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Research paper

Selected design studies on office skyscrapers in Warsaw as examples of implementation of modern achievement of the global developmen of elevator technology

Marcin Goncikowski[1]

Abstract: The work is devoted to the definition of solutions for skyscraper office buildings in Warsaw against the background of the latest global technology of vertical communication systems. For this purpose, the paper presents the examples of research by design of four high-rise buildings in Warsaw, which indicate the adopted methodology of developing optimal solutions in the field of elevator service as well as the results of research and finally selected systems. The aim of the research was to achieve the initial criteria for the system's operation. The research was carried out by iterating and varianting various configurations of the system and checking it as the basis for building core solutions. Solutions that met the defined criteria were optimal in terms of building efficiency and rental flexibility. Empirical research and its results are presented against the background of world achievements. The results indicate that both the research methodology and the systems used follow the contemporary development of the latest globally present solutions.

Keywords: elevators, high-rise buildings, office, skyscraper, system, Warsaw

[1] PhD, Eng., Warsaw University of Technology, Faculty of Architecture, ul. Koszykowa 55, 00-659 Warsaw, Poland, e-mail: marcin.goncikowski@pw.edu.pl, ORCID: 0000-0003-3848-2810

1. Introduction

1.1. The Subject, background and purpose of the paper

The reason for writing this text is scientific and design activity related to skyscrapers, and the intention is to outline the important role that modern solutions of mechanical vertical circulation play in the design and realizations of high-rise buildings. The design practice shows that from the concept stage, it is not possible to define proper solutions for high-rise buildings without carrying out analyzes and simulations of vertical circulation and preliminary selection of types and parameters of devices. This is due to the fact that the number and size of the installed elevators affect the:

– structural solutions, especially in terms of the size of the core of the building;
– architectural solutions, especially in terms of the distribution of functions and the possibility of their distribution around the core;
– services solutions, as a derivative of the arrangement of the main shafts serving the building, spatially integrated with the core.

As both practitioners and scientists point out, the development of high-rise construction, which rapidly gained momentum in the 21st century, would not have been possible without the innovations that have been implemented in the technology of elevator devices [1]. The efficiency of vertical transport of users to the floors of a skyscraper is crucial for its operation. Without it, such a building could not function, despite the technical possibilities in terms of load-bearing capacity and rigidity of the structure and correct solutions of installation service. For example – with the wrong selection of elevator equipment, the travel time to the building would often be shorter than the journey from the ground floor elevator lobby to the selected floor during the morning rush hour.

Improvements in vertical transport technology introduced in recent years concern speed, size, drive, and materials as well as control algorithms and energy efficiency. Against this background, Polish projects, in particular those in Warsaw, seek new types of elevator systems. This process is worth examining because it has consequences for designing solutions that can be valuable for researchers and practitioners. The importance of this is reflected in the fact that ambitious high-rise projects are being implemented in Poland. An example of them is the Warsaw Varso Tower, commissioned in 2022 – which is the tallest building in the European Union at the time of writing this text.

The subject of this article is a description of research by design related to selected projects and implementations of high-rise buildings in Warsaw and their location against the background of trends in the development of technologies of elevator devices. The aim of the paper is to accumulate and present knowledge not only for the scientific level purposes but also for practical use – as an overview of trends and the description solutions which were investigated.

1.2. Global trends in vertical circulation in high-rise buildings

The basic aspects of the development of elevator systems in the 21st century are energy efficiency and operational efficiency [2–9]. The most important solutions for both of them are as follows:

Energy efficiency

Energy efficiency is one of the most important challenges faced by contemporary architecture. In terms of vertical circulation solutions, as research by Thyssen Krupp [10] indicates, elevator systems in high-rise buildings may be responsible for 2–10% of total energy consumption. During peak periods: morning, lunch, and afternoon in office buildings, this consumption can reach 40% of the building's energy use. These are significant amounts, which, when translated into the number of buildings, makes the increase in the energy efficiency of elevator systems an important issue on a global scale and an important aspect of efforts to counteract the climate crisis.

The currently developed solutions that improve energy saving by elevators are: lowering the weight of cabins, reducing energy consumption by winches, and the use and developing energy recovery and production systems.

The last of these aspects take place braking and the downward movement of the elevators. In the latter case, the load on the counterweights drives the motor, which in this case acts as a generator, giving energy to the grid or energy storage facilities that the building can be equipped with.

In recent years, the development of energy saving has gained momentum. Compared to construction from the beginning of the 21st century, modern elevator systems are about 30-40% less energy-consuming. It is worth emphasizing that research and development of energy-efficient elevators have received the standard "Energy efficiency of lifts, escalators, and moving walkways" – PN-EN ISO 25745-2: 2015, however, there is little awareness of the importance of using "green" solutions in the selection of elevators by designers and developers, especially in multi-family residential buildings. This is notably the case when the designed and implemented buildings are not subject to environmental assessments – e.g. LEED or BREAM. Such assessment systems contain criteria and requirements for carrying out energy savings analyses of elevators at the stage of their selection and building equipment. Of both of the above systems, in the BREEAM standard in 2021 there were 78%, and in LEED 17.3% of certified buildings in Poland. In total – in 2021, as much as 54% of newly constructed office buildings and only 8% of multi-family residential buildings were certified in them. It should be noted, however, that the share of certification in new projects continues to increase [11]. This illustrates a trend that increasingly calls for innovation in terms of the energy efficiency of elevators and their actual use in buildings.

Operation efficiency

The efficiency of vertical circulation is improved by innovations in the design of the systems and their control.

Design innovations include:

- power supply: widespread use of alternating current instead of direct current;
- technologies with winches located in the shaft, which do not require engine rooms and gearless motors with lower power losses and higher speed of cabin movement;
- new suspension systems, utilizing lightweight materials, e.g. aramids or carbon fibers, and changing the commonly used ropes to belts or bundles. The last of these treatments allow for the reduction of suspension masses and horizontal movements

of ropes in the shaft, which translates into an increase of lifting height, speed, and energy savings;
- advanced materials of rolling elements and brakes, guide rail connection systems that reduce resistance, improve operation at temperature changes and building deflections;
- air drag reduction systems;
- the use of twin (T) and double-decker (DD) systems in addition to traditional single deck lifts (SD), improving the efficiency of service. They consist in placing two independently moving cabins in one shaft (T) or using two-level cabins (DD). This improves the economic efficiency of the building by reducing the number of shafts built and at the same time increasing the area generating income from rent or sale;
- LED lighting that allows to save energy needed for lighting and reduces heat gain in the cabins;
- integration of control devices in shafts.

Control systems innovations concern:

- traffic management systems (DCS) – reducing waiting time and improving handling capacity, and reducing energy consumption and mechanical systems through less frequent stops of cabins;
- access control, integration of access control with the building, solutions allowing for the contactless calling of elevators and user recognition using cards or mobile phones of users, introducing facilities for people with disabilities, such as voice control or longer door openings;
- switching to standby mode allowing for significant energy savings.

2. Research methods

The research methods consisted in combining the method of logical analysis and logical argumentation as well as the empirical method combined with simulation research [12].

Logical analysis and reasoning were carried out by investigation of contemporary scientific and specialist literature and research results as well as the review of latest implementations of leading device manufacturers, along with interviews with representatives of technical departments of Kone, Otis, Schindler, and Thyssen Krupp.

Empirical, practical research by design was applied during designing high-rise buildings. They consisted of several defined steps which included:

1. simulations of the operation of various vertical communication systems on the basis on initial architectural concept which was the base for defining the high of the building, distribution of functions and the population. Simulation were performed until variants meeting the criteria of effectiveness were found;
2. checking variants of systems through design solutions of cores and floorplans to check the flexibility and effectiveness of the layouts and the building as well as the concept of structural and service solutions;
3. iterations if variants of elevator systems did not meet the criteria set in point b;

4. selection of an optimized variant accepted for implementation or subsequent phases of the project;

Empirical, applied research concerned projects at various final stages of advancement: from conceptual to completed projects. The common feature is the methodology: each time during the research in the above-mentioned projects, in a conceptual phase simulation studies of the elevator service were carried out to optimize architectural solutions due to the selection of elevator devices.

The results are given in the results part. They refer to the presentation of the technical basis of empirical research and the results assigned to individual research cases.

3. Results

3.1. The basis for the evaluation of empirical research

Optimization of the elevator system in terms of architectural solutions has the following criteria resulting from the need to ensure the best spatial configuration of the system:

- commercial criteria: including ensuring flexibility of the floor plan, consisting in the possibility of introducing from 1 to 4 tenants without increasing the area of common space, achieving maximum efficiency of the floor plan (NLA to GBA area ratio), and providing the required the standard of the system operation;
- criteria of coordination of construction and installation systems and rational shaping of the core of the building.

In terms of the standard of operation of the system, which directly indicates the criteria for elevators to meet, the requirements come from several sources, which are:

- internal requirements of developers;
- international standards;
- recommendations and efficiency categories of equipment manufacturers;
- good practices and standards prevailing on the market.

None of the above are legally mandatory requirements for use in Poland. In design practice, priority is usually given to requirements of developers, which are the standard referred to in contracts with designers.

The requirements of developers formulated so far do not directly indicate the choice of specific manufacturers or types of elevator devices. They define the parameters that the system should meet, and – in some cases – also the methodology of population calculations. Comparing the requirements of leading developers related to the construction of high-rise office buildings in Warsaw, it can be observed that in the case of the recommended methodologies, calculations are made for: densities from 8 to 12 m^2 NLA (net rentable area) / person, taking into account absenteeism from 10% to 15% and assuming the following parameters: ATTD < 90 s, AWT (up peak) < 30 s, HC5 > from 12% to 15%. ATTD is the average time to reach the destination, ATD is the average waiting time for the elevator, and HC5 is the percentage of the population that the system is able to transport within 5 minutes. The ranges in the quoted values indicate differences between the standards of individual developers. There is no uniform standard among investors in Poland, and the biggest differences, having a very large impact on the results, are in the acceptance of the density of users in office spaces. In addition, the selection of elevator equipment in high-rise buildings is indirectly affected by the requirements of developers:

- adopting environmental friendliness certification, e.g. BREEM or LEED, or the goals of reducing the carbon footprint – which affects the adoption of energy-saving devices;
- the efficiency of the building area expressed as the ratio of the lease area to the gross area or as the maximum share of the area of the lift shafts to the gross area of the floor – which influences the preference for choosing TWIN or Double Decker devices.

International standards do not play a direct role in Polish conditions as the basis for elevator simulations. Only in 25% of the examined cases (1 developer) the following standard was used as the basis: ISO / DIS 8100-32:2020 (E) 5.4.2. Other international standards – e.g. CIBSE, Guide D: Transportation systems in buildings (2020) are not used by Varsovian developers.

Recommendations for the effectiveness of vertical communication in buildings formulated by manufacturers are currently primarily treated by developers as references for possible optimization of systems. In this case, the basis is the developers' internal requirements, and in the case of optimization, the results should not be lower than those defined by the producers as "good". These are verbal designations assigned to the following values: unacceptable: AWT > 30 s, HC5 < 12%, acceptable: AWT < 30%, HC5 > 12%, good, AWT < 25 s, HC5 > 13%, very good: AWT < 20 s, HC5 > 15% (or: unacceptable, fair good, excellent). The methodology and goals set for the selection of elevators as a description and averaging of market practices are presented in the publication Modern Office Standard Polska [13], indicating the acceptance of densities as a maximum of 14 m^2 NLA / person, HP5 as 15%, and AWT as 30 s.

From the point of view of the practice of the design of high-rise office buildings in Warsaw, simulations of the operation of elevator devices are always commissioned to device manufacturers, and additionally, in some cases, from one to two offices specializing in calculations of the efficiency of elevator systems if such a recommendation is formulated by the developer.

3.2. Results of selected empirical research by design

Individual cases are listed below in the order in which they were performed. They refer to selected projects that have been built as well as design studies that have not been realized. In all cases, detailed multi-disciplinary solutions were developed, which were accepted by investors and developers. Each time, the steps of the simulation were similar: conceiving building data, selecting the lift traffic pattern, simulating the lift traffic, analysis, and conclusions, correcting the data, performing subsequent iterations until the simulations end in an optimized version.

A. Office and multi-use building complex in Warsaw, at Puławska Str.

The project shown in Fig. 1, completed in 2013, covers a total of 76,134 m^2 of-gross above-ground space, of which 36,417 m^2 is net leasable office space (NLA). This space is organized in a six-story stylobate and a twenty-three-story tower. Part of the stylobate had mechanical circulation organized as an independent of the tower portion system which consists of elevators and escalators. Research on the high-rise, included simulations of the operation of groups of elevators combined with analyzes of the shape of the elevator shaft in the tower. Simulations were performed four times, by three leading device suppliers. In total, 12 simulations were made, and checked by research on the shape and placement of the core and layout of the floors of the tower. The assumptions of the simulation were: a story height of 3.6 meters, a population of 87 people per tower story (the density was assumed to be 1 person / 10 m^2 NLA), and a lifting height of 82.75 m. The optimal results adopted for the project was the distribution of vertical circulation into two groups of lifts: low-rise – serving the six-story podium and high-rise serving floors 7–23. Low rise was assumed as a group of four 1000 kg lifts (13 people) with a speed of 1.6 m/s, high-rise as a group of six 1275 kg lifts (17 people) with a speed of 3, 5 m/2. In addition, a cargo and fire lift with a load capacity of 1000 kg and a speed of 3 m/s was designed. The following results were finally achieved for the tower part: AWT (Two-way) – 22 s, ATTD – 78.1, HC5 > 15% using DCS control which met the systems' operating criteria very well.

The division into both groups and the arrangement of lift devices are shown in Fig. 1.

Fig. 1. Cross-section and projection of the ground floor of the building with an indication of the groups of lifts and their scope of operation; source: Author's study

B. Office building in Warsaw, John Paul II Alley

The project, completed in 2016, covers a total of 74,000 m^2 of above-ground gross space, of which 54,000 m^2 is net rentable office space. This area is organized in a sixteen-story stylobate and a forty-one-story tower. The height of the building is 158.55 m. The whole, which is illustrated in Fig. 2, was implemented in the form of one solid. Elevator service was assumed as a set of groups of elevators serving the building in the stylobate and tower parts.

Multi-variant simulations were performed by four leading device suppliers. In total, 14 simulations of elevator operation were performed. Simulations were performed for densities from 12 to 10 m^2 NLA / person, adopting a density of 10 m^2 NLA for the final solutions. The optimization process was demanding, which resulted from the high-efficiency factor of the building required by the developer, which was to be more than 70% NLA/overground GLA. Therefore, the tests were to meet the requirements of the comfort of elevator service, as well as the requirements related limiting the area of the lift shafts to rise the efficiency of the building.

Variants of the arrangement of traditional lifts, double-decker lifts, and twin lifts were analyzed. Two final variants based on the double-decker and Twin systems were developed. Both assumed the service of the above-ground stories of the building by 3 lift groups: a low-rise (LR) group, four-shaft, serving 15 floors, a mid-rise (MR), three-shaft group, serving 16 floors, and a high-rise (HR) group, three-shaft, serving 10 floors. All double-decker and twin elevators had a stop on the ground floor and the +1 floor to provide access to the lifts on the two levels. A set of escalators led from the ground floor to level +1. In addition, two cargo and fire lifts with a load capacity of 1200 kg and 3500 kg and a speed of 3 m/s were designed. Devices with energy-saving systems were selected – energy production, LED lighting, and switching the system to stand-by. The division into groups and the arrangement of lift devices are shown in Fig. 2.

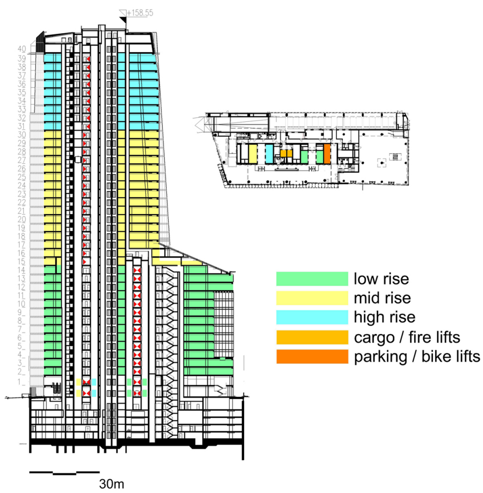

Fig. 2. Cross-section and projection of the ground floor of the building with an indication of the groups of lifts and their scope of operation; source: Author's study

The double decker variant assumed the use of 2 ×1600 kg lifts in each shaft. For the LR group – 3 m/s, for the MR group – 4 m/s, for the HR group – 6 m/s. Reached respectively: AWT: 23.3 s, 31.1 s, 27.6 s, AWTTD: 71.8 s, 82.3 s, 77.8 s and HC5 > 16% for LR and

HC5 > 20% for MR and HR. The twin variant consisted of lifts with a load capacity of 1,500 kg running in pairs in one shaft. Speed 2 ×2.5 m/s for LR, 4 m/s for MR., and 2.5 m/s. For HR – 6 m/s and 4 m/s. Achieved respectively: AWT: 19.5 s, 25.1 s, 22.1 s, AWTTD: 79.4 s, 98.6 s, 95.2 s and HC5 > 13% for all groups. The final solution implemented was the option with Twin lifts, with the use of which a 73% NLA/ov.GLA ratio was achieved.

C. Multifunctional complex with office towers, at Towarowa Str.

The unrealized project was made in 2017. The program included a service part: a modern shopping mall with a rich shopping, entertainment, and gastronomic program organized in a stylobate integrated with two office towers with a height of 198 m (tower A) and 140 m (tower B), as shown in Fig. 3. The total gross above-ground area of the complex was 295,131 m^2. Both office towers were planned as having entrances on the ground floor, and the office space above the service stylobate – up to the 3rd floor. Tower A had a total of 48 floors with an NLA of 71,000 m^2, and tower B had 33 floors with a total NLA of 44,900 m^2.

The division into groups and the arrangement of lift devices are shown in Fig. 3.

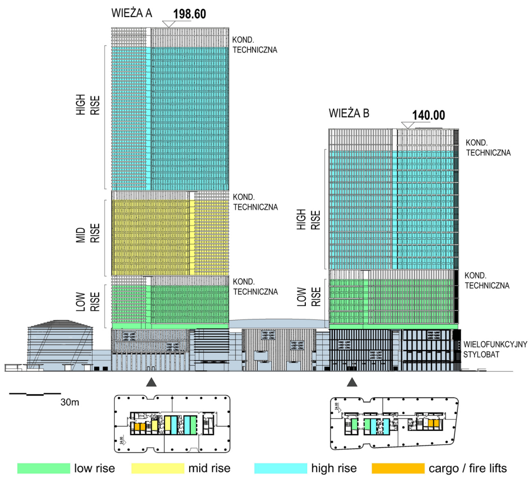

Fig. 3. The eastern elevation and the projection of the 5th floor of tower A and B with an indication of the groups of lifts and their scope of operation; source: Author's study

Lift simulations were performed as multi-variant, by four leading device suppliers. A total of 12 simulations were performed. For both towers, the initial assumption was to place the entrances on the ground floor, and the transit of elevators serving offices through the floors where services were organized. For tower A, the office floors will be serviced by 3 groups of elevators, and for tower B – by 2 groups of elevators. For both towers, simulations were performed for density with the parameters of 1 person per 10 m^2 NLA and 1 person per 12 m^2 NLA. For these compaction variants, simulations were performed for traditional devices (single deck – SD), double-deck (DD), and Twin (T) in various combinations. For tower A, combinations of groups were checked: SD+SD+SD, SD+DD+DD, SD+T+T, for tower B: SD+SD, SD+DD, SD+T, where the lowest groups were always SD groups.

Ultimately, the density of 10 m^2 was combined in the lowest group and, due to the higher standard of higher offices – 12 m^2 in the upper groups. Due to the need to minimize the core, a solution was finally adopted consisting of the use of Twin devices in the upper groups of towers A and B. The final solution for tower A was a combination of a low-rise group, serving 7 floors, containing 4 SD units with a load capacity of 1600 kg and a speed of 2 m/2, a mid-rise group, serving 12 floors, containing 5 twin elevator shafts – 2 ×1600 kg (4 m/s and 2.5 m/s) and high-rise group, serving 19 floors, containing 8 twin elevator shafts 2 ×1600 kg (7 m/s and 6 m/s). In both buildings, the simulations included the use of an intelligent elevator control system. For this configuration, the results of AWT 35 s, ATTD 90 s, and HC5 – 12% were achieved. In addition, two fire and goods lifts with a load capacity of 2000 kg and a speed of 3.5 m/s are provided. For tower B, the solution was a combination of a low-rise group, serving 6 floors, containing 4 SD units with a load capacity of 1,600 kg and a speed of 2 m/2 and a high-rise group, serving 17 floors, containing 6 Twin elevator shafts, 2 ×1,600 kg (6 m/s and 4 m/s). For this configuration, the results of AWT 32 s, ATTD 90 s, HC5 – 13% were achieved.

Devices with energy-saving systems were selected – energy production, LED lighting, and switching the system to stand-by.

D. Multifunctional complex with office towers, at Solidarności Alley and Towarowa Str.

The project which has not been realized yet, was completed in 2023. The above-ground part of the building consisted of a tower with a height of 133 meters and 30 above-ground stories, integrated with a stylobate with 4 above-ground stories. The functional program included offices for rent and services provided on the floors of the stylobate, including, among others: trade, gastronomy, possible sports services, and medical services. The total overground area of the complex was 57,646 m^2. The area of NLA was 36,600 m^2.

During the work on the project, simulations were performed as multi-variant, by four leading lift suppliers and two independent specialist companies. In total, over 20 vertical transport efficiency simulations were performed during the project. Variant systems of traditional, double-deck, and twin lifts were tested for two groups: low-rise and high-rise. The densities tested were: 8 m^2 per person and 10 m^2 per person for the whole building or different groups of floors. After a series of iterations, a decision was made to choose a variant with a density of 8 m^2 for the low-rise part (serving floors up to the 13th floor) and 10 m^2 for the high-rise part (serving floors from 14 to 30 floors) with absenteeism of 10%. Transfer floor was designed with access to both low-rise and high-rise parts. The division of the building into groups is shown in Fig. 4.

The final choice was the low-rise service by 6 lifts with a load capacity of 2000 kg and a speed of 2.5 m/s and the high-rise service by 4 double-deckers with a load capacity of 2 2000 kg and a speed of 6 m/s. DCS control is provided (with the dedication of the target floor by the user). The choice of double decker units and the DCS system was determined by the achieved reduction in the size of the core and increasing the efficiency of the building. Devices with energy-saving systems were selected – energy production, LED lighting, and switching the system to stand-by. In addition, two fire-fighting lifts with a load capacity of

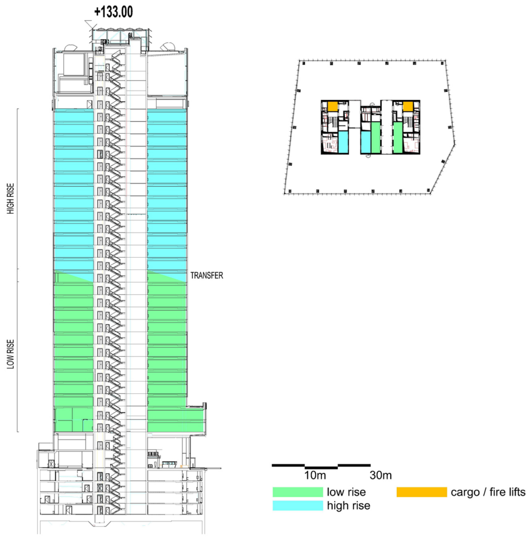

Fig. 4. Cross-section and projection of the fifth floor of the building with an indication of the lift groups and their scope of operation; source: Author's study

2500 kg and 1800 kg and a speed of 3 m/s and separate lifts serving the underground car park were designed.

In the configuration selected for the project, the following results were achieved: for the low-rise group AWT = 29 s, ATTD = 87 s, HC5 > 15%, for the high-rise group: AWT = 25 s, ATTD = 76 s, HC5 > 15%.

The comparison of studies is shown in Table 1.

Table 1. The comparison of results

The case:	No. of groups	Type of lifts	AWT	ATTD	HC5
A	2: LR+HR	SD	22 s	78.1 s	15%
B	3: LR+MR+HR	Twin	LR: 19.5 s MR: 25.11 s HR: 22.1 s	LR: 79.4 s MR: 98.6 s HR: 95.2 s	13%
C	3: LR+MR+HR	LR: SD MR: Twin HR: Twin	35 s	90 s	12%
	2: LR+HR	LR: SD HR: Twin	32 s	90 s	13%
D	2: LR+HR	LR: SD HR: DD	LR: 29 s HR: 25 s	LR: 87 s HR: 76 s	LR: 15% HR: 15%

4. Discussion

High-rise buildings – especially those referred to as skyscrapers (i.e. over 100 m high) are a technical challenge entailing the latest engineering achievements. From the architectural point of view, they are characterized by a large scale of the program located inside the mass and a high density of users in relation to the development area. Apart from the economic issues of their construction, it can be pointed out that in the era of sustainable buildings, in the case of a conscious urban location, skyscrapers give benefits related to spatial management.

If we look at the space used by humans as a limited resource, high-rise buildings offer an environment with a higher density of use. This contributes to limiting the sprawl of the cities.

Skyscrapers bring usable functions closer to each other: services, workplaces, and residential areas, which leads to confined communication. These features make them, with proper planning, a rational means of creating sustainable, ecological 15-minute cities. Realizations of skyscrapers in the 21st century are more frequent than in the period preceding it. They will continue to be – and will be – an attractive type of building both from the investment point of view and due to the above-mentioned planning advantages. This trend can be maintained only if their engineering solutions are simultaneously being improved, new materials introduced and energy savings in the supporting systems enhanced.

The development of vertical circulation solutions is crucial for the operation of skyscrapers and the increase of their. In this regard, it should be noted that progress in elevator technologies is continuous. Currently, existing technologies allow for the operation of buildings with a height of 1000 m [7], an example of which is the Kingdom Tower project in Saudi Arabia. This achievement is primarily the result of material innovations that allow the production and implementation of ropes of appropriate length and strength. Similar innovations have been achieved in the speed of the cabins. Currently, the maximum speed of the installed elevators is approx. 20.5 m/s (Shanghai Tower, Shanghai designed by Gensler where Mitsubishi elevators were installed) and 20 m/s (CTC Finance Center in Guanghzou, designed by KPF where the elevators were delivered by Hitachi), and 10 m/s for double-decker lifts (Burj Khalifa, Dubai designed by SOM, where Otis lifts were installed). The conducted research on the technology, which may result in the future innovations, in addition to the above-mentioned scopes, also concerns the use of recycled materials [14], (e.g. for cabin decoration), improvement of hygienic conditions: equipping cabins with air purifiers and germs, introducing systems for self-disinfection of devices [15], introducing elevators with cabins that control the pressure inside the cabin and the speed of its change (which reduces the effect of pressure on the eardrum when driving a high-speed device to higher altitudes). New access systems currently being tested will be introduced: e.g. facial recognition, voice or gesture control systems [16, 17]. The integrated software of high-rise buildings will allow for taking into account the operation of vertical circulation systems with streams of people moving in front of the DCS Destination Dedication System panels and the external space [18]. The control systems will be based on evolutionary algorithms [19, 20]. Certainly, solutions related to safety will be further developed in all its areas – from the introduction of new solutions related to braking and mechanical failure, to alarm and diagnostic systems. In terms of security, parallel to the development of IT systems, there will be the development of protection against hacking – an unauthorized takeover of control over the operation of the system or theft of information. Among the current research, breakthrough technologies related to the propulsion and movement of devices stand out: the introduction of electromagnetic elevators [21], the increase in the number of cabins simultaneously operating in a shaft or a set of combined shafts, and the development of multi-directional elevators – able to move vertically and horizontally servicing very large-scale high-rise objects, e.g. the tested Multi Thyssen-Krupp system, or the tested 3d Otis systems [22]. On the horizon, there are also theoretical ideas of ropeless winds [23], vacuum lifts [24] that can move in a way analogous to the assumptions of hyperloop (Zobel H., et. al., 2022).

In the coming years, the innovations in standard of environmentally friendly elevators should also be expected. The above-mentioned global trends in research and implementation of their latest achievements will also penetrate Poland, especially Warsaw, which is the place of the largest concentration of skyscrapers in the country. As the conducted and described selected empirical studies indicate, the latest achievements of vertical communication techniques are have been constantly implemented in the realizations and projects in Warsaw. This applies to the use of devices with ever-increasing speed, solutions that increase efficiency and handling capacity of systems – e.g. double decker and twin, the use of solutions that make it possible to resign from the construction of engine rooms, solutions related to the use of modern control – Digital Control Systems and, to an increasing extent – pro-environmental solutions – primarily related to energy saving. Against this background, it should be noted that subsequent realizations and projects in Warsaw will implement world achievements in parallel with their implementation outside Poland. In the first place, as evidenced by talks with representatives of producers and design works which have been carried out, this will concern the issues of safety, hygiene, control, and access. In addition to new implementations and projects, a trend of renovation and replacement of systems in existing buildings can also be expected. It will be associated with a tendency to increase the quality of service – installation of faster devices, and energy savings, as well as a tendency to pro-environmental certification for existing, older buildings.

From the perspective of conducting research by design on skyscrapers, the described methodology for determining the optimal solution for the selection of a mechanical vertical communication system in high-rise buildings has no alternative. It can be hypothesized that it is possible to develop an integrated software that, based on the given output data: mainly system operation criteria, population size, building outline, number, and types of installation shafts, and the layout efficiency criterion, will be able to generate an optimal solution for the selection of devices in the planned building. However, until the possible creation of such a tool, the methodological cycle and optimizations through iterations of solutions presented in this article will be applicable in practice.

5. Conclusions

Conclusions from the presented results of research by design indicate that in the investment practice of the realization of office skyscrapers in Warsaw, the use of the latest global elevator technologies is visible. The reasons are consistent with world-wide trends: efforts to save energy, pro-environmental solutions, and new control and access control systems. The modern cabin systems are used: double-decker and twin. This is mainly due to the desire to increase economic efficiency of the building (efficiency ratio of the layout).

The use of both of twin and double decker is also a derivative of the trend of increasing the user density parameter in elevator simulations. This is evidenced, among others, by the use of parameters lower than those indicated in the MOSP 2020 [13] investment standards, i.e. 8 or 10 m^2 per person in design practice, which is confirmed in interviews with simulation contractors and in current development standards. This is a conscious action with positive effects on the comfort of using buildings. As a consequence, the operation of elevator systems is improved: they can potentially serve larger populations than previously designed systems, which allows for faster transport, a reserve in the event of random events resulting in a one-time influx of more than expected number of travelers, and a reserve for densifying some floors in buildings – e.g. for call-center services. Increasing the density of users as the basis for elevator simulations and, as a result, the selection of an elevator communication system solution proves the awareness of investors of the importance of the comfortable operation of vertical communication in skyscrapers. This is a clear effect of the fact that office buildings compete in the rental market: buildings with an incorrect solution are perceived as defective, and their reputation is ruined by the long queue of people who form every day in the morning rush hours trying to get to the upper floors.

Among the current Warsaw solutions, the parameter that seemingly differs from the maximum global results is the speed of the elevators. In Warsaw conditions, the fastest devices currently used are in the Varso office building [26] – 8 m/s, where the highest shaft heights are 221 m. In this respect, a 30% progress can be seen in about 17 years – in the first decade of the 21st century, the fastest devices in Warsaw were the elevators used in the Rondo 1 facility in the high-rise part, with a speed of 6 m/s [27].

Far from the world's fastest speeds, the speeds result only from the lower height of Warsaw buildings than their global counterparts. The elevators with a speed of 20 m/s indicated in the text serve higher buildings, with an appropriate length of the path allowing the cabin to be accelerated to such a high speed. In terms of the applied methodology for the development and selection of the vertical communication system in high-rise buildings, it should be noted that it is identical to the methodology used globally. In this respect, the use of the latest achievements related to the simulation of the operation of elevator systems is carried out on an ongoing basis – programs [28], methodologies of the simulation itself [29] and calculation [30] used by manufacturers are their global standard, while independent consultants operating in Warsaw are primarily foreign companies participating in projects implemented around the world.

To sum up: the presented empirical studies clearly indicate the presence of the latest global solutions applied appropriately to the scale of high-rise buildings present in Warsaw. Varsovian and Polish projects follow the same step in implementing the latest solutions in design methodology and equipment selection as their global counterparts. There are no signs that this situation could change in the near future.

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Wybrane badania projektowe wysokościowców o funkcji biurowej w Warszawie jako przykłady wdrożeń współczesnych osiągnięć światowego rozwoju technologii windowej

Słowa kluczowe: budynek biurowy, drapacz chmur, system, windy, wysokościowiec, Warszawa

Streszczenie:

Praca poświęcona jest umiejscowieniu rozwiązań warszawskich wysokościowych budynków biurowych na tle najnowszych rozwiązań światowych pod względem systemów komunikacji pionowej. W tym celu wybrano przykłady badań przez projektowanie czterech budynków wysokościowych w Warszawie które wskazują przyjętą metodologię opracowania optymalnych rozwiązań w zakresie obsługi windowej oraz przedstawienie wyników badań – ostatecznie wybranego systemu. Celem badań było każdorazowo osiągnięcie wyjściowych kryteriów działania systemu oraz osiągnięcia zakładanych parametrów elastyczności i efektywności rzutu kondygnacji. Badania prowadzono przez iterację i wariantowanie różnych konfiguracji systemu oraz sprawdzanie go jako podstawę rozwiązań trzonów budynku. Wybierano rozwiązania spełniające kryteria i jednocześnie będące optymalne pod względem efektywności budynku oraz elastyczności najmu. Badania empiryczne i ich wyniki przedstawiono na tle osiągnięć światowych. Wyniki wskazują że zarówno metodologia badań jak i stosowane systemy podążają w ślad za współczesnym rozwojem obecnych globalnie najnowszych rozwiązań.

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