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Effect of Corridor Design on Energy Consumption for School Buildings in the Cold Climate

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ABSTRACT

This paper discusses the energy impact of corridor design for school buildings in the cold climate of China. Local school buildings were classified into three types in terms of the corridor design patterns. Architectural related parameters of corridors which could have a potential impact on the energy consumption were summarized and discussed, including: form and orientation, temperature control, opaque envelope components, glazing, ventilation and infiltration. The annual heating, cooling, lighting and total energy consumption were compared. Results showed that form and orientation have the most significant influence on building energy consumption while opaque envelope insulation of corridors shows the least effect on energy demand. By combining the most beneficial strategies at each step, this study resulted in a better performing corridor design that increases the energy-saving by around 6% for the double-sided corridor building type and 17% for the one-sided enclosed corridor type of school building respectively.

Keywords: *school building, corridor design, energy saving*

1. INTRODUCTION

School buildings account for a considerable proportion of public buildings. Research has shown that school campuses are among the major energy consumers and energy conservation enforcement of school campuses would reduce Car-bon Dioxide emissions up to 25% (Zhou et al., 2013). There is a large body of research on the relationship between school building design and energy or environmental performance. The focuses have been put on the classroom due to the large proportion of school surface they occupy in school buildings (Perez et al., 2009). However, little attention has been paid to the common area in school buildings such as the corridor space. Their energy consumption also accounts for a certain proportion of the school energy consumption (Pitts and Saleh, 2007). Besides, such common areas play an important role in the ability for students to rest and communicate. A comfortable common area can have a potential impact on students' study results (Kwong et al., 2009).

The performance of transitional space in schools did not get a lot of attention from researchers. Though some researchers have investigated specific energy saving measures for transitional spaces like temperature control (Pitts and Saleh, 2007), but other parameters like the geometry or the glazing design of corridors are seldom considered. Furthermore, the relative importance of these strategies on the energy consumption is much less studied. Thus, the effect of school transitional space such as corridors on building energy consumption needs to be studied.

2. METHODOLOGY

The main objective of this study is to find energy-saving solutions for the corridor design of school buildings in the cold climate of China. First, local school buildings were characterized to establish specific school corridor models. Secondly, the design parameters of the corridor space that can have a potential influence on the performance were classified and then tested by category using Designbuilder software (Designbuilder, 2014). Then a sensitivity analysis was done to compare the relative importance of the different strategies. Last, integrated design solutions were defined by combining the strategies that provided the highest energy benefits for the building in each step. These combined strategies were also tested to examine the energy saving potential of corridor design.

School building model

The corridor typologies to be studied were identified based on literature and on the investigation of local school designs in the cold climate of China (Zhang and Li, 2000). In total, three corridor designs were identified (Figure 1): Double-sided corridor (Type A), in which classrooms are on both sides of a corridor, one-sided enclosed corridor (Type B), in which classrooms are positioned on one side of an enclosed corridor, one-sided open corridor (Type C), in which classrooms are positioned on one side of an open corridor.

Double-sided corridor school building (Type A)	One-sided enclosed corridor school building (Type B)	One-sided open corridor school building (Type C)

Figure 1: Classification of three types of school buildings according to corridor design in the cold climate of China

To simulate the three corridor designs in Designbuilder, a rectangular volume was selected as the basic shape since the rectangular shape accounts for a large proportion of school buildings in China. The size and numbers of various rooms were kept identical for each type as shown in figures in Table 1. The U values of external walls, internal walls and roofs were set as 0.35, 1.05 and 0.49 W/m^2K separately. Moreover, the zones were assumed to be occupied between 8:00-12:00 & 14:00-17:00 (Monday–Friday). Typical Chinese school holidays including vacations in the hot summer and cold winter accounting for 95 days in a year were considered. In addition, the minimum required illuminance level of classrooms is 300 lux and the corridor and staircase require at least 100 lux (Code for design of school, 2011).

Corridor space characteristics

Corridor design parameters were classified into five categories: form and orientation, temperature control, opaque envelope components, glazing, ventilation and infiltration. A summary of the corridor design variables are presented in Table 1 and introduced as below.

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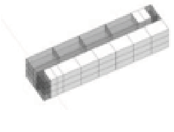
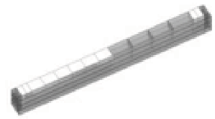
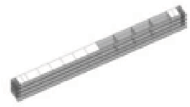
	Double-sided corridor (Type A)	One-sided enclosed corridor (Type B)	One-sided open corridor (Type C)
Configuration.			
Floor plan.			
			
Orientation.	0°*, 90°,180°, 270°	0°*, 90°,180°, 270°	0°*, 90°,180°, 270°
Corridor width	1.5m*, 2.4m[a], 3m[a]	1.5m*, 2.4m[a], 3m[a]	1.5m*, 2.4m[a], 3m[a]
Temperature control.	16°C-26°C*, 14°C-28°C, 12°C-30°C	16°C-26°C*, 14°C-28°C, 12°C-30°C	-
Wall insulation.	0.35*,0.30,0.25 [b] W/m^{2}K	0.35*,0.30,0.25 [b] W/m^{2}K	-
Roof insulation.	0.49*,0.35,0.15 [b] W/m^{2}K	0.49*,0.35,0.15 [b] W/m^{2}K	-
Glazing type.	Single glass, double glass*, triple glass, double low-e glass	Single glass, double glass*, triple glass, double low-e glass	Single glass, double glass*, triple glass, double low-e glass
Window to wall ratio of external surfaces.	20%,30%,40%*	20%,30%,40%*	20%,30%,40%*
Mechanical ventilation.	10, 19*, 30 m^3/h•p	10, 19*, 30 m^3/h•p	-
Infiltration.	0.75, 1.0*, 1.5 ac/h	0.75, 1.0*, 1.5 ac/h	-

* The base case settings of the reference model.
[a] Mean value of different periods of school design in China from the 1980s to the present (Wang, 2007).
[b] Best practice building from Designbuilder (Designbuilder, 2014).

Table 6: Three school building models and investigated corridor design parameters

The four principal orientations: 0° (south), 90° (west), 180° (north), and 270° (east) were considered. The orientation variations were obtained by rotating the whole building clockwise. The width of corridor were set as 1.5m, 2.4m and 3m, which represent the mean value of three periods (before 1980, 1980s, 1990s to now) of school design in China (Wang, 2007). In accordance with the code for school design (Code for design of school, 2011) the standard temperature range of corridors in schools is 16°C-26°C. Two of these ranges for internal temperature in the enclosed corridor spaces were also simulated with following values: 14°C-28°C and 12°C-30°C. This strategy is inapplicable for the open-sided corridor building type. For Types A and B, the U values of external corridor walls were changed to 0.30 and 0.25 W/m^{2}K, and the U values of roof insulation changed to 0.35 and 0.15 W/m^{2}K. The double glazing was set as the base case of the experiment, and then replaced by single glazing, triple glass and low-e double glazing. Table 2 shows the different characteristics of each glazing type. For Type A and B, the variations were applied to the exterior corridor walls, and for Type C changes were applied to the external walls of the classrooms adjacent to corridor. The range of exterior window to wall ratio was 20% to 40% according to local standards (Code for design of school, 2011). Lastly, different mechanical ventilation rates combined with various basic infiltration rates for enclosed corridors were also simulated for Types A and B.

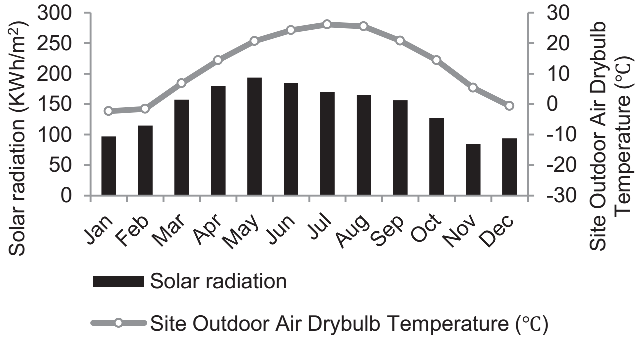


Figure 2: Yearly solar radiation and outdoor air temperature of Tianjin

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Glazing description	Solar transmittance	U-value (W/m² K)
Type A. [Sgl: Clr 6 mm]	0.82	5.78
Type B. [Dbl Clr 6mm/13mm Air/6mm]	0.70	2.70
Type C. [Trp: Clr 6mm/6mm air/6mm/6mm air/6mm]	0.61	2.13
Type D. [Dbl LoE (e2=0.1): Clr 6mm/13mm Air/6mm]	0.57	1.76

Table 7: Characteristics of the different glazing types

Climate data

This study employed the climate data of Tianjin (39.13N, 117.20E) in China, known as a cold climate city based on the climatic classification of Köppen–Geiger. The solar radiation and outdoor dry air temperature are presented in Figure 2.

3. RESULTS AND DISCUSSION

3.1. Effect of each corridor design parameter

Figure 3 shows the influence of form and orientation on the energy demand of school buildings. As expected, Type C consumes the least energy in most cases with no extra air conditioned corridor space, while Type B has the highest energy demand in all cases. Moreover, buildings with 0°(south) and 180°(north) rotation angle show less energy use than other orientations. This is explained by the significant variation in cooling energy demand. For heating and lighting, there are only small variations. Considering corridor depth, the energy demand increases steadily as the corridor width increases except for Type C where the effect is marginal. In addition, it can be observed that for the two enclosed corridor types (Type A and B), the energy variation can primarily be attributed to the increased energy demand of the corridor itself (Figure 4).

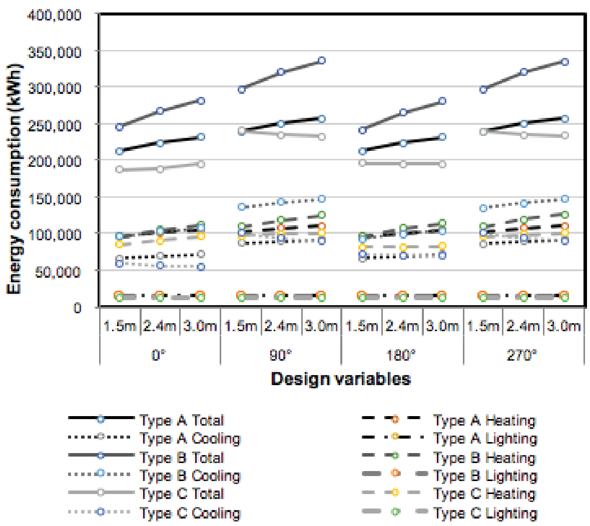

Figure 3: Annual energy consumption for different forms and orientations

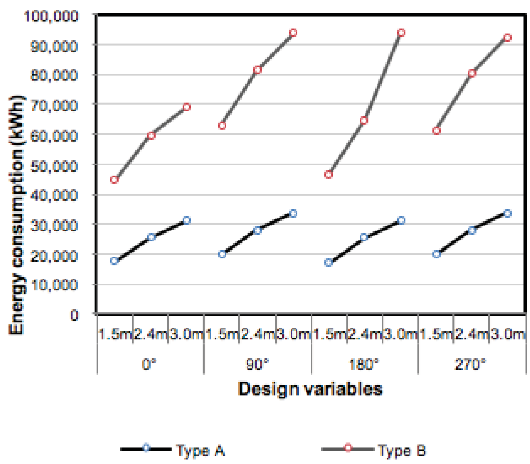

Figure 4: Annual energy demand of corridor space for different forms and orientations

Figure 5 shows that building energy demand decreases with the increase of the allowed temperature range in the corridor; however the trend is much more apparent for Type B but becomes less obvious for Type A. It can be explained by the fact that the corridors in Type A have less interfaces connected to the outside and it therefore becomes easier to maintain the indoor temperature. Figure 6 shows that annual energy savings of corridor space can reach 29,000 kWh for Type B but only 11,000kWh for Type A.

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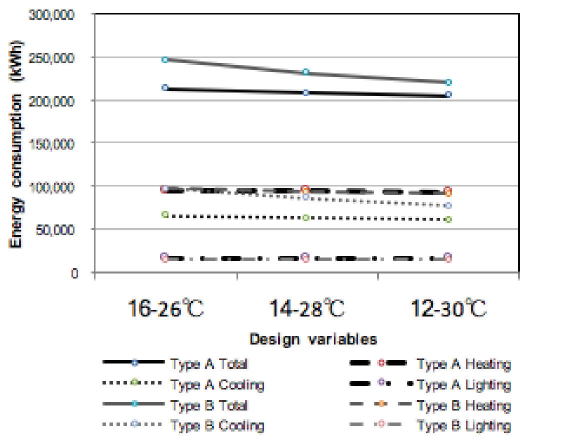

Figure 5: Annual energy consumption for different temperature control

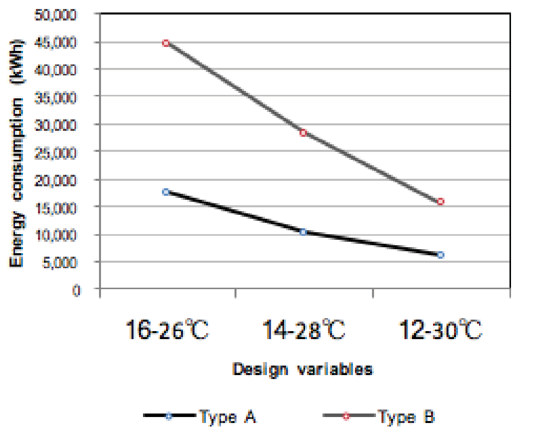

Figure 6: Annual energy demand of corridor space for different temperature control

For opaque envelope component design (Figure 7 and Figure 8), the change in building energy demand is only marginal and does not appear to be affected by varying the U values for corridor walls and roofs. This result suggests that simply increasing corridor wall and roof insulations regardless of other parameter designs may not lead to expected energy savings in the cold climate of China.

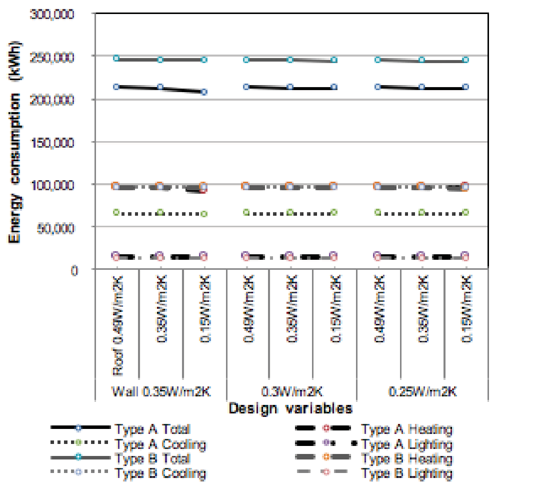

Figure 7: Annual energy consumption for different opaque envelope designs

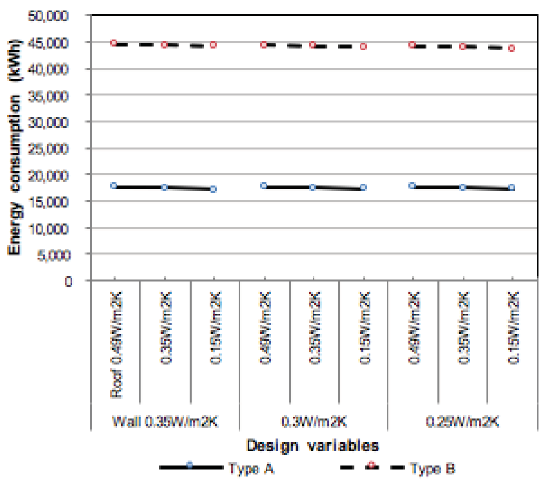

Figure 8: Annual energy demand of corridor space for different opaque envelope designs

Figure 9 shows the effect of various glazing ratios and types on the energy demand. Low-e double glazing performs slightly better than the other three glazing materials for Type B. But it has almost no effect for Type A and C. Moreover, for Type B and C, heating energy demand increases when the WWR decreases while cooling energy demand steadily decreases with the decrease of WWR. This leads to a marginal decrease of the total energy demand of Type B and a slow energy increase for Type C when the WWR decreases. Furthermore, Figure 10 shows that the energy savings with the decrease of the window to wall ratio is more obvious in low performance glazed rooms (double and single glazing) but becomes less significant in high performance glazed rooms (triple and low-e glazing). In addition, for Type A the energy variation in all aspects is negligible due to much less window area of the corridor space.

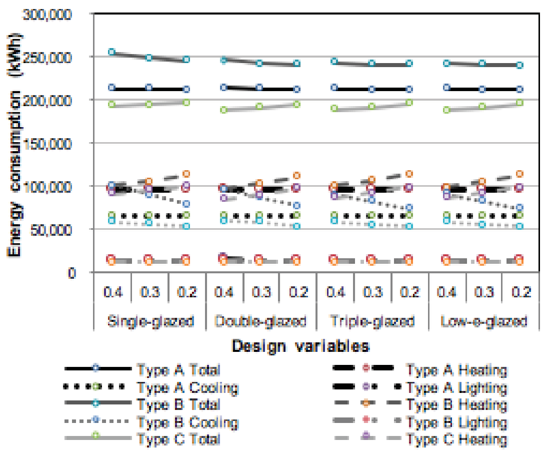

Figure 9: Annual energy consumption for different glazing

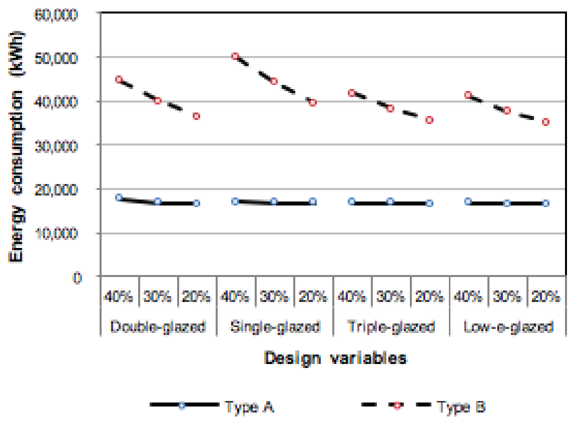

Figure 10: Annual energy demand of corridor space for different glazing

Figure 11 and Figure 12 show that both the total building energy demand and the corridor energy demand increase steadily as the ventilation and infiltration values increase. The reason is that the heating energy growth rate is larger than the decrease rate of cooling energy demand. In winter, a higher air exchange rate allows more cold air into the building, thus leading to the increase of heating energy demand. In contrast, in summer, a higher air exchange can dissipate indoor heat more quickly to the outside resulting in a lower energy demand.

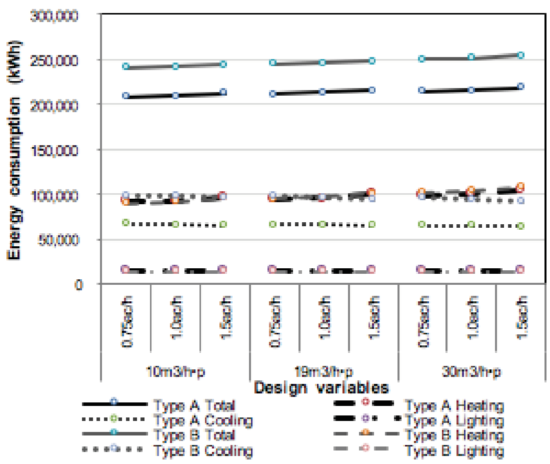

Figure 11: Annual energy consumption for different ventilation and infiltration

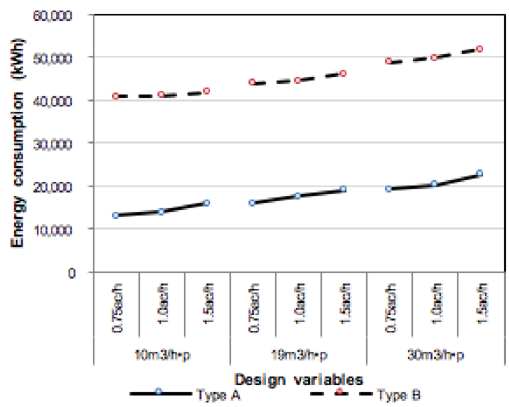

Figure 12: Annual energy demand of corridor space for different ventilation and infiltration

A sensitivity analysis was set up in order to understand the influence of each corridor design variable series. The total building energy consumptions for five design series were summarized and displayed using a boxplot shown in Figure 13. Form and orientation of corridors has the highest effect on total energy consumption for all building types especially for Type B, of which the energy variation can be 93,000kWh. This indicates that inappropriate design of form and orientation may result in very high energy consumption. Contrary, opaque envelope design results in a minimal energy change. Both glazing ratio and the corridor material have a relatively larger influence on the total energy demand of building types B and C while the effect on Type A is marginal. In addition, temperature control in corridors is more influential for Type B whereas the ventilation and infiltration strategy has a similar modest effect on building types A and B.

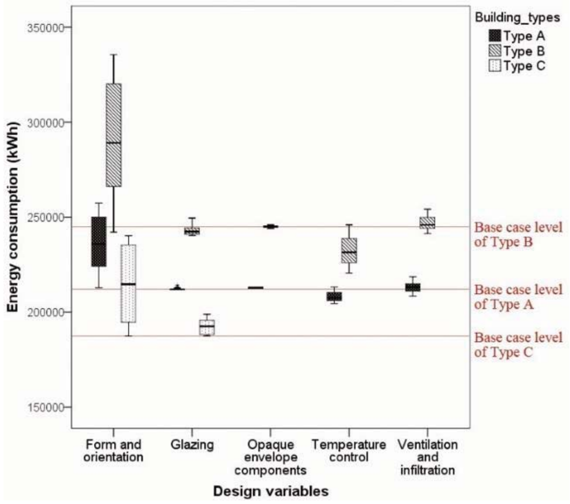

Figure 13: The relative importance of corridor design variables

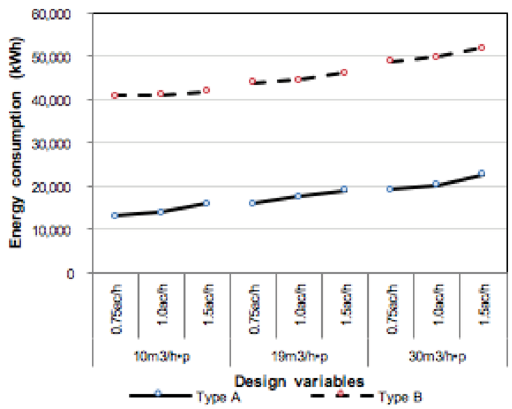

Figure 14: Comparative energy analyses of the optimized design and the basecase design

3.2. Integration of corridor design strategies

According to the results obtained from the previous analyses, an integrated design solution was defined. The final combination of the design of the corridor was selected based on the strategies that provided the highest energy benefits for the building in each step. Comparing the results of the optimized design to the base case shows that the strategies are quite effective. The combination of energy-saving measures reduces the total energy consumption by 6% for Type A and 17% for Type B (Figure 14). It is noteworthy that for Type C the base case has the best energy performance parameters thus there is no energy variation for the optimized design.

4. CONCLUSION

In this study, the effect of corridor design parameters on building energy demand was assessed for three types of school buildings in cold climates. Considered design strategies are: form and orientation, temperature control, opaque envelope components, glazing, ventilation and infiltration. The main findings of this study are as follows:

- Generally, Type C consumes the least energy annually while Type B has the highest energy demand.
- Form and orientation of corridors can significantly affect the total building energy consumption. Buildings with 0°and 180°rotation angle perform better than other orientations. Narrow corridors have the best performance for Type A and B while the effect is only marginal for Type C.
- Considering glazing, we found that corridors equipped with a 20% WWR of low-e double glazing results in the highest energy-savings for both Type A and B. For Type C a double glazing with a 40% WWR has the lowest energy demand. Moreover, the influence of glazing on the building energy consumption is larger for Type B and C whereas the effect on Type A is marginal.
- The design with the widest temperature range and the lowest ventilation and infiltration rates can achieve the minimal building energy consumption. However, temperature control brings more energy benefits for Type B than A while ventilation and infiltration strategy has a similar, modest, effect on both types.
- The design of the opaque envelope component for corridors has little effect on the energy demand.
- Finally, the integration of the corridor design solutions offers a saving in total energy by around 6% and 17% for Type A and B respectively. For Type C, the base case has the best energy performance.

This study indicates that corridor parameters should be carefully addressed when designing school buildings. Proper design of form and orientation combined with other elements, such as glazing, temperature control, ventilation and infiltration will noticeably reduce building energy demand. Further research will try to clarify other corridor design parameters like shading which could also have potential effect on the energy consumption.

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