Chapter 6

A BIM-Based Study on the Sunlight Simulation in Order to Calculate Solar Energy for Sustainable Buildings with Solar Panels

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Additional information is available at the end of the chapter

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Abstract

With the construction industry moving rapidly toward building information modeling (BIM), pursuit of sustainability in buildings will require the use of renewable energy analysis tools in the early stages of building design, as well as establishment of BIM-compliant practices. Planning for sunlight is essential to obtain sustainable benefits from the sun in and around buildings, which process requires understanding and making allowances in building attributes that affect how sunlight can be used. This chapter presents a model for simulation of sunlight's effect on building design under BIM technology while calculating the potential energy capacity of roof- and façade-mounted photovoltaic solar panels. For this purpose, it is suggested in the study to use statistical construction data as well as 3D digital models obtained from BIM software (Revit and THSWARE) to measure the useful sunlight duration and derivable energy of representative sample of buildings. By measuring the solar energy absorbed by the building facades, the electricity converted from solar energy and collateral savings can be calculated. Taking the cost of solar panels and feasibility of the project into consideration, this study shows using solar panels of a certain quality contributes greatly to social, economic, and environmental benefits.

Keywords: BIM, sunlight, solar energy, solar panels, sustainable design

1. Introduction

As many nations face pressure from shrinking energy resources, awareness and concerns about sustainable building design are growing. As a result, green building that applies sustainable design is holistic concept increasing significance in the construction sector. Policies that advocate energy conservation for green buildings have been promoted, wherein the building energy efficiency upgrade program for reducing power consumption in buildings is one of the crucial contents outlined in the policy. Green building's three main pillars are environmental, economic, and social in aspect. Considered a paramount method to maintain quality of life, designed to replace use of environmentally harmful products, we could say that sustainable design is an important process involving science and arts from all fields [1]. In China, estimates indicate that more than 80% of annual new buildings and over 95% of existing buildings have high-energy consumption designs [2]. Low energy-efficiency buildings account for 98% of more than 4 × 1010 m^2 of urban buildings in China [3]. As well, the advent of "green legislation" together with increased green building construction is forcing architects, planners, and builders to consider the environmental impact of buildings they design and construct [4]. Aside from the moderate amount of sunlight required for the health and comfort of occupants, solar radiation is particularly useful as an energy resource [5]. Apart from this, sunlight provides light more efficiently than electric light sources, while producing less heat for the same amount of light. With the development of sustainable design, researchers are attaching much more importance to energy savings related to sun exposure on buildings, an important component of sustainable development. One of the performance analyses done by architects is to predict how buildings are performing in terms of their luminous environment as a result of daylighting [6]. If energy savings from harvesting sunshine on buildings are considered in the building design stage, an optimal energy design can be selected.

Demand for solar power has expanded in recent years for domestic and industrial needs. Solar power is produced by collecting sunlight and converting it into electricity, which is normally done by use of large, flat solar panels composed of many individual solar cells. Solar arrays are most often located remotely, although urban sitting is becoming more popular as well. As the cost of solar energy falls, more and more buildings are being outfitted with photovoltaic systems and some even generate more electricity than they use, which structures are called "energy positive," an impressive feat. In some areas, solar-enabled buildings actually turn a profit from surplus energy, which is sold to local utility companies and fed it onto the grid. In practice, photovoltaic materials (like solar panels) are normally used to replace conventional building materials in parts of the building envelope such as roofs, skylights, and facades. As a principle or ancillary source of electrical power, solar panels are increasingly incorporated into the construction of new buildings, although existing buildings may be retrofitted with similar technology.

However, current analysis of solar energy extraction in comparison with the complexity of sunlight models needed for energy calculations clearly reflects the limited use of building information modeling, as well as the lack of effective visualization techniques. Sunlight analysis is performed by hand calculations or by computer simulation tools. In the process of hand calculation, the preparation of initial data can be a very lengthy and laborious, consisting as it does mostly of manual or semimanual translation from architectural model data to simulation data, which often results in numerous coding errors [7]. To solve the problem, graphic user interfaces have been created in simulation tools for defining model geometry. In addition, 3D digital technology, such as building information modeling (BIM), has been applied to sunlight simulation. BIM integrates all kinds of relevant information from construction projects, while related software enables energy consumption to be predicted and adjusted during the design stage, thus providing great convenience for sustainable design.

The objective of this research is to simulate sunlight's effect on building design using BIM technology and to calculate the potential energy capacity of surface-mounted photovoltaic solar panels. To measure the useful sunlight duration of a representative sample of buildings, statistical construction data were applied, as well as 3D digital models obtained from BIM software (Revit and THSWARE). Among the factors considered were building type, orientation, roof and surfaces, location, shading, and climatic information. Subsequently, the solar energy potential of a structure can be estimated by calculating the effective sunshine duration on surfaces available for solar panel installation, from which the economic benefit of surface-mounted solar panels can be evaluated. Furthermore, the cost of solar panels is considered here in determination of cost-benefit value and increased sustainability of solar panel installation on the sample building.

2. Background

2.1. BIM and sustainable design

With the importance of BIM becoming increasingly appreciated, BIM and sustainable design strategies in the building industry have drawn more and more attention. A number of published papers on BIM-related sustainable design have focused mostly on energy usage analysis alone [8]. Wang and Xuan [9] suggest a BIM-based parametric design method to establish the BKE (Bio-inspired Kinetic Envelop) system combined with utilization of solar radiation to make buildings acclimate to temperature swings, thus minimizing the energy needs. Wong and Fan [8] find two most significant benefits of BIM for sustainable building design: integrated project delivery (IPD) and design optimization. Hardin [10] established three main areas of sustainable design with a direct relationship to BIM, which are "material selection and use," "site selection and management," and "systems analysis." In addition, Azhar and Brown [11] investigate the development of a conceptual framework to illustrate the use of BIM for sustainability analyses throughout the project life-cycle.

In previous study on the integration BIM and building performance, it has been indicated that BIM can aid in the sunlight analysis [12]. BIM technologies offer new insights into the dynamic relationship and specificities of sunlight conditions and the individual building's use and properties, helping us identify the balancing points of solar gains and daylight conditions resulting from urban geometry [13]. Welle et al. [14] designed an automated product model decomposition and re-composition methodology for BIM-centric climate-based daylighting simulation called the BIM-Centric Daylight Profiler for Simulation (BDP4SIM). Joo et al. [15] developed a tool capable of analyzing various design schemes during the early stages of design by building a reasonable BIM data system for sustainability analysis and using the architectural BIM model to carry out sunshine and energy analysis in a Web environment. Generally, two main methods are used for sunlight analysis in building design. One method is the graphing method, which includes normal shadow-graph, pole shadow-graph, instantaneous shadow-graph, and hours shadow overlay. The other method is the modeling test, which performs analysis based on a scale-model of buildings and a sundial. Though the sun spacing coefficient table was widely used in China during the late 1990s, table's usefulness is restricted by some limitations that require compliance during early building layout design, where the sun spacing factor is applied in parallel with layer settings for the building. Shadow graphs created for software applications offer a new detailed representation of shadow constraints. Overall, the solar analysis model using BIM has advantage of being importable to related software, generating shadow animations for target periods and simulation results that can be saved on BIM database for property management and quality control.

2.2. Solar energy and buildings

Solar energy is the portion of the sun's energy available at the earth's surface for useful applications, such as exciting electrons in a photovoltaic cell and indoor illumination. Solar energy system is currently the most widely installed renewable energy system in the building sector in an effort to reduce the energy consumption of buildings [16]. Developing the calculation model for solar energy in buildings is helpful to describe the mathematical relations between the solar energy and building attributes such as orientation, location, height, area, etc. An important aspect in calculating solar energy is the accuracy of the developed model, which is evaluated using initial data input [17]. The large volume of residential building construction in recent years and the deficit of conventional energy sources justify any initiatives conducive to the construction of self-sustainable residential buildings that are capable of producing their own energy for illumination, HVAC, electrical appliances, etc. [18].

The design of alternative energy devices is a predictable way to develop a wide range of new technologies for a more sustainable future. To achieve energy sustainability, the installation of building-integrated solar panels is a viable option. Solar panels are a type of semiconductor device that converts the energy from sunlight into electric energy. Solar panels do not use chemical reactions to produce electric power, and they have no moving parts. Rooftop and vertical surfaces on buildings are convenient installation position to supply solar energy to meet growing energy demands. Depending on material, solar panels can be classified into different kinds: silicon solar cell, compound solar cells, polymer solar cell, nanocrystal solar cell, organic solar cell, and plastic solar cell. Many of factors play part in determining the practicality of a given solar installation and the selection of solar panels. One major factor is the available sunlight. Considering the sun is what combines with the photovoltaic panels to produce the energy, an area rich in sunlight is highly desirable [19]. Glasnovic and Margeta [19] performed an analysis of photovoltaic pumps versus diesel pumps and concluded that photovoltaic pumps were more efficient than diesel pump. Photovoltaic solar cells are thin silicon disks that convert sunlight into electricity. These disks act as energy sources for a wide variety of uses, such as rooftop panels on buildings. The past decade has seen a remarkable evolution in mainstream silicon solar cell technology, documented by greatly increased production volumes and greatly reduced costs.

By using solar panels, electricity costs from outside sources are negated by the electricity produced by the building's surface installations. Additionally, emissions that are the environmental cost of burning coal to produce electricity are significantly reduced. Although solar energy is renewable, more efficient than fossil fuel and environmentally friendly, it is costly. According to Borenstein [20], the high cost of power from solar panels has been a major deterrent to the technology's market penetration, while the current direct cost of photovoltaic solar panels is widely acknowledged to be much greater than fossil fuel generation or many other renewable energy sources. The initial cost of the solar panels may be expensive, but it is the only cost plus their installation provides potential complete relief from electric utility costs. Maintenance can be perceived as an added cost, but in reality, all the panels need is dusting and/or washing. Therefore, the cost analysis of solar panels is an important factor to be considered when making decisions about solar systems in building design.

3. Methodology

3.1. Analysis method

The importance of developing an integrated approach for potential solar energy analysis of buildings using BIM technology has been established above. Integration of quantitative results for energy consumption by building objects and 3D visualization of spatial modeling requires a well-managed framework that combines sunlight simulation and the calculation of solar energy. Such a framework should be designed to transmit data in the basic steps used for developing an effective building sunshine model. Our research aims to estimate the solar energy consumption and cost analysis of photovoltaic solar energy systems that could be installed on the rooftops and vertical walls of buildings with the use of BIM for building performance simulation and sunlight analysis. In order to estimate total harvestable solar energy and to analyze cost of photovoltaic systems, the following four-level research framework was executed (see **Figure 1**):

Level 0: CAD drawing. The building object selected in this study was described according to construction drawings made on AutoCAD Architecture. Original 2D image information is provided in regard to points, lines, surfaces, text, etc.

Level 1: 3D modeling. In the course of preparing 3D building models, the virtual data are exported from the CAD system to a suitable CAD exchange format (e.g., DWG), then processed to re-build the plan in a 3D environment with the aid of BIM software system (e.g., Revit). The BIM 3D model is used to generate traditional building abstractions: plans, sections, details, and elevations. 3D models produced using BIM also possess interactive viewing properties.

Level 2: Sunlight simulation. Building environment analysis (like energy analysis and sun-hour analysis) is normally carried out as part of BIM based design. In this step, the representative rooftop and surface area of the sample building are selected. Sunlight simulation is made by input of the Industrial Foundation Classes (IFC) model into the sunlight analysis program, followed by additional related analysis on occlusion relationship, sunshine duration sheet, isohel map, shadow outlines, etc.

Level 3: Solar energy analysis. The main objective of Level 3 is to assess the geometric characteristics under sunlight models in solar energy analysis. This step obtains dimensions of the useful rooftop and vertical surfaces, where photovoltaic solar panels could be installed, from which the solar energy generation potential and the energy costs are calculated for the sample building.

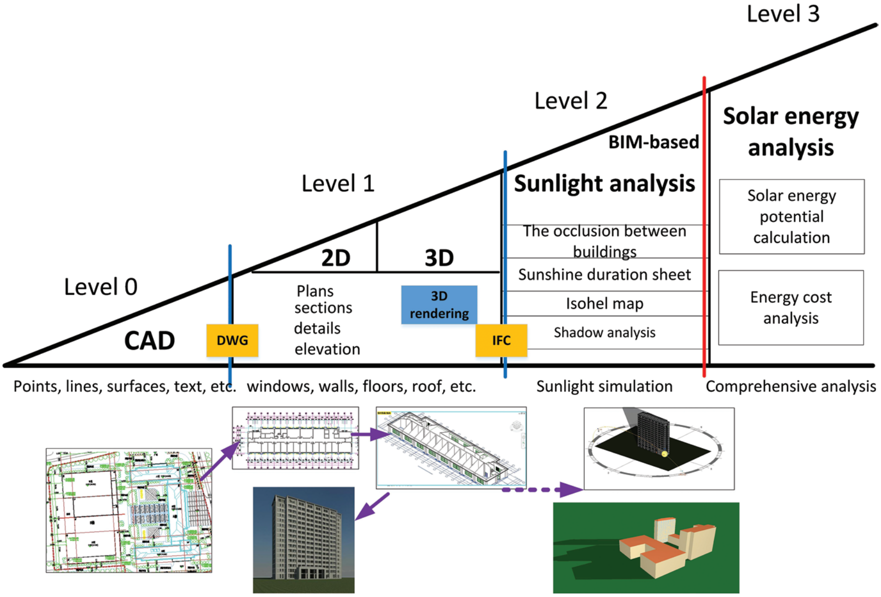


Figure 1. Overview of four-level research framework for solar energy analysis.

3.2. Simulation models and settings

The study case in this paper refers to the Civil Building located on the Jiulonghu Campus of Southeast University in Nanjing, China. The Civil Building is designed to be a 16-storey, technology-rich learning environment, hosting over 1000 classroom seats in-state-of-the-laboratory classrooms, with conference rooms and professors' offices. The building will be home to undergraduate and graduate students in Department of Civil Engineering and all staffs in that department. Surrounded by the newly-built Traffic Building, Laboratory Building (Building B) and Lecture Hall (Building A3), the sample building is sheltered from the sun in this sunlight simulation and analysis. The sample building's structure information is listed in **Table 1**.

In order to achieve the objective stated above, a schema converter is proposed in this paper to facilitate the information exchange between BIM tools and sunlight modeling tools. In this

Name	Status	Height (M)	Floor areas (M2)	Orientations	Use
Civil Building	Proposed	61.89	16559.05	South by east4°	Teaching
Building A3	Built	18.44	3747.08	South by east4°	Lecture and conference
Traffic Building	Built	54.67	20419.2	South by east 4°	Academic
Building B	Built	25.6	13210.18	South by east 4°	Teaching

Table 1. Information of civil building, traffic building, building A3 and B.

study, the technology for systematic sustainable design modeling that enabled sunlight simulation and analysis is driven by a Revit platform, which is able to design all of the required processes and components from a 2D building digital drawing to a 3D model. This platform uses an attribute driven modeling engine to simulate overall building design and create the network of building element relationships (inferred by the software and/or set by the user). The relationship network is the basis by which to achieve information exchange and to later generate sunlight analysis results.

3.3. Building modeling process

In this study, Autodesk Revit is applied to simulate the sample building in 3D with 2D drafting elements and export building data from the model database, as a BIM solution to plan and track various stages in the building's lifecycle from the concept to construction for architectural, structural and MEP design. The modeling process refers to generation of completed 3D models and related building information database. In general, the modeling process begins by analyzing initial data in 2D CAD environment followed by creation of Revit-parametric families, and then establishment of the Revit 3D model based on which the IFC file is transformed and exported.

3.3.1. Initial data analysis

Initial data acquisition is a process of selecting, extracting, and transforming information from the source systems. In BIM modeling, initial data are normally prepared using AutoCAD drawing, which stores layers, floors, rooms, and footprints of the buildings in 2D environment on dwg and dxf formats. The boundaries of building elements need to be determined carefully in the AutoCAD process. The optimized AutoCAD drawing will be imported into Revit in terms of creating a geometric model.

3.3.2. Revit model establishment

A key understanding is that both standard and custom-building elements can be added in Revit model by using a predefined family that is composed of elements with common parameters, allowing users to make design changes easily and to manage projects more efficiently.

Family classification and building component attribute setting are key phrases of the modeling stage. In Revit, basic building components/elements like walls, windows, doors, and so on are created using the responding category including families and family types. The building component or model element which is defined in terms of family contains a broad array of information in addition to dimensional aspects. At this stage, the initial parameters are set to define family attributes. The initial settings will affect the project environment and include types for levels, grids, drawing sheets, and viewports. The project model can be established using the generic families in Revit. After identifying the position of the building components inserted on an axis, the defined family types can be load one by one from top down, and the attributes of the model elements can be modified separately.

3.3.3. IFC transformation

Using the Revit model requires transformed of data into the IFC format for compatibility with THSWARE software, based on which sunlight would be simulated in this study. The IFC file format is designed to provide interoperability between different BIM-related software applications. Enabling importing and exporting of building objects and their properties, the IFC format covers core project information such as building elements, geometric and material properties of building products, etc. The major computer-aided design (CAD) systems, such as THSWARE, can transfer imported IFC data directly to the database elements, using a parsing subsystem described by Revit families of building elements.

3.4. Sunlight simulation settings

The Ministry of Construction for China has published a series of national codes, such as Code of Urban Residential Areas Planning and Design (GB 50180-93), Standard for Daylighting Design of Buildings (GB/T 50033-2001), Residential Building Code (GB 50368-2005), and others. With these codes, the Ministry of Construction for China has clearly prescribed requirements for the standard of available sunlight for buildings design and placement. On the basis of Code for Planning and Design on Urban Residential Areas (GB 50180-93) (2002), there is a code for sunlight standard in clause 5.0.2.1. Therefore, the sunlight simulation and analysis in this study conform to clause 5.0.2.1: The sunlight standard of buildings should accord with the regulations in **Table 2** and conform to the prescribed regulations listed below under particular conditions:

1. The sunlight on the Winter Solstice day in residential buildings for elderly people should be no less than 2 h;
2. Increasing of facilities outside the original design should not lower the original sunlight standard of adjacent residence;
3. In terms of reconstruction of old dwellings, the sunlight standard of new residential buildings could be reduced conditionally but should not be reduced to less than 1 h on the Great Cold day (Jan 20/21).

Architectural climate zone	**I, II, III, VII Climate zone**		**IV Climate zone**		**V, VI Climate zone**
	Large city	**Medium/small city**	**Large city**	**Medium/small city**	
Day for sunlight standard	Great Cold day Either 20 or 21 January depending on the year			Winter Solstice day Either 21 or 22 December depending on the year	
Sunlight hour (h)	≥2	≥3		≥1	
Effective sunlight hour	8 am~4 pm			9 am~3 pm	

Table 2. Sunlight standard of civil building.

A city with a population of one-half million people can be defined as a metropolis. Reaching that population standard, together with high level of economy, politics and culture, Nanjing qualifies as a metropolis that belongs to climatic region III, and its sunlight standard is therefore no less than 2 h of sunshine on the Great Cold day. The sunlight standard in Nanjing Technical Codes of Sunlight Analysis Management for High-Rise Building (Nanjing codes for sunlight in buildings) is adopted in this study, of which the Clause 4 (sunlight analysis object) is used for the planning of high-rise buildings.

The Civil Building with 16 stories is a high-rise building, whose planned design and blueprints are considered to conform to the prescribed regulations. Here, the sunlight simulation and analysis standard is defined in Clause 6 (technical parameter) of Nanjing Technical Codes of Sunlight Analysis Management for High-Rise Building. The start and ending times for sunlight analysis are 8 a.m. and 4 p.m. on Great Cold day, 9 a.m. and 3 p.m. on Winter Solstice day, while the calculating point is 32.04 north latitude (Nanjing), the sampling distance is 1.0 m, the time interval is 10 minutes, and the sill height is 0.9 m. The finalized start and ending time of the sunlight simulation are 8 a.m. and 4 p.m. on the Great Cold day, while standard for access to sunlight should be no less than 2 h on that day.

3.5. Sunlight simulation

The Sunlight-analysis function module of THSWARE which has an AutoCAD-oriented user interface focus on parameter setting and shelter influences. Before sunlight analysis begins, the THSWARE model is required to set some parameters including sunshine duration, window exposure, sunshine standards, simulation accuracy, etc.

3.5.1. Occlusion between buildings

For analysis of a building’s window-accessible sunlight, a precondition is to identify occlusion by neighboring structures that prevents penetration of light into living space. In **Table 3**, building occlusion relationships focus on occasions when objects block sunlight (in **Figure 2**). By overlaying the sun occlusion path of a particular sample building, the area of sun blockage could be determined by projecting lines out from this point to each surrounding object. Since the shading diagram will be constructed with all buildings, the result is always a hard-edged shading block with the observation window shaded or not.

3.5.2. Sunshine duration sheet

The sunshine duration sheet on THSWARE is designed to measure the length of time which the sun shines through a given window.

Occluded building	Occlusion building
Civil building	A3, B, Traffic building

Table 3. Occlusion between buildings.

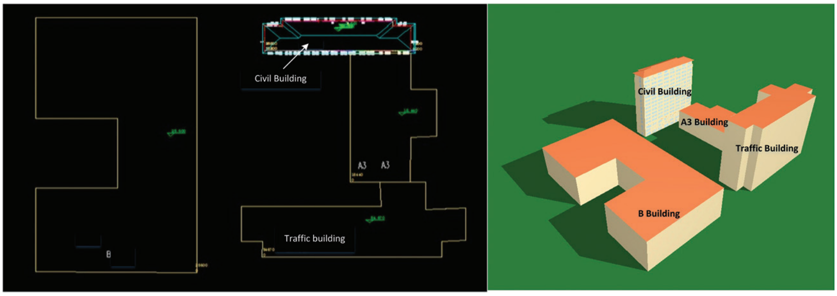


Figure 2. The occlusion between sample buildings.

Table 4 shows the simulation results of sunshine duration on the first floor of the Civil Building 8:00 AM–4:00 PM on Great Cold day, which is the last solar term in 24 solar terms and comes around January 20th or 21st each year. According to Code for Planning and Design on Urban Residential Areas (GB 50180-93) and Nanjing Technical Codes of Sunlight Analysis Management for High-rise Building, sunshine duration on Great Cold day cannot be less than 2 h. In **Table 4**, a red figure represents a window exposed to sunshine less than 2 h sunshine a day, while blue represents a window with 2 h sunshine on that day.

Analysis results are configured in the BIM model by marking the windows' positions as in **Figure 3**, where the blue line on the south face of the Civil Building represents the boundary of windows receiving less than 2 h of sunshine on Great Cold day. The serial number of the windows are 1/33-1/34, 2/36-2/38, 3/36-3/38 (windows no. 33-34 on the first floor, windows no.36-38 on the second floor, and windows no.36-38 on the third floor). On the North face of the Civil Building, the red line identifies windows areas, where the sunshine duration is zero on Great Cold day. The serial number of the windows are 1/4-1/13, 1/36-1/41 (windows no. 4–13 and No. 36–41 on the first floor).

3.5.3. Isohel map

An isohel is a line on a solar map which connects points that receive equal amounts of sunshine. In this study, two types of isohel map were produced to measure sunshine intensity: an isohel map for building elevation and an isohel map for the building plan.

3.5.4. Isohel map of building elevation

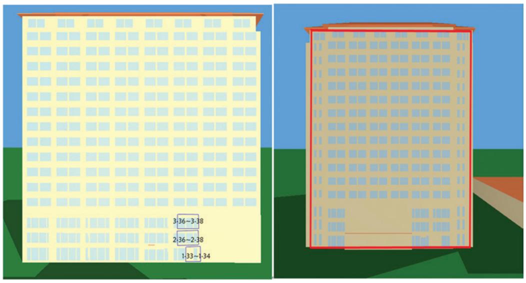
In this step, isohel maps were produced from average values of light intensity at measuring points for the area between the isohels on the building elevation including all four cardinal points, as shown in **Figures** 4 and **5**, wherein a, b represents the serial number of window located in ath floor is b.

Figure 4 shows the isohel map for the 6th–9th windows on the 10th–12th floor of the South elevation of the Civil Building. The white figures calculated in the isohel map indicate areas that will receive approximately 8 h of sunshine on Great Cold day.

Floor	Window position	Window height (m)	Sunshine duration	
			Time	Effective time duration (hour)
1st	1	0.50	12:01–14:15	02:14
	2	0.50	08:55–08:59 09:51–14:19	04:32
	3	0.50	09:55–14:23	04:28
	4–13	0.50	0	00:00
	14	0.50	09:57–14:29	04:32
	15	0.50	09:11–09:15 09:59–14:35	04:40
	16	0.50	09:19–09:21 10:05–14:41	04:38
	17	0.50	10:07–14:45	04:38
	18	0.50	10:11–14:49	04:38
	19	0.50	10:13–14:53	04:40
	20	0.50	10:15–14:59	04:44
	21	0.50	10:15–15:01	04:46
	22	0.50	10:15–15:05	04:50
	23	0.50	10:23–15:09	04:46
	24	0.50	10:39–15:13	04:34
	25	0.50	10:53–15:15	04:22
	26	0.50	11:07–15:19	04:12
	27	0.50	11:15–15:21	04:06
	28	0.50	11:35–15:25	03:50
	29	0.50	11:51–15:27	03:36
	30	0.50	12:21–15:29	03:08
	31	0.50	12:45–15:31	02:46
	32	0.50	13:35–15:35	02:00
	33	0.50	14:13–15:35	01:22
	34	0.50	15:07–15:41	00:34
	35	0.50	08:00–12:01	04:01
	36–41	0.00–0.50	0	00:00

Table 4. Sunshine duration sheet of first floor.

Figure 5 shows the isohel map for 18th windows in 16th floor on east elevation of Civil Building. The blue figures calculated on the isohel map indicate areas that will receive more than 4 h of sunshine on Great Cold day, while green figures indicate areas receiving more



(a) (b)

Figure 3. The windows which do not reach the sunshine requirement. (a) South face, (b) North face.

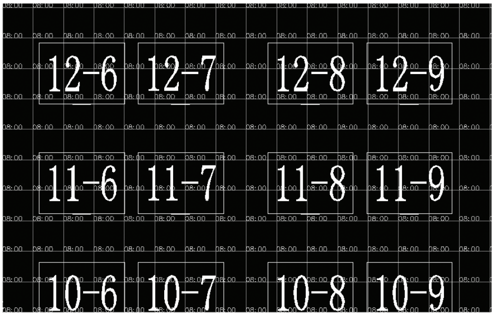


Figure 4. Isohel map for windows in 10th–12th floor on south elevation of civil building.

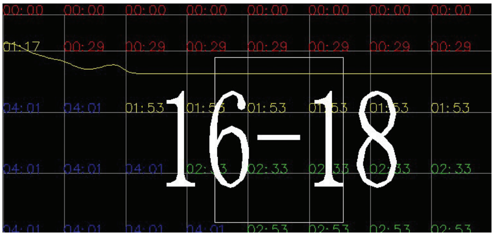


Figure 5. Isohel map for the 18th window on 16th floor of the East elevation of the building.

than 2 h of sunshine and yellow figures indicate areas with more than 1 h of sunshine. Note that the area of red figures that receives less than 1 h of sunshine is mainly the result of shadowing by the building roof.

3.5.5. Isohel map of building plane

The isohel maps of building planes, which is similar to the map of building elevation, apply plane partition according to sunshine duration. The isohel lines shown in building plane mode indicate clearly those areas receiving equal amounts of sunshine.

Figure 6 above shows division on the basis of sunshine duration of a given building plane. The image shows analysis of sunshine duration on the first floor, in which dark blue represents areas receiving sunshine for more than 4 h, light blue represents more than 3 h of light, green represents more than 2 h, yellow represents more than 1 hour, and red represents less than 1 h of light. Results indicate very little sunshine on the North plane, and the windows no. 33-34 have a sunshine duration of zero, due to occlusion by the Traffic Building (Building T) from the south, which is in accordance with the analysis above.

3.5.6. Area analysis

Area analysis (in **Figure 7**) yields sunshine duration values for different areas within the same plane of a building. Theoretically, analysis of isohel lines is in accordance with area analysis, which facilitates cross-confirmation. The object of sunlight analysis in the image above is the first floor, from which the obtained data represent the length of time that area receives sunshine. The results accord with actual conditions, where N represents sunshine duration greater than or equal to N, but less than N + 0.5 and N+ represents sunshine duration greater than or equal to N + 0.5 but less than N + 1.

3.5.7. Shadow outline and shadow range of building

1. Occlusion of and by the Civil Building

Figure 8 clearly shows the shadow size at 11:00 of each building in this study. Three windows of the South side on floors 1-3 of the Civil Building are shaded by the Traffic Building (Building T), falling it far from the insolation standards on Great Cold day of 2 h.

2. Shadow range of the Civil Building

Figure 9 shows shadow range of Civil Building and its continuous shadow envelope on the ground on Great Cold day.

3.5.8. Screenshot of sunshine simulation

This research section examines sunshine of the Civil Building 8:00–16:00 h (in **Figure 10**). The shadow area is relatively large around 8:00, while most windows on the North side can

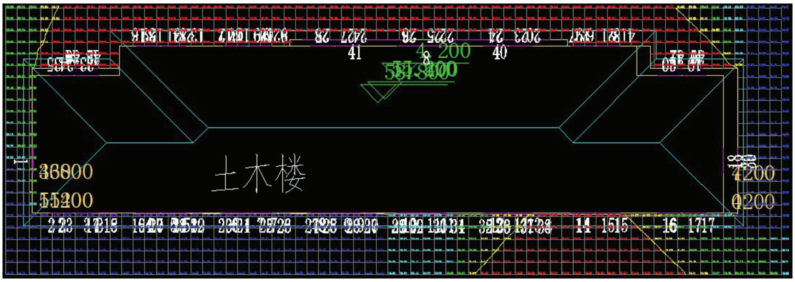


Figure 6. Isohel map of building plane.

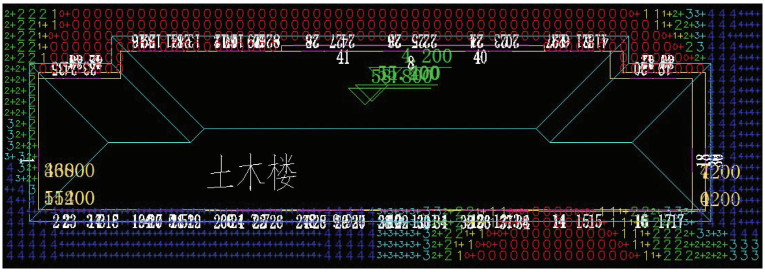


Figure 7. Area analysis map.

Figure 8. Shadow outline of civil building.

Figure 9. Shadow range of civil building.

receive sunshine. The shadow area at 12:00 is much less than any other time of the day, which means that windows receiving sunshine increase and sunshine duration is much longer. 16:00 is the latest time point used for analyzing sunshine duration on the Civil Building on Great

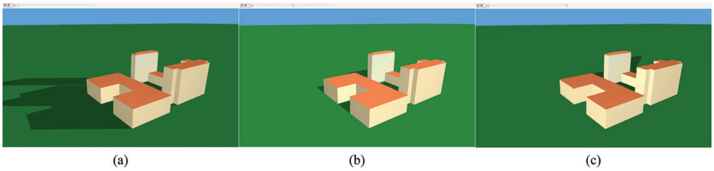


Figure 10. Sunshine simulation at (a) 8:00 A.M., (b) 12:00 P.M., and (c) 16:00 P.M.

Cold day, and the shadow is accordingly stretches. According to the three images above, no windows on the nightside can receive sunshine at any time of the day, which is in accordance with the sunshine analysis of windows as shown above.

4. Results and discussion

4.1. The assumption of energy calculation

In this study, the analyzed building is treated as one system, where the amount of solar energy gained by any facade of building is the main research target. Related data used to calculate solar energy are generated in the sunlight simulation by BIM modeling, which shows the sunshine duration on facades of a selected building. For solar energy calculation in this study, it is assumed that Civil Building meets the following conditions:

1. Solar panels can be installed on the rooftop and vertical walls with a sunshine duration more than 5 h.
2. In order to satisfy required cost savings, the solar panels will not be installed on the north-facing vertical wall of the building because of its insufficient sunshine all year around.
3. Every solar panel is made up of the same material, and the absorbed sunlight can be converted into electricity to attain efficiency in stable networks.
4. The energy cost analysis mainly considers the cost of solar panels.
5. The analysis period for energy cost is classified into Vernal Equinox, Summer Solstice, Autumn Equinox, and Winter Solstice. The duration time is assumed to be the average of each solar term.
6. According to the weather statistics over the last 3 years, the average number of sunny days each year accounted for 55%.
7. The duration of the sunshine period on the facade of the building is considered to be the average length of the period as estimated by sunlight simulation on THESWARE.
8. The rate paid for electricity is 0.88 RMB per kilowatt-hour.

The assumptions mentioned above are made in order to facilitate investigation easy and to make the comparison more realistic. In this study, direct solar radiation was calculated, ground reflected, and diffused radiations are neglected under the assumption that they will be equal for all shapes. Additionally, effects of the other factors, like shading and type of building material, are assumed to be equal for all situations. These assumptions do not change the main results of this study.

4.2. Energy consumption calculation and cost analysis

In this study, each surface of the building was first analyzed separately, and then all systems were discussed. Surfaces of the building were encoded by using abbreviations ("South," "East/West"), as seen in **Table 5**. Instant and hourly solar energy from the surface of a building depend upon some parameters, like the time of day, day of year, effective area of the wall, sunshine duration, etc. According to the BIM model of the Civil Building described above, the total area and effective area of walls on each floor can be summarized in **Table 5**. Note that the north-facing surface is not taken into consideration because its sunshine duration is less than 5 h. As well, the sunshine duration of different surfaces in each solar term is shown in **Table 6**, where the surfaces labeled in italics are the vertical walls with a sunshine duration of less than 5 hours.

In this part of the study, sunshine striking a given surface between sunrise and sunset is of concern. First, the total amount of annual solar energy striking surface for more than 5 h was

Floor	Surface	Total area (m^2)	Windows area (m^2)	Effective area (m^2)
Roof		867.8	0	867.8
1	South	255.78	89.64	166.14
	East/west	66.78	6.3	60.48
2	South	219.24	77.76	141.48
	East/west	57.24	5.67	51.57
3	South	219.24	67.2	152.04
	East/west	57.24	4.2	53.04
4-5	South	219.24	89.6	129.64
	East/west	57.24	5.67	51.57
6-10	South	219.24	89.6	129.64
	East/west	57.24	5.67	51.57
11-14	South	219.24	89.6	129.64
	East/west	57.24	5.67	51.57
15	South	219.24	89.6	129.64
	East/west	57.24	5.67	51.57
16	South	216	64	152
	East/west	56.16	5.67	50.49

Table 5. The area of the wall.

Floor	Surface	The spring equinox	The summer solstice	The autumnal equinox	The winter solstice	Effective sunshine duration in a year (h)
Roof		12	14	12	10	2376
1	South	5.4	4.8	5.4	3	920.7
	East	6	7	6	4.5	1163.25
	West	*3.3*	*4.5*	*3.3*	*2.4*	
2	South	6	4.8	6	4	594
	East	6	7	6	5	1188
	West	3.6	4.5	3.6	2.6	
3	South	7	4.7	7	4.5	1148.4
	East	6	5	6	5	1188
	West	*4*	*3*	*4*	*3*	
4-5	South	8.6	6.5	8.6	6.5	1470.15
	East	6	7	6	5	1188
	West	*4.75*	*6*	*4.75*	*3.5*	
6-10	South	12	6	12	10	1980
	East	6	7	6	5	1188
	West	6	7	6	4.8	1178.1
11-14	South	12	4	12	10	1881
	East	6	7	6	5	1188
	West	6	7	6	5	1188
15	South	12	1.5	12	10	1757.25
	East	6	6.5	6	5	1163.25
	West	6	6.5	6	5	1163.25
16	South	6.8	0.5	6.8	9	1143.45
	East	*3.4*	*3.6*	*3.4*	*3.5*	
	West	*4.3*	*4.5*	*4.3*	*4*	

Table 6. Sunshine duration of different surfaces (unit: h).

calculated for each solar term over a whole year, which calculation was performed for every surface of the building. The related and required parameters for cost calculation were then assigned. According to the sustainable design plan of the Civil Building, polycrystalline silicon solar panel at 240 W and 18% conversion efficiency (1.65 m long, 0.991 m wide, and 0.04 m light) are suitable components for a larger photovoltaic energy generation and supply system. The installed photovoltaic system will receive 3 RMB per watt capacity in construction subsidies, thus each solar panel 240 W will yield 720 RMB in subsidy.

The total number of solar panels n that can be installed on the surface is given in Eq. (1), where Ai is the combined effective area of the facade and rooftop of the Civil Building, while S is the cross-sectional area of the solar panel.

$$n_i = \left[\frac{A_i}{S}\right] \tag{1}$$

The total electrical energy Q generated by solar panels installed on the Civil Building can be calculated by Eq. (2), where η is the conversion efficiency of the solar panel, w is the power output of solar panels, and Ti is the effective sunshine duration per year of each surface.

$$Q = \eta \sum_{i=1}^{42} n_i w T_i = \eta \sum_{i=1}^{42} \left[\frac{A_i}{S}\right] w T_i \tag{2}$$

The amount of the electricity converted by solar panels can be calculated in Eq. (3).

$$Q = 18\% \times 240 \times 3600 \times \sum n_i T_i = 651860789.2\text{kJ} \tag{3}$$

As is shown in Eq. (3), the solar panels yield more than 60 billion joules of savings in electricity, which shows that the solar panels installed on “Civil Building” reduce traditional energy consumption and in turn contribute to the overall energy efficiency. To assess economic benefit of solar panels, the payback period for solar panel cost can be calculated using Eq. (4).

$$C = \sum_{i}^{42} \left[\frac{A_i}{S}\right] \times p = 2544 \times 720 = 1831680 RMB \tag{4}$$

In this case, p is the price of each solar panel and C is the operating cost of solar panels. Considering an average electricity price 0.88 RMB per kilowatt-hour in Nanjing, the daily saving on electricity rates P and the recovery period T can be calculated as follows.

$$P = 0.88 \times (651860789.2/3600) = 159343.7485 RMB$$

$$T = C/P = 1831680/159343.7485 = 11.5\ years$$

Through the cost analysis, after year 11, the investment status solar panels become positive, which means that after 11.5 years, the solar panel system will operate as a positive cash flow source. Based on the 30-year estimated lifespan of the solar panels, there will be more years benefitting from the solar panel installation than years paying for it. After fully analyzing all the results, the investment is definitely cost-beneficial.

5. Conclusions

The switch to alternative energy sources of electricity is increasing, especially solar energy. The installation of solar panels is advertised throughout the world including China by use of information technologies. Based on the application of building energy modeling and sunlight simulation by BIM technology, and taking advantage of information modeling with 3D visualizations, the sunshine duration and energy consumption of buildings can be calculated with a fair level of accuracy. As a widely used tool in construction sector, BIM has great prospects. With a three-dimensional digital technology, the concept of BIM integrates various kinds of relevant information from construction projects, aiding in complex building performance analyses to ensure an optimized sustainable building design. As well, related software enables energy consumption to be predicted and adjusted during the design stage, thus providing great convenience for sustainable design.

This case study presents both method and technology for integration of building energy simulation and cost calculation with building information modeling (BIM). The early feasibility study stage included sunlight simulation using Revit and THS-WARE, after which the solar energy production was investigated based on the application of solar panels. Initial sunlight analysis and energy use calculations by BIM software were generated based on a number of building specifications and environmental data. According to analysis of solar energy as absorbed by facades, the expense saved by electricity generated from the solar energy can be calculated. Taking the cost of solar panels and project feasibility into consideration, the study shows that application of the studied solar panels contributes greatly to social, economic, and environmental benefits. The energy-saving proposal is feasible in this case and realizes the sustainable design.

Though application of building information modeling (BIM) technology assists effective decisions-making as related to sustainable building design in the early stages, BIM is still developing and limited by software compatibility. If the following aspects can be improved while applying sunshine simulation to real projects through BIM, the long-term benefits of a sustainable design will be realized. (1) Strengthen software analysis area. In order to provide a more comprehensive analysis, apart from the analysis of sunlight condition of the building, indoor lighting, ventilation, and air conditioning should be taken into consideration. (2) The result of calculation on solar energy converted to electricity has effect on the development of solar panels. Optimizing the utilization of solar panels contributes to energy saving. (3) A new plug-in is needed to combine solar energy analysis with sunshine simulation, which can solve related practical problem more efficiently.

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