The impact of retrofitting elevators on the indoor thermal comfort of existing urban residential buildings: A case study of a typical levelling entrance scheme

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Abstract. In pursuit of urban sustainability, retrofitting elevators in existing residential buildings has emerged as a pivotal strategy to enhance accessibility and marketability. However, the impact of such retrofits on indoor thermal comfort remains underexplored. This study aims to bridge this gap by investigating the effects of elevator retrofitting on the indoor thermal environment of a typical residential building across different climate regions. This study, first, defined the research object as a typical six-story old residential building. The retrofitting method involved adding a steel-structured, glazing-enclosed elevator on the north side of the building adopting a leveling entrance method. Then, this work conducted simulations using ITES software to compare the time proportion of indoor adaptive comfort temperature (P-value) in the original state of typical buildings in five climate regions. Additionally, simulations were performed for the same buildings retrofitted with low-performance or high-performance glazing-enclosed elevators (Scenarios 1 – 5 or 6 - 10). The results demonstrate that retrofitting a glazing elevator shaft on the north side of an old building positively impacts indoor comfort in warmer climates but has minimal positive or slightly negative effects in colder regions.

Keywords: urban construction, indoor thermal environment, old community, aging population, building renovation, elevator shaft.

1 Introduction

Amidst the ongoing urban regeneration and quest for sustainable development, retrofitting existing residential buildings has emerged as a pivotal strategy[1]. One significant retrofit measure is the installation or modernization of elevators, which not only enhances accessibility and livability but also boosts the market value of multi-story residential buildings[2]. However, this intervention often comes with consequences for the indoor environmental quality, particularly its thermal comfort[3], which in turn impact the well-being of occupant and the energy consumption patterns.

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Previous studies[4,5] have delved into the general effects of elevator operation on building energy use and indoor environments. For instance, research has demonstrated that elevator movement can induce stack effect, a phenomenon where air pressure differences cause air to rise or descend through building shafts, affecting indoor air quality and temperature distribution and potentially leading to discomfort for residents. While these studies provide valuable insights, they primarily focus on the broader impacts of elevator operation rather than the specific effects of retrofit strategies on the indoor thermal environment of existing residential buildings.

The limited understanding of how elevator retrofit strategies influence the indoor thermal environment represents a knowledge gap. This gap is crucial because it hinders the ability to optimize retrofit designs for enhanced indoor comfort and energy efficiency. Although a study conducted in China showed that retrofitting elevators in residential quarter has minimal effect on the three-dimensional urban morphology and outdoor thermal environment[6], the evaluation of retrofitting elevators in the perspective of indoor thermal environment remains rare.

This study aims to bridge this knowledge gap by conducting a detailed case study of a typical elevator retrofit scheme involving a leveling entrance in different climate regions. Through numerical simulations, the work seeks to quantify the changes in indoor thermal and humidity levels resulting from the retrofit. Additionally, it identifies the contributing factors to these changes, providing a more comprehensive understanding of the retrofit's impact on indoor thermal comfort.

2 Research Objectives

The primary goal of retrofitting elevators in existing residential buildings is to improve the functional use of the structure, especially to facilitate the last few tens of meters of the journey home for those with mobility impairments. Consequently, the barrier-free, leveling entrance mode has become the main approach for retrofitting elevators in existing residences. The addition of structures like elevator shafts to the exterior of the original building inevitably alters its form, impacting the building’s passive performance attributes such as natural lighting and ventilation. However, existing studies have primarily focused on the impact of adding elevators on the outdoor environment of residential areas[6], with less consideration given to changes in the indoor thermal environment.

The objective of this study is to assess the impact of retrofitting elevators on the indoor thermal comfort of existing residential buildings. Therefore, this study takes a typical scheme of a leveling entrance as an example to investigate the impact of retrofitting elevators on the indoor thermal comfort of existing residential buildings under different climatic conditions:

- Quantify the changes in indoor thermal comfort resulting from the retrofit of glazing-enclosed elevators.
- Identify factors that contribute to these changes, including the performance of glazing materials and climate conditions.
- Provide theoretical support for policy formulation and practical implementation of elevator retrofit projects in existing residential buildings.

3 Materials and Methods

3.1 Study Area

As retrofitting elevators in old residential areas becomes a significant aspect of aging infrastructure revitalization in China, this study selects the country as its focal point. Drawing reference from the Chinese national Code for Thermal Design of Civil Buildings (GB 50176-2016), the research categorizes climate regions into five distinct zones: severely cold areas, cold areas, hot summer and cold winter areas, hot summer and warm winter areas, and mild areas. Accordingly, five representative cities from these zones are chosen. As depicted in Fig. 1, located in the severely cold areas of China, Ordos, located in the severely cold area, experiences harsh winters characterized by low temperatures, necessitating highly insulated buildings for effective heat retention[7]. Beijing, a city typifying the cold area, has prolonged chilly winters and occasional intense summer solar radiation, requiring a delicate balance between thermal insulation and solar heat gain control in building design. Chengdu, situated in the hot summer and cold winter area, faces the challenges of a temperate climate with moderate winters and hot, humid summers, demanding ventilation and moisture control considerations. Guangzhou, representing the hot summer and warm winter area, experiences warm and damp winters with hot summers, calling for buildings adept at facilitating natural ventilation and ensuring year-round thermal comfort. Finally, located in the mild area with a subtropical climate, Panzhihua boasts relatively stable temperatures throughout the year, enabling architectural designs emphasizing natural lighting and passive cooling methods.

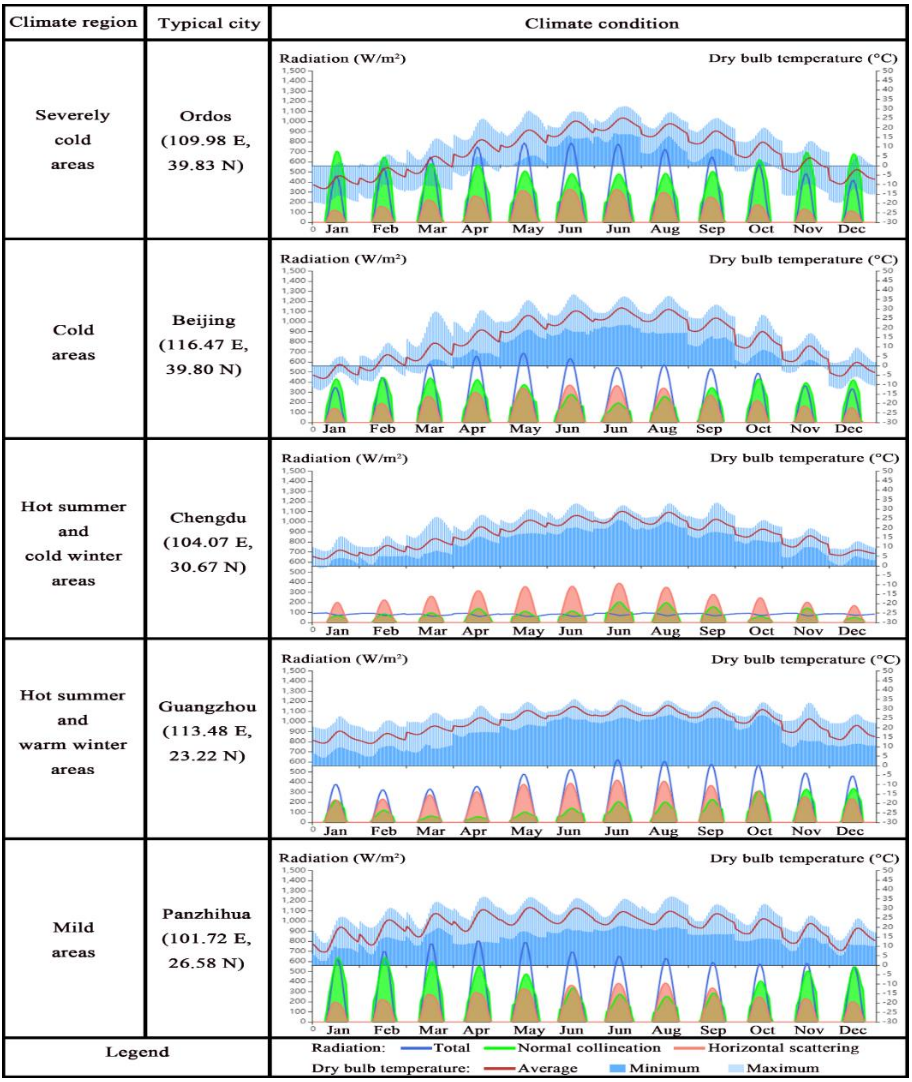


Fig. 1. Climate condition in of the typical cities[12]

3.2 Building Case

For this study, a standard design of a 6-story residential building[8] has been chosen as the reference case (Fig. 2). This particular case features a south-facing structure, constructed of brick and concrete. Each floor of the building comprises two units: one with a layout consisting of two bedrooms, two living rooms, and one washroom, while the other unit includes three bedrooms, two living rooms, and one washroom. The retrofit plan involves adding a transparent glass elevator shaft and associated corridor bridges to the north side of the existing structure.

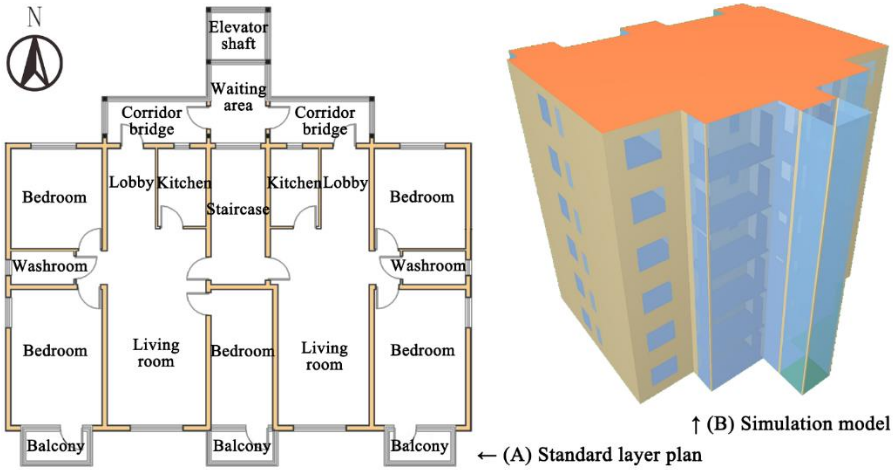


Fig. 2. Standard layer plan and simulation model

This building case implements the leveling entrance method for elevator retrofitting. As shown in Fig. 3, leveling entrance, also known as "full-level access," differs from the half-leveling entrance configuration and offers distinct advantages[9]. Retrofitting elevators often entail structural and envelope modifications, which can potentially alter airflow dynamics and the building's thermal characteristics.

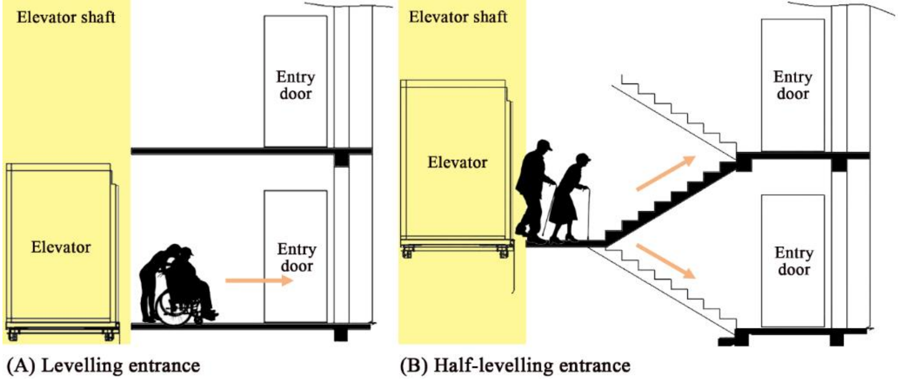


Fig. 3. Sketch maps of levelling entrance and half-levelling entrance

3.3 Scenario Settings

To explore the potential thermal environmental impacts of the elevator retrofitting scheme across various climate regions, five scenarios have been established based on conventional building envelope practices specific to each region. These scenarios detail the construction materials, exterior wall compositions, glazing (windows or glass curtain walls), and balcony designs (enclosed or open), as outlined in Table 1. The remaining engineering parameters for the study have been set using default values from the

ITES2024 software, a commonly-used indoor thermal environment simulation tool developed by GBSware[10] in China.

Table 1. Settings in scenarios

Scenario	Climate region	Typical city	Exterior wall			Exterior glazing					Balcony
			Material	λ	D	Material	λ	G/W	Se	T	
1	Severely cold areas	Ordos	370 mm Brick	5.724	0.249	6 mm clear glass + 12 mm air + 6mm clear glass	3.9	0.85	0.750	1.00	Enclosed
2	Cold areas	Beijing	240 mm Brick	1.926	3.156						
3	Hot summer and cold winter areas	Chengdu				6 mm clear glass	6.5	0.75	0.813	0.77	
4	Hot summer and warm winter areas	Guangzhou									Open
5	Mild areas	Panzhihua									
6	Severely cold areas	Ordos	370 mm Brick	5.724	0.249	5 mm ultra white glass + 12 mm air +5 mm ultra white glass + Vacuum +5 mm ultra white low-E glass	0.9	0.75	0.534	0.62	Enclosed
7	Cold areas	Beijing	240 mm Brick	1.926	3.156						
8	Hot summer and cold winter areas	Chengdu									
9	Hot summer and warm winter areas	Guangzhou									Open
10	Mild areas	Panzhihua									

Note: λ - heat transfer coefficient (W/m^{2}K); D - heat inertia index; G/W - glass-to-window ratio; Se – shading coefficient, T - visible transmittance.

3.4 Indoor Thermal Comfort Assessment

The indoor thermal comfort of the building cases under consideration is evaluated through a rigorous computational process that involves several key steps.

Determination of Comfort Temperature Range.

Given the focus of this research on older residential buildings without heating, ventilation, and air conditioning systems, we have established a method for determining the comfort temperature range. When the indoor average air velocity (v_a) remains at or below 0.3 m/s, the comfort temperature range is delineated as presented in Fig. 4. This figure incorporates outdoor monthly average temperatures sourced from the "Chinese Standard Weather Data for Building Thermal Environment Analysis"[11]. If 0.3 m/s $< v_a \leq$ 0.6 m/s, Δt = 1.2 °C; if 0.6 m/s $< v_a \leq$ 0.9 m/s, Δt = 1.8 °C; if 0.9 m/s $< v_a \leq$ 1,2 m/s, Δt = 2.2 °C. Furthermore, Table 2 illustrates the outdoor average monthly temperatures and the corresponding indoor thermal comfort temperature ranges for select cities.

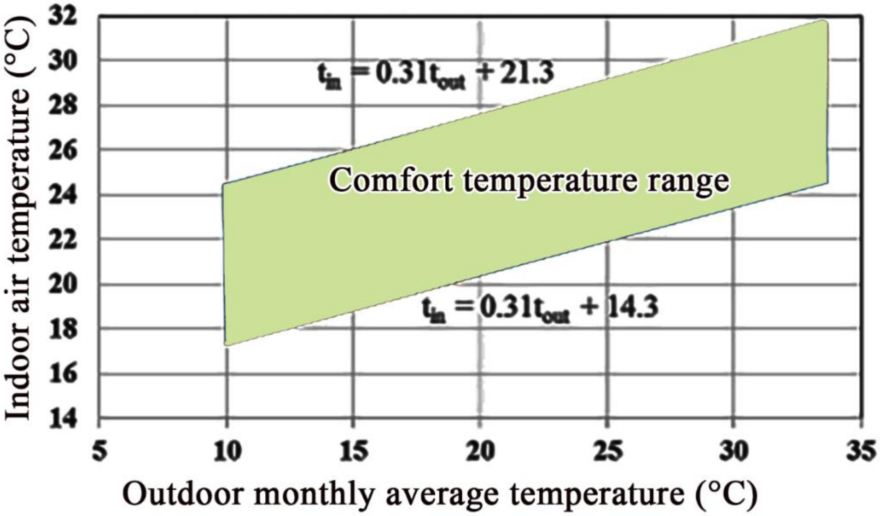


Fig. 4. Indoor comfortable temperature range of naturally ventilated buildings[10]

Table 2. Outdoor average monthly temperatures (T_m) and indoor thermal comfort temperature ranges (T_c) of the typical cities (°C)

Month	Ordos		Beijing		Chengdu		Guangzhou		Panzhihua	
	T_m	T_c	T_m	T_c	T_m	T_c	T_m	T_c	T_m	T_c
Jan	-8.0	17.4~24.4	-3.8	17.4~24.4	5.8	17.4~24.4	13.9	18.6~25.6	8.0	17.4~24.4
Feb	-4.9	17.4~24.4	-1.5	17.4~24.4	8.2	17.4~24.4	14.2	18.7~25.7	9.8	17.4~24.4
Mar	1.5	17.4~24.4	7.7	17.4~24.4	12.8	18.3~25.3	18.3	20.0~27.0	13.7	18.6~25.6
Apr	7.7	17.4~24.4	14.4	18.8~25.8	16.1	19.3~26.3	22.4	21.2~28.2	17.7	19.8~26.8
May	14.9	18.9~25.9	19.3	20.3~27.3	21.2	20.9~27.9	26.1	22.4~29.4	19.5	20.3~27.3
Jun	19.0	20.2~27.2	24.5	21.9~28.9	23.8	21.7~28.7	27.2	22.7~29.7	20.9	20.8~27.8
Jul	21.7	21.0~28.0	26.4	22.5~29.5	25.8	22.3~29.3	28.8	23.2~30.2	20.7	20.7~27.7
Aug	19.6	20.4~27.4	25.6	22.2~29.2	25.1	22.1~29.1	28.0	23.0~30.0	20.3	20.6~27.6
Sep	13.1	18.4~25.4	20.4	20.6~27.6	21.5	21.0~28.0	27.4	22.8~29.8	18.8	20.1~27.1
Oct	7.2	17.4~24.4	13.0	18.3~25.3	17.9	19.8~26.8	24.3	21.8~28.8	16.7	19.5~26.5
Nov	0.2	17.4~24.4	5.4	17.4~24.4	13.6	18.5~25.5	20.2	20.5~27.5	11.7	17.9~24.9
Dec	-6.2	17.4~24.4	-0.5	17.4~24.4	7.1	17.4~24.4	15.5	19.1~26.1	7.9	17.4~24.4

Calculation of Indoor Temperature.

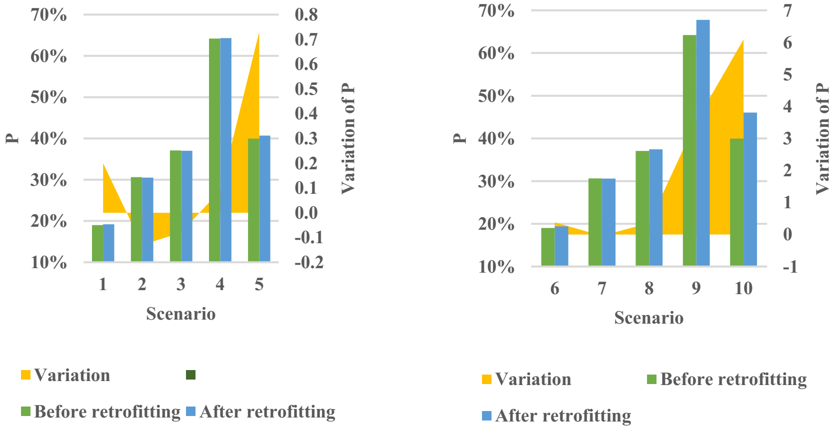
To determine indoor temperatures under natural ventilation and combined ventilation conditions, this study employs the DeST 3.0 kernel integrated into the ITES2024 software. This approach ensures accurate and reliable temperature calculations, crucial for assessing thermal comfort in existing multi-story residential buildings.

Calculation of the Time Proportion of Indoor Adaptive Comfort Temperature (P). The time proportion of indoor adaptive comfort temperature (*P*) is calculated by dividing the number of hours when the indoor temperature falls within the thermal comfort range by the total annual operating hours of the building. This metric offers a quantitative measure of indoor thermal comfort, providing valuable insights into the performance of existing multi-story residential buildings. By analyzing this metric, one can gain a deeper understanding of the thermal comfort conditions experienced by occupants and identify potential areas for improvement.

4 Results

4.1 Indoor Thermal Comfort Before and After Retrofitting Elevator with Low-Performance Glazing

To assess the ramifications of retrofitting elevators on the indoor thermal comfort of pre-existing multi-story residential buildings, a rigorous evaluation of the variations in indoor thermal comfort across different building scenarios is paramount. As illustrated in Fig. 5 (A), the installation of elevators exerts minimal influence on the indoor thermal environment of these buildings. In regions characterized by persistently cold temperatures (Ordos) or persistently hot temperatures (Guangzhou and Panzhihua), there is a slight enhancement in indoor thermal comfort. Conversely, in areas with distinct seasonal variations, such as cold areas (Beijing) and hot summer and cold winter areas (Chengdu), the indoor thermal comfort may experience a marginal decline. In the ensuing subsections, we delve into the specific impacts on different rooms in Scenario 2, where the comfort level diminishes the most, and Scenario 5, where the comfort level augments the most.



(A) Scenarios 1 – 5 (B) Scenarios 6 – 10

Fig. 5. Indoor thermal comfort in scenarios

4.2 Indoor Thermal Comfort Variation in Scenario 2

In Scenario 2 (Beijing), prior to the installation of elevators, the thermal comfort level was optimal on the ground floor and least satisfactory on the top floor. The introduction of elevators yields the most pronounced positive impact on the ground floor while exerting the most significant adverse effect on the top floor. Although the rooms affected vary across floors, the kitchens in west-facing units consistently exhibit the greatest impact. Specifically, on the ground floor, the *P*-value in the west kitchen increases by 0.44%, whereas it decreases by 0.16% on the top floor. Evidently, in older multi-story residential buildings located in cold areas, the installation of elevators, while significantly bolstering the convenience for top-floor residents, may come at a minor sacrifice in terms of their comfort level.

4.3 Indoor Thermal Comfort Variation in Scenario 5

In Scenario 5 (Panzhihua), the thermal comfort level was optimal on the top floor and least satisfactory on the ground floor before the elevator installation. The addition of elevators has the most substantial impact on the ground floor and the least impact on the top floor. Across all floors, the west kitchen experiences the greatest positive variation, while the northeast bedroom undergoes the most significant negative variation. The affected rooms on each floor remain consistent: the kitchens in west-facing units are consistently the most impacted, similar to Scenario 2. Specifically, on the ground floor, the *P*-value in the west-facing kitchen increases by 3.09%, while that in the northeast bedroom decreases by 0.71%. Clearly, in older multi-story residential buildings located in temperate regions, the installation of elevators not only enhances the convenience for top-floor residents but also elevates their comfort level.

5 Discussion

5.1 Indoor Thermal Comfort After Retrofitting Elevator with High-Performance Glazing

The preceding simulation analysis, focused on uninsulated masonry-concrete buildings, has revealed that the installation of elevators using ordinary low-performance glazing has a minimal, albeit noticeable, impact on the indoor comfort of existing buildings. Given the global push towards carbon-neutral construction, it is imperative to adopt high-performance building materials during renovation works wherever economically feasible. To this end, this work has established a second set of scenarios (Scenarios 6 - 10) that mirror Scenarios 1 - 5 but with a critical difference: the exterior glazing material and its performance characteristics have been upgraded, as detailed in Table 1.

As illustrated in Fig. 5 (B), the introduction of elevators featuring high-performance exterior glazing has a pronounced effect on the indoor thermal environment across different scenarios. In severely cold areas and hot summer and cold winter areas, there is a modest improvement in indoor thermal comfort. However, in hot summer and warm winter areas, as well as mild areas, the improvement is more significant, with the *P*-

value increasing by 3.54% and 6.09%, respectively. Unexpectedly, in cold areas, the indoor thermal comfort may experience a slight decrease, indicating that the upgraded glazing does not uniformly enhance comfort in all settings.

5.2 Indoor Thermal Comfort Variation in Scenario 7

In Scenario 7 (Beijing), the trend in indoor comfort across different rooms affected by the elevator addition is similar to that observed in Scenario 2. However, the magnitude of the impact is more pronounced. Specifically, on the ground floor, the *P*-value in the west kitchen increases by 0.68%, while it decreases by a marginal 0.09% on the top floor. These findings suggest that, although high-performance glazing offers some improvement to the indoor environment, the added cost may not always justify the minimal gains in comfort.

5.3 Indoor Thermal Comfort Variation in Scenario 10

The use of high-performance glazing in elevator retrofits significantly enhances the indoor comfort of existing residences in mild areas, as evidenced by the data presented in Table 3. Across the entire building analyzed, only the northeast bedrooms on the ground floor show a minor negative impact. Among all floors, the rooms least positively impacted are also the northeast bedrooms. Conversely, kitchens located on both the east and west units experience the most significant positive impacts. Notably, the west kitchen on the ground floor exhibits the highest increase in the *P*-value, a substantial 21.29%.

Table 3. P-values (%) in Scenarios 2 and 5

Floor	Room	Area (m^2)	*P* before retrofitting	*P* in Scenario 5	Variation of *P* in Scenario 5	*P* in Scenario 10	Variation of *P* in Scenario 10
Ground floor	Bedroom (southwest)	22.2	44.16	44.53	0.37	48.64	4.48
	Living room (west)	42.8	35.02	36.89	1.87	41.85	6.83
	Bedroom (middle)	15.4	44.78	45.5	0.72	56.7	11.92
	Living room (east)	41.0	34.38	36.27	1.89	41.21	6.83
	Bedroom (southeast)	22.2	41.72	42.23	0.51	45.41	3.69
	Bedroom (northwest)	16.4	32.11	31.82	-0.29	32.25	0.14
	Bedroom (northeast)	16.4	31.02	30.31	-0.71*	30.66	-0.36*
	Kitchen (west)	6.9	47.73	50.82	3.09**	69.02	21.29**

	Kitchen (east)	6.9	47.55	50.43	2.88	68.50	20.95
Middle floors	Bedroom (southwest)	22.2	45.47	45.79	0.32	49.59	4.12
	Living room (west)	42.8	38.98	40.38	1.40	44.58	5.60
	Bedroom (middle)	15.4	46.7	47.48	0.78	58.20	11.50
	Living room (east)	41.0	38.64	39.98	1.34	44.08	5.44
	Bedroom (southeast)	22.2	43.37	43.85	0.48	47.17	3.80
	Bedroom (northwest)	16.4	34.79	34.68	-0.11	36.02	1.23
	Bedroom (northeast)	16.4	33.45	33.15	-0.30*	33.88	0.43*
	Kitchen (west)	6.9	50.13	53.08	2.95**	67.74	17.61
	Kitchen (east)	6.9	50.01	52.92	2.91	67.91	17.9*
Top floor	Bedroom (southwest)	22.2	45.42	45.61	0.19	48.79	3.37
	Living room (west)	42.8	39.82	41.13	1.31	43.39	3.57
	Bedroom (middle)	15.4	46.4	47.08	0.68	57.37	10.97
	Living room (east)	41.0	39.53	40.74	1.21	43.11	3.58
	Bedroom (southeast)	22.2	43.49	43.87	0.38	46.50	3.01
	Bedroom (northwest)	16.4	35.59	35.54	-0.05	36.77	1.18
	Bedroom (northeast)	16.4	34.42	34.28	-0.14*	34.98	0.56*
	Kitchen (west)	6.9	50.13	52.87	2.74**	66.30	16.17
	Kitchen (east)	6.9	50.05	52.73	2.68	66.51	16.46**

Note: * - the most negative effect value of the floor; ** - the most positive effect value for the floor.

6 Conclusions

As living standards continually rise, the need for retrofitting elevators in aging multi-story residential buildings becomes increasingly urgent. This study focused on a prototypical six-story old residential building to investigate the impact of elevator retrofitting on indoor thermal comfort. The retrofitting approach entailed the installation of a steel-structured elevator, enclosed by glazing, on the northern façade of the building, incorporating a leveling entrance design.

Utilizing the ITES software, this work conducted simulations to ascertain the *P*-value for the original state of representative buildings in five distinct climate regions: severely cold areas, cold areas, hot summer and cold winter areas, hot summer and warm winter areas, as well as mild areas. Subsequently, further simulations were carried out to assess the same buildings retrofitted with low-performance glazing-enclosed elevators (Scenarios 1 to 5). The findings revealed that while the retrofitting scheme exerted a moderately favorable influence in mild areas (0.73% improvement), it had a marginally adverse effect in colder regions (-0.13%), indicating a limited overall impact.

Moreover, this study delved into the simulations of retrofitting high-performance glazing (λ = 0.9 W/m^{2}K) enclosed elevators in buildings typical of different climate regions (Scenarios 6 to 10). The results highlighted that enhancing the thermal properties of the glazing led to improved indoor environments across all climate regions when compared to Scenarios 1 to 5. Once again, the most pronounced improvements were observed in mild areas, whereas colder areas showed less significant changes.

In essence, this research underscores that retrofitting a glazing elevator shaft on the northern side of an older building favorably affects indoor comfort in warmer climates, but its effects are minimal or marginally adverse in colder regions. To substantially enhance the indoor thermal environment in cold areas, sole reliance on the addition of an elevator shaft proves inadequate; instead, prioritizing the performance of the building envelope emerges as a more viable solution.

Future research should explore a wider range of building types and retrofitting strategies, including different elevator designs and materials, to develop a more comprehensive understanding of the impact on indoor thermal comfort. Additionally, the study suggests further investigation into the optimized integration of elevator retrofitting with energy-efficient envelope retrofits to achieve optimal indoor environments in colder regions.

Author Contributions

Conceptualization, D.D.; methodology, D.D.; software, D.D.; validation, D.D.; formal analysis, D.D.; investigation, H.W. and Y.Q.; resources, D.D.; data curation, D.D.; writing—original draft preparation, D.D.; writing—review and editing, D.D. and H.W.; visualization, D.D.; supervision, D.D.; project administration, H.W.; funding acquisition, D.D. and H.W. All authors have read and agreed to the published version of the manuscript.

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Declaration of Conflicting Interests

The Authors declare that there is no conflict of interest.

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