Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
July-August 2022 Page No. 1084-1108
Article History: Received: 30 March 2022, Revised: 8 April 2022, Accepted: 15 April 2022, Publication: 30 April 2022

Research on Optimization Measures of Thermal Environment in Dunhuang Traditional Dwellings in Winter

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Abstract:

The dwellings in Dunhuang area are a kind of special dwellings that are adapted to the local climate and formed under the cold and arid climate. As the times change, local residents begin to transform traditional dwellings to meet the needs of modern people. Whether the measures used in the transformation are suitable for local traditional dwellings is a question worthy of attention. In this paper, by selecting typical traditional dwellings in Dunhuang area and traditional dwellings spontaneously transformed by residents, the indoor and outdoor thermal environment parameters are measured in winter, and the indoor thermal environment of the two types of dwellings is compared. The indoor thermal environment is poor in winter, so it is necessary to improve and optimize. According to the winter thermal environment of two types of Dunhuang traditional residences, the protection and optimization design measures of building orientation, building space and outer protective structure are respectively proposed. The improved indoor temperature can meet the requirements of energy-saving design specifications. The research results are expected to provide a basis and an effect evaluation mechanism for the thermal environment improvement and optimization design of Dunhuang traditional dwellings.

Keywords: *Traditional dwellings, Measured thermal environment, Ecotect simulation*

I. INTRODUCTION

As the pace of economic construction speeds up in China, the rural revitalization strategy, as an important part of economic construction [1], has received more and more attention from all walks of life. As a characteristic part of the rural revitalization strategy, traditional dwellings have become the hotspot of academic research. According to the research, thermal environment is a key factor affecting the protection and development of traditional dwellings. A suitable indoor thermal environment is the basis for the sustainable development of dwellings. In recent years, with the gradual improvement of economic

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development in Dunhuang area, residents have increasing requirements for better living environment and greater indoor comfort. The architectural design pattern, construction techniques and building materials of dwellings can no longer meet the needs of modern people [2]. Dunhuang is one of the four counties in the Hexi Corridor. Study on thermal performance of dwellings in the Hexi Corridor area has gradually started [3-5], but research on thermal environment comfort is only in its infancy [6]. Investigations found that traditional dwellings in Dunhuang area are relatively well protected, still accounting for the majority of local residential buildings. In order to meet the needs of modern life, local residents spontaneously renovate the original traditional dwellings. In recent years, various dwelling construction forms out of residents' self-renovation appear in Dunhuang area, but most research on traditional dwellings in Dunhuang area is qualitative [7-10], and the research on the improvement and optimization of the indoor and outdoor thermal environment of traditional Dunhuang dwellings has not aroused local concern. Therefore, this study takes the existing typical dwellings in the Dunhuang area as the research object. The indoor and outdoor thermal environment is measured and improved in winter. The ecological software is used for simulation and optimization in attempt to propose an optimization scheme so that the traditional dwellings in Dunhuang area have more comfortable, energy-saving and healthier indoor living environment.

II. MEASUREMENT AND ANALYSIS OF THERMAL ENVIRONMENT

2.1 Overview of the study area

Dunhuang is located in the northwest inland of China, with a continentality of 69.2% and a typical continental climate [11]. According to our current "Technical Guidelines for Energy Conservation in Severe Cold and Cold Rural Housing" [12], Dunhuang is divided into cold regions characterized by cold and long winters, and the average temperature of the coldest month is 0-10℃. Buildings in this area should have heat storage requirements in winter while preventing overheating in summer [13].

According to the index and classification system designated for the national climate division of the Central Meteorological Administration in 1966, Dunhuang is classified into the southern temperate arid zone (i.e. IIID). Regarding the overall climate characteristics of the local area, there are long and cold winters, dry and hot summers, strong solar radiation, windy and sandy springs, short frost-free periods, very little annual precipitation but high variability, and great evaporation [14]. Therefore, through field investigation, it is found that local traditional dwellings mostly use sunshade components to cope with the local arid climate environment. In this study, two typical traditional san-ho-yuan in Dunhuang area was selected as the research object. According to the different sunshade components, they are divided into dwellings using traditional wooden frame sunshade in courtyards and those using additional glass ceiling in courtyards. The research objects are set as sample A and sample B respectively. Sample A is located in Lvjiabao, Dunhuang City, built in 1987, with a total construction area of 214.45m^2 and a building height of 3.5m. The building is made of brick-column adobe wall with a thickness of 500mm. The courtyard has no window, with doors and windows opposite to the courtyard. External sunshade component is set in the courtyard, which is a traditional wooden frame sunshade (Figure 1). Sample B is located in Group 2,

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Banqiao Village, Dunhuang City. Built in 1991, it has a total construction area of 220.45m^2 and a building height of 3.8m. The building is made of brick-column adobe wall with a thickness of 500mm. In 2013, the building was renovated and reinforced, with a glass steel ceiling built over the courtyard, which is 1.7m high (Figure 2). The building is made of brick and column raw earth wall, with wooden doors and windows opposite to the inner courtyard. The courtyard walls have no windows. The dwelling samples all sit in the north and face the south, with wooden frame single-layer windows. Indoor doors are solid wood composite doors, and the roofs are all grass and mud roofs. The slope is single, with a gradient of 5%~7%. The house adopts independent heating.

Figure 1 Sample A

Figure 2 Sample B

2.2 Field measurement

This field measurement is mainly to collect on-site data on the indoor and outdoor temperature and humidity of traditional Dunhuang dwellings. The parameters of the measuring instrument are shown in Table 1. 24h continuous uninterrupted monitoring was implemented, and the instrument was placed 1.5m away from the ground. The actual measurement was carried out in 2020, from 17:30 on January 3 to 18:30 on January 10, a total of 7 sunny days without snow. The climate in Dunhuang entered the coldest month then.

All the tested central rooms of Sample A and Sample B adopt independent heating such as stoves and heated kangs in winter. Therefore, in order to guarantee a more rigorous comparison of indoor and outdoor thermal environment tests in winter, the side bedroom of Sample A is added as a comparison measurement point without independent heating. The layout of the instrument mainly considers how to avoid the influence of irrelevant factors in the acquisition of instrument data. Referring to the requirements of "Evaluation Standards for Indoor Thermal and Humid Environment in Civil Buildings" (GB/T 50785-2012), the main measuring points were selected according to the use function of the room [15]. The measurement points of sample A are arranged as: outdoor, central room, secondary bedroom. When selecting the indoor space measurement point of the dwelling sample B in winter, the building space that residents use more frequently is selected for comparative analysis. The test points are arranged as: outdoor, courtyard and central room, and the central room is equipped with independent heating (Figure 3).

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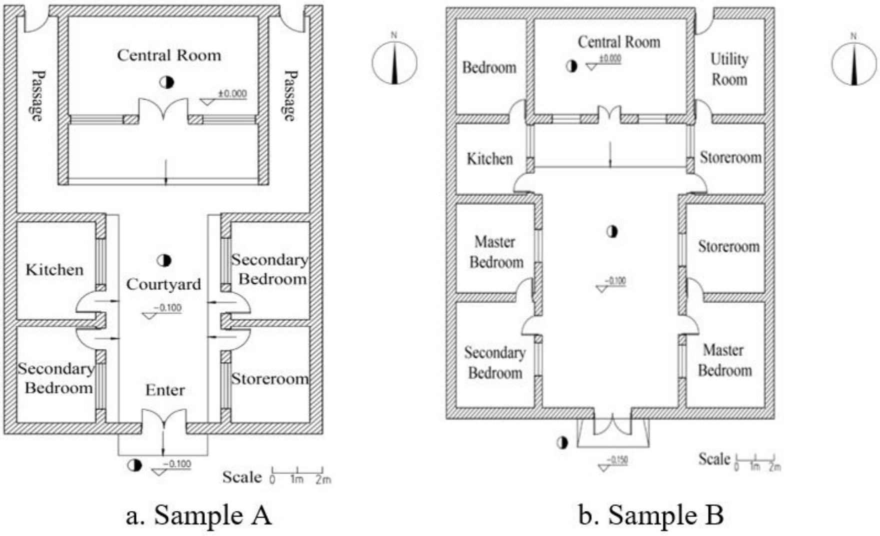

Figure 3 Layout of measuring points for testing dwellings

Table 1. Measuring instrument performance

Instrument Name	Accuracy	Acquisition Interval
TES-1361	Humidity ±3％RH Temperature ±0.5℃	5min

2.3 Data Analysis

The measured winter temperature and relative humidity change curves during the outdoor test in Dunhuang are shown in Figure 4. The relative humidity and temperature show opposite change trend. The courtyard of test sample A is set with a traditional sunshade in a semi-closed state, so the courtyard temperature and humidity are the same as the outdoor temperature and humidity, and the indoor central room has the same temperature curve change trend as the side bedroom. Since the central room adopts independent heating equipment in winter, its temperature is 19.7°C higher than that of the secondary bedroom, as shown in Figures 5 and 6. According to the actual measurement, compared to the outdoor temperature and the indoor temperature in the secondary bedroom, the indoor temperature change curve of the secondary bedroom fluctuates little, and the average temperature is 2.7 °C higher than the indoor temperature, as shown in Table 2 and Figure 9.

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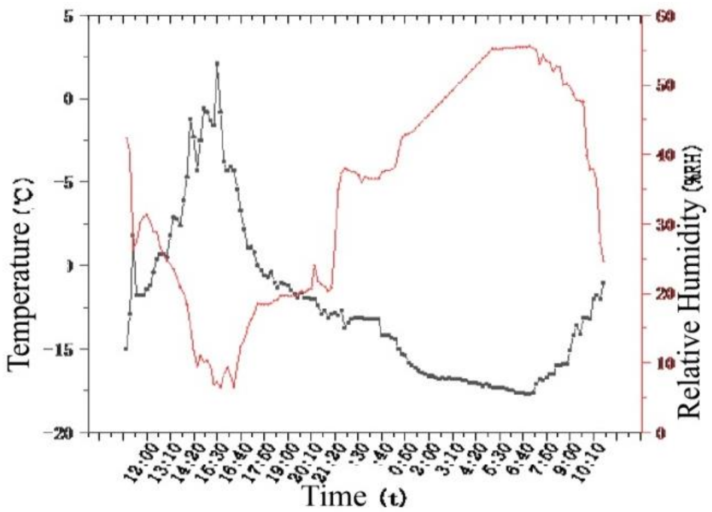

Figure 4 Change curve of all-day outdoor air temperature and relative humidity in winter

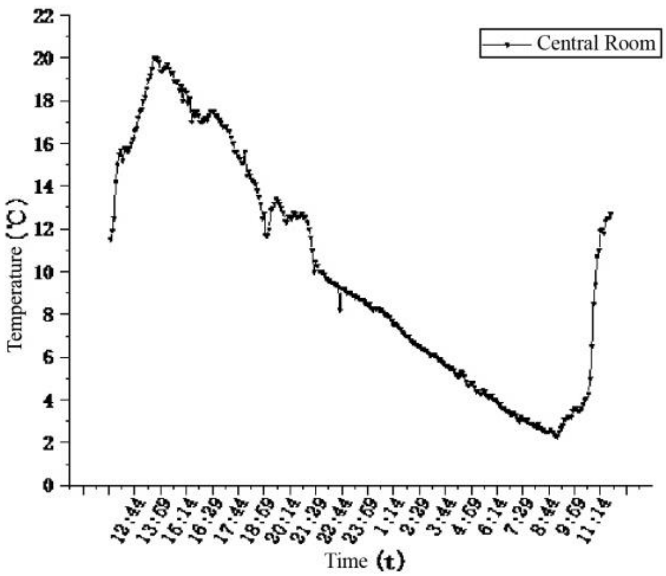

Figure 5. All-day temperature curve of the central room of sample A in winter

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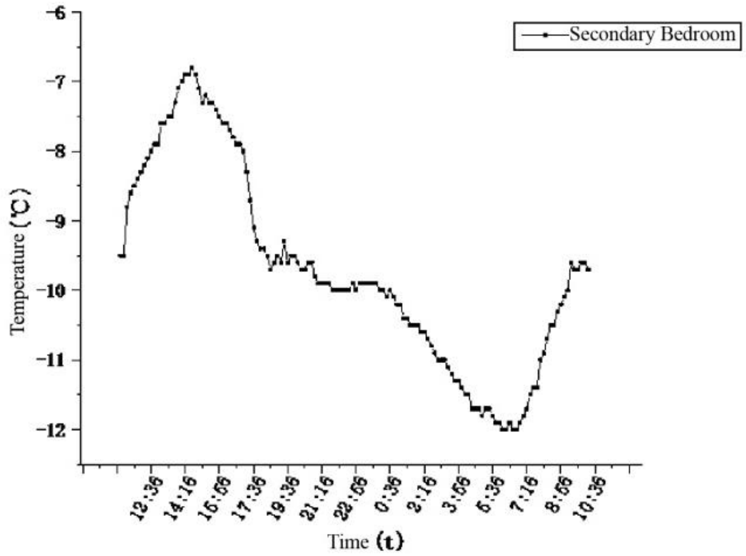

Figure 6. All-day temperature curve of the secondary bedroom of sample A in winter

Table 2. Comparison of indoor and outdoor temperature of dwelling sample A in winter

	Outdoor temperature (°C)	Central room temperature of sample A (°C)	Secondary bedroom temperature of sample A (°C)
Maximum	-0.6	20	-6.9
Minimum	-17.7	2.3	-12
Volatility	17.7	17.7	5.1
Mean	-12.4	10	-9.7

The measured temperature and relative humidity change curves of sample B during the test period are shown in Figures 7 and 8. The relative humidity and temperature have opposite change trend. Comparison of the outdoor temperature curve in winter proves that addition of a glass ceiling to the courtyard can effectively increase the courtyard temperature in winter, and the temperature of courtyard with glass ceiling is 21.7°C higher than the average outdoor temperature. The central room of sample B adopts independent heating, with great fluctuations in temperature curve, as shown in Table 3 and Figure 9.

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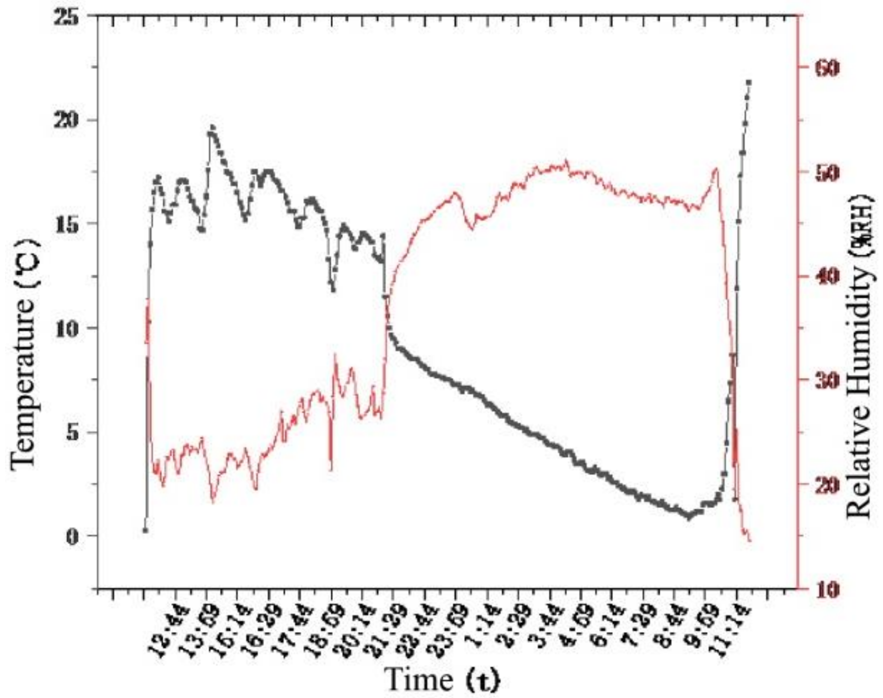

Figure 7. Change curve of courtyard temperature and relative humidity of sample B in winter

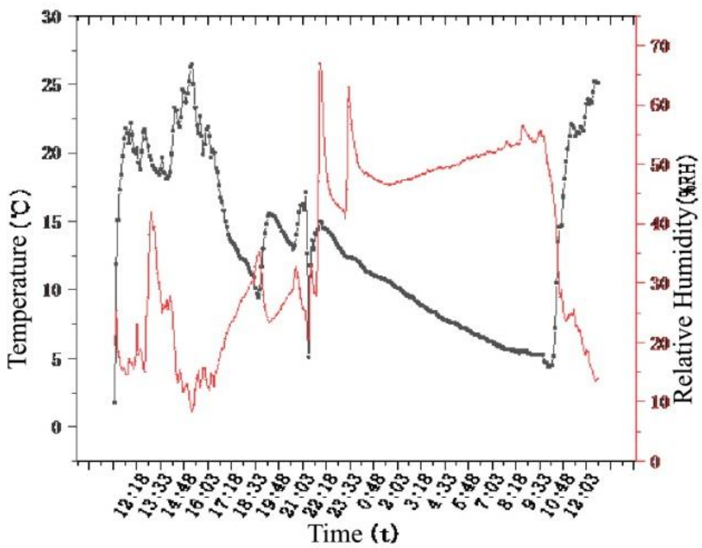

Figure 8. Change curve of central room temperature and relative humidity of sample B in winter

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Table 3. Comparison of indoor and outdoor temperature of dwelling sample B in winter

	Outdoor temperature (°C)	courtyard temperature of sample B (°C)	central room temperature of sample B (°C)
Maximum	-0.6	21.8	26.5
Minimum	-17.7	0.9	4.4
Volatility	17.7	20.9	21.9
Mean	-12.4	9.3	13.3

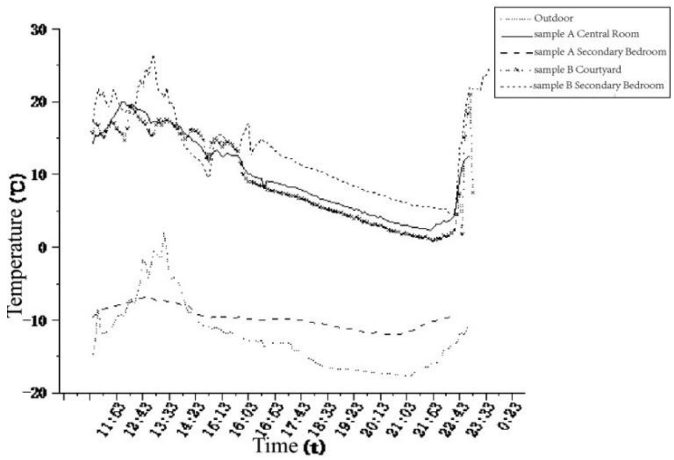

Figure 9. Comparison curve of all-day indoor and outdoor temperature of traditional dwelling in winter

2.4 Comparison of analysis results

According to the “Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings”, the indoor temperature of independent heating room in cold areas should meet the thermal comfort level I. The thermal comfort level should be high, with a temperature range of 18℃~24℃ [16]. Both the central rooms of sample A and sample B adopt independent heating, and the maximum indoor temperature of the central room is within the range of the most comfortable winter ambient temperature, but the minimum and mean indoor temperature fail to reach the minimum comfortable temperature in winter. Compared to the average indoor temperature of secondary bedroom of sample A, the addition of glass ceiling to the courtyard of sample B significantly increases the average indoor temperature by 19°C, but the indoor temperature of sample B still fails to meet the thermal comfort level I. Hence, it is proved that the indoor thermal environment of traditional Dunhuang dwelling is poor in winter, demanding optimization and improvement.

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III. THERMAL ENVIRONMENT IMPROVEMENT MEASURES

3.1 Building orientation

Dunhuang area has plenty of sunshine. The dwellings should make use of abundant natural resources and select the optimal orientation range in building, so that the courtyard sunshine and indoor daylighting can achieve the best effect. By using the Weather Tool in Ecotect Analysis, the optimal orientation of buildings in Dunhuang area is analyzed according to the meteorological data of Dunhuang area over the years [17], as shown in Figure 10. The yellow area indicates the optimal orientation range, ranging from 30° to the west to 15° to the east. The recommended optimal orientation is 15° south by west. According to the orientation suggestions given by the software and the actual on-site research, the prevailing wind in the local area is east-west wind. In order to avoid the poor thermal environment caused by the prevailing wind direction parallel with the entrance, the dwelling orientation should be as due south or south by west. The outer wall of the east-west room is the windward side, and no windows should be set on the outer wall, so as to reduce the heat loss when the prevailing wind passes through the doors and windows. In this way, the indoor air temperature will not be too low in winter.

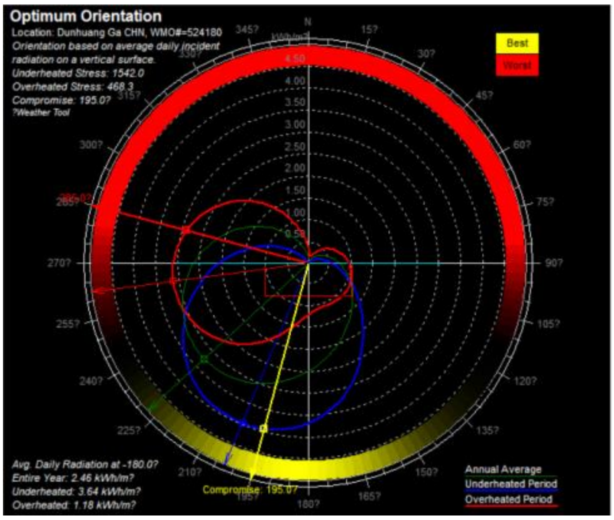

Figure 10. Recommended best orientation

3.2 Building space

Figures 11 and 12 show the plan views of the architectural space of the traditional dwelling sample A before and after the optimization. In order to gain more sunshine in the central room in winter, increase the indoor temperature and improve the indoor light environment, the size of the shielding walls on the east and west sides of the front porch of the central room is optimized, with 2800mm depth optimized to 1600mm. According to the needs of local residents for the dwelling use functions, the size of the building space is optimized to improve the original living room. The original living room face width of

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4800mm×3600mm is optimized to 6000mm×3600mm. The optimized room size is adapted to the local closed courtyard shape. The living room also functions as a bedroom and a drawing room, which accords with local customs. In winter, the irradiation time of solar radiation is short, and sufficient solar radiation is needed to increase the indoor temperature. Compared with the east wall, the west wall gathers more solar radiation heat. Therefore, after optimization, sample A uses the west living room as the living space in winter to save heat resources. In terms of functional use, the bedroom is connected to the living room, so that children can better take care of the elderly with greater convenience. South-oriented windows in the bedroom enhance the light environment of the living space.

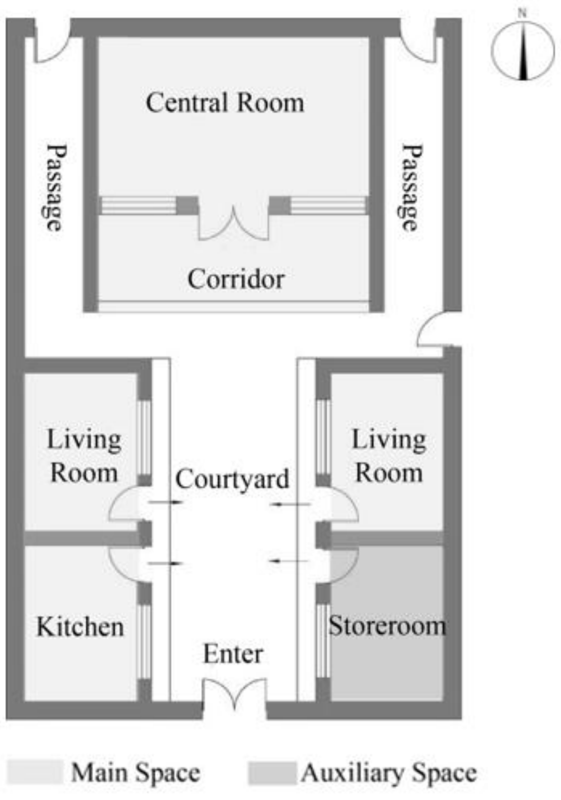

Figure 11. Plan view of sample A before optimization

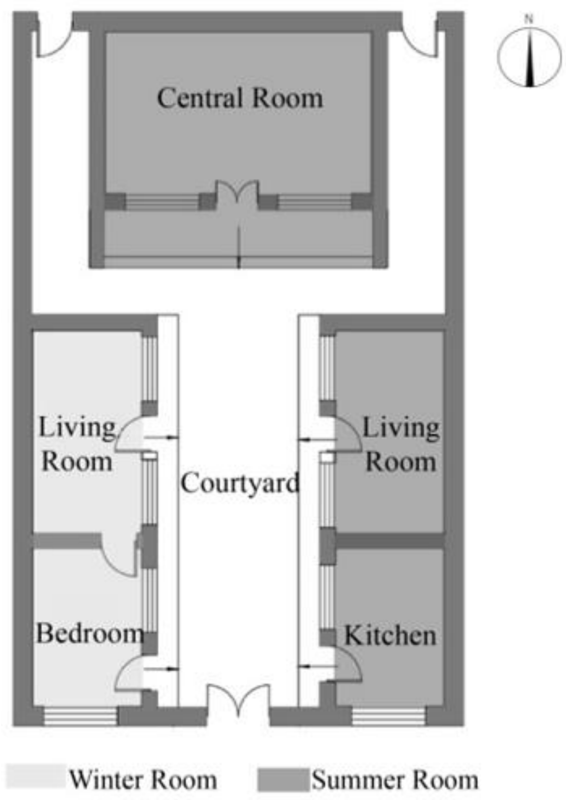

Figure 12 Plan view of sample A after optimization

Figures 13 and 14 show the plan views before and after optimization of traditional dwelling sample B. The courtyard of sample B is equipped with a glass ceiling, the building is of brick and wood structure, with small indoor space and poor indoor light. The north-oriented secondary bedroom lies close to kitchen, making the room a black space without window, which is very detrimental to human body health. A 3m-deep eaves corridor is set in front of the central room. After the glass ceiling is added, there is no direct daylighting in the central room, and the interior is cold in winter. To optimize the design in view of the above problems, the original front porch depth of the central room is optimized from 3m to 1m, and light is introduced to improve the indoor thermal environment. The east and west wing rooms are set as living

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room and bedroom. The west living room, bedroom and central room are suitable for living in winter. Compared with the west room, the east living room has lower indoor temperature, which is suitable for living in summer and storage. The kitchen space is set on the north side to connect with the central room. The elders of the family usually live in the central room. When the kitchen is independently heated in winter, the indoor temperature of the central room will also be higher. The rear door is opened on the north wall of the kitchen, which is connected to the dwelling backyard to facilitate pickup of winter heating materials. The east side of the central room is connected to a storage room, which is cool without summer heat. Dunhuang area has a bumper harvest of melons and fruits in summer and autumn. The locals are accustomed to storing them. The east room is cool in summer and is thus suitable for storage. Compared with the west-oriented rooms scorched by solar radiation for a long time in summer, the east-oriented rooms have a relatively lower temperature suitable for storage. The storage room opens to the north and connects to the backyard, making it convenient for residents to transport daily items from the backyard. The south-oriented bedroom is added with windows to improve the indoor thermal environment and light environment.

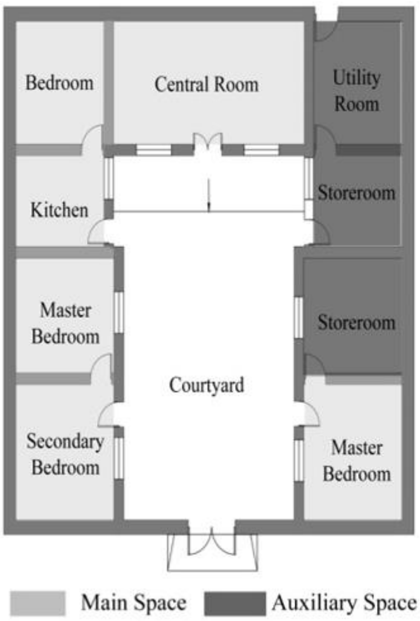

Figure 13. Plan view of sample B before optimization

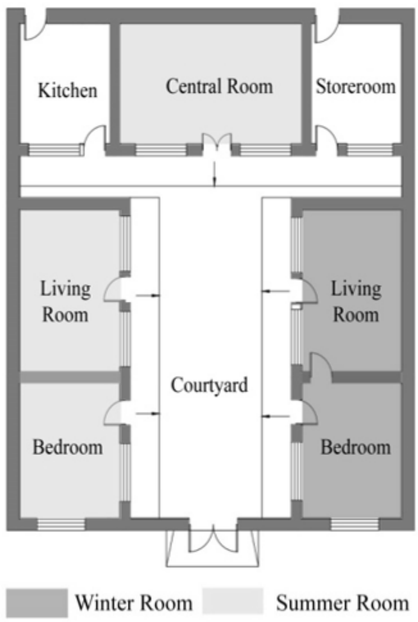

Figure 14. Plan view of sample B after optimization

3.3 Outer protective structure

According to the actual survey and research, central heating measures cannot be implemented in the Dunhuang area, and only single independent heating in dwellings cannot meet the indoor comfort requirements in winter. Therefore, dwellings need apply respective thermal insulation measures to cope with the harsh outdoor climate environment. According to the requirements for thermal performance parameters of external walls in the specification "Energy-saving Design Standards for Rural Residential

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Buildings" [17], the heat transfer coefficient is 0.65 (Table 4). After careful calculation, the dwellings of Sample A and Sample B are made of 500mm thick raw earth wall with heat transfer coefficient of 1.69, which cannot meet the thermal performance requirements of the protective structure in cold regions.

Table 4. Limits of heat transfer coefficient for the protective structure of rural dwellings in cold regions

Heat transfer coefficient of protective structure [W(m²·K)]				
Exterior wall	Roof	Exterior window (south orientation)	Exterior window (other orientation)	Exterior door
0.65	0.5	2.8	2.5	2.5

Thermal conductivity calculation: $\lambda_1 = d / R$
The thickness of the wall used: $d_1 = 500\text{mm}$
Thermal conductivity of the wall used: $\lambda_1 = 1.16$ W/ (m·k)
Thermal resistance of the wall used: $R_1 = R_i + \sum R + R_e = 0.59$ (m^2·K)/W
Heat transfer coefficient: $K_1 = 1 / R_1 = 1/0.59 \approx 1.69$

In order to improve the thermal environment comfort in winter, the outer protective structure of traditional dwellings is optimized. Raw earth has excellent physical properties and can well maintain and store heat thanks to its high intensity in a dry climate environment. In order to protect the architectural style of the Dunhuang area, reduce the construction cost of dwelling renovation, and improve the outer protective structure of the dwelling wall, the existing raw earth wall is optimized. The existing raw earth wall is added with external insulation layer so that the heat transfer coefficient of the external wall meets the thermal performance requirements (Figure 15). The insulation layer material is extruded polystyrene board (XPS board). The extruded polystyrene board has excellent physical properties such as lasting heat insulation, durability, water resistance, moisture resistance, corrosion resistance and environmental protection, which can meet the thermal insulation needs of local residents in winter. According to the thermal performance requirements of the wall for the thermal insulation layer, the thickness of the extruded polystyrene board needs to be calculated as follows:

$$d_2 = (1/K_2 - R_i - d_1/\lambda_1 - \mathrm{R_e}) \bullet \lambda_2$$

In the formula, K_2=0.65 is the external wall heat transfer coefficient required for thermal performance, $d_1 = 500\text{mm}$ is the thickness of the raw earth wall, $\lambda_1 = 1.16$ is the thermal conductivity of the compacted clay, d_2 is the required thickness of the extruded polystyrene board, and $\lambda_2 = 0.030$ is the thermal conductivity of the extruded polystyrene board. According to the calculation, it is necessary to set 28mm thick extruded polystyrene board with external thermal insulation to achieve the heat transfer coefficient required for the wall.

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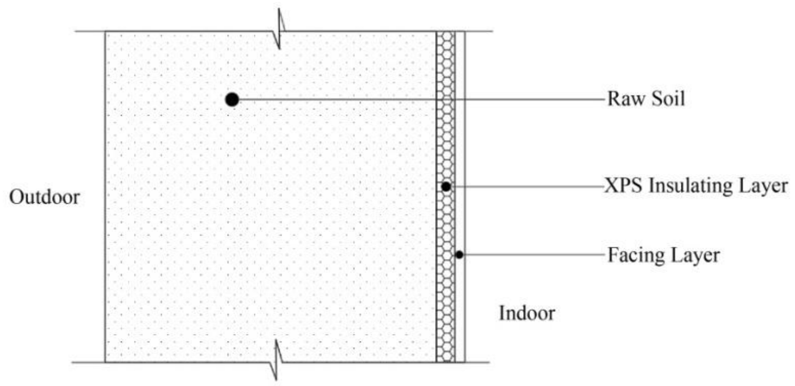

Figure 15. Schematic diagram of internal and external thermal insulation measures for traditional dwellings

As an important part of the outer protective structure of dwellings, roof controls the heat gain and loss inside and outside the entire building. Roof structure optimization plays an important role in improving the indoor thermal environment. The roof of the test dwelling sample is a wooden truss (Figure 16) and a grass-mud roof (Figure 17). Traditional grass-mud roof has a simple structure and quick indoor temperature dissipation, which is inconducive to dwelling insulation in winter. In order to slow down the heat loss in winter, maintain a constant indoor temperature, and improve the indoor thermal environment, the roof structure needs to be equipped with an insulation layer. Extruded polystyrene board is selected as the roof insulation layer to calculate the insulation material thickness required for the roof:

$$d_3 = (1/K_0 - R_i - d_4/\lambda_4 - R_e) \bullet \lambda_2$$

(K_0 is the heat transfer coefficient 0.5 required by the specification, d_4 is the traditional roof thickness 50mm, λ_4 is the thermal conductivity of the roof structure). According to accurate calculation, a 52mm thick extruded polystyrene board can meet the thermal specification requirements for the roof heat transfer coefficient.

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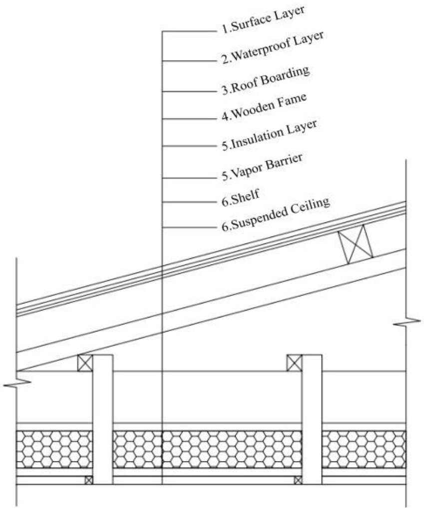

Figure 16. Sloping roof sketch map of wood roof truss

Figure 17. Grass mud roof

Dunhuang area has an extreme climate, with strong radiation in summer and long and cold winters. The traditional wooden frame sunshade (Figure 18) is set in the courtyard of the traditional dwelling sample A, which has sunshading effect in summer. According to actual measurement and analysis, the traditional wooden frame sunshade blocks the sunlight from entering the courtyard in winter, which directly affects the amount of light entering the room. The rooms have poor daylighting, cold winter and poor ventilation, demanding much heating resources. The sun shield is now optimized by adding keel member supported by the lower part of the sun shield, and the cover plate of 0.5m-1m thickness is set in the middle. This plate is the movable sun shield. In summer, Dunhuang area has strong solar radiation, so movable wooden boards or havelocks are needed. Dunhuang area has short sunshine time in winter, so no coverage is added to directly improve the light environment in the courtyard and the interior, and increase the indoor heat in winter. At the same time, it conforms to the local people's living habit of sunbathing in winter, and meets the local production and living needs of drying dried fruit, as shown in Figure 19. The optimized improvement scheme of dwelling sample A is shown in Table 5, Figure 20, Figure 21, and Figure 22.

Figure 18 Traditional dwelling sunshade of sample A before optimization

Figure 19 Traditional dwelling sunshade of sample A after optimization

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Table 5. Building Structural Improvement Scheme of Traditional Dwelling Sample A

Name	Building structure
courtyard wall	Raw earth wall (500mm) + south exterior finish coat (15mm)
Building exterior wall	Raw soil wall (500mm) + XPS insulation layer (28mm) + interior finish coat(15mm)
Wooden roof truss sloping roof	surface layer + waterproof layer +roof boarding + roof truss + XPS insulation layer (52mm) + plastic film + scaffolding board+ ceiling
Window (building)	Aluminum alloy double-layer window (2100mm×2000mm)
Door (highlight)	hollow wooden door (1000mm×2100mm, courtyard door: 1800×2400mm)
Sunshade	timber frame + light wood board (20mm)

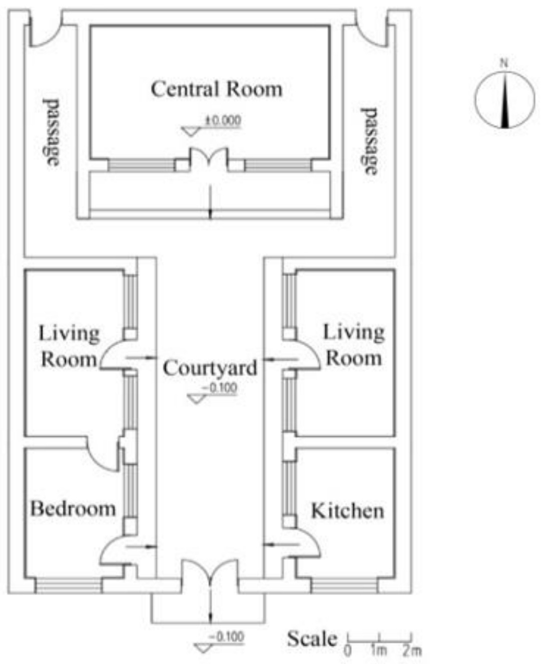

Figure 20 Plan view of Scheme 1

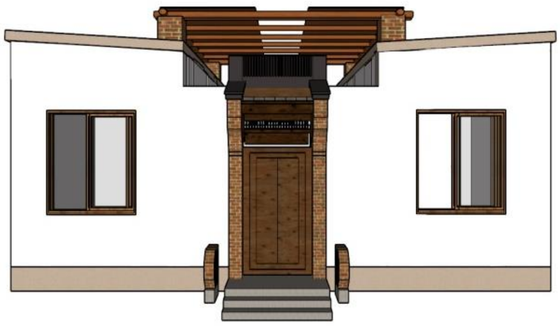

Figure 21. Front elevation of Scheme 1

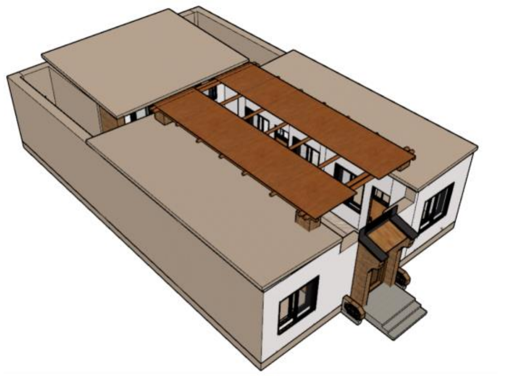

Figure 22. Axonometric schematic diagram of scheme 1

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Table 6. Building Structural Improvement Scheme of Traditional Dwelling Sample B

Name	Building structure
Building exterior wall	Raw earth wall (500mm) + XPS insulation layer (28mm)+ finish coat(15mm)
Wooden roof truss sloping roof	surface layer +waterproof layer+ roof boarding+wooden fame+ XPS insulation layer (52mm)+ plastic film + scaffolding board+ ceiling
Window (building)	Aluminum alloy double-layer window (2100mm×2000mm)
Window (glass ceiling)	Aluminum alloy single-layer window
Door	hollow wooden door (1000mm×2100mm, courtyard door: 1800×2400mm)
Sunshade	Aluminum alloy single-layer window + steel truss + color steel plate

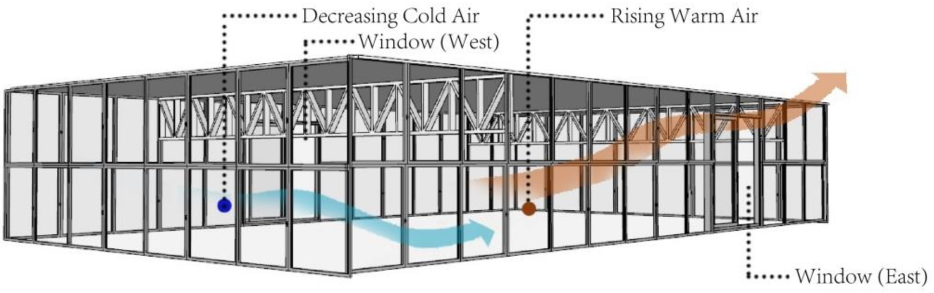

Figure 23. Traditional dwelling sunshade of sample B after optimization

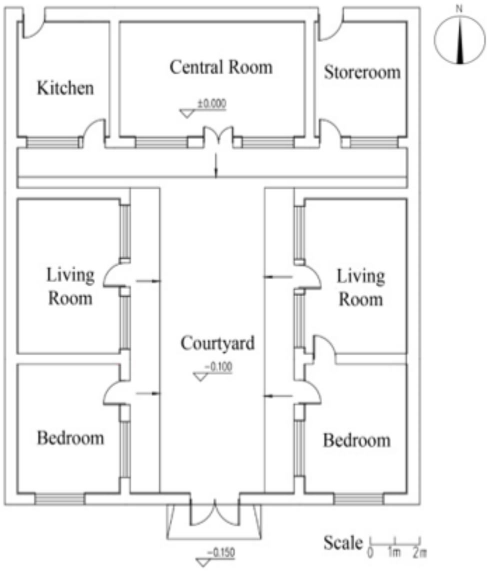

Figure 24 Plan view of Scheme 2

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Figure 25. Front elevation of Scheme 2

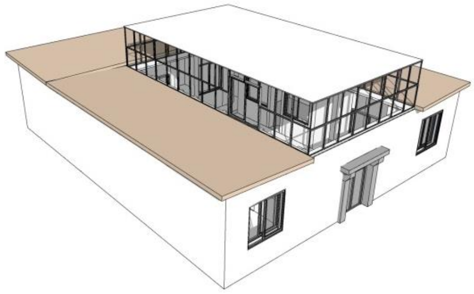

Figure 26. Axonometric schematic diagram of schem2

IV. SIMULATION EVALUATION BEFORE AND AFTER OPTIMIZATION

4.1 Scheme 1

The indoor environment of sample A in optimization scheme 1 is analyzed using ecological analysis software Ecotect. Schematic diagram of the annual solar radiation simulation of optimization scheme 1 is shown in Figure 27. Based on the special characteristics of sunshade components used in traditional Dunhuang courtyards, the courtyard and indoor light environment are simulated and optimized. Through the simulation test, the vertical incident radiation from the courtyard to the interior before and after optimization is compared as shown in Figure 28. The comparison of the simulation diagram shows that the courtyard using optimized sunshade component has significantly more light than the traditional sunshade component before optimization, which is a purple area. The courtyard daylighting environment is significantly improved. The comparison of the indoor light environment before and after optimization is shown in Figure 29. Through the rearrangement of the building space, the optimization of the sunshade, and the size and position optimization of the window, the optimized traditional dwelling has light entering from the window, which is light purple, indicating entry of natural light. There is no light entering the interior of the blue unoptimized dwelling; the optimized south-oriented room has obvious light entry, which is dark purple, indicating strong light. Simulation proves that the indoor light of the building increases a lot after the optimization.

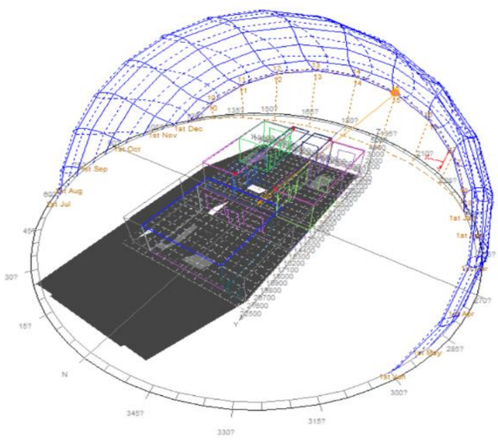

Figure 27. The simulation diagram of annual solar insolation in Scheme 1

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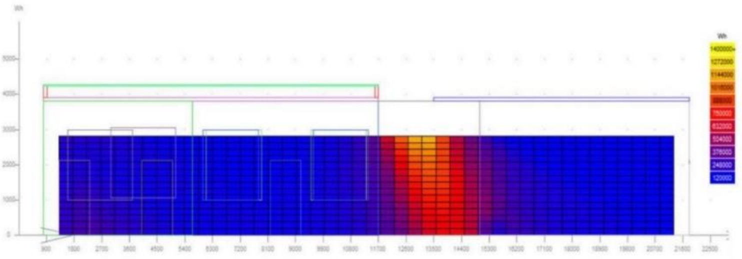
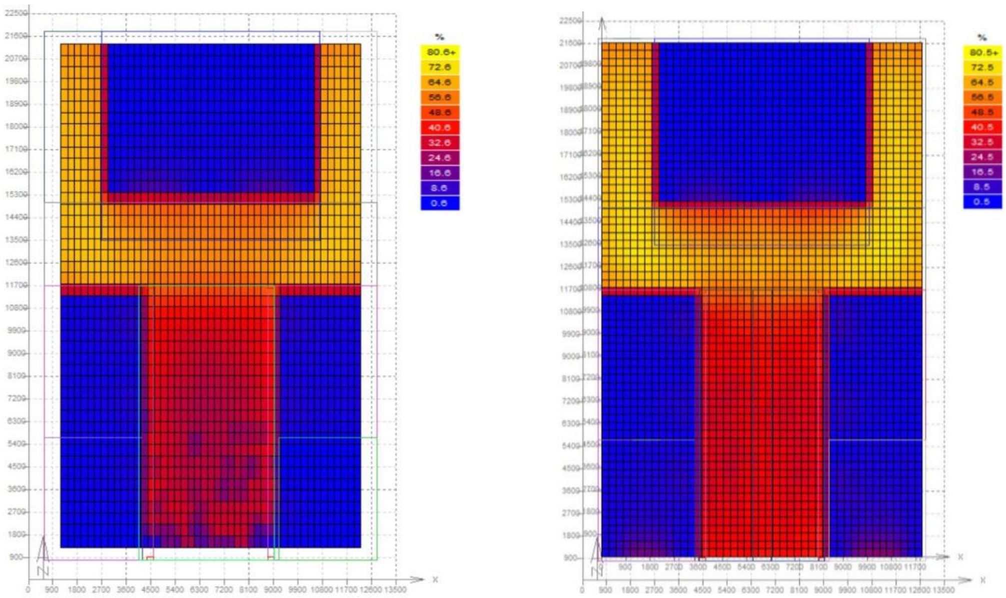


The Incident Radiation Diagram of Courtyard before Optimization

The Incident Radiation Diagram of Courtyard after Optimization

Figure 28. Simulation and comparison of vertical incident solar radiation in the courtyard of scheme 1 before and after optimization



a. Before optimization

b. After optimization

Figure 29. Comparison of indoor daylighting simulation of scheme 1 before and after optimization

Most central rooms in the traditional Dunhuang dwellings are inhabited by elders, so there is high requirement for indoor temperature in winter. According to the actual measurement, east-oriented living room has poor indoor thermal environment in winter. In order to improve indoor thermal comfort, it is particularly necessary to improve and optimize the central room with high indoor temperature requirements and the east-oriented living room with poor thermal environment. The indoor temperature and wind speed before and after simulation optimization are shown in Figure 30. The indoor thermal environment is simulated without independent heating during the coldest day in winter (January). The

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figure shows that the indoor temperature increases during the day and decreases at night with the outdoor temperature change. The outdoor air temperature changes in the range of -18°C~-2°C; the central room temperature changes in the range of -9°C~-1°C, (purple line); the east living room temperature changes in the range of -8°C~-4°C (green line) . After optimization, the indoor air temperature in the central room changes in the range of -4℃~2℃ (Figure 31), and the temperature in the east living room changes in the range of -6℃~2℃ (Figure 32). After optimization, the indoor temperature is effectively improved, and there is little fluctuation in indoor temperature from 0:00 to 7:00 at night, which means that the temperature is relatively constant. Comparison shows that the optimized indoor temperature is significantly higher.

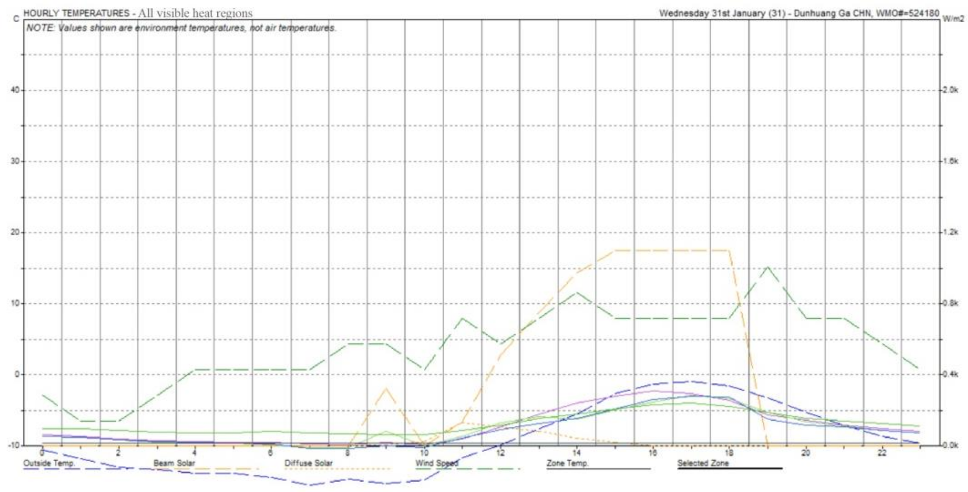

Figure 30. Scheme 1 before optimization-simulation of the central room, east living room, and average wind speed

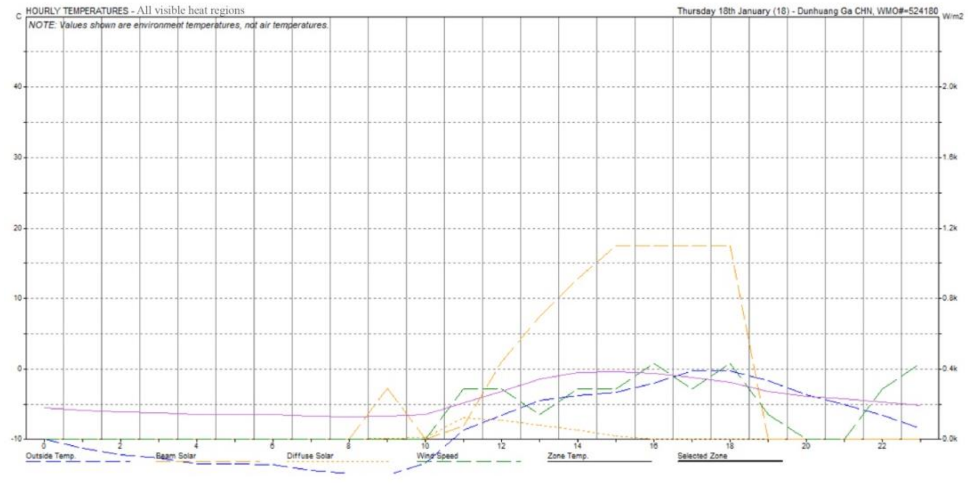

Figure 31 Scheme 1 after optimization-simulation of the average temperature and wind speed in the central room

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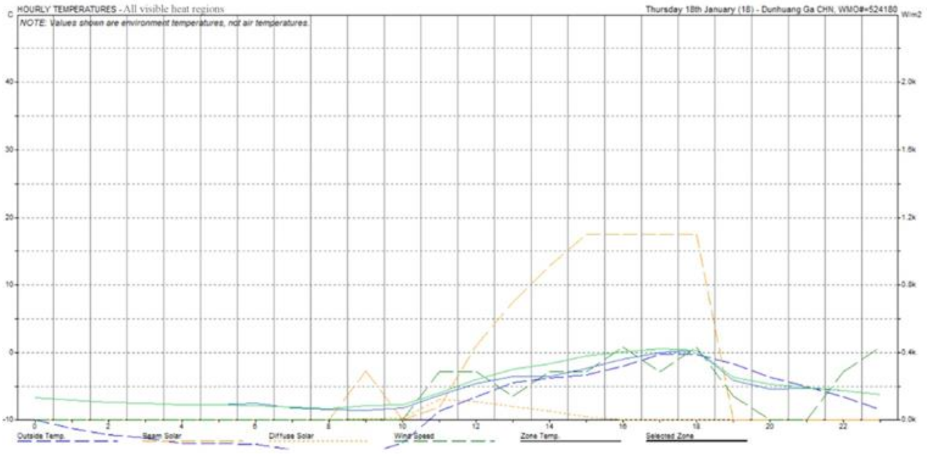

Figure 32 Optimization scheme 1 - simulation of the average temperature and wind speed in the east living room

4.2 Scheme 2

The indoor thermal environment is simulated and analyzed for the sample B optimization scheme 2 by using Ecotect. The schematic diagram of the annual solar radiation simulation of the optimization scheme 2 is shown in Figure 33. The vertical incident sunlight simulation of the courtyard before and after optimization is shown in Figures 34 and 35. The comparison of the indoor daylighting simulation of traditional dwellings before and after optimization is shown in Figure 36. Through optimization of the architectural space layout of scheme 2, it can be clearly seen that the interior light is significantly stronger, and the rooms in the northeast and northwest corners of the building are no longer dark spaces. The courtyard and indoor daylighting is obviously optimized, with more light sources, and the courtyard light environment is superior after optimization. By optimizing the size of residential windows and adding south-oriented windows, there is more dwelling indoor light, with good daylighting in the south-oriented bedroom. By comparing the vertical incident solar radiation of the courtyard with and without glass ceiling, it shows that the courtyard light environment can be obviously optimized after the addition, and the simulation proves that the optimization and transformation are effective.

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www.forestchemicalsreview.com
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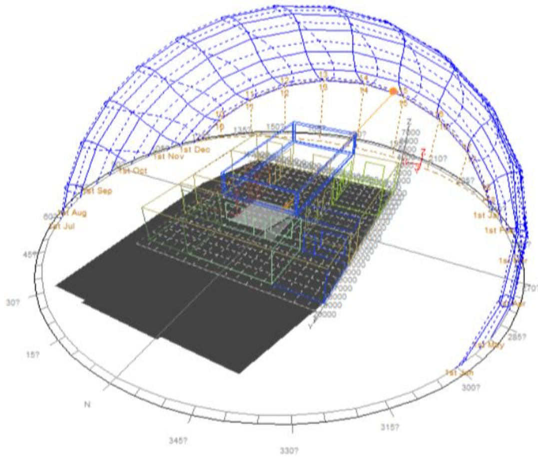

Figure 33. The simulation diagram of annual solar insolation of Scheme 2 (Data source: Ecotect Analysis)

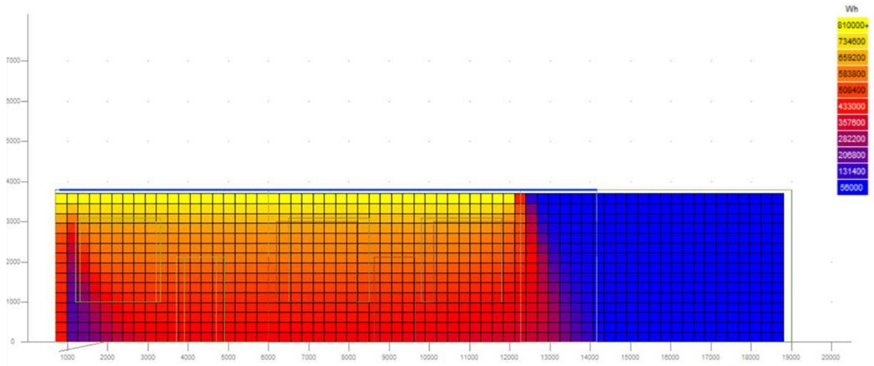

Figure 34. The simulation diagram of vertical incident sunlight in the courtyard of scheme 2 before optimization

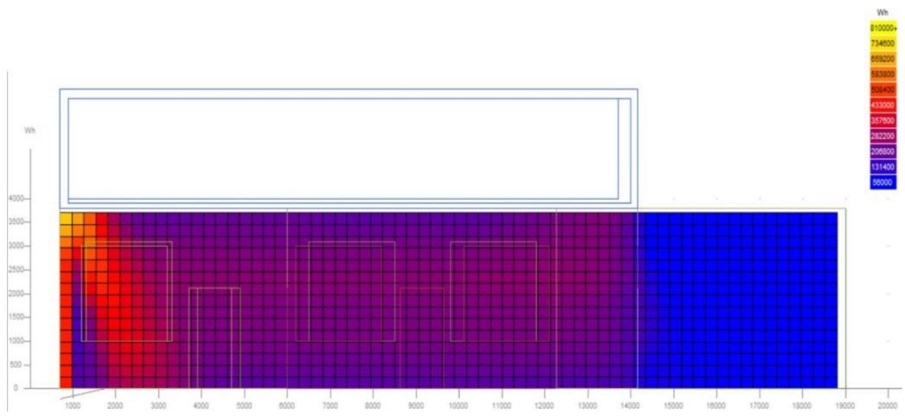

Figure 35. The simulation diagram of vertical incident sunlight in the courtyard of scheme 2 after optimization

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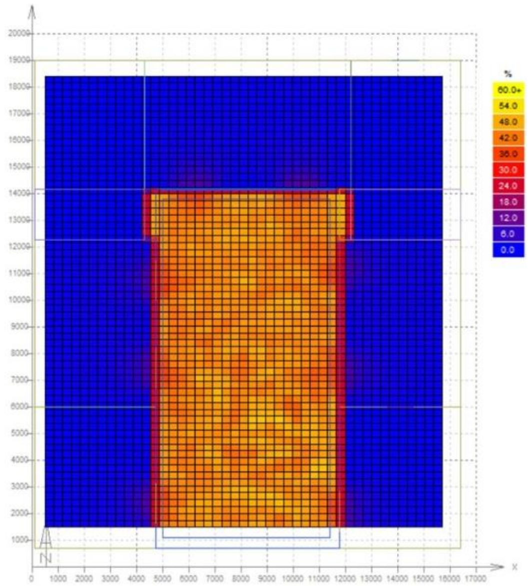
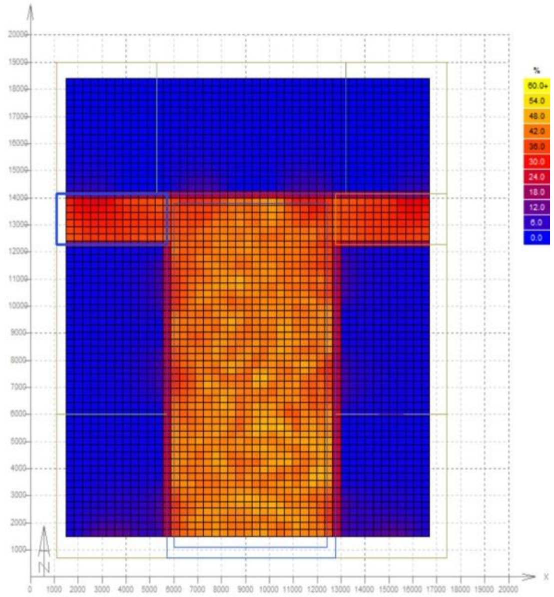


a. Simulation diagram of indoor light environment before optimization



b. Simulation diagram of indoor light environment after optimization

Figure 36. Comparison of indoor daylighting simulation of scheme 2 before and after optimization

Here, indoor temperature and wind speed in winter before and after the optimization of Scheme 2 is simulated in Figure 37. The figure shows that indoor and outdoor temperature change in traditional dwellings is consistent, which temperature decreasing at night and increasing during the day. The simulation results show that the outdoor temperature changes in the range of -10℃~3℃. Before optimization, the central room temperature changes in the range of -2℃~4℃(light green), and the temperature in the east living room changes in the range of -2℃~3℃. After optimization, Figure 38 shows that the temperature of the central room (light green) changes in the range of -3℃~ 8℃. After optimization, Figure 39 shows that the temperature of the east living room changes in the range of -4℃~ 5.5℃(green line). Through the above comparison, it is proved that the indoor temperature is significantly increased after optimization, so the optimization measures are effective.

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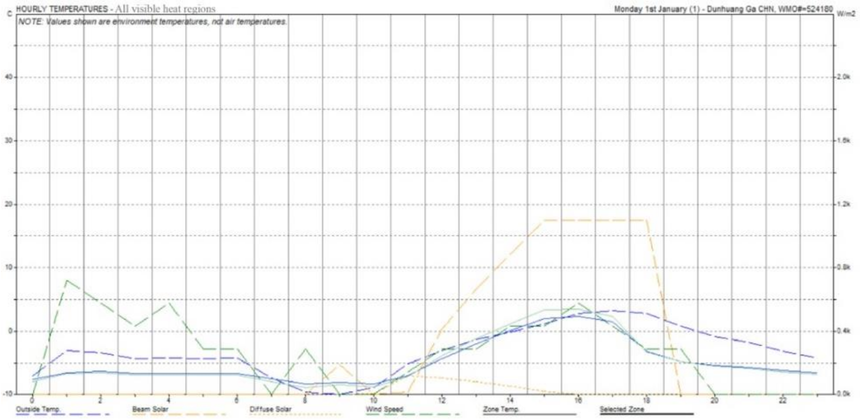

Figure 37. Scheme 2 before optimization—simulation diagram of the average temperature and wind speed in the central room and east living room

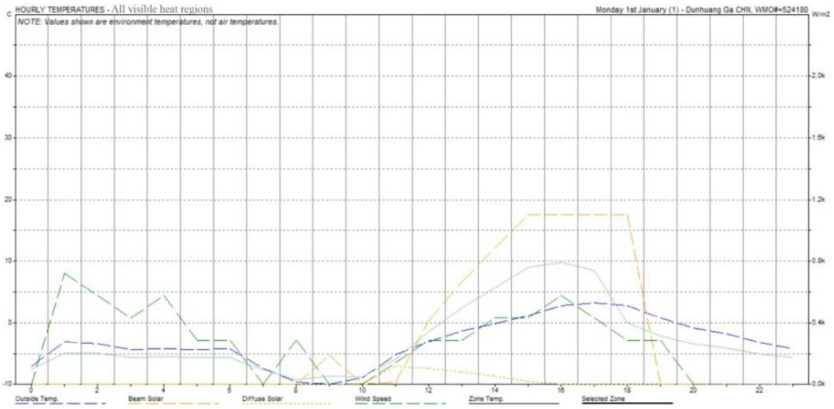

Figure 38. Scheme 2 after optimization—simulation diagram of the average temperature and wind speed in the central room

V. CONCLUSIONS AND DEFICIENCIES

In this study, the indoor and outdoor thermal environment of two types of traditional Dunhuang dwellings is measured in winter through field investigation. It is concluded that the indoor thermal environment of dwellings in this area cannot reach the standard thermal comfort level I in winter, demanding urgent improvement and optimization. The indoor temperature of dwellings using the traditional wood frame sunshade and those using additional glass ceiling is compared. It is concluded that addition of glass ceiling can effectively increase the indoor temperature in winter, but it still cannot reach the thermal comfort level I required by the specification. Moreover, there are problems of poor indoor daylighting and poor ventilation in winter. In view of the above problems, effective optimization measures of meeting the specifications and improving the indoor thermal environment are proposed, and two optimization schemes are recommended for traditional Dunhuang dwellings respectively. After reasonable simulation and verification by the ecological software Ecotect, it is proved that the optimization measures can directly increase the indoor temperature of dwellings in winter, improve indoor daylighting and ventilation, and effectively improve the indoor environment comfort of traditional Dunhuang dwellings. This paper believes that the special climatic environment of Dunhuang area makes traditional dwellings form architectural style with regional characteristics. The large number of existing traditional dwellings in the area should be transformed and optimized on the basis of the existing dwellings, so as to prolong the building life and protect the local architectural style. In the improvement scheme, the strategy of shielding the wind and sand is proposed, but no analysis is made on the wind environment of dwellings. More in-depth research is needed on improving and optimizing the wind environment of dwellings.

ACKNOWLEDGEMENTS

This research was supported by National Natural Science Foundation of China (51208243); Research project of Department of Housing and Urban-Rural Development of Gansu Province (JK-2022).

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