A Review on the Impacts of Building Energy Consumption with a Focus on Outdoor Thermal Environments and Residents’ Habits

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Abstract. Energy consumption is becoming a crucial economic issue and an unsolved priority problem for policymakers around the world. The demand and supply of unsustainable energy sources significantly influence family budgets and international relations. Currently, the energy consumption is becoming an increasingly important index in the building construction. This article analyzes building models under different conditions to explore factors influencing building energy consumption in outdoor thermal environments and variables attributed to different local habits.

1. Introduction
Regarding building energy consumption, the majority of the proceeding studies focused on whether the amount of energy saving can satisfy the requirement of local government or not. In this respect, the previous research cannot make an accurate calculation of building energy consumption due to its general analyzing processes and imprecise models. However, analyzing and calculating the building energy consumption by the Building Information Modelling (BIM) technology not only enable buildings to meet the mandatory requirements but also minimize the consumption as much as possible while maintaining similar function. Additionally, the whole process is transparent, which allow the participants to simulate the energy consumption directly after building components are transformed through 3D digital information model.

According to the International Classification for Standards, building energy consumption refers to the energy consumption of civic buildings such as residential buildings and public buildings. Factors that affect energy consumption include heating system, air conditioning, ventilation, hot water supply, lighting, cooking, household appliances, and elevators. To be specific, building energy consumption includes energy consumption in the construction process and the living process. Energy consumption in the construction process refers to the production and transportation of building materials, construction components, construction equipment, and energy consumption in construction and installation. While in the living process, it means energy consumption in heating, ventilation, air conditioning, lighting, household appliances, and hot water supply.

2. Literature review
A number of scholars have indicated the importance of comprehending energy consumption and substantial impact towards environment in constructing buildings. In Monahan and Powell’s 2011 article, they conducted a case study “to calculate the primary energy used and the associated embodied
carbon” by using “life cycle assessment” as a theoretical framework. The authors concluded that “types of construction employed” has a significant influence upon the “consequential carbon embodied in buildings”[1].

In their recent work, Liang and Chen established a model of “annual power consumption and annual fuel consumption” to “calculate the energy consumption of buildings” in the regions of cold climate at the phase of designing. Their research findings provide significant information for future research on “energy consumption analyses and quantitative evaluations on building energy conservation”[2].

Bilec and other scholars used the same methodology of LCA (life cycle assessment) to examine “the environmental impacts due to the construction phase of commercial buildings”. The study results showed that the stage of construction, “is as important as other life-cycle stages” of buildings[3].

There are “two climate change models (HadCM3 and CESM)” being used to investigate the impacts of climate change on annual building energy[4]. Energy consumption ratio was determined by using “the mean value method, the factor normalization method, and the cumulative frequency distribution method”[5].

Asadi and other scholars proposed “a new regression model to predict and quantify energy consumption in the early stages of building design”[6]. Rahman and Smith presented “a modeling framework that uses machine learning algorithms to make long-term, i.e. one year-ahead predictions, of fuel consumption in multiple types of commercial prototype buildings at one-hour resolutions”[7].

3. Model development

Drawing on the previous studies, this article uses a multifamily building surrounded by eight same buildings within a community as the model to study. The building has ten floors, and each floor is four meters in height, has 37.082 subtract and 36.576 square meters. The target percentage glazing of the building is 33 percent. The building’s exterior wall is Lightweight Construction with Typical Mild Climate Insulation, and its interior wall is Lightweight Construction with No Insulation, the roof is Typical Insulation with Cool Roof, the floor is Lightweight Construction with No Insulation, and the slab is High Mass Construction with No Insulation. Both glazing and skylight are Double Pane Clear glasses with High Performance, Low-E, High Tvis, and Low SHGC. After adding two different geographical conditions to this model, two different models of building energy consumption will be generated.

4. Research analysis

4.1. Two different outdoor thermal environments

Outdoor thermal environment of buildings includes various climatic factors. These climate factors can affect indoor climatic conditions through building envelope structure, external doors and windows, and multiple openings. Closely related to buildings, the climatic factors are solar radiation, air temperature, air humidity, wind, and precipitation.

Xi’an is located between 107.40 degrees to 109.49 degrees east longitude and 33.42 degrees to 34.45 degrees north latitude. In the plain area of Xi’an, the temperature is warm, and the city belongs to the semi-humid continental monsoon climate region. Figure 1 and Figure 2 shows the temperature and precipitation in Xi’an from January to December (basic meteorological date) during the 30-year period.
Figure 1. Temperature fluctuation and precipitation change of 30-year period in Xi’an.

| Month | Mean Daily Minimum Temperature (°C) | Mean Daily Maximum Temperature (°C) | Mean Total Precipitation (mm) | Mean Number of Precipitation Days |
|-------|-------------------------------------|-------------------------------------|-------------------------------|----------------------------------|
| Jan   | -4.2                                | 4.8                                 | 6.0                           | 4.0                              |
| Feb   | -1.8                                | 7.7                                 | 11.0                          | 5.0                              |
| Mar   | 3.2                                 | 14.0                                | 26.0                          | 7.0                              |
| Apr   | 8.9                                 | 20.4                                | 50.0                          | 9.0                              |
| May   | 13.8                                | 25.8                                | 65.0                          | 9.0                              |
| Jun   | 18.8                                | 31.6                                | 51.0                          | 9.0                              |
| Jul   | 21.6                                | 32.0                                | 93.0                          | 11.0                             |
| Aug   | 20.8                                | 31.1                                | 67.0                          | 9.0                              |
| Sep   | 16.5                                | 24.7                                | 108.0                         | 12.0                             |
| Oct   | 14.8                                | 19.3                                | 60.0                          | 11.0                             |
| Nov   | 9.8                                 | 13.3                                | 66.0                          | 11.0                             |
| Dec   | -2.9                                | 6.1                                 | 6.0                           | 3.0                              |

Figure 2. Basic meteorological date in Xi’an.

Pittsburgh is located in Pennsylvania of the United States, covering an area about 79°59′45″west longitude, and 40°26′26″north latitude. The city is on the east coast and at the confluence of the Allegheny, Monongahela, and Ohio rivers. Pittsburgh belongs to the humid continental climate area.

Figure 3. Temperature fluctuation and precipitation change of 30-year period in Pittsburgh.

| Month | Mean Daily Minimum Temperature (°C) | Mean Daily Maximum Temperature (°C) | Mean Total Rainfall (mm) |
|-------|-------------------------------------|-------------------------------------|--------------------------|
| Jan   | -5.7                                | 2.1                                 | 69.3                     |
| Feb   | -4.4                                | 4.1                                 | 68.1                     |
| Mar   | -0.6                                | 9.4                                 | 78.7                     |
| Apr   | 5.3                                 | 16.4                                | 80.0                     |
| May   | 10.4                                | 21.4                                | 105.9                    |
| Jun   | 15.2                                | 25.9                                | 102.6                    |
| Jul   | 17.4                                | 28.0                                | 95.8                     |
| Aug   | 16.9                                | 27.3                                | 89.2                     |
| Sep   | 13.0                                | 23.1                                | 85.1                     |
| Oct   | 6.7                                 | 17.0                                | 64.0                     |
| Nov   | 2.1                                 | 10.4                                | 85.1                     |
| Dec   | -3.1                                | 4.2                                 | 74.2                     |

Figure 4. Basic meteorological date in Pittsburgh.

By comparing the temperature fluctuation and precipitation change of basic meteorological date in the two cities over 30 years, it is noticeable that humidity in Pittsburgh is higher than that of Xi’an. In the case of Xi’an, the Mean Daily Maximum Temperature in a year is 32.0-degree Celsius while the
Mean Daily Minimum Temperature in a year is -4.2-degree Celsius. The corresponding figure for Pittsburgh is 28.0-degree Celsius and -5.7-degree, respectively.

4.2. Indoor humidity

In Figure 5, it is apparent that the highest morning average indoor humidity and the highest afternoon average indoor humidity appeared over the period between August and September in Xi’an. The semi-humid continental monsoon climate caused high temperature and high-amount of rainfalls between August and September. Besides, the Mean Total Precipitation is 108.0 mm, and the Mean Number of Precipitation Days is 12 days in September. Thus, it is reasonable to assume that the climate influences the indoor humidity. Furthermore, when temperatures become hotter, transpiration of indoor plants becomes stronger, and more moisture to air would be provided. This phenomenon explains why an upward trend was seen from June to July in Figure 5.

Figure 5. Indoor humidity in Xi’an.

Figure 6 shows indoor humidity change in Pittsburgh. In comparison with Xi’an, the indoor humidity in Pittsburgh is higher than that in Xi’an, and the discrepancy was increasing from May to June. It is because, at that time, Pittsburgh has a higher temperature and stronger Mean Total Rainfall.

Predictably, the indoor humidity will start decreasing during the period between July and August due to the high temperature. However, the long-lasting rainfall and increasing use of air conditioners make the indoor humidity stay at a high level.

4.3. Electricity consumption

Nowadays, electricity is a vital energy in everyday life. Figure 7 shows information about how electric power is used in Xi’an for various purposes. In detail, HVAC (heating, ventilation, air conditioning) has massive portions, at just under 60 percent, of the total electricity consumption, and lighting makes up 18 percent of the entire electricity usage. The reason for the large proportion of HVAC lies in high temperature in summer and low temperature in winter. People use heating devices and air conditioners when experiencing extreme weather, which generates high costs in electricity bills.
Figure 7. Energy consumption: electricity in Xi’an.

Figure 8 shows the proportion of electricity consumption in Pittsburgh. On the one hand, the proportion of HVAC represented 55 percent of the total electricity consumption in building. On the other hand, 19 percent of the electricity use came from the category of lighting.

Notably, a similar figure in electricity consumption for lighting was seen from Figure 7 and Figure 8, whereas the electricity consumption of HVAC has a slight difference in two cities due to the different outdoor thermal environment. Xi’an has a higher temperature in winter and summer than that in Pittsburgh. It means that people who live in Xi’an will use air conditioners for a longer time in summer, while people live in Pittsburgh will use central heating for a longer time in winter. Besides, people in these two areas have different habits. For example, people in Xi’an tend to use radiators to elevate the indoor temperature in winter, the radiator uses a pipeline to supply hot water to the operating system, and this process reduces considerable costs of electricity. Meanwhile, people in Pittsburgh use air-conditioning to raise the temperature, which costs a larger quantity of power than the radiator.

Figure 9. Monthly peak demand in Xi’an.
Monthly peak demand indicates how much electricity needed in peak time each month. The building’s monthly peak demand for electricity in two cities has a close connection to temperature change and the population. The relationship between electricity consumption and temperature has been demonstrated in the above discussion. The argument about the population of people indoor will be discussed in the following part of this section.

Figure 9 illustrates that July requires the highest monthly peak demand for electricity because of the summer vacation in China, students have more time to stay in the house and to use air conditioners indoor. By comparing Figure 9 and Figure 10, it is evident that residential density also needs to be considered as an influential factor. Typically, household residential area in China is smaller than that in America, which means that there are more Chinese residents live in the same building. Therefore, the monthly peak demand for electricity in Xi’an is higher than that in Pittsburgh.

4.4. Fuel consumption
Fossil fuel usage in everyday life includes gas, oil, and hot weather gas. It is shown in Figure 11 that domestic hot water accounted for 39 percent of the total fuel usage in buildings of Xi’an and the consumption of fuels for HVAC represented 61 percent of the whole fuel usage.

It can be seen clearly from Figure 12 that the proportion of domestic hot water consumed in buildings of Pittsburgh, which accounted for 35 percent of the total fuel consumption. In contrast, the massive portion of fuel usage in Pittsburgh is on HVAC, which makes up 65 percent of whole fuel use. The different distribution of fuel usage between two places is related to outdoor thermal environments and habits of indigenous people of the area. The winter in Pittsburgh is colder, and people prefer to use the fireplace. Therefore, the fuel usage on HVAC is higher in Pittsburgh. On the contrary, most residents live in Xi’an use natural gas for heating water and cooking.
5. Recommendation

By comparing the figure of indoor humidity and energy consumption, it can be concluded that the building energy consumption is related to the outdoor thermal environment and habits of the residents. To be specific, extreme weather directly leads to an increase in energy consumption. Moreover, the amount of electrical power consumed tends to be large if the local inhabitants prefer to use electronic devices in everyday life. On the contrary, if people use natural gas frequently, fuel consumption will increase. Therefore, factors related to the outdoor thermal environment cannot be overlooked in designing for constructions. For instance, when extreme weather appears, high-quality insulation materials in buildings enables the HVAC systems to be used at maximum efficiency.

6. Conclusion

The above discussion shows that both outdoor thermal environment and habits of residents have a considerable impact on building energy consumption, including the amount of electricity and fuel...
consumption. Analysis of building energy consumption plays a crucial role in building design. A complete analysis of building energy consumption is an essential step in constructing a green building with low energy consumption. With respect to the recommendations mentioned above, it is reasonable to assume that more models for building design will be proposed in future research.

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