Cooling and Heating Load Calculation and Energy Consumption Analysis for Single-family Residences in New York

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Abstract. Building energy consumption analysis is a crucial component of sustainable design, allowing for efficient planning of energy use and effective control of energy consumption. This paper focuses on a single-family residence located in Brooklyn, New York. Utilizing Revit software, and primarily analyzes the impact of geographic location and building orientation on energy consumption, ultimately selecting the most suitable architectural design. The total site energy consumption of the building is 203907.34 kBtu, and the total source energy consumption is 523300.15 kBtu according to the simulation. Overall, the climate of the building's location significantly influences energy consumption. Therefore, it is advisable to enhance the building's thermo control capabilities to effectively reduce energy consumption.

Keywords: Building energy consumption, single-family residence, New York.

1. Introduction

In facing the environmental crisis, sustainable design is the next step to be responsible on the harm we cause. Sustainability fundamentally shifts the way we envision and pursue the design and construction process. It is not only addressing the problems like climate change, but also providing a choice in the harmonious coexistence between humanity and the planet. Currently, building energy consumption accounts for approximately one-third of total societal terminal energy consumption, making it a major component of energy consumption with a rising trend. Therefore, controlling building energy consumption is a crucial aspect of energy conservation and sustainable development. Reducing building energy consumption promotes the rational utilization of energy and alleviates conflicts between energy demand and resource supply. Sustainable design helps to fundamentally reduce energy consumption and waste during the construction and maintenance phases, thereby reducing the building's environmental impact and improving the health of the ecosystem. Additionally, sustainable design extends the building's lifespan, reducing long-term material waste. Building energy consumption analysis is a vital part of sustainable design, optimizing energy use through design.

Mark Obrinsky and Caitlin Walter point out there are different measurements in energy consumption according to types of residential structures. Building size and residence member are the two major factors which influence the consumption under such circumstances [1]. Mingtong Li suggests that there are three kinds of construction strategy model which aim for lower energy consumption: conventional construction model, preventive construction model, and life cycle maximization prediction model [2].

This project focuses on a single-family residence located in Brooklyn, New York, utilizing Revit software to primarily analyze the impact of geographic location and building orientation on energy consumption, ultimately selecting the most suitable architectural design.

2. Background

New York City is located at the entrance of the Hudson River on the northeast coast of the United States, characterized by a flat terrain with an average elevation of 10 meters. The climate is classified as a temperate continental humid climate, featuring distinct seasons, abundant rainfall, and occasional extreme weather conditions. The average summer temperature in New York City ranges from 16-24 degrees Celsius, while the average winter temperature ranges from 0-7 degrees Celsius. The city has a dense population, with the central urban area having a population of approximately 8.9 million, resulting in high building density. This project is situated in the central part of Brooklyn, New York City.

3. Methods

The project is a single-family residence consisting a series of three free standing brick-structured buildings each assigned with different programs. The site has one side facing the street and remaining three sides adjacent to other buildings (Figure 1). Table 1 and Table 2 show the basic building parameters.

Figure 1. 3D Model of the Building

Table 1. Basic Building Information

Parameters	Details
Geographic Location	New York City 40°43’0”N,74°0’0”W
Climate	Temperate Continental Humid Climate
Building Type	Single-Family Residence
Building Orientation	North
Building Area	245.5m2
Building Volume	1562.83m3
Number of Floors	2
Building Height	9.9m

Table 2. Building Parameter Settings

Parameters	Details
Building Parts	Materials
Exterior Wall	Brick Structure
Interior Wall	Gypsum Board
Floor	Concrete
Roof	Asphalt Shingles
HVAC System Settings	Central VAV System

4. Results

The following two pie charts illustrate the distribution of total energy consumption among various end uses. Fig. 2a indicates that cooling and heating each account for one-third of the total energy consumption, while the remaining one-third is attributed to interior equipment and interior lighting. Fig. 2b shows that district cooling, district heating, and electricity each constitute one-third of the total energy consumption. Table 3 shows the energy simulation result on total site energy, net site energy, total source energy, and net site energy. Fig. 3 presents the sunlight simulation result in four moments of the day.

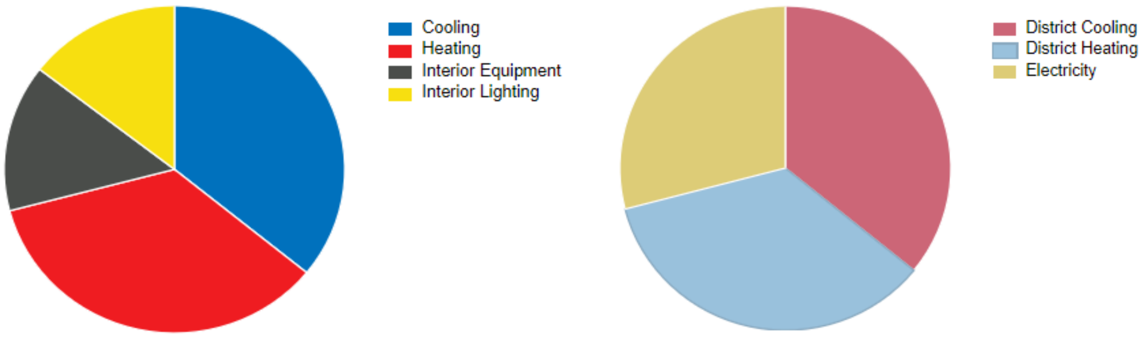

Figure 2. (a) Energy Distribution Chart; (b) End Use Chart

Table 3. Energy Simulation Results

	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]	Energy Per Conditioned Building Area [kBtu/ft2]
Total/Net Site Energy	203907.34	77.16	77.16
Total/Net Source Energy	523300.15	198.03	198.03

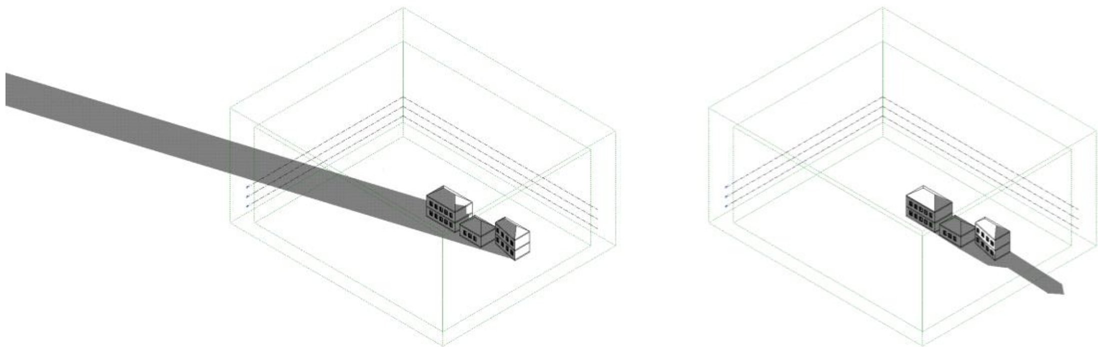

Figure 3. Sunlight Simulation Result

5. Discussion

5.1. Primary Energy Consumption Factors

Overall, the energy consumption for cooling and heating in this building is roughly equivalent, accounting for about two-thirds of the total energy consumption. This is closely tied to the climate conditions in New York City.

5.2. Impact of Geographic Location on Energy Consumption

Geographic location and climate have a significant impact on building energy consumption. For example, locations experiencing extreme temperatures require more energy to maintain indoor temperature balance. New York City, with its temperate continental humid climate, experiences hot and humid summers and cold winters. To analyze the impact of New York's climate on building energy consumption, the project's location was compared to four cities with diverse climates in the United States: Seattle, Los Angeles, and Kansas City.

(1) Seattle

Seattle is located on the Pacific coast in the northwest of the United States. It experiences a temperate maritime climate characterized by distinct seasons. The climate is humid and mild, with cool summers and cold winters.

(2) Los Angeles

Los Angeles is situated on the southwestern coast of the United States. It has a Mediterranean climate characterized by year-round dryness with minimal rainfall. Summers are characterized by extremely high temperatures, while winters tend to be mild.

(3) Kansas City

Kansas City is located in the central part of the United States. It experiences a temperate continental climate characterized by distinct four seasons. Summers are hot, and rainfall is evenly distributed throughout the year.

Table 4 shows the comparison of total site energy between the four locations; Table 5 shows the comparison of total source energy between the four locations; Table 6 shows the comparison of end uses between the four locations. By comparison, it is evident that different climate conditions lead to significant differences in energy consumption for the building. To further analyze the specific reasons, a comparison of end use was conducted for each location.

Table 4. Total Site Energy Comparison

Areas	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]
New York	203907.34	77.16
Seattle	160386.52	60.69
Los Angeles	175075.72	66.25
Kansas City	226577.57	85.74

Table 5. Total Source Energy Comparison

Areas	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]
New York	523300.15	198.03
Seattle	446814.38	169.08
Los Angeles	347172.84	131.38
Kansas City	519618.93	196.63

Due to the setting of equal daily lighting usage hours, the difference in electrical consumption was not reflected. However, in reality, factors such as daily sunlight duration due to geographical location will also impact electrical consumption.

Table 6. End Use Comparison

	Electricity [kBtu]	District Cooling [kBtu]	District Heating [kBtu]
New York	29637.34	73124.76	71507.89
Seattle	29637.34	41545.41	59566.43
Los Angeles	29637.34	101255.50	14545.53
Kansas City	29637.34	106591.33	60711.56

In terms of cooling and heating energy consumption, it's noticeable that seasonal temperatures have a significant impact on energy consumption. In cooler summer regions like Seattle, the cooling energy consumption is relatively lower. Conversely, in hotter summer regions like Los Angeles and Kansas City, the cooling energy consumption is higher. In warmer winter regions like Los Angeles, the heating energy consumption is lower; whereas in colder winter regions like New York, Seattle, and Kansas City, the heating energy consumption is higher.

The comparison shows differences in energy consumption across different climates. Compared to New York, Seattle, which has maritime temperate climate, experiences milder temperatures over the year. Thus, there is less need for extensive heating or cooling systems, leading to lower energy consumption in the building. On contrary, Los Angeles, characterized by Mediterranean climate, has extremely hot summers and mild winters. Demand for air conditioning largely increases during the summer months, elevating energy consumption in comparison to the other cities. Kansas City undergoes a continental climate with harsh winters and hot, humid summers, which results in a more severe energy challenge, requiring both substantial heating and cooling efforts. Therefore, the energy consumption in Kansas City buildings demonstrates a distinct pattern from the coastal cities.

Taking into account the data above, it can be observed that the building's energy consumption is lowest when located in Los Angeles. This is primarily due to the consistently higher temperatures in Los Angeles throughout the year, resulting in lower heating demands. This highlights the significant influence of geographical location on building energy consumption. It also emphasizes the need to consider seasonal factors in the design process to address high or low temperatures at the building's location.

5.3. Impact of Building Orientation on Energy Consumption

Building orientation affects factors include daylight duration, temperature, and wind direction. By comparing energy consumption data for the building facing North, East, South, and West, the optimal orientation can be selected as a reference for the final design (Table 7 and 8).

Table 7. Total Site Energy Comparison

Areas	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]
North	203907.34	77.16
East	209465.79	79.27
South	198324.18	75.05
West	210372.12	79.61

Table 8. Total Source Energy Comparison

Areas	Total Energy [kBtu]	Energy Per Total Building Area [kBtu/ft2]
North	523300.15	198.03
East	550740.68	208.41
South	538881.08	203.92
West	542532.61	205.30

By comparison, it's apparent that the energy consumption for buildings with north-south orientation is slightly lower than those with east-west orientation, though the difference is small. Overall, maintaining a north-facing orientation is the most energy-efficient option.

5.4. Measures for Energy Efficiency and Emission Reduction

Due to the extreme temperatures in New York City during summer and winter, both seasons require significant energy consumption to maintain indoor temperature. Therefore, adding insulation layers within the walls and enhancing the building's thermal insulation effect are recommended to further conserve energy. For example, the use of energy-saving glass products can effectively reduce building energy consumption [3-5]. Many western developed countries have taken the lead in giving full attention to building energy conservation, using various policies to promote energy conservation of building materials and the use of energy-saving glass. According to foreign research estimates, if all buildings in the European Union are double-layer low-radiation energy-saving glass, the annual energy savings can be 14.264 million euros, as well as saving the equivalent of 26 million tons of oil energy and reduce up to 82 million tons of CO_2 emissions. In addition, the buildings in New York should maintain a north-facing orientation to achieve energy savings. Furthermore, implementing temperature control systems with higher efficiency such as programmable thermostats or HVAC and can optimize the energy usage of the building by adjusting settings based on occupancy and exterior temperature.

Incorporating natural shading elements like deciduous trees on the exterior facade can help reduce the impact of direct sunlight, particularly in the summer months. For instance, green roofs and rooftop gardens can also be an option which not only contributes to energy conservation, but also promotes urban biodiversity and reduces the heat island effect of the entire city. Some research data show that the same building with a green roof room can save 70% of the air conditioning energy compared to the room without a green roof; In the hot summer, the indoor air temperature of the building with wall greening is 3°C-5°C lower than the indoor temperature of the building without wall greening, and the relative humidity of the air can be increased by 10%-20%. In addition, three-dimensional greening can also absorb carbon dioxide, reduce dust, reduce noise; Rainwater storage, storm retention, flood relief [6-8]. Companies like Brooklyn Green Roof llc near the site has a mature system in installing green roofs, which can be accessible by the project.

The installation of energy-efficient building designs and upgrading existing structures is an investment for the future. It not only reduces the environmental impact but also leads to long-term cost savings for both residents and property owners. When choosing materials, priority should be given to new building materials with environmentally friendly and energy-saving properties. For example, light steel keel walls, thermal insulation materials, solar panels, etc., are environmentally friendly and energy-saving building materials. These materials not only have better thermal insulation performance, but also can reduce energy consumption and environmental pollution.

The use of energy-saving equipment and energy-saving control system is one of the key measures to realize environmental protection and energy saving in industrial buildings. For example, energy-saving lamps, intelligent lighting control systems, intelligent air conditioning control systems and other devices can be used to reduce energy consumption. In addition, advanced energy-saving technologies such as energy recovery technology can be used to improve energy efficiency [9-10].

6. Conclusion

This report analyzed the potential for energy improvement in a single-family residence located in Brooklyn, New York. Through the analysis of energy simulation results, we gain a clear understanding of the distribution of building energy consumption. In summary, cooling and heating each account for one-third of total energy consumption, while interior equipment and lighting together constitute the remaining one-third. Additionally, district cooling, district heating, and electricity each account for one-third of total energy consumption, demonstrating balanced utilization of various energy types. Geographic location and building orientation play crucial roles in energy consumption. The research results indicate that New York's temperate continental humid climate significantly impacts energy consumption. In comparison, other climate conditions in cities such as Seattle, Los Angeles, and Kansas City exhibit different patterns of energy utilization. This underscores the need to adopt corresponding strategies for different climate conditions during the design process to minimize energy consumption. To improve energy efficiency and reduce emissions, it is recommended to maintain a north-facing orientation and focus on enhancing insulation structures to cope with extreme weather conditions in New York City, ultimately saving energy in the long run. Overall, by analyzing energy consumption results, influencing factors, and feasible measures, this analysis provides valuable insights for energy management in single-family residences in New York, enabling more sustainable and efficient energy utilization.

Sustainable design participates in the community engagement as residents witness the positive changes in their surroundings. This can lead to a collective agreeness towards environmental protection and sustainable living. Moreover, the integration of green spaces and sustainable features in building design creates healthier and more vibrant urban environments, improving the overall quality of life for inhabitants. In the context of New York City, a hub of culture and influence, adopting and showcasing sustainable architecture can set a powerful example for other cities worldwide. It can inspire policymakers, urban planners, and developers to prioritize sustainability in their projects, leading to a global shift towards greener, more resilient cities. Sustainable architecture can also serve as a catalyst for innovation and research in the construction industry. It will further encourage the development of new materials, technologies, and construction methods that further enhance energy efficiency and environmental performance. These innovations can have a ripple effect, influencing future design processes towards a more sustainable direction.

The benefits of sustainable architecture extend far beyond individual buildings. Its effect spreads through communities, cities, and the planet as a whole. By investing in sustainable building practices, we not only address pressing environmental challenges but also pave the way for a more harmonious and prosperous future for generations to come. This collective effort is essential in building a sustainable, resilient world that can thrive in the face of evolving environmental realities.

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