On the Outdoor Microclimates of Building Clusters in Cold Regions

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Abstract. Building clusters are settlements that are gradually formed by people living in cold regions after long-term resistance to the cold climate. For those facing extreme living environments, building clusters can effectively produce a cluster effect to generate a more comfortable outdoor microclimate for humans. In this paper, building clusters are summarized into 4 types, and a comparative study on the outdoor microclimates of the different types of building clusters is provided. In the study, the microclimate-based equivalent temperature (MBET) is used as the main parameter, and the micro-climate simulation software ENVI-met is used as a simulation tool. The results validate the important role of the building cluster type in producing the microclimate and provide a new basis for the type selection and design of building clusters in cold regions.

1. Introduction
With increasing demand for outdoor living environment quality and the realization of refined outdoor environment measurement and simulation technology, the research on the outdoor microclimates of building clusters has a long history that has developed rapidly. In 1963, Olgyay [1] discussed the relationship between the shape of building clusters and the microclimate from the perspective of the relationship of the organism to the climate. Based on the research by Olgyay, Knowles [2] conducted a study on the effect of building cluster shadows on microclimate in 1981. Givoni [3] outlined the design principles for building clusters in climate-sensitive areas in 1998 and highlighted the important effect of the microclimate on outdoor environments in cold regions. In 2008, Bourbia [4] proposed that the street interface has an impact on street microclimates. In 1996, Anderson et al. [5] proposed that the main factors that affect the microclimates of building clusters are scale, density, and form. In recent years, concepts such as passive design and climate resilience have been gradually applied to the study of microclimates. Professor Perry Yang [6] of the Georgia Institute of Technology is committed to the design and research of low-energy cities, and put forward the concept of zero-carbon cities. In the research of zero-carbon cities, it is emphasized that the layout of urban buildings has a significant effect on improving outdoor microclimate and increasing urban climate resilience. Chinese scholar Leng Hong [7] emphasized the impact of the space environment on microclimate in her article "International Experience and Enlightenment of Urban Microclimate Environment Control and Optimization,” and stated that buildings have enhanced effects on wind speed and eddy currents, and that street canyons can increase regional temperature. She also put forward the components of microclimates, namely sunshine, wind, temperature, and humidity. Along with the refinement of research, it has also become more
detailed, and has included the investigation of the influences of the heights and skin materials of buildings on microclimates. Taleghani et al. [8] studied the outdoor thermal comfort of five standard Netherland urban forms via ENVI-met, an advanced outdoor microclimate simulation platform. In recent years, research on microclimates tend to special urban forms and special climate. Muniz-Gaal et al. [9] studied microclimate of urban street canyon in tropical climate. Zamani Z., Heidari S., Hanachi P. [10] reviewed the thermal and microclimate function of courtyards and emphasise the importance of length-to-height ratio. Shareef S. and Abu-Hijleh, B. [11] discussed the effect of urban geometry and building morphology on environment in hot climate.

2. Building cluster typology

2.1. Previous research on building cluster typology

In 1970, the University of Cambridge's Martin Lab proposed a concise urban texture model for microclimate research. Based on the characteristics of European cities, it summarized six different urban block shapes. Since then, the Martin model has been widely used in urban microclimate research. To summarize the types of building clusters in cold regions, Jull [12] in the University of Virginia Polar Research Group proposed eight different models of living forms. The Matthew models can better summarize the textures of cities in cold regions. However, for microclimate analysis, the differences between these models are not obvious; the microclimate analysis results do not well reflect the differences, and it is not easy to determine laws. In recent years, Olgyay and Oke proposed five different types of blocks for outdoor microclimate analysis, namely the east-west cell, north-south cell, east-west linear, south-north linear, and inner courtyard. Olgyay’s model simplifies the block model into five types, and the simplified model is more conducive to the analysis of microclimates; it is convenient for the identification of the characteristics and the determination of the differences in the impacts of different types of unit block layouts on settlement microclimate. However, for building clusters in cold regions, the building has obvious phototaxis. Because of sunlight is important in cold region, the north-south direction in Olgyay’s model is not conducive to direct lighting; thus, this form rarely occurs in cold settlements. Figure 1 summarises types of building clusters in this research.

![Figure 1. Building cluster types](image)

2.2. Four main types of Building Cluster in Cold Region
By integrating the Martin model, the Matthew model, and the Olgyay model, and by observing the layout patterns of cold settlement buildings (Figure 2), this article proposes four simpler models for the basic units of building cluster layouts: the north-south cell model, east-west cell model, east-west linear model, and courtyard model. These four models are used in this paper as the basis for simulation analysis, and the microclimates of the corresponding cold settlements are then studied. For the east-west and north-south unit models, each unit represents a house; for the east-west linear model, the houses are arranged in a row; for the inner courtyard model, the model is an induction of the courtyard-style residential form. The depth of the north-south room of the cold region house is larger, and that of the east-west room is smaller; however, for the sake of calculation, the differences in the building depth are ignored in this model. As has been determined by existing cold building research, 10×10 m houses are more common in cold settlements, so the single parameter is set to 10×10 m in this study. For townhouses, there are often less than 4 units, so the linear building parameter is defined as 10×40 m in this study. For the inner courtyard building, the parameter is defined as 40×40 m in this study (Figure 3).

![Figure 2. Example of building cluster types.](image)

![Figure 3. Four types of building cluster in cold region.](image)

3. Microclimate evaluation

As the purpose of the research on outdoor microclimate is to provide a more comfortable outdoor environment for people, research on outdoor microclimate is often combined with "comfort". The so-called "comfort" refers to the physiological Comprehensive evaluation with psychological satisfaction. The comfort of the outdoor climate can be understood as the human body's perception of the climate. This outdoor climate comfort is reflected in the overall perception of the temperature, humidity, wind speed, and direct solar radiation in the outdoor environment.

3.1. PMV and PET

In 1914, Hill[13] first studied outdoor comfort and proposed a method for the integrated measurement of outdoor radiation, outdoor temperature, and outdoor wind speed. In 1919, the American Society of Heating, Refrigerating and Air-Conditioning Engineers proposed the concept of somatosensory temperature, which is calculated by ET (Equivalent temperature) and is also referred to as sensory temperature or comfort. The ambient temperature perceived by humans is often different from the real temperature. Somatosensory temperature is affected by many factors including the actual ambient temperature, humidity, sunlight, and wind speed. In 1970, Fanger[14] studied the accuracy of somatosensory temperature, emphasized the exchange of the human body and ambient temperature, and proposed the concept of the PMV index. The PMV index uses the basic equation of human thermal
balance and the level of subjective thermal sensation in psychophysiology as the starting point, and considers a comprehensive evaluation index of many related factors of human thermal comfort. Pasachoff [15] reviewed the wind chill index to express temperature perception in cold wind environments. In recent years, the calculation method of the wind chill index has been continuously reformed. The calculation formulas composed of customary units are widely used. The Wind Chill equivalent is:

$$\text{Wind Chill} (\degree F) = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$ (1)

Where, T=Ait Temperature($\degree F$) V=Wind Speed(mph)

The physiological equivalent temperature (PET) is defined as the temperature at which the temperature of human skin and the internal temperature reach the same thermal state as in a typical indoor environment in either an indoor or outdoor environment. This indicator simplifies the previous evaluation indicators and is more suitable for outdoor microclimate evaluation calculations. Table 1 presents the relationship between PMV and PET.

The PET equivalent is:

$$S = M \pm W \pm R \pm C \pm K - E - RES$$ (2)

Where, $S =$ heat storage, $M =$metabolic heat, $R =$ radiation heat transfer, $C =$convection heat transfer, $K =$heat conduction, $E =$evaporation heat transfer, and $RES =$respiratory heat transfer.

| PMV   | PET°C | Thermal Sensation European Climate | Thermal Sensation Tropical Climate | Grade of Physiological Stress |
|-------|-------|------------------------------------|-----------------------------------|------------------------------|
| <-3.5 | <4    | Very Good                          | Extremely cold                    | Extremely Cold Stress        |
| -3.5—-2.5 | 4—8  | Cool                      | Very Cold                        | Strong Cold Stress         |
| -2.5—-1.5 | 8—12 | Cool                      | Cold                              | Moderate Cold Stress       |
| -1.5—-0.5 | 12—16 | Slightly Cool             | Cool                              | Slight Cold Stress        |
| -0.5—0.5 | 16—24 | Neutral                  | Neutral                           | No Thermal Stress         |
| 0.5—1.5 | 24—28 | Slightly Warm            | Slightly Warm                     | Moderate Heat Stress       |
| 1.5—2.5 | 28—32 | Warm                     | Warm                              | Strong Heart Stress        |
| 2.5—3.5 | 32—36 | Very Hot                 | Hot                               |                             |
| >36    |       |                       | Very Hot                          |                             |

3.2. MEBT

For the simulation of outdoor microclimates, these indicators are too complicated and contain variables that are not related to the impact of microclimates. By sorting out the above comfort calculation methods, the comfort calculation in this study is based on a simplified PET calculation method. A calculation method of MEBT (microclimate-based equivalent temperature) is thus proposed. Environment-independent variables, only simulation analysis of microclimate. The formula of this calculation method is as follows:

$$S = R + KT$$ (3)

where $S$ is the overall heat, $R$ is the solar radiation heat transfer, $T$ is the outdoor ambient temperature, and $K$ is the somatosensory temperature correction index in different environments.

4. Simulation and result analysis

Via simulation conducted by ENVI-met, many climatic factors including wind pressure, partial speed, wind speed change, wind direction, air temperature, air temperature change, sunshine, humidity, and others can be obtained[16]. The wind speed data, air temperature data, and sunshine data are extracted
in this study. X and Y are the coordinates of the point in the simulation space (50×50 grid), and X (grid) and Y (grid) respectively express the horizontal and vertical coordinates of the point. X (m) and Y (m) respectively express the distance in reality, and the content expressed by the data is the current air temperature at that point. The analysis results in ENVI-met can be directly visualized by the associated software Leonardo 2014. Figures 4 and 5 respectively present visualized outdoor temperature and wind speed data.

![Figure 4](image1.png)  ![Figure 5](image2.png)

**Figure 4.** Outdoor temperature simulation of 4 types of building cluster.

**Figure 5.** Wind speed simulation of 4 types of building cluster.

The current version of ENVI-met does not have the function of integrating temperature data, wind speed data, and sunshine data. Thus, to obtain a parameter that can more accurately describe the outdoor microclimate, these three types of data are integrated in this research via ArcGIS 10.5, a software operating platform based on the Geographic Information System that has the function of superimposing raster files (Figure 6).

![Figure 6](image3.png)

**Figure 6.** Relevant parameter of MBET

The distribution maps of the temperatures and wind environments of different types of layouts can be obtained via ENVI-met simulation, as presented in Figure 7. From the temperature distribution data, it can be determined that the outdoor space microclimates are different for different building layouts, i.e.,
the building layout can affect the outdoor microclimate. In addition, it can be found from the analysis results that the temperature distributions of the east-west linear layout and the north-south linear layout are more balanced, and the temperature becomes a gradual distribution; additionally, the temperature distribution of the east-west linear layout is greatly different from that of the north-south linear layout. For the courtyard layout, the temperature of the courtyard is similar to the south temperature of the building, and it presents a large difference from other azimuth temperatures. It can be seen from the wind environment analysis that the east-west unit layout and the east-west linear layout can effectively prevent cold wind from intruding into the south direction and the center area of the settlement unit. Additionally, the north-south unit layout is more likely to generate wind corridors, thereby resulting in a poor comfort of the central space of the settlement unit. Finally, courtyard-type buildings can also block cold winds, but the northern edges of the buildings are more likely to form eddies with faster wind speeds.

5. Conclusion
Via the study of the spatial layouts of cold settlement buildings and outdoor microclimates of them, the following conclusions can be drawn. First, it is clear that the building layout can affect the outdoor microclimate, and different layout forms can create different outdoor microclimate comfort distributions. Secondly, the layout of the unit type can make the overall comfort distribution of the outdoor environment more even. In the centralized layout, the difference in the distribution of outdoor comfort is obvious. In addition, in extremely cold winter conditions, a small range of outdoor activity spaces with high comfort can be created by a linear layout or courtyard layout.

6. References
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