Analysis of Spatial Elements Affecting Human Thermal Perception and Thermal Landscape Design

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Abstract

The energy consumption and carbon emissions for indoor heating and cooling in the building field are getting higher and higher. At the same time, the steady thermal environment regulated by equipment for a long time is not only harmful to the health of users but also reduces the energy utilization rate. Therefore, from the perspective of space combination and detail design, the paper analyzes the six spatial elements of human body heat perception, including space material, color, scale, shape, natural proportion, and human flow density. Breaks through the traditional design method of thermal environment, but from the perspective of space thermal perception analysis puts forward landscape design method, respectively, attraction, for the space diversity, energy saving and guides the architect in the thermal environment design and energy-saving building design, coordination of thermal environment, space combination, the relationship between the thermal perception, make buildings more energy efficient, make people healthier.

Keywords

Thermal perception · Thermal landscape · Energy-saving design

8.1 Introduction

The global sustainable development goals mention making cities and human settlements inclusive, safe, resilient and sustainable, promoting sustainable construction industry activities. The world's cities account for only 2% of the Earth's land area, yet they consume 60–80% of energy and produce 75% of carbon emissions. Building energy usage cannot be disregarded. It is vital to examine how building energy is utilized from a new perspective and decrease energy consumption waste in order to reduce resource and energy consumption. A number of physical and mental health issues, including "sick building syndrome" and "inadequate air-conditioning adaptation," are on the rise as a result of "constant temperature and humidity" environments. The main objective of environmental control shouldn't be to maintain a constant interior thermal environment. It is easier to meet human demands in a dynamic thermal environment, and this makes people more thermally adaptable (Zhu et al. 2016). There are currently few thermal environment creation techniques and environmental energy-saving design guiding methods in

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A. Hasan et al. (eds.), *Design for Health*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-031-36316-0_8

building environmental control design, despite the extensive study of active and passive energy-saving measures of building space from the standpoint of energy consumption. The idea of soundscape in architecture was first put forth with a lot of research findings (Mengqi and Kangjian 2018). The idea of a light landscape was developed later, but it has now found widespread use in both landscape architecture and urban planning. Architectural thermal landscape is a little-discussed physical aspect of architecture. Few relevant studies have considered the architectural spatial scale of the architecture itself; the majority have concentrated on the urban thermal environment (Wenrui et al. 2014), climatic map (Chao et al. 2012), and block scale. This work reexamines the energy-saving building space design methods and advances the idea of spatial thermal landscape development in this setting. Building science and technology stimulate creative thought and architectural design while creating a more comfortable thermal environment for people and reducing energy consumption in buildings. The goal of this study is to promote the achievement of the global sustainable development goals' building energy-savings goal.

A thermal environment that one or more people perceive, comprehend, and feel in space is referred to as a thermal landscape. The thermal expression of architectural design, the thermal form of architectural space, and the new architectural language all revolve around creating a dynamic, healthy, and enjoyable thermal environment. Thermal landscape refers to a pleasant thermal environment as sensed by the body rather than a visual landscape. People experience space as well as use it, and it is this type of experience that gives space its unique qualities. The thermal environment, heat source, space materials, openness, color, natural qualities, etc., as well as elements like people's psyche and expectations, are some of the spatial characteristics that influence how people perceive heat. More and more research has shown that people's perception of heat can be influenced by spatial contexts besides the physical surroundings and indications. As a result, this study proposes the idea of a thermal landscape in an effort to develop a healthy thermal environment in a more systematic, sophisticated, and rational manner.

A thermal environment that one or more persons perceive and experience in space is referred to as a thermal landscape. A type of thermal environment is a thermal landscape, however this type of thermal environment isn't just a static physical thing; it's also a dynamic, healthy thermal environment that people can sense. The properties of heat conduction are connected to the thermal landscape's conductivity. The skin system, which determines that people are more sensitive to the thermal environment, is the primary organ through which people perceive the thermal environment. The application of thermal landscape spatial orientation in space design can efficiently direct the flow of people. Heat transmission modes, which can be categorized into three categories: conduction, convection, and radiation, determine the variety of the thermal landscape. As a result, the "thermal landscape" can be customized to fit various settings, e.g., a centralized heat source, sun radiation to produce a thermal landscape, or improved air convection. The diversity of heat conduction determines the diversity of an architectural space, and under the influence of a vibrant "thermal landscape," the space can have a particularly rich spatial effect.

Heat perception can be influenced by vision, spatial proportions and openness, a building's material composition, and more. The spatial arrangement, distribution, openness, and features of the building all have an impact on how heat is perceived. People will feel more depressed in a room with a narrow floor height at the same temperature, for instance, yet in a room with a relatively open floor plan, they will feel more comfortable even in a room with a greater temperature. When designing a space, keep in mind that hot air rises and cold air falls. Often, a hierarchical analysis is used to place the requirements for high temperature space at the top and conveniently chilly area at the bottom. Because we frequently cannot alter some aspects of the local environment, such as the local climate, but we can influence other aspects of it

within a certain range, the openness of space offers great potential and possibility for architectural design. Through the creative use of space, space combination, and environmental control, designers can push the boundaries of climate design. Different spatial arrangements and intricate designs result in various thermal field distributions, as seen in Fig. 8.1.

Similar to how the air-conditioning system is positioned above the room, the thermal distribution of the room exhibits obvious changes due to the qualities of hot air ascending and cold air falling. The spatial heat distribution will undoubtedly be impacted by the specific architectural elements, such as vents, outdoor spaces, skylights, and the interaction between people and

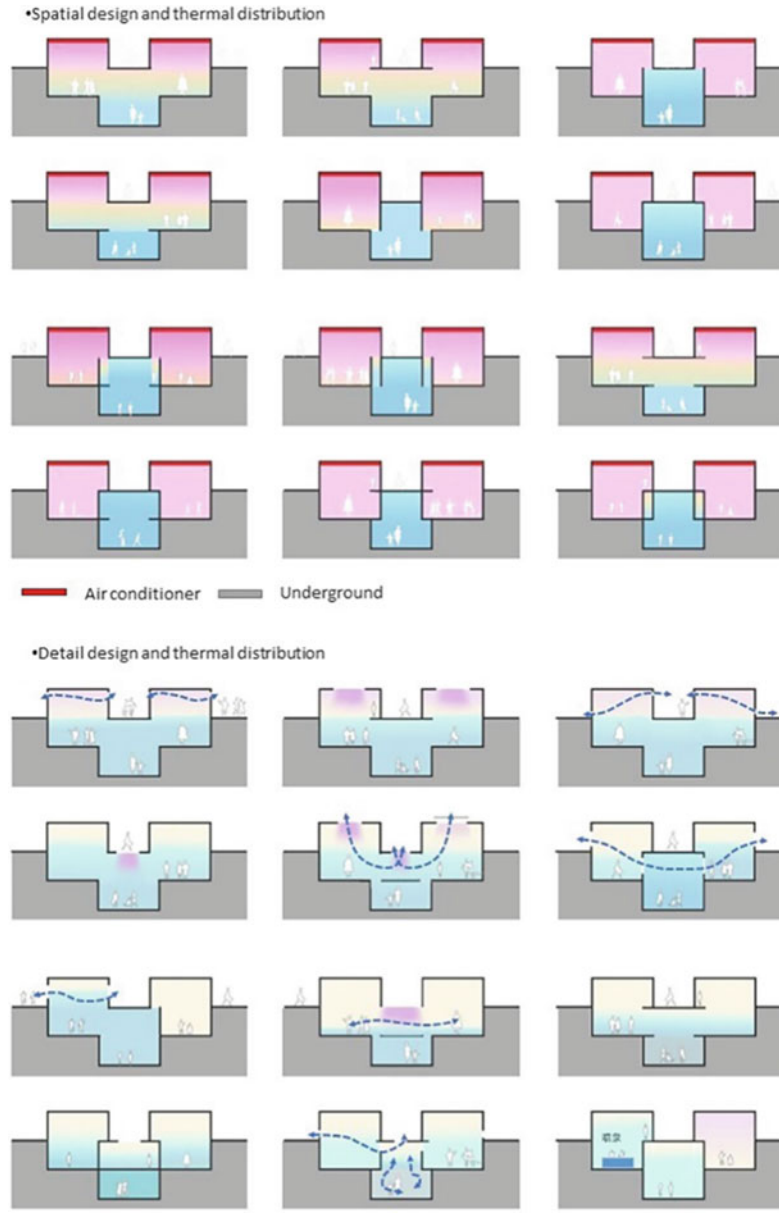

Fig. 8.1 Effect of spatial composition and detail design on thermal distribution. *Created by* authors

the space. The quality of the thermal landscape will be impacted by how heat, space, and people interact. As a result, other factors that we frequently overlook, such as the characteristics of the space and the people and objects carried in the space, also have an impact on the thermal environment of a building. These other factors include the outdoor environment, air-conditioning, fans, and other equipment. Heat perception in people is complicated, involving psychological, physiological, and emotional factors. So that energy may be used successfully, the thermal landscape can be more precisely designed using a thorough examination of the components of heat perception.

8.2 Design and Thermal Perception

8.2.1 Materials, Color, and Thermal Perception

There are few studies on how objects in space affect how hot individuals feel. However, because they have varying thermal conductivities and heat transfer coefficients, concrete, wood, stone, and even the present will change how hot people perceive it to be. Additionally, the color of the materials in space will also have an impact on how hot people perceive it to be. Relevant research by Professor Fanger demonstrates that: people in the extreme red environment can stay inside comfortably at a temperature that is 0.4 °C lower than in the extreme blue environment. Thermal sensation, thermal comfort, and environmental comfort are known to be influenced by both temperature and environmental color. Warm colors can ease cold-weather discomfort, while cool colors can ease hot-weather discomfort. Human physiological indicators such as blood pressure and heart rate will be impacted by color. Blood pressure and heart rate will rise in a red or yellow environment while falling in a green or blue one. Additionally, there are some differences in the human body's comfort zone below cool and warm color tones. The wavelength of different colors affects the human thermal comfort. The findings demonstrate that the thermal sensory voting value of the human body is highest in the red environment and lowest in the purple environment according to the shortest wavelength. In warm color environments, the thermal sensory voting value is higher, but in cold color environments, it is lower. Attention should be given to the combination of building materials and colors in space design, particularly in public places and open areas, to create a thermal landscape (Fig. 8.2).

8.2.2 Shape, Scale, and Thermal Perception

The quality of the indoor environment is also influenced by the size and shape of the room. In a room that is big and well-ventilated, people are more likely to feel satisfied. A space will feel chilly and serious if it has too many right angles and acute angles, while a space with more smooth curves would feel pleasant to the touch. There are few studies on this type of space shape's effects on thermal sensation, which may primarily affect people's psychological well-being. In contrast, spatial scale has a greater impact on people's experience of heat. A variety of psychological discomfort will be produced in a small area, and this discomfort will be transmitted to the demanding thermal environment. Numerous related research on the impact of spatial scale on temperature perception are currently available. Researchers who looked at the thermal comfort in five different types of spaces in the summertime east of the Netherlands discovered that the spatial shape and type has an effect on the comfort of the thermal environment (Taleghani et al. 2015). Space form, which encompasses the shape, size, aspect ratio, height, and aspect ratio of the space plane, is the most intuitive feeling provided by space. People's psychological and spiritual states will be influenced by the volume, scale, shape, proportion, and other aspects of an architectural space. To some extent, the size of an architectural space can affect how individuals feel psychologically and spiritually. People's psychological and spiritual states will alter their breathing rate, pulse,

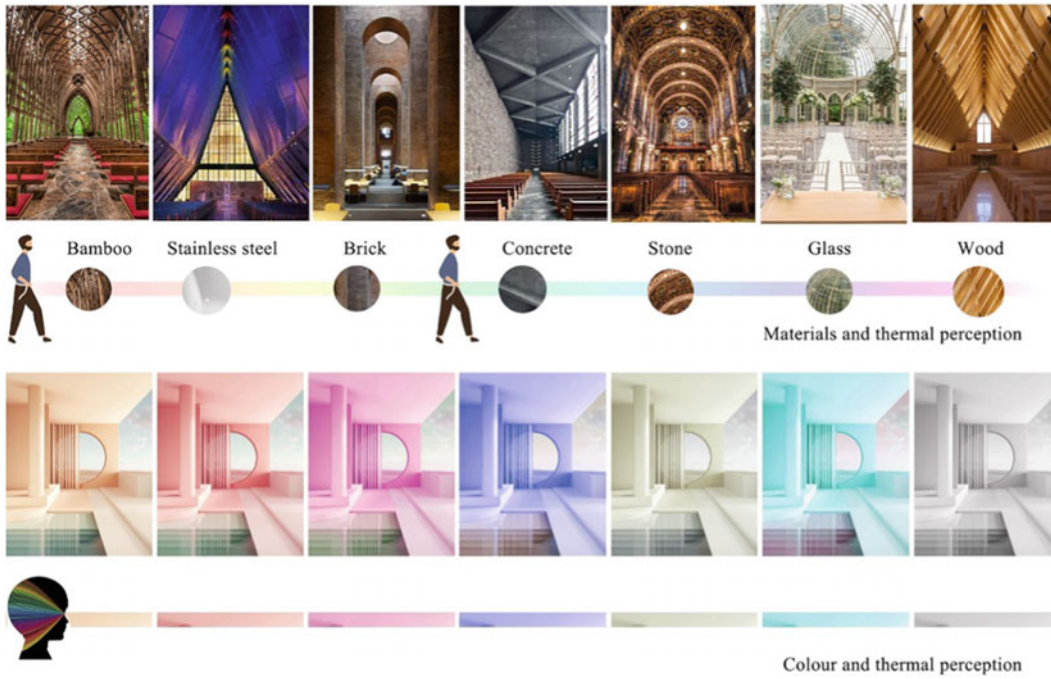

Fig. 8.2 Materials, color and thermal perception. *Created by* authors

blood pressure, and other physiological aspects, and these aspects directly affect how comfortable they feel with their body temperature. As a result, while designing an interior thermal landscape, care should be taken to evaluate the size and layout of the area, with an early emphasis on the need for comfort and energy efficiency (Fig. 8.3).

8.2.3 Nature, Human Flow, and Thermal Perception

It makes a lot of sense how natural components interact with objects and spaces. The genuine construction materials and integral components of the building and urban system, water, air, land, and water all have a significant impact on the design. From an ecological standpoint, the city was built by a system of people, space, and natural and cultural landscapes, as well as building integration for the integration of a metabolic system, human material production and consumption, and participation in social and cultural activities. The quality of the building space will improve as the natural environment is expanded. The University of Michigan professors Rachel Kaplan and Stephen Kaplan developed the idea of restorative environments, which emphasizes the resilience of people who frequently interact with the outdoors and defines restorative environments as "environments that better enable people to recover from psychological fatigue and stress-related negative emotions." However, because so much of the technology and materials used in architecture are manufactured, people frequently feel unhappy and exhausted. Therefore, the amount of natural environment, including indoor plants, water features, fountains, areas exposed to sunshine, and the degree of connectivity to the outdoors, is a crucial aspect. The natural landscape of demand with the seasons are different than quantity, is influential, and in a very hot summer, if there is too much sun exposure area, will lead to people not feeling comfortable. Therefore, from the perspective of space, about the rationality of the natural elements of mainly comes from two aspects, it is a quantitative indicator that is

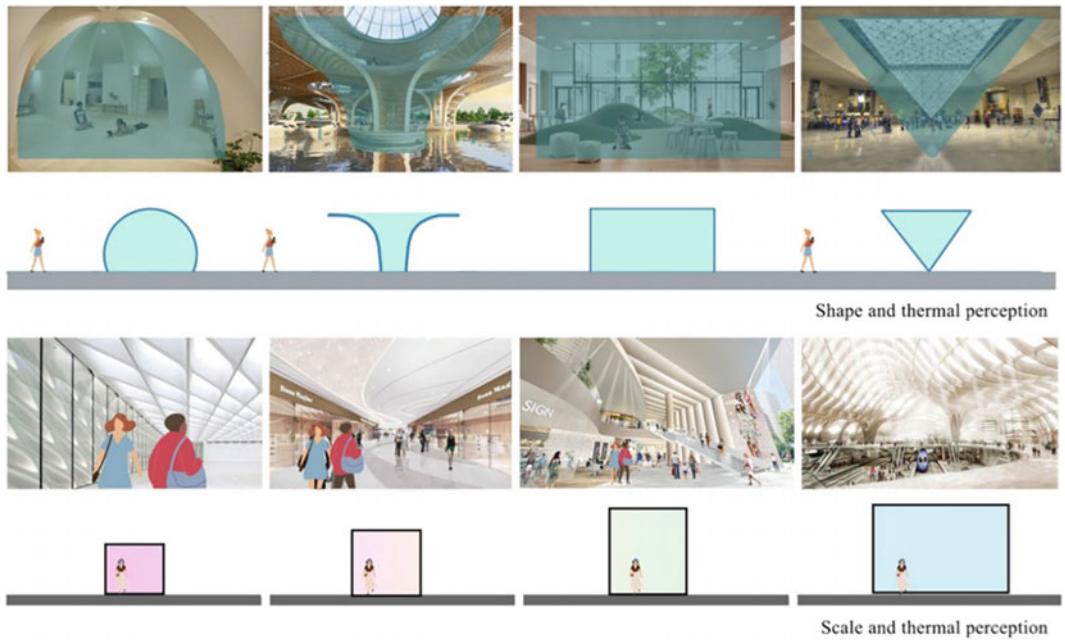

Fig. 8.3 Shape, scale, and thermal perception. *Created by* authors

primarily based on the research of associated fields. Historical experience is derived from the analysis and summation of architectural spatial form under particular climatic circumstances. According to research, people are better able to withstand thermal comfort variations and are more likely to feel content and joyful in an area that is close to a window. The potential cause is that windows can draw attention away from thermal discomfort and toward the more varied sensory inputs outside, so enhancing thermal comfort. It's also likely that people's expectations of indoor thermal settings are influenced by their visual acceptance of sunlight and warmth in nature. The building's ability to create green space is favorably connected with its users' happiness and satisfaction scores. People will instinctively seek out green spaces since they subjectively associate them with love of greenery, thus it's important to take that into account when designing a space's environment (Klemm et al. 2015). Since people generally give the natural environment high marks for thermal comfort, architects can raise people's contentment with the thermal environment by designing spaces with a natural feel. In addition, the function of space will affect the number of people. The more people, the larger the radiation generated, traffic density is too high in areas of the body of radiant heat accumulation, the heat accumulation, if not promptly dissipated, also produces thermal discomfort, and the entertainment value of a strong space can also affect a person's metabolic rate. The function of the space and the human flow density in the space will affect the thermal perception , and these effects can not be ignored (Fig. 8.4).

8.3 Construction Method of Thermal Landscape

While engineers are more accustomed to employing equipment to solve issues in the building environment control process, thermal landscape places a greater emphasis on maximizing the environment and improving energy utilization through design strategies. Thermal landscape research takes into account not just precise numerical figures but also the well-being

Fig. 8.4 Nature, human flow, and thermal perception. *Created by* authors

and good moods of the participants. Additionally, they focus on the application of heat transfer concepts in conjunction with findings from the fields of architecture, anthropology, and environmental psychology in order to actively create a more hospitable and environment that is better suited for human life. Thermal landscapes are built using techniques including space combination, place gathering, varied composition, and energy-saving adaptation. Following that, four perspectives—space design, site attraction, zoning design, and energy-saving scheme—are used to introduce the situations and techniques of thermal landscape design.

8.3.1 Space Combination

The properties of heat conduction are connected to the thermal landscape's directivity. When compared with heat transmission, light and sound transmission are more susceptible to environmental obstructions such as noise and other debris. There are two benefits to the thermal landscape. One is that heat transfer has clear anti-interference properties and is significantly less influenced by the outside environment. The other is that people primarily use their skin system to sense heat, rather than specialized organs. The flow of people and the functional zoning of building space can therefore be efficiently guided by the characteristics of thermal landscape space orientation in space design. For instance, the German convection apartment depicted in Fig. 8.5 employs the idea of warm air rising and cold air falling to produce a thermal landscape together with space functions. The highest temperature differential in this apartment between the floor and the ceiling is 10 °C. Each room in the residence has a varied temperature because of the variations in clothing thermal resistance and the activity of the people in those rooms. If a person is covered with a quilt in the bedroom, the temperature is 18 °C, thus the bedroom is designed in the lowest location, and the bathroom is setup in the area with the highest temperature. Temperatures and relative humidity fluctuate depending on height. People are free to

Fig. 8.5 Analysis diagram of convection apartment in Germany (https://www.philipperahm.com/)

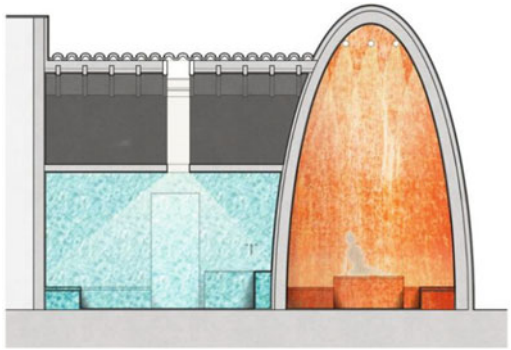

Fig. 8.6 Section of Hamam Hot Spring (https://www.archdaily.com/946020/hammam-spa-ressano-garcia)

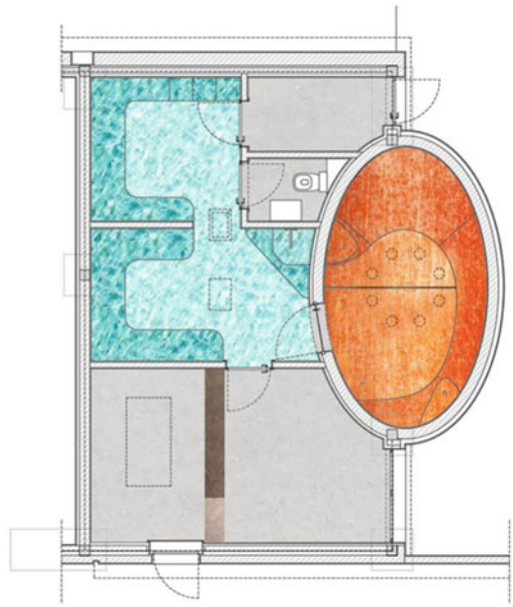

Fig. 8.7 Plan of Hamam Hot Spring (https://www.archdaily.com/946020/hammam-spa-ressano-garcia)

go around in search of a particular, comfortable thermal environment. Buildings have the potential to save a lot of energy. Figures 8.6 and 8.7's depiction of Hamam Hot Spring serves as another illustration. The geometry of the space is directly influenced by the temperature there. The shape of a room in a warm environment is a flowing curve, as if the room were melting; in a cold environment, the shape is straight lines and incisions, as if everything had solidified. To increase the level of stimulation that users experience, each room stresses temperature in a distinctive way.

8.3.2 Site Gathering

The perfect thermal environment will inevitably develop into a gathering place for people. As an illustration, European and American families once gathered around the hearth. A basic dwelling feels more cozy with the dancing lights, the scent of smoke, and the crackling sound of burning (as shown in Fig. 8.8). In Northeast

Fig. 8.8 Gathering of fireplace. *Created by* authors

China, the heated kang also serves as a place for sleeping, eating, communicating, and relaxing (as shown in Fig. 8.9). However, excessive air-conditioning use maintains a constant temperature throughout the entire structure,

Fig. 8.9 Gathering of Chinese heated kang. *Created by* authors

homogenizing the area. Family members' ability to communicate and feel connected to one another has been hampered by the activities that were earlier concentrated in one area of the building due to a heat requirement. Warm kang and fireplaces, as opposed to air conditioners, cause our impression of the thermal environment to be influenced by a range of thermal elements, such as temperature, humidity, and airflow. People's perceptions of the thermal landscape will vary if one or more influencing elements change. As a result, thermal landscape contains a greater amount of scene information. People will have a strong feeling of connection to the architectural space once they become accustomed to a particular and rich thermal environment. People will depend on the space and exhibit the features of the location once they have a positive impression of the thermal landscape, which will increase the building's appeal. This method can improve the quality of the space while saving energy.

8.3.3 Diversified Composition

Diversity depends on the amount of heat being transmitted by the thermal landscape design. Since there are three different ways that heat is transmitted—through conduction, convection, and radiation—the thermal landscape can be modified to fit various design scenarios, including centralized heat sources, solar radiation, strengthened air convection, and plant control. As an illustration, consider Qingcui Garden in Taichung City. The weather in Taichung is often tropical. People prefer to stay in air-conditioned indoor spaces and are cut off from nature due to the area's severe air pollution and hot, humid weather. Therefore, lowering pollution, temperature, and humidity is the main goal of the design. To start, the architects calculated the site using fluid mechanics to identify its coldest, driest, and cleanest regions (Fig. 8.10). Then, the cool, dry, and clean regions were built based on these places. In order to improve the natural qualities of these locations and create thermal landscapes, a range of climatic devices including sprays, bladeless fans, concrete panel radiant tubes, dew collectors, ultrasonic insect repellents, and trees with thermal conditioning functions were devised. Tourists can select their own climate zone based on their individual preferences and activities; each zone offers a distinctive thermal environment experience. In the cool zone, people can engage in quiet activities like reading and chit-chatting; in the dry zone, people can exercise; and in the scene area, the entire family can get together and have a picnic. In spite of the humid and hot weather outside, people can still find a comfortable spot in the park, and the thermal landscape building increases park enjoyment and usage.

8.3.4 Potential for Energy Savings

Vernacular architecture all over the world has complex ways of dealing with temperature, and the shapes and materials used in the original architecture work well to make up for climate problems. In deserts, for example, materials like sand and soil have a high specific heat capacity, which means they absorb solar radiation during the day and slowly release it at night. In the tropics, houses are made of lightweight materials like bamboo and reeds to block thermal radiation and improve ventilation. Folk houses can only be built by people who know how to do construction. Only by following their laws can they shape them, which is why the culture of traditional folk

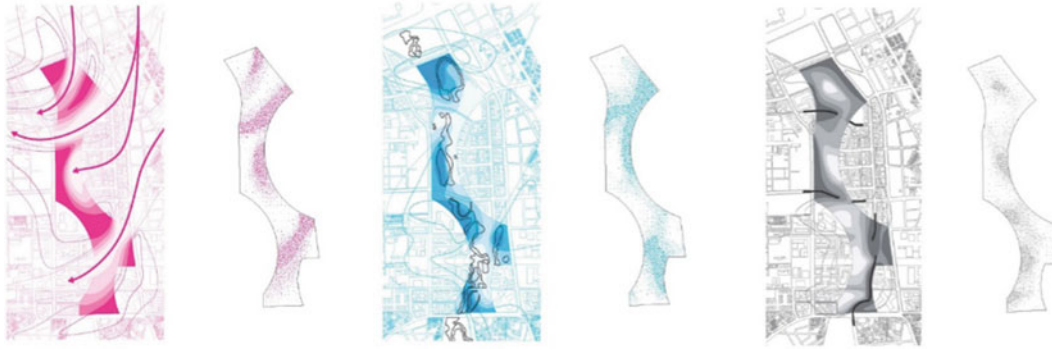

Fig. 8.10 Site calculation, analysis, and planning of Qingcuiyuan (www.Philipperahm.com)

houses has been passed down for so long (Qun et al. 2020). But because people use air-conditioning too much, architects can't show off their original thermal environment design skills, and the wisdom of traditional residential building is slowly going away. If you use your air conditioner too much, you will forget things about your region and culture. Traditional building methods are respected in thermal landscape construction, which focuses on bringing people into and back to nature while saving energy, e.g., in the Austrian National Pavilion at Expo Milano 2015 (Fig. 8.11), there are a lot of plants, and high-pressure spray devices are put in place to help the leaves evaporate water. Even without air conditioners, the temperature inside is still 5–7 °C lower than the temperature outside.

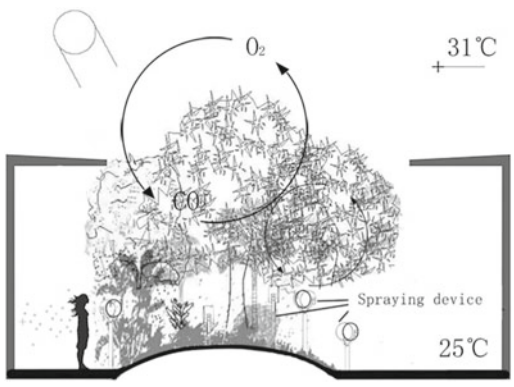

Fig. 8.11 Energy conservation analysis of Austrian National Pavilion (https://www.metalocus.es/en/news/austrias-pavilion-expo-milano-2015)

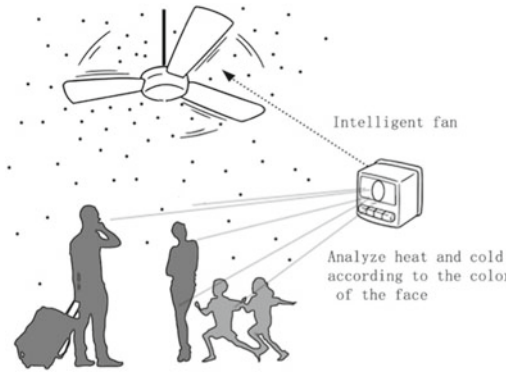

Fig. 8.12 Schematic diagram of intelligent on-demand ventilation. *Created by* authors

This saves a lot of energy. Also, the intelligent communication system of risk control technology can achieve on-demand ventilation (as shown in Fig. 8.12). Some scholars have designed a system of feature extraction and analysis of thermal sensation (Wang et al. 2021), which can adjust the ventilation rate based on the user's facial color and how hot or cold they look. It can also tell how many people are in the room.

8.4 Conclusion

The world's current energy and climate crises serve as a reminder to architects to be mindful of their usage of energy. The only way to maintain the thermal comfort of the space while lowering building energy consumption is to use energy consumption in a more precise and refined way.

A thermal landscape concept is a brand-new area of study and way that architectural environment control science is being used. When designing spaces in the past, designers typically focused on functional aspects and organizational simplicity rather than environmental control and energy-efficient building design. This article suggests the following five techniques for designing thermal landscapes:

(1) The idea of a thermal landscape broadens the scope of the initial design. The thermal landscape approach stresses eliminating reliance on air conditioners while the standard environmental control method promotes neutral space, which uses more energy to maintain a lukewarm atmosphere. Pay attention to how well people adapt to heat and the need for a dynamic thermal environment at the same time, use architectural design strategies to create a cozy thermal environment, follow the rule that warm air rises and cold air descends, and make the most of windows, sunshades, and building materials. The relationship of space and thermal environment, space requirements, human behavior, and physiological factors should all be taken into consideration by architects when designing the thermal environment of a building to save energy.

(2) Warm colors can make people feel warm, while cold colors can make people feel cool, depending on the material and hue used. Therefore, it is important to understand that people's perception of heat can be influenced by the color of lighting and décor while designing an architectural structure. To change how people perceive heat, you can use warm lighting in the winter and cold lighting in the summer in conjunction with interior design. The choice of materials should be made in accordance with the thermal environment requirements of the building and acceptable materials should be selected for the design of spaces with diverse needs. Concrete and steel will make people feel cool, while wood and brick will make people feel warm.

(3) The scale of the space should not be pursued excessively during the design process because the larger the scale, the more obvious the sense of emptiness will be, the colder the people in the space will feel, and more energy consumption is required to maintain comfort. On the other hand, the more private the space, the more it can increase people's sense of security. To prevent energy waste, the relationship between human thermal perception and scale should be taken into account for visual effects with a big scale. Using human thermal experience features can reduce building energy usage. When designing small spaces, curves can make people feel comfortable, but too many edges and corners can make people feel chilly and serious.

(4) The presence of more natural features, such as indoor plants, ponds, and fountains, as well as windows that open to the outdoors, will increase customer happiness in the area, regardless of whether the temperature is high or low. People are better able to handle temperature variations because of the architecture. To increase people's enjoyment with the environment and lessen the energy use of air-conditioning, it is therefore important to pay attention to how nature interacts with architecture and to employ more flowers, trees, water features, skylights, and windows in public spaces of buildings.

(5) Smart devices can be used to intelligently adjust the temperature and wind speed in the space, as well as adjust the indoor temperature at different times of the day in accordance with people's physiological habits, in order to control the energy consumption of buildings in conjunction with the needs of human behavior. Thermal environment, for instance, after employees arrive at the office following a commute, the demand for temperature is not great within 30–60 min after arriving at the office because the metabolic rate during commuting is relatively high. The temperature might be reduced during this time. Then gradually raise the air conditioner's temperature. When there are few individuals present in a broad area, it is sufficient to employ heaters

or fans to locally warm up or cool down the area. Energy can be saved by switching to the proper temperature adjustment equipment. Additionally, workers should turn off air conditioners and lights in buildings promptly after leaving work as part of the energy management process for buildings. Attention should also be made to energy consumption regulation at night.

The study of thermal landscapes is based on an examination of the components of thermal perception and human body adjustment. It entails a thorough planning and designing of the thermal landscape of an architectural space from the viewpoints of scale, color, material, location, and the positioning of natural elements, among other things. Design the space's thermal environment from one perspective, use fewer air conditioners, increase user comfort and thermal adaptability, and realize synchronous improvement from equipment thermal environment control to human body thermal adaptability and comfort based on thermal landscape, all while lowering building energy consumption, usage, and preventing energy waste.

Acknowledgements This work was supported by the National Natural Science Foundation of China [Grant No. 52078341].

References

Chao R, En-Rong W, Zhi-Xiong F (2012) The development and application of urban environmental climate map. J Appl Meteorol 5(23):593–603

Klemm W, Heusinkveld BG, Lenzholzer S, van Hove B (2015) Street greenery and its physical and psychological impact on thermal comfort. Landsc Urban Plan 13887–13898

Mengqi, Kangjian (2018) Study on the soundscape of urban fringe area: a case study of Harbin Sugar Mill Community Planning. Urban Plan 4(42):94–99

Qun Z, Shaopeng L, Qing W (2020) Study on wall construction techniques of traditional Tibetan dwellings in Yushu Area. J West China Hum Settlements Environ 03(25):84

Taleghani M, Kleerekoper L, Tenpierik M, van den Dobbelsteen A (2015) Outdoor thermal comfort within five different urban forms in the Netherlands. Build Environ 8365–8378

Wang J, Huang J, Feng Z, Cao S, Haghighat F (2021) Occupant-density-detection based energy efficient ventilation system: prevention of infection transmission. Energy Build 240110883

Wenrui Y, Feng L, He Y (2014) Characteristics of urban thermal landscape change in Beijing from 2003 to 2011. Acta Ecol Sin 15(34):4390–4399

Zhu Y, Ouyang Q, Cao B, Zhou X, Yu J (2016) Dynamic thermal environment and thermal comfort. Indoor Air 26(1):125–137