natural water pressure. Therefore, such hot-water heaters can generally be best used in high-latitude regions. Furthermore, a direct hot-water system that does not require a water tank to be installed on the heater or an additional small water pump may be used to address the aforementioned problems. If the water heater is installed on the balcony, then the balcony fence may be considered integrated into the system to form a multi-functional building component, thereby achieving the perfect integration between the solar hot-water heater and building. In this manner, the use of solar radiation can also be maximized to satisfy various types of water demands (Figure 12a). Sun-shading panels may be integrated with windows and walls to form unique aesthetic patterns for solar-energy buildings.

(5) Integration with sun-shading devices

This type of integration not only preserves all of the functionality of sun-shading plates but also ingeniously uses the sun-shading plates to block sunlight to the greatest possible extent. PV panels with a high conversion rate are installed on a sun-shading device to combine their sun-shading and electricity-generating functions. There are two types of external sun-shading plates – auto-tracking and fixed. Auto-tracking sun-shading plates automatically track the sunlight based on the changes in the elevation and orientation angle of the sun to achieve the maximum electricity-generation potential. However, the technology of auto-tracking sun-shading plates is complex. Fixed sun-shading plates are installed at the optimum sun-facing

Figure 13: Solar-energy collectors that are integrated with sun-shading devices.

(a) Fixed sun-shading devices .

(b) Smart, controllable sun-shading devices.

angle based on the geographical location of the building to achieve the maximum mean electricity-generation potential and the best shading effect and thus achieve high cost performance. Figure 13a shows that the optimum sun-facing angle (□CAE) in Nanjing is 30°, the extended length (AE) of the shading devices is 600 mm, the edge length (CD) is 800 mm, and the length (AB) of the shading devices = CD+DF+FG+GH+HI, in which DF and GH are the widths of the windows and FG is the width of the wall between the windows. Figure 13b shows smart, controllable sun-shading devices that are integrated with PV panels.

The entire design of such a sun-shading system is based on the PV component. The question of how to design a sun-shading system based on the features of various solar-energy materials has become key to the success of sun-shading system designs.

1) The first step in designing a PV sun-shading system is to select a solar battery panel based on the electricity-generation requirements, the designer's requirements for the external appearance, and the structural requirements of the sun-shading system. For example, for high electricity-generation capability, a crystalline silicon panel should be selected; if the architect requires a specially shaped sun-shading system, then a flexible, thin panel should be used. A light curtain wall requires a light sun-shading component; therefore, the most advanced solar-energy technology should be used to produce the maximum possible amount of electricity in the minimum possible area.

2) A PV battery panel has a certain number of modules. During the initial stage of design, the number of battery arrays is determined (how many are in series and how many are in parallel). Therefore, the size of the external sun-shading component can be essentially determined after the panel is selected. The PV sun-shading component not only provides the sun-shading function but also supports the PV battery component. Therefore, the maximum electricity-generation requirement should be fully considered during the design process. Generally speaking, PV sun-shading components are larger in size and are more widely spaced than general sun-shading components so that the maximum electricity-generation capacity can be achieved and sun blocking can be reduced.

3) PV components are dark in color and are heat-absorbing materials. Therefore, cooling is even more important for PV sun-shading components than for general sun-shading components. The pressure difference generated by the thermal pressure or wind pressure can be exploited to establish a rapid air flow to solve the cooling problem. In practice, there should be sufficient distance between the sun-shading component and curtain wall; an open-ended design should be used for the sun-shading component, such as a fishbone style, and a perforated structure is recommended for the non-PV portion of the sun-shading component to achieve the maximum cooling area.

In short, the integration of a BIPV system with sun-shading devices to create a multi-functional building component permits the utilization of one component for multiple applications; it uses space effectively and simultaneously provides energy, perfectly integrating aesthetics with functionality.

4.3.3. Integration of the solar-energy transfer and storage equipment with the building

After the solar energy is collected, it must be transferred to the storage component of the system and then further transferred to the application component. If the pipelines of a solar-energy system and its equilibrium equipment, its storage equipment, and the layout of its examination and maintenance space are considered only after the construction of the building is complete, then the following problems may arise: 1) If the pipelines are overly long, then the cost of the hot-water-system preservation will rise or the loss of the PV wiring system will increase, reducing the efficiency of the solar-energy system. 2) The pipelines are directly exposed to outdoor air and solar radiation; thus, mechanical failure, corrosion, and aging of the coating are more likely to occur. 3) The layout of the pipelines necessitates destroying the existing building envelope (i.e., it is necessary to drill through the already constructed roof, floors, and walls) and reduces the insulation, sound-insulation, and waterproofing performances. 4) There may be a lack of space for maintenance and examination access and equipment (making it necessary to install the equipment to the structure's ladders, hooks, pulleys, and faucets for cleaning water), and there may be no baffle plate to prevent a broken collector from falling, making it impossible to guarantee the convenience and safety of maintenance operators and pedestrians. 5) The system may affect the designed indoor layout and detract from the external appearance of the building. Therefore, although the focus of research on the integration of a solar-energy system with a building is the collector component, the layout of the tube wells, holes, and platforms must be first addressed during the design process to ensure the integration of the solar-energy system with the building and its maintainability during operation. The design includes the determination of the method of connection to the water and electricity systems; the layouts of the water pipelines, cable holes, and equilibrium equipment; the layout of the water tanks; and the size and location of the maintenance tube wells and platforms (Kuang, 2006).

5. CONCLUSIONS

The connotations and denotations of the term NZESB have been in constant flux because of continuous developments in solar heating technology, solar PV technology, building energy-storage technology, regional energy-storage technology, and energy-management systems. In this paper, we focused on innovative strategies for implementing NZESBs in Nanjing – integrated architectural design, including PSD and ASD. The conclusions are presented below.

(1) PSD

- One should avoid constructing buildings in concave regions.
- It is preferable to construct buildings in areas close to water.
- The amount of solar radiation on walls can be ranked (from highest to lowest) as south > west > east > north.
- To receive sufficient sunshine and use natural ventilation during the cooling season, the optimum building orientation is in the range from 15° south by east to due south.
- The building's south face should receive sunlight between the hours of 9:00 A.M. and 3:00 P.M. (sun time) during the heating season.
- In the design of a building layout, the spacing between the buildings should be greater than 1.35 times of the height of the southern building. Moreover, the spacing between the buildings should not be determined by sunshine duration alone; instead, sunshine quality should also be considered.
- Interior spaces requiring the most light and heating and cooling should be along the south face of the building, and lesser used spaces should be located on the north face.

- The SCs of single-family houses, multi-story residential buildings, and high-rise buildings are 0.55, 0.40, and 0.35, respectively
- The WWR of north, west and east, and south sides of building envelopes are 0.40, 0.35, and 0.45, respectively
- The limitation of the heat transfer coefficient U for roofs, walls, and doors and windows decreases with an increasing SC. The limitation of the heat transfer coefficient U for windows similarly decreases with the increase of WWR.

(2) ASD

- 17° is the optimal inclination angle for a PV plate.
- PV can be integrated with or directly replace tiles.
- BIPV/T can be integrated with the domestic hot water system and HVAC system, but redundant thermal power collected in the summer must be exhausted outdoors.
- The ratio of the building area to the collector area ranges from 16:1 to 20:1 for multi-story high-rise heated residential buildings with an emphasis on a transverse appearance, whereas the ratio of the building area to the collector area ranges from 14:1 to 16:1 for multi-story high-rise heated residential buildings with an emphasis on a vertical appearance.
- Double-channel solar walls are perfect to resolve the conflicts among collecting solar thermal energy, the wall's thermal mass and insulation, and maintaining the indoor air quality.
- DSFs are also recommended because they can produce energy and increase the air-conditioning's efficiency.
- Solar collectors can be integrated with balconies.
- If integrated with sun-shading devices, the optimum sun-facing angle is 30°, the extended length of the shading devices is 600 mm, and the edge length is 800 mm.
- The integration of the solar-energy transfer and storage equipment with the building should be considered.

Therefore, it is feasible that NZESBs can be realized in Nanjing if solar energy technologies are appropriately integrated with the characteristics of Nanjing's geography, climate and buildings.

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