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Determining the courtyard thermal efficiency and its impact on urban fabric: A contextual study of Baghdad, Iraq

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Abstract: Many researchers advocate readopting the courtyard pattern in hot climate regions for being more thermally efficient than the modern western ones, such as the detached housing. The courtyard helps through reducing heat gain and having sufficient natural ventilation to have a comfortable indoor environment. But, it is suggested that this building pattern loses its efficiency by being out of its compact urban fabric context due to having high exposure to the solar radiation. Aiming at finding a thermally efficient solution for the hot climate regions, this research investigates the thermal efficiency of courtyard pattern and examines its relevance in the present urban context. To achieve this aim, the thermal performance of a courtyard and a detached non-courtyard house was simulated. The courtyard house was tested in two locations: a traditional compact urban fabric and a modern less compact one. DesignBuilder simulation tool was used for this purpose. The simulation results are derived from fieldwork carried out in Baghdad, where both traditional and contemporary neighbourhoods can be found. They clearly demonstrate the efficiency of courtyard pattern in the compact urban environment. These results support adopting the courtyard pattern in contemporary and future buildings, with due consideration for the urban environment.

Keywords: Baghdad, DesignBuilder simulation, Courtyard buildings, Thermal efficiency

Introduction

The thermal performance of buildings has been one of the main considerations in building design. It affects occupants health and productivity in addition to its impact on buildings' energy performance (Indraganti and Rao 2010). In the hot-arid climatic zone, many studies advocate re-using the traditional courtyard pattern to achieve a thermally comfortable indoor environment. Through having various experimental studies, they showed that it is more thermally efficient than the other patterns, such as the detached, semi-detached and row patterns (Ratti, Raydan et al. 2003; Manioğlu and Yılmaz 2008; Al Jawadi 2011). Its main characteristic is that it includes an open space in the building's core to which all spaces access and open to get light and ventilation. Supported by other environmental elements, such as the thermal mass, the basement and the wind-catcher (Behbood, Taleghani et al; Ali, Turki et al. 2013; Manioğlu and Yılmaz 2008), the courtyard works to regulate buildings' thermal conditions (Sthapak and Bandyopadhyay 2014; Edwards 2006). Its environmental performance depends on two environmental strategies: to protect the building for heat gain and to reduce temperature through, basically, controlling building exposure to the solar radiation and having natural ventilation (Al-Hemiddi and Megren Al-Saud 2001; Muhaisen 2006). But, it is suggested that its thermal performance is highly governed by being in a compact urban fabric (Khan and Majeed 2015; Behbood, Taleghani et al. 2010), which is significantly different from the modern less compact one (Al-Thahab, Mushatat et al. 2014).

Out of its context, its performance might reverse as courtyard buildings will get higher heat gain resulted from having larger area exposed to the direct solar radiation and heat exchange (Gupta 1987; El-deep, El-Zafarany et al. 2012).

Aiming at determining the thermal impact of having a courtyard in buildings and the possibility of adopting the courtyard pattern in the modern less compact urban fabric, this research investigates the thermal performance of a courtyard building and a modern detached building in Baghdad, which has hot climate and both building typologies. It also tests the change in the courtyard building's thermal performance if it is moved to a context of modern less compact urban fabric.

Research aim, methodology and limitations

Within the ongoing efforts to define a thermally efficient solution for the hot climate regions, this research aims to investigate the thermal performance of the courtyard pattern. It focuses on determining the thermal impact of using the courtyard, this pattern's featured environmental element, and testing the urban fabric impact on its performance.

This study used the experimental research method to determine the relationships between buildings' thermal performance, their urban context and the existing of the courtyard. The experiment included using DesignBuilder as a simulation tool, which has been widely used to simulate buildings thermal performance with sufficient accuracy (Baharvand, Ahmad et al. 2013). Baghdad, the capital of Iraq, was selected as a case study and one of its traditional courtyard houses was used as a sample. This city has hot climate and traditional and modern housing patterns. The selected Baghdadi courtyard house was used to represent three cases. The first one involved simulating the thermal conditions of the selected courtyard house in its original conditions in a compact urban fabric (TCH). The second one is similar to the first case, but with relocating the courtyard house in a context of a modern neighbourhood as a detached house (DCH). The third case involved using the same context of the second case but with closing the courtyard and placing spaces' windows on the outside, to represent the detached modern housing pattern (DNCH). Comparing the performance of three cases indicate the courtyard pattern thermal efficiency and the impact of urban fabric pattern on courtyard buildings' thermal performance.

Analysing the three cases thermal performance

Baghdad context: climate and housing patterns

Baghdad has a long and hot summer, when the temperature might reach 51.0 C° (Iraqi Meteorological Organization, 2016), while the comfort limits have been defined to be between 18C° and 30C° (Saleem 2011). Regarding Baghdad's houses, until the middle of the last century, the courtyard pattern had been used as the housing pattern in the city. However, a number of factors including the social, cultural, and political changes, the development in the construction industry and the changing in the architectural styles have led to adopt the modern western housing patterns, including the detached houses, which do not have courtyards (Al-Thahab, Mushatat et al. 2014; Mohamad 2012). Spaces' windows have been placed to the outside. The new building patterns and the use of cars have led to a less compact urban fabric with wide streets instead of being compact with narrow organic roads (Al-Thahab, Mushatat et al. 2014; Ali 2009; Mahmood 2004).

Defining the research variables

Occupants' thermal comfort has been used by studies to determine the built environment thermal performance. It is affected by a number of factors, which have been defined by researchers to include six key factors: occupants' activity level, clothing thermal resistance, air temperature, Mean Radian Temperature, air velocity and humidity (Fanger 1970; CIBSE 2016).

Building on this, occupants' thermal sensation is this research's dependent variables and the affecting factors are the independent variables. The research measures the former through considering the Operative Temperature, which is of the indices that have been developed to measure occupants' thermal sensation, but it has been defined as the most correspondent index to occupants' sensation. It combines the integrated impact of air temperature and Mean Radiant Temperature (De Dear, Brager et al. 1998; Nicol and Humphreys 2010), which are in turn affected by heat gain and natural ventilation (Doick and Hutchings 2013; Armson, Rahman et al. 2013; Atmaca, Kaynakli et al. 2007; Amos-Abanyie, Akuffo et al. 2013). Accordingly, this research's independent variables are air temperature, Mean Radiant Temperature, natural ventilation and heat gain.

Selecting and modelling the study sample

To reduce the factors that might affect the thermal performance other than the courtyard space and the urban fabric compactness, a simple courtyard house was chosen, which has the typical features of Baghdad's courtyard houses, to be used for the thermal simulation purpose. It is a two floors house with a basement and a central open courtyard (Figure 1).

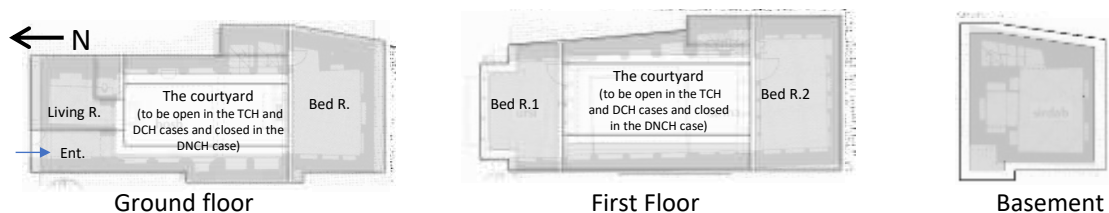


Figure 1. The selected Baghdadi courtyard house.

Floor plans were drawn in DesignBuilder depending on (Warren and Fethi 1982)

The simulation included determining the thermal conditions, the heat gain and natural ventilation of the research three cases: TCH, DCH and DNCH on the 21st of July, which is one of the hottest days in Baghdad. All of the three cases have neither mechanical ventilation nor cooling systems. They were modelled to include only natural ventilation. The research considered in modelling the three cases to make them identical in all aspects, except the considered aspects for the test (Figure 2) (Table 1) .



Figure 2. The three simulated cases

Table 1. The simulated model properties

The model properties		TCH	DCH	DNCH	
Areas	The house total area: 65.5 m ² - GF. Bed R. area 17.2 m ² - GF. Living R. area: 7.2 m ² GF. Living R. area: 7.2 m ² - 1 st F. Bed R. 1 area: 19.2 m ² - 1 st F. Bed R. 2 area: 13.2 m ²				
Construction	External walls	The option 'Bes practice, Heavy weight' used from DesignBuilder list	Super insulated block/brick wall (This will clearly show the impact of urban fabric compactness on building's thermal conditions as it will be compared with a detached building of high insulation level)		
	Internal walls				
	Roofs		100mm concrete slab		
	Floors		Combined external floor – Heavyweight		
Windows	GF. Bed R. windows	All single glassing 95% of the windows area is openable	3 m ²		
	GF. Living R. windows		1 m ²		
	1 st F. Bed R. 1 windows		19 m ²	5 m ² (Inevitable difference)	
	1 st F. Bed R. 2 windows		4 m ²		
	Shading devices		Blind with high reflectivity slats (always on) and 0.5m overhang		
Nat. Ven. settings	Windows opening schedule	'Dwell_DomLounge_cool' (selected from the DesignBuilder's schedules list). Windows are open during the nights and early mornings			
	Nat. Vent. condition 1	Outside Min. tem. is 15C° and Max. tem. is 30C°		according to the thermal comfort limits	
	Nat. Vent. condition 2	Min. difference between inside and outside tem. is 2C°			
	Nat. Vent. condition 3	Max. inside tem. is 30 C°			

The results: Analysis and Discussion

The results show that there are significant differences between the thermal conditions of the three tested cases (Figure 3), (Figure 4). Regarding the heat gain, the results demonstrate that heat gain happens during the night through the three mechanisms of heat transfer in buildings: convection, conduction and heat radiation (Stein 1997). From 18:00 o'clock until 00:00 o'clock, heat gain is higher in DNCH and DCH than TCH. This can be attributed to the time lag in heat radiation from the construction materials in DNCH and DCH typologies. At this time, Walls are protected in the TCH typology; they do not get direct solar radiation and, as a result, do not have stored heat radiation. On the other hand, from 00:00 o'clock until 8:00 o'clock, TCH and DCH have heat gain, which happens at the same time as occupants operate windows to get natural ventilation. This heat gain can be traced back to impact of opening the windows to the courtyard where the air temperature is higher than the outside temperature, but still have cooling impact as its temperature is less than the spaces' temperature (Figure.4- A,D,E), (Figure.5- A,D,E). The maximum measured heat gain is 0.35kW in (Bed R. 1) on the first floor of the DCH typology due to having the highest exposure to the solar radiation. As a consequence, It has the highest air temperature, the highest Mean Radiant Temperature, and the highest operative temperature, which is around 33C° (Figure 4 –A,D). The low heat gain in the first evening hours in the TCH case can be traced back to the use of the courtyard, which enables to have buildings attached to each other, which protects the outer walls from the solar radiation.

Natural ventilation works to during the night time to reduce the temperature by replacing the hot air with cold one. It is more active in TCH and DCH than the DNCH (Figure. 4-E,F), (Figure.5-E,F). The courtyard stimulates air movement through having the heated air by the walls heat radiation going up to be replaced by cold air (Mohammad 2010)

As a result of heat gain and natural ventilation, spaces' air temperature and Mean Radiant Temperature change and affect the operative temperature (Figure.4-A, B, C), (Figure.5-A, B, C). The lowest measured Operative Temperature is around 21 C°, which is in

the TCH's ground floor bedroom. This space has the least exposure to the solar radiation and one of the highest heats loose through natural ventilation. In total, DNCH has the highest operative temperature. This result might be different if the tested houses are of low thermal insulation, as, in this simulation, the DCH higher exposure to the solar radiation might be overcome by the natural ventilation cooling impact and the high insulation level. On the other hand, the TCH has the lowest operative temperature. It is around 7 C° less than the outside temperature in the ground floor and 2 C° in the first floor. The open courtyard space itself provides a stable air temperature during the whole day which is up to 7.5 C° less that the outside temperature in the midday.

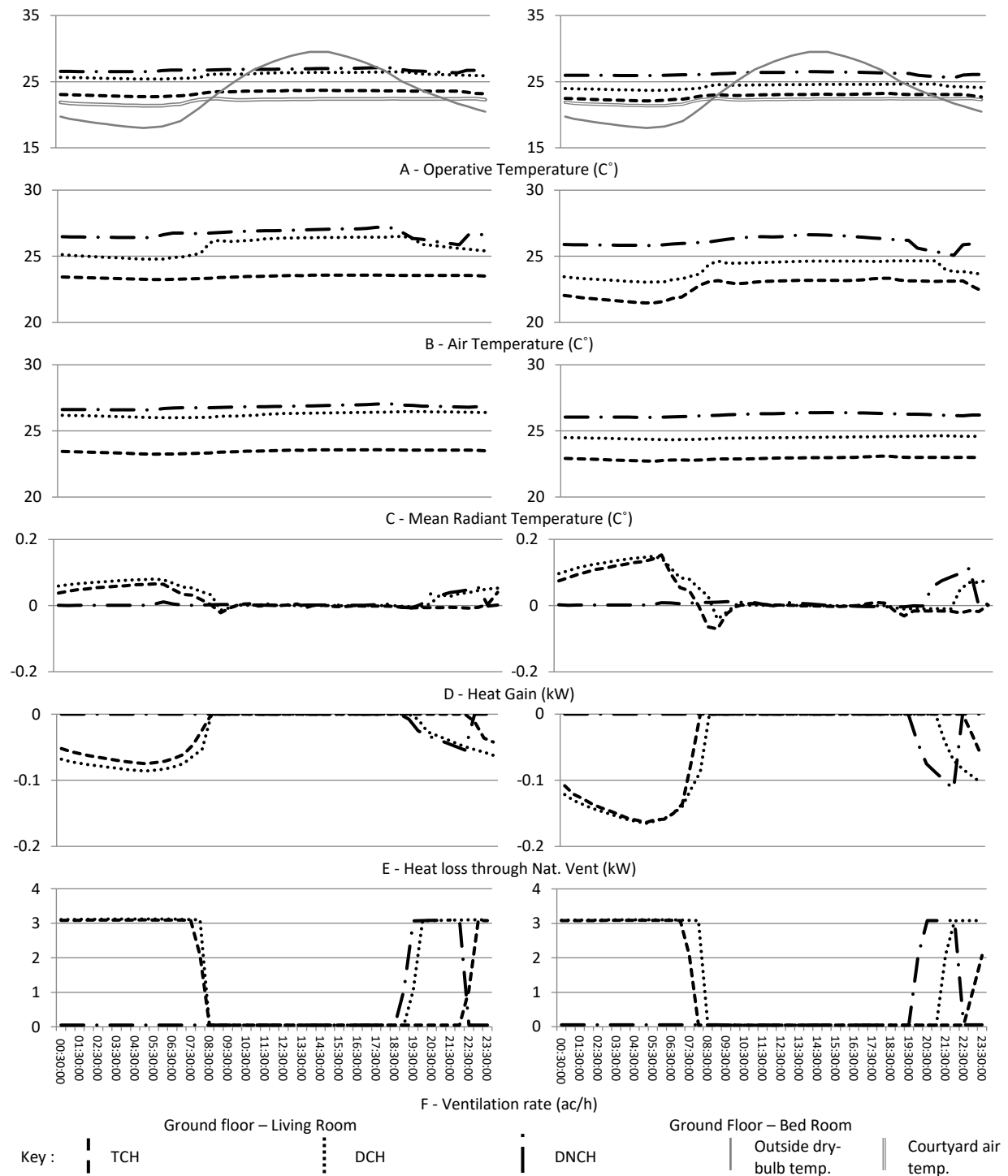


Figure 3. The ground floor two residential spaces thermal conditions.

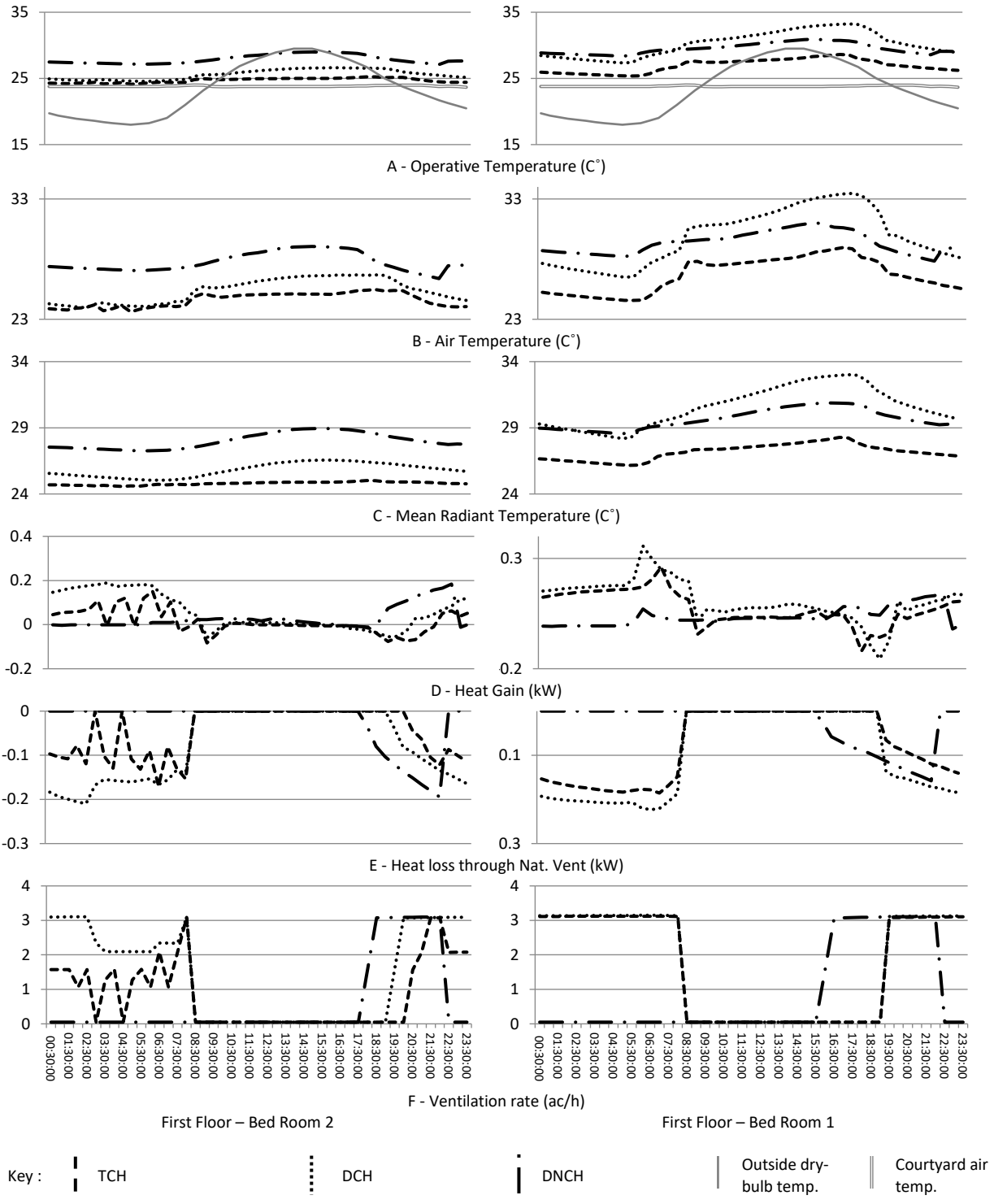


Figure 4. The first floor two residential spaces thermal conditions.

Conclusions and Recommendations

The courtyard pattern might offer an opportunity to have thermally comfortable indoor environments. Comparing the thermal performance of the TCH and the DNCH cases indicate the courtyard pattern efficiency, which can be traced back to the use of the courtyard element inside buildings. It enables to have buildings attached to each other as spaces have their openings to the inner courtyard. On the first hand, this protects external walls from the direct

solar radiation and the resulted heat gain. On the other hand, it offers air with lower temperature to be used to have sufficient natural ventilation.

This research demonstrates that the courtyard house offers its maximum thermal efficiency by being in a compact urban fabric. This efficiency decreases by being in a less compact urban fabric where the courtyard building becomes more exposed to the solar radiation and as a result, having higher heat gain during the day time. The decrease in its efficiency depends on how much heat will the building gain during the daytime. To a specific extent, it might become less efficient than the other housing patterns. However, having high insulation level, as what has been considered in this research, might help to keep the heat gain in the minimum rates and enable the courtyard building to keep a sufficient level of thermal efficiency.

This research recommends adopting the courtyard house for the current and future housing developments in the hot regions with considering having compact urban fabric. For future studies, it recommends conducting further studies on testing and quantifying the courtyard pattern thermal performance. A special consideration should be given to determining the impact of each of its elements and environmental strategies to help in developing this pattern to have more efficient and comfortable buildings.

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