Thermodynamic Design of Public Space Based on Outdoor Thermal Comfort——Take Yangpu Bridge Riverside Park Competition Scheme as an Example

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Abstract. This paper attempts to make outdoor thermal comfort as an evaluation index to apply in the public space design, trying to make the design achieve the goal of ideal comfort environment from the beginning to the completion, and to form a simulation optimization method of ‘Design Follows Comfort’. And the attempt takes a case in Shanghai, China as an example. In this case, UTCL is used as the evaluation index and ladybug simulation tool is used to evaluate outdoor thermal comfort and assist in optimizing architectural design. Optimizing the goal of thermal comfort in different stages of the design will help to integrate various elements of architecture so that the considerable comfort in severe climatic conditions will be provide to users.

1. Introduction
At present, under the influence of global warming and urban heat island effect, the urban thermal environment is deteriorating. Therefore, environmental performance and energy consumption are getting more and more attention. People are inseparable from the natural environment and have the demand for outdoor activities. Especially in our country, the aging population is accelerating. The elderly people are increasingly demanding outdoor public space, which is also one of the main places for children's outdoor activities. Outdoor public space provides a place for people to carry out outdoor communication, leisure, fitness, entertainment and other activities. Creating a comfortable outdoor environment which could make people feel happy, is conducive to human health and building energy conservation, so it is particularly important. In recent years, some scholars at home and abroad have conducted researches on outdoor thermal comfort, which mainly focusing on outdoor thermal environment testing and human thermal comfort research, and have achieved a large number of research results. It is of great significance to improve environmental performance and reduce energy consumption by introducing thermal comfort perspective intervention scheme design at the design stage. In the existing practice process, architects often judge the thermal comfort and energy consumption based on experience and existing cases, with low accuracy and weak comparison of many similar schemes. Therefore, an innovative thermodynamic design of public space with thermal comfort as its evaluation index is becoming more and more important.
2. Theory and Model of Outdoor Thermal Comfort

2.1. Outdoor Thermal Comfort
Thermal comfort is closely related to human physiological response and is a kind of psychological feeling. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as a subjective judgment of whether a human individual is satisfied with the surrounding thermal environment. ISO 7730 defines thermal comfort as people's subjective satisfaction with their thermal environment. Danish scholar Fanger defines thermal comfort as the physiological state when the human body produces and loses energy in a balanced state. There are two opinions on the evaluation of thermal comfort. Gagge and Fanger et al. believe that thermal comfort is equivalent to thermal sensation. As long as thermal sensation voting is near thermal neutrality (i.e. within thermal comfort zone), people will feel thermal comfort. Ebbecke, Hensel and Cabanac et al. believe that thermal comfort only exists in some dynamic processes, but not in a steady-state environment. The study of human thermal comfort has experienced a process from simple to complex, from stable to dynamic.

Research on thermal comfort was mostly conducted indoors in the early stage. The thermal sensation PMV-PDD index and standard effective temperature index take specific environmental physical parameters or human-related parameters as input parameters to predict the human thermal state in a certain indoor environment. However, human thermal comfort is not limited to indoor, outdoor thermal environment is also extremely important. The first research on outdoor thermal comfort can be traced back to 1930, which was first carried out by Gehl and A. Ishii et al. Later, the research on outdoor thermal comfort was carried out one after another, but the overall development speed was slow. Until the recent 20 years, outdoor thermal comfort has developed rapidly.

2.2. Evaluation Index and Model of Outdoor Thermal Comfort
With the development of outdoor thermal comfort models, various outdoor thermal comfort models have been proposed one after another, but PMV (Predicted Mean Vote), OUT_SET* (Standard Effective Temperature), PET (Physical Equivalent Temperature) and UTCI (Universal Thermal Climate Index) are still the most commonly used outdoor thermal comfort models.

The PMV model thinks that human thermal sensation at a certain activity level is related to the human thermal load, which can be adjusted by the average skin temperature and sweat rate of the human body. When PMV=0, the human body is in a comfortable state.

The OUT_SET* model considers that the main difference between indoor and outdoor is solar radiation and infrared radiation. Through this model, the uniform surface temperature of an imaginary wall surrounding a standard object can be calculated. In the full wave radiation, complex and real solar radiation and infrared radiation environment, the heat exchange capacity of the wall is the same as that of the surrounded standard object.

The PET model is established by using the Munich human body heat balance model (MEMI), based on the human body heat balance and the Gagge two-node model, which introduces the equations on "heat flow from human body core to skin" and "heat flow from skin to garment outer surface" on the basis of the heat balance equation.

The UTCI model adopts Fiala human body model, which can better reflect the whole and local physiological and thermal reactions of human body.

Based on the above comparison, PMV is proposed based on indoor stable environment, which is suitable for thermal evaluation near thermal comfort state. When PMV is less than -2 or greater than +2, there will be large deviation, especially at the hot end. OUT_SET* has a wide range of applications and is one of the most widely used evaluation indexes of all outdoor thermal environment evaluation indexes at present. PET model is a real meteorological index, which is widely used in meteorological forecast and urban planning and design. UTCI differs greatly from PMV, OUT_SET*, PET in that it is based on an unsteady model and takes into account the thermal adaptability of the human body. It can simulate any climatic condition, any season or city scale.
2.3. Adaptive thermal comfort
With the research, scholars found that the individual's ability to adapt to the external environment has a great impact on thermal comfort, and put forward the theory of adaptive thermal comfort. In the process of adaptation, individuals tend to adapt to the current environment and improve their tolerance to the environment, so that the actual comfort range of individuals is often wider than the range indicated by the comfort index.

Thermal comfort in dynamic environment is called adaptive thermal comfort. In dynamic thermal environment, people accept the environment as adaptive thermal comfort through interaction with the environment and repeated adjustment of physiology and psychology. Therefore, adaptive thermal comfort is thermal comfort with timeliness and dynamics. The main influencing factors of adaptive thermal comfort are climate, architecture and adaptation time. Among its climate influencing factors, temperature, humidity, solar radiation, wind speed and atmospheric pressure are always interacting and coupling with each other, and jointly acting on the thermal adaptation of human body. This paper will analyze the above factors and take adaptive thermal comfort as the main driving target.

3. Methodology
3.1. Project overview
The base is located in the riverside area of Yangpu Bridge Riverside District in Shanghai, China. The design goal is to create a public space and activity place to provide services for citizens. The development of Yangpu Bridge Riverside District is part of the city's overall planning strategy, and in recent years the city has developed miles of the riverside. This program is essential for citizens to experience the pleasures of the city, and is at the heart of a sustainable modern model that not only attracts visitors from all over the world, but also creates the happiest and healthiest living experience as a leading global city. The main goal of the design is to create public spaces (streets, parks) with thermal comfort as a way of providing people with high quality experiences.
3.2. Climate analysis
We have used energy models for the evaluation of the climate of Shanghai. The data is based on historical records from the city. We see that the climate data in Shanghai are characterized by hot and humid in summer while cold and humid in winter. The level of solar radiation in Shanghai is pretty good, but also have very important diffuse radiation. This will be considered when designing solar protection from buildings, since direct solar protection will only be partly useful.

Local conditions in the waterfront of the Yangpu river offer the extra data. Winds in summer specially comes from the Yangpu river (specially wet), which will be interesting, since the temperature will be lower. This lower temperature will be caused by the effect of the cooling from the enormous river mass. Winds in winter comes from north-east-west. Orientation in the built masses has specially put emphasis in the minimization of the impact of cold winds in winter.

Figure 3. Wind-rose, Shanghai.

Figure 4. Monthly horizontal solar irradiation.

3.3. Design Strategies
Urban space and architecture can create diverse comfort opportunities not only by means of shape or scale, but also by understanding well the environment and adapting to it. Factors such as pollution, temperature, moisture, the exposure to winds or direct sunlight, the dynamic character of a place or even color and material affect how we use space and therefore who will feel comfortable using it. On the other hand, the physical or emotional condition of a person regulate factors like the energy that we have, the comfort temperature, our willingness to move or rest, concentrate or be part of a multitude, interact, or retreat, all of which vary along our lives and from one person to another. Based on the above considerations, we try to optimize the design scheme with outdoor thermal comfort as the evaluation index.

3.3.1. The selection of evaluation index and simulation tools. Based on the research and analysis of outdoor thermal comfort theory, evaluation index and model, we decided to select UTCL evaluation index as outdoor thermal comfort evaluation standard and assist in optimization design.

The Universal Thermal Climate Index (UTCI), derived from the Fiala multi-node model, is defined as the air temperature (ta) of the reference condition causing the same model response (strain: sweat production, shivering, wet skin and skin blood flow as well as in rectal, mean skin and face temperatures) as the actual conditions. The difference between UTCI and air temperature depends on the actual values of air temperature (ta), mean radiation temperature (Tmrt), wind speed (v), and water vapor pressure (vp). The general mathematical terms can be written as below: UTCI = f (ta; Tmrt; v; vp) = ta+ Offset (ta; Tmrt; v; vp).

We chose ladybug installed on rhino platform as a simulation tool to assist in the scheme design. The simulations by ladyBug in rhino used the equation above to calculate the UTCI. The important value calculated by the simulation is the mean radiant temperature (Tmrt). We have used Albedos index of 0.25 for grass and 0.08 for cement and asphalt. This phase has maximized the green surface and minimized the concrete surfaces exposed to the Sun.
3.3.2. Outdoor thermal comfort simulation. We have done a thermal behaviour analysis of the condition of the existing streets and outdoor areas. From this study, we defined design strategies to achieve thermal comfort in the street for people. This research focused on design strategies and their possible effects on thermal comfort within the area of the Yangpu river in Shanghai. This was all limited to the street, where landscaping could be done, and shading systems created. The thermal behavior of the street is simulated using the software Ladybug + TRNLIZARD (TRNSYS). To quantify the comfort, we used the Universal Thermal Climate Index (UTCI). The UTCI is calculated using the dry bulb temperature, mean radiant temperature (Tmrt), humidity ratio, wind speed, metabolism and clothing. The UTCI indicates what the temperature feels like, in °C. We assume that the comfortable range without thermal stress is 9-26°C.

If we compare the first two phases with the current proposal, green spaces have been significantly maximized, to optimize the outdoor comfort for final users, as we’ll see in the UTCI diagrams.

![Figure 5. Heat map of the site.](image)

3.3.3. Optimal design. Central areas and areas protected by urban developments are especially comfortable in summer, using the UTCI index. In order to improve open spaces, some of the façades have been moved 20 meters back, to create huge porches where outdoor sports can be practiced. Meanwhile, green spaces are significantly increased. Evapotranspiration from green spaces and green roofs improves significantly the radiant temperature of the area and reduces urban heat island effects.

Using the thermal comfort criteria, we have made a segmentation between optimal areas for sport (less hot in summer, no matter how cold in Winter), and for children and elderly (under the bridge, but with potential radiation in winter). This way social diversity is maximized, and zoning maps have been developed, allowing the best areas for lineal sports, static sports and outdoor activities.

All these thermodynamic criteria have been optimized, together with the reduction of noise (an important aspect for outdoor comfort), the maximization river visibility and local air pollution reduction, thanks to pollutant absorption from the vegetation (trees) proposed.

![Figure 6. Crowd and activity characteristics.](image)
4. Conclusion
With the rapid development of computer-aided design methods, green building performance simulation technology, parametric design methods and tools, and aiming at thermal comfort and energy consumption, many optimization methods have been studied at home and abroad, but there are still defects of "retrospective" checking calculation. This study focuses on the significance of simulation optimization in the whole design stage, introduces simulation optimization based on outdoor thermal comfort evaluation standard into public space design. The main purpose of the study was to develop and validate an integrated design method of public space design considering outdoor thermal comfort as a main index with a case in China that has been designed from the beginning of design to the completion for optimizing the environmental performance and simulation. In this case, UTCL is used as the evaluation index and ladybug simulation tool is used to evaluate outdoor thermal comfort and assist in optimizing architectural design. The findings of this research have both practical and guiding significance.

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