
Yuan HUANG

Comparative Study on Traditional and Modern Urban Textures: Form, Energy and Climate

Yuan HUANG[1], Zhen WANG[2],

[1] *Southwest Jiaotong University, Xibu Park, Chengdu, P.R. China, yuanhuang@home.swjtu.edu.cn*

[2] Huazhong University of Sci. and Tech., 1037 Luoyu Road , Wuhan, P.R. China, 232265522@qq.com

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1. Introduction

The elemental revolution from traditional urban texture to modern urban texture shows that: the fractal development of continuous courtyards has been displaced by the replicated copies of isolated buildings. Huge volume and great height have become the most popular modernism ways to compensate for the reduction in site coverage (urban density); therefore the scale of modern urban texture far exceeds the scale of traditional urban texture.

In the tide of anti-Modernism in the20th Century, there are a large number of studies that proved the superiority of the traditional urban texture compared with the modern urban texture, from sociological and historical view [1,2]. However, from physical view (climate and energy), there are few studies focusing on the comparison of the traditional and modern urban texture, especially on the dialogue between urban forms and urban microclimate in hot-summer and cold-winter area in China.

Ventilation, irradiation exchange and other physical phenomena in urban space are deeply influenced by the difference of theses urban textures, which finally lead to the different urban microclimates that determine buildings' energy performance. In this paper, the classical examples of traditional and modern urban texture in hot-summer and cold-winter climatic area in China are extracted and studied comparatively. The key characteristics such as buildings' archetype, urban density and street section are discussed in the proposed case studies in Wuhan. Their environmental performances such as buildings' energy consumption and outdoor thermal comfort are compared comprehensively by the numerical simulation.

2. Comparative study on buildings' energy consumption

2.1 Establishment of case studies

2.1.1 Archetype

The archetype of slabs, pavilions /tours and courts are extracted from the real urban texture such as the city of Wuhan in hot-summer and cold-winter area. The case studies are composed of three typical generic built forms – slabs, pavilions /tours and courts respectively, with uniform layout and invariable plot ratio (3.0) based on the representative density value of the central district of Wuhan [3] (Fig. 1). The courts that present the traditional archetype are compared with the slabs and pavilions /tours that present the modern archetype.

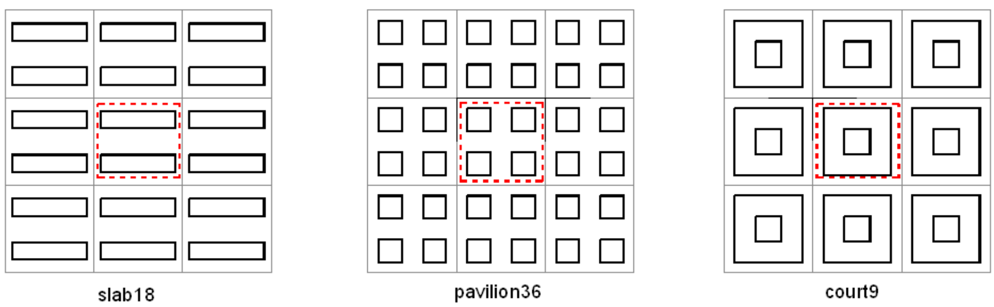

Fig. 1 The schematic layouts of the three generic built forms

2.1.2 Density

Urban districts composed of pavilions /tours with uniform layout and fixed plot ratio (PL=3.0), the number of floors varies from n=5 to 19, meanwhile site coverage (SC) varies from 0.60 to 0.16, with is composed of 7 case studies. The discussion focuses on the comparison of the district with the low SC value that presents modern urban forms and the district with the middle-high SC value that presents traditional urban forms.

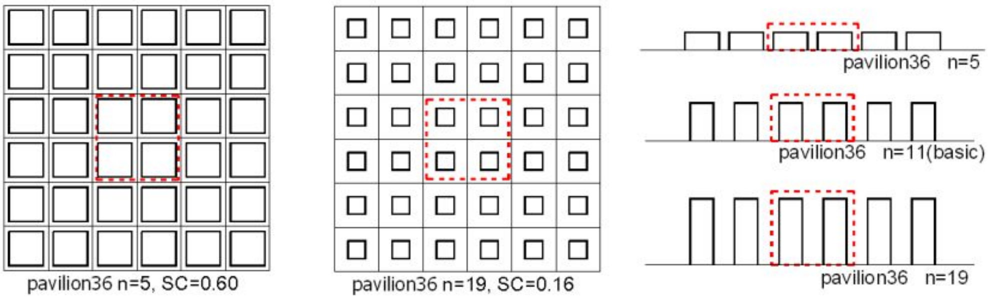

Fig. 2 The schematic layouts of the case studies of SC

2.2 Methodology

The accumulated values of the relevant components of heating and cooling loads are calculated as following:

$$\mathbf{Q_{total} = Q_{start} + Q_{trans} + Q_{cond} + Q_{air} + Q_{qin}} \qquad (1)$$

where Q_{total} is the total heating or cooling load in the standard day; Q_{start} is the start energy for heating or cooling the indoor air to a comfort temperature before 8:00; Q_{trans} is the transmitted solar energy gain through windows; Q_{cond} is the conductive energy exchanged on the internal surfaces of walls and roofs (heat storage/release in the walls is considered); Q_{air} is the thermal energy exchange through ventilation; Q_{qin} is the internal heat generation. The unit of all these components is *kWh*. When heating and cooling loads are compared, the amounts of all kinds of energy exchange of the whole district are unified in the value per unit floor area ***E****(Wh/m²)*. Therefore the equation of heating and cooling loads per unit floor is transformed as follows:

$$\mathbf{E_{total} = E_{start} + E_{trans} + E_{cond} + E_{air} + E_{qin}} \qquad (2)$$

As the variation tendency of E_{total_w} in winter and E_{total_s} in summer is analyzed respectively in case study group, the amount of heating and cooling loads of *case n* is compared with the pertinent values of *case 0*, the proposed index for the quantification work is as follows:

$$\mathbf{\Delta X_n = X_n \quad X_0} \qquad (3)$$

$$\eta = {}^{\mathbf{\Delta X_n}}/_{\mathbf{X_0}} \qquad (4)$$

where X_n is the observed value of *case n*, such as the values of E_{total_w} or E_{total_s}, X_0 is the pertinent value of *case 0* (basic case). ΔX_n is the different value between *case n* and *case 0*. The proposed index η focuses on the comparison of E_{total_w} and E_{total_s} in the case study group and on the variation tendency analysis of E_{total_w} and E_{total_s} respectively.

2.3 Key result analysis

2.3.1 Archetype

Table 1 shows the energy load per unit floor area of a standard day in winter and in summer. We can find that the different archetypes of built form have evident impacts on heating and cooling loads. The district of slabs and courts are more favorable types for buildings' energy efficiency. For the district of slabs, the value of its shape factor is not high; meanwhile it has the best solar energy performance. The performance of thermal energy load of the district of courts is very close to slabs, but it gets the better energy load performance in a different way. It mainly takes the advantage of its low value of shape factor to reduce conductive energy exchange. The district of pavilions is the least desirable type for buildings' energy efficiency. Compared to *case 0*(slabs), the heating load increases by 27.08% due to the worst performance of conductive energy exchange; the cooling load increases by 18.97% due to the worst performance of transmitted solar energy in summer.

Table.1: Comprehensive analysis of heating and cooling loads of the three generic built forms

Case	Types	E_{total_w}	E_{total_s}	ΔE_{total_w}	ΔE_{total_s}	η_w	η_s
0	slab18	181.36	593.81	0.00	0.00	0.00%	0.00%
1	pavilion36	230.47	706.43	49.11	112.62	27.08%	18.97%
2	court9	182.76	600.48	1.41	6.67	0.78%	1.12%

2.3.2 Density

In the discussion of the variation of SC value, *case 0* with n = 11 floors (SC = 0.27) is taken as the basic case, and the differences of E_{total} of the case studies are compared with *case 0* (see table. 2).

Table. 2: Comprehensive analysis of heating and cooling loads of the case group of SC

Case	n	SC	E_{total_w}	E_{total_s}	ΔE_{total_w}	ΔE_{total_s}	η_w	η_s
1	5	0.60	230.94	601.80	0.47	-104.64	0.20%	-14.81%
2	7	0.43	220.43	651.91	-10.04	-54.53	-4.35%	-7.72%
3	9	0.33	222.97	682.70	-7.50	-23.74	-3.25%	-3.36%
0	11	0.27	230.47	706.44	0.00	0.00	0.00%	0.00%
4	13	0.23	239.01	727.44	8.54	21.00	3.71%	2.97%
5	15	0.20	246.06	746.19	15.59	39.76	6.76%	5.63%
6	17	0.18	257.27	764.53	26.80	58.10	11.63%	8.22%
7	19	0.16	267.01	782.13	36.54	75.69	15.86%	10.71%

From this table, we can find that the variation of SC value has an evident impact on heating and cooling loads. Generally speaking, the decrease of SC value leads to worse thermal energy performance. In winter, *case 2* (*n=7, SC=0.43*) shows the best performance of heating load. The balanced point is fund between E_{trans} and E_{cond}, whose heating load decreases by 4.35% compared to *case 0*. In summer, the performance of cooling load becomes worse with the decrease of SC value. The best performance happens at *case 1* with the lowest SC value (*n = 5, SC=0.60*) in the case group, the cooling load decreases by 14.81% compared to *case 0*. When we consider the performance of thermal energy load in winter and in summer comprehensively, *case 1* (*n=5*) and *case 2* (*n=7*) are the most favorable cases in the case group. When PL value is fixed, higher SC value is better for the performance of transmitted solar energy in winter, lower SC is better for buildings energy efficiency due to better performance of conductive energy exchange.

3. Comparative study on outdoor thermal comfort

3.1 Establishment of case studies

3.1.1 Block layout categories

4 block layout categories are extracted from the real urban textures in Wuhan: determinant layout, courtyard layout, tours layout, mixed layout (Fig. 3). Each district is composed of 4 blocks (*98m×98m*) with the same value of plot ratio. The ground floor of the buildings inside the block is elevated, street width between the blocks is *21m*, the mains building height of the block is *20m* and the average street podium's height is *8m*. Street axe oriented E-W is orthogonal to the wind from south.

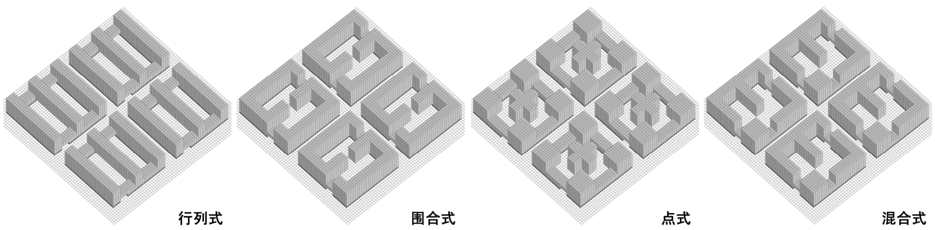

Fig. 3 From left to right: determinant layout, courtyard layout, tours layout, mixed layout

3.1.2 Street section

Street canyons with galleries of different space ratios (H/W) are extracted from the traditional arcade form in Boacheng Road district in Wuhan and compared with the street canyons without galleries. 2 groups of case studies are proposed as follows: **Group 1**: urban canyons with H/W = 2, oriented E-W. The case studies of urban canyons with galleries of H/W = 0.5, 1, 2 are compared with the urban canyons without galleries. **Group 2**: Urban canyons with H/W = 2, oriented N-S. The case studies of urban canyons with galleries of H/W =1 is compared with the urban canyons without galleries.

3.2 Methodology

3.2.1 Mean radiant temperature

T_{mrt} is the key variable in evaluating thermal sensation outdoors during the daytime in summer regardless of the comfort index used, which has the strongest influence on the physiologically equivalent temperature PET concerning human thermal comfort. For its determination particularly in complex urban environments, ENVI-met gives a good approximation of T_{mrt} at street level [4], which is expressed for each grid point (z) as follows:

$$T_{mrt} = \left[1/\sigma \left(E_t(z) + \frac{\alpha_k}{\varepsilon_P} \left(D_i(z) + I_t(z) \right) \right) \right]^{0.25} \quad (4)$$

σ is the Stefan–Boltzmann constant (5.67×10^{-8}W/m^{2}K^4), α_k is the absorption coefficient of the irradiated body surface for short-wave radiation (≈0.7), ε_P is the emissivity of the human body (≈0.97). The surrounding environment consists of the building surfaces, the free atmosphere (sky) and the ground surface. All radiation fluxes, i.e. direct irradiance $I_t(z)$, the diffuse and diffusely reflected solar radiation $D_t(z)$ as well as the total long-wave radiation fluxes $E_t(z)$ from the atmosphere, ground and walls, are taken into account.

3.2.2 Mean radiant temperature

The physiologically equivalent temperature PET [5] is employed as the key index of outdoor thermal comfort in this study. PET is based on the human energy balance model MEMI and includes the physiological thermoregulatory processes of human beings in order to adjust to a climatic situation outdoors. PET (unit degree Celsius *1℃*) is defined as the air temperature at which, in a typical indoor setting ($T_{mrt} = Ta$; *VP= 12 h Pa; v =0.1 m/s*), the heat balance of the human body is maintained with core and skin temperatures equal to those under the conditions being assessed. Moreover, the isotherm chart that describes the spatial and temporal variation of PET value at 1.4m above the ground is employed to analyze the outdoor thermal comfort in an observed street section

3.3 Key result analysis

3.3.1 Block layout categories

From Fig. 4, it shows that the peak PET value and its distribution area of tours layout are significantly greater than the other 3 block layout categories, especially in the urban canyon section oriented N-S. However, the spatial and temporal variation of PET value of courtyard layout is slightly better compared with determinant layout and mixed layout.

3.3.2 Street section

Compared with urban canyons without galleries, the microclimate of urban canyons with galleries is evidently improved. Taking the galleries of H/W=1 for example, PET value is significantly decreased in the area of canyon's both sides (see Fig. 5 and Fig. 6). PET value of the both sides of the galleries especially the side facing south that receives direct solar radiation is well controlled in a comfortable zone (≤29℃). From the study on the variation of galleries' H/W value, PET value of the galleries of H/W=0.5 is similar to the galleries of H/W=1. There is just the difference between the urban canyons' widths. Compared with the results of urban canyon oriented W-E, the influence of galleries on outdoor thermal comfort of urban canyon oriented N-S is less obvious.

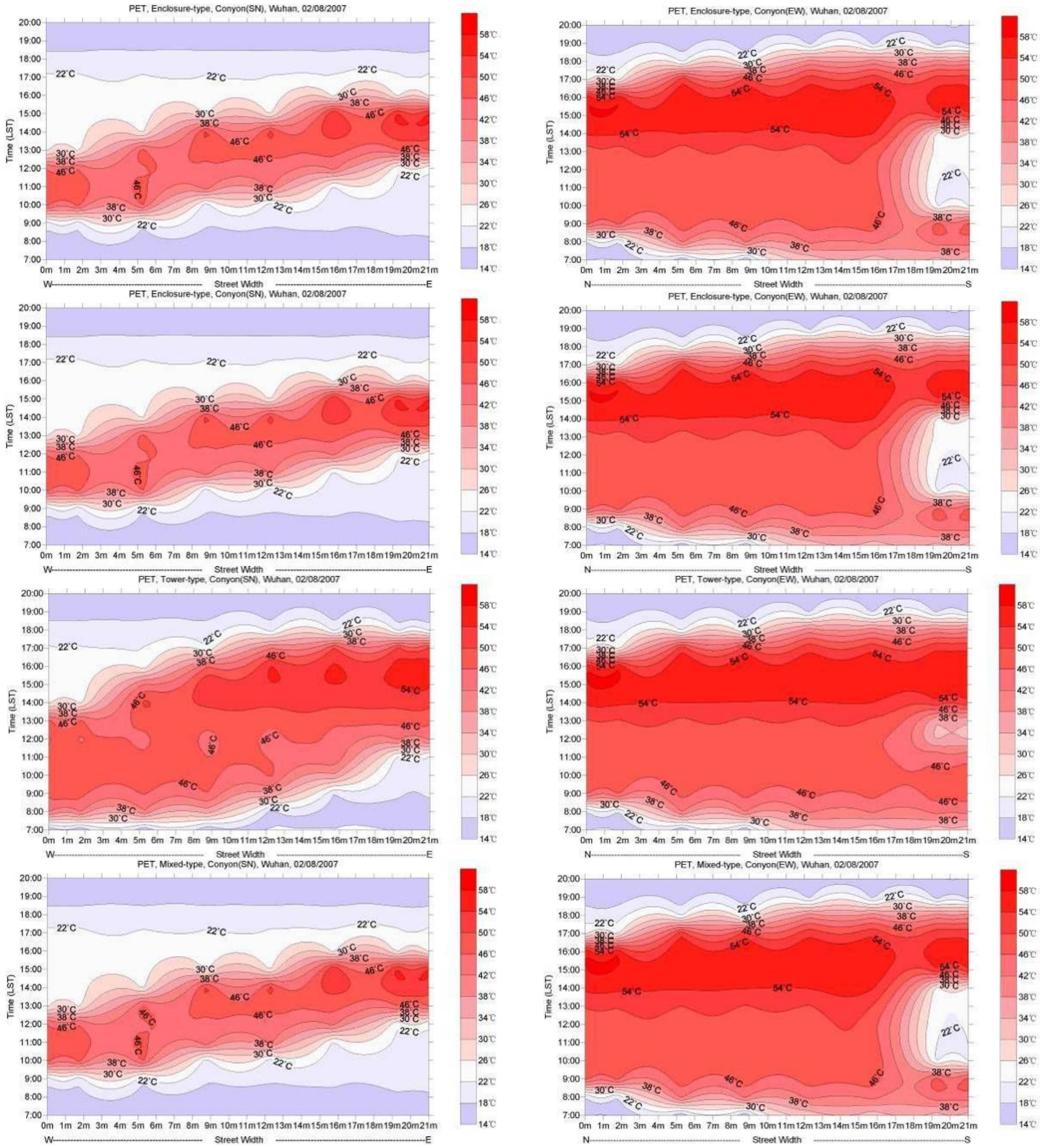

Fig. 4 Spatial and temporal variation of PET at 1.4m above the ground of block layout categories
From left to right: urban canyon section oriented N-S, W-E
From top to bottom: determinant layout, courtyard layout, tours layout, mixed layout

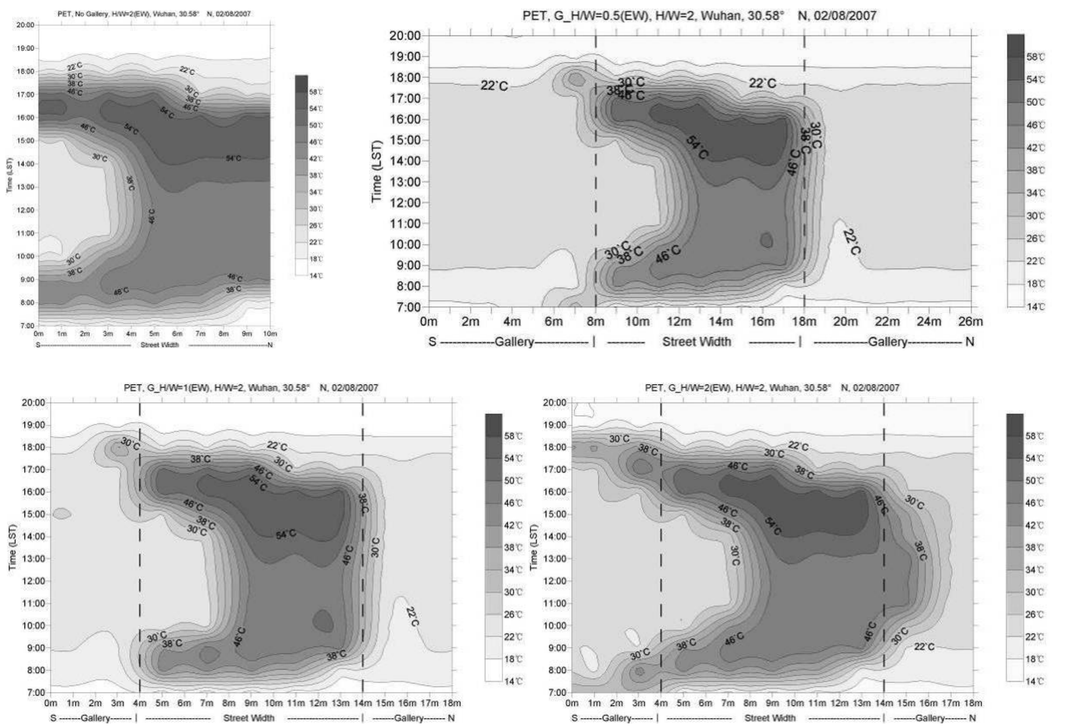

Fig. 5 Spatial and temporal variation of PET at 1.4m above the ground of urban canyons, H/W = 2, oriented E-W

Left-top: without galleries; right top: with galleries of H/W = 0.5; left-bottom: with galleries of H/W = 1; right-bottom: with galleries of H/W = 2

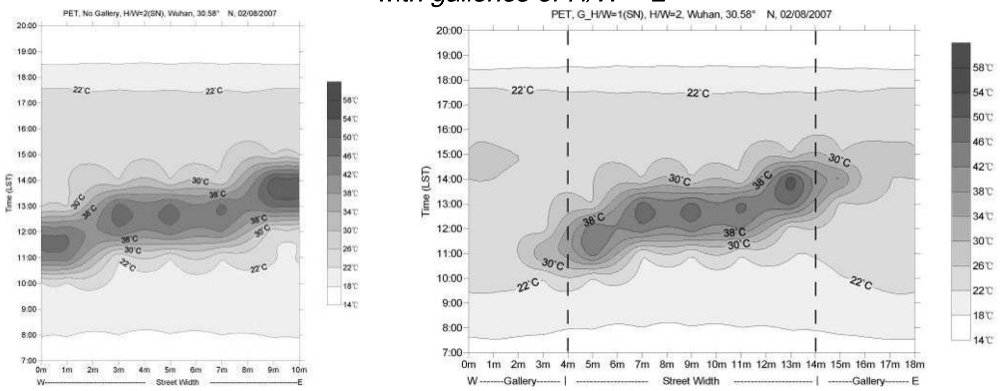

Fig. 6 Spatial and temporal variation of PET at 1.4m above the ground of Urban canyons, H/W = 2, oriented N-S Left: without galleries; right: with galleries of H/W = 1

4. Conclusion

Based on the numerical simulation and key results analysis of the urban form case studies in hot-summer and cold-winter area in China, the preliminary regulations has been found on the comparison between traditional and modern textures:

- The buildings' energy performance and outdoor thermal comfort of the archetype of courts that is extracted from the traditional urban texture is more favorable than the modern layout of pavilions /tours, as the archetype of courts is more compact and more conducive to the growth of shadow in urban canyon.
- With the fixed PL value (0.3) and the variation of SC value, the most optimal buildings' energy performance appears in the case study of multi-story pavilion with middle-higher site coverage (0.43) that presents the typical density and form of traditional urban texture;
- The galleries (arcade form) of urban canyon as the microclimate buffer space brings more shadow in summer, the improvement effect of galleries is more evident on the side facing south of urban canyon oriented W-S.

The results lead to further revelation to urban designers for ameliorating urban microclimate and buildings' energy efficiency from the view of urban form. However, the comparative studies of environmental performances on the traditional and modern forms of real urban complex are expected in the near future.

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