New Evidence on Lift Passenger Demand in High-Rise Office Buildings

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Abstract. The planning and selection of passenger lifts for a prospective building relies on requirements on peak traffic patterns, which are usually expressed by peak passenger demand in conjunction with a traffic mix. These requirements mostly determine the size of the lift installation and should therefore be realistic to ensure proper passenger service without excess capacity during the whole life cycle of the building. Despite their importance, real-world surveys on peak traffic patterns are still scarce in literature. In such surveys, human observers typically record passenger demands, but an automated method is required to obtain data on a larger scale and to contest the current requirements.

This paper proposes an algorithm that automatically recognizes peak periods occurring in an office building during a day from people flow data, as well as computes peak passenger demands and traffic mixes for the peaks. The challenge is first to recognize the start and end time of a particular peak period, and second, to scale the observed peak demand to the actual population using the lifts during the day. The scaling is crucial when comparing the measured peak demand to the required peak demand, which is usually expressed as a percentage of population.

The procedure is developed using measurements of two lift groups in a high-rise office. It is then applied to measurements from other offices to recognize trends in peak traffic patterns. The observed results are then contrasted with the current requirements for planning and selecting lift configurations.

1 INTRODUCTION

Surveys on lift passenger demand in existing high-rise buildings are still scarce in literature, which may reflect the effort required to manually count people. The first results were obtained in the 1960s by observing people arriving at or leaving lift lobbies, which, however, only reveals incoming and outgoing traffic [1]. An observer travelling in a lift car can also count interfloor traffic [2]. A large-scale study of lift passenger demand, however, requires automated methods. Large amounts of people flow data can be collected, e.g., by a lift control system or a temporary sensor mounted in a lift with human detection algorithms [3,4].

In the case of office buildings, design standards set requirements on both morning uppeak and midday lunch traffic [5,6,7]. The lift configuration is required to have a handling capacity that at least matches with assumed peak passenger demand to avoid congestion and extensive waiting times. In complex cases, the lift configuration is simulated with a specified traffic mix that defines the proportions of incoming, outgoing and interfloor traffic. Hence, people flow data from existing buildings provide important feedback for planning new buildings. To enable the processing of large-scale data, this paper develops an algorithm to automatically recognize morning uppeak, midday lunch-peak and evening downpeak periods from people flow data. The algorithm is applied to a unique data set of 25 offices around the world to find trends in peak traffic patterns.

The rest of the paper is organised as follows. Section 2 introduces methodology to collect people flow data, i.e., building population and lift passenger demand, from automated counts of boarding and alighting lift passengers. Section 3 describes the algorithm to automatically recognize peak periods in offices using people flow data. The algorithm is used to capture peak traffic patterns (Section 4), which are compared to the requirements used in the planning and selection of a lift configuration (Section 5). Section 6 concludes the paper.

2 AUTOMATIC COLLECTION OF PEOPLE FLOW DATA

Boarding and alighting lift passengers can automatically be counted either by a lift control system or by a temporary sensor mounted in a lift. The counts recorded during an office day lead to two important data points that characterize people flow in the building, namely, the population of daily lift users and lift passenger demand throughout the day. As the counts consider passengers transferring to and from a lift, passengers waiting in the lobby are invisible before they step in. Therefore, the counts lag the true passenger arrival times at the lobby. The lag may become significant if waiting passengers do not fit in a lift but need to wait for the next one. Therefore, in lift groups, where peak passenger demand exceeds its handling capacity, true peak demands could even be higher than recorded this way.

In the following, these concepts are concretised by showing data from an office building located in Singapore. The data was collected by temporary sensors that are capable of identifying boarding and alighting passengers with greater than 95% accuracy [4]. The building has 22 office floors above the main entrance floor and three underground levels for car parking, which are also considered as entrance floors. The office floors are split into two sets of consecutive floors, the Low- and the High-rise, both of which are served by a group of four lifts.

The number of people inside the building (within a particular rise) at any time of the day is defined as the cumulative difference of lift passengers boarding and alighting on entrance floors. For the sake of clarity, the building (rise) is assumed empty if the cumulative sum appears negative, i.e., for some period, the number of outgoing passengers exceeds the number of incoming passengers and people already inside the building (rise). The negative number of people inside can arise from stair usage, incorrect passenger counts, or counting started when some people were already inside. The population of daily lift users can be defined as the maximum number of people inside the building (rise) during the day [2].

Fig. 1 shows the cumulative number of people inside the building. In both rises, maximums occur at about 11 o'clock while about 90% of occupants had arrived by 9:30. The data implies that population in the Low-rise was 279 persons while it was 635 persons in the High-rise on the day of collecting the data. Hence, the Low-rise was much less densely populated than the High-rise.

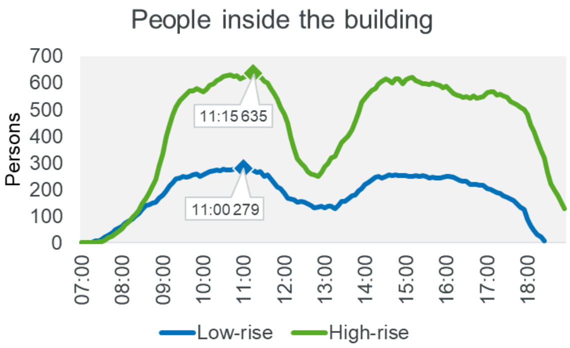

Figure 1 Building population throughout the day in both rises

Lift passenger demand can be divided into its components: incoming, outgoing and interfloor traffic. Passengers boarding a lift on entrance floors form incoming traffic while passengers alighting a lift on entrance floors belong to outgoing traffic. Interfloor traffic occurs between populated floors. It comprises passengers boarding a lift on a populated floor and travelling upwards as well as of passengers travelling downwards and alighting a lift on a populated floor.

In lift traffic planning, passenger demand is usually expressed as a percentage of population per five minutes [5,6,7]. The planning of office lifts is based on requirements that are set on this percentage passenger demand. Hence, the observed percentage passenger demands can be contrasted with the current design criteria given in standards and guidelines. It is worth noticing the difference between the observed population in an operational building and design population of the standards and guidelines, which designate a maximum for which a building is being designed [5].

Fig. 2 demonstrates percentage passenger demand throughout the day in both rises. In the charts, incoming, outgoing and interfloor passenger demands are stacked on top of each other. These daily traffic profiles show striking differences considering that they are observed in the same building. The Low-rise clearly represents an office with multiple tenants where peak traffic patterns are spread over a long period and interfloor traffic is almost non-existent. Conversely, the High-rise exhibits characteristics of a single-tenant office: demand peaks are sharp and the proportion of interfloor traffic is high especially during lunch-peak. Furthermore, peak demands in the High-rise are much higher than in the Low-rise.

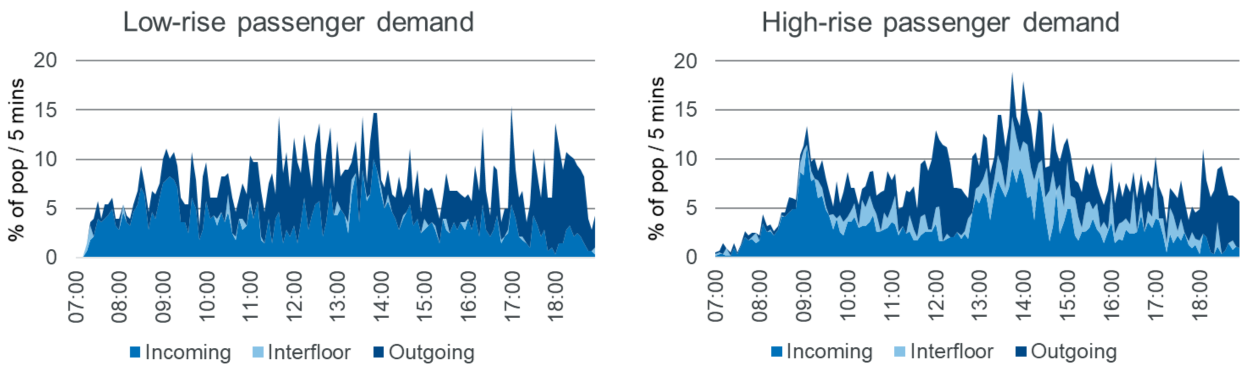

Figure 2 Percentage passenger demand in the Low-rise (left) and in the High-rise (right)

3 RECOGNITION OF PEAK TRAFFIC PATTERNS FROM PEOPLE FLOW DATA

Peak periods in offices occur typically in the morning, around midday and in the evening. In the following, a method to recognize them from people flow data is described using the data of the office building in Singapore described above. As could be seen in Fig. 2, traffic mix and passenger demand vary from interval-to-interval characteristic to the rise. Therefore, general rules to automatically recognise peak periods and underlying traffic patterns cannot only rely on the observed traffic mixes and passenger demands. Especially in the case of the High-rise, traffic mixes vary significantly between five-minute intervals. Hence, five-minute intervals are too random for a reliable algorithm to recognize peak conditions, which benefits from a rather stable traffic mix and passenger demand. Therefore, peak period recognition is carried out in 15-minute intervals.

Fig. 3 shows the Low- and the High-rise traffic mixes as stacked proportions of incoming, outgoing and interfloor traffic in 15-minute periods throughout the day. The figure also contains a line that helps to detect when the proportion of incoming or outgoing traffic exceeds 50%. In the morning, incoming traffic is predominant as people arrive at work and travel from entrance floors to populated floors where their workplaces are located. Around midday, office workers first go for lunch and then come back to their workplaces. If restaurants are located on an entrance floor or people exit the building through an entrance floor to have lunch, people flow is predominantly outgoing in the beginning and incoming at the end of the lunch-peak period. Typical to lunch-peak period, a significant portion of people may also travel to the direction opposite to the predominant direction as well as between the populated floors. In the evening, people exit offices through entrance floors, which results in predominantly outgoing traffic.

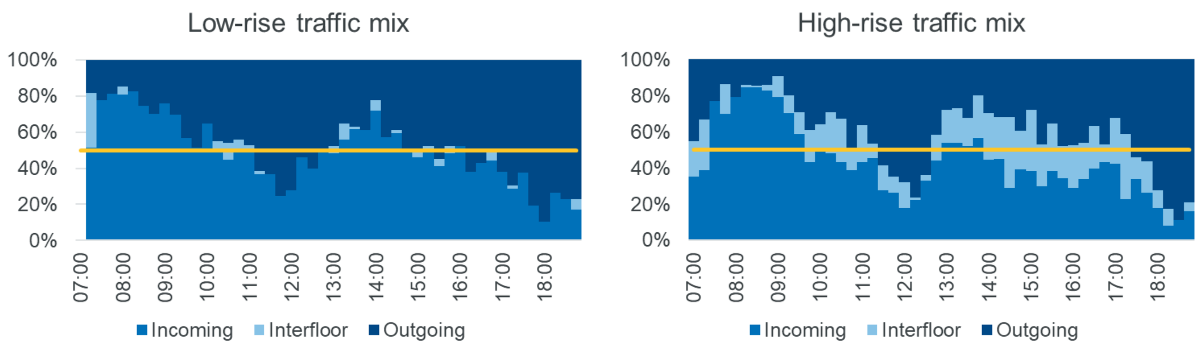

Figure 3 The Low- and the High-rise traffic mixes throughout the day

During peak periods, passenger demands vary from interval to interval as shown in Fig. 4 for 15-minute periods. Peak passenger demands for morning uppeak and midday lunch-peak are clearly distinct from the off-peak demand, which varies around 7% of population per five minutes. However, evening downpeak in the High-rise does not rise above the off-peak level although the Low-rise exhibits a clear peak.

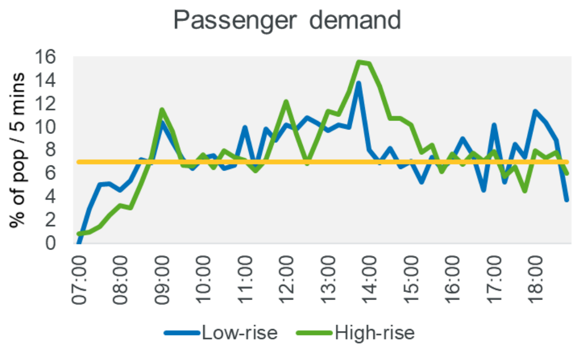

Figure 4 Passenger demand in the Low- and the High-rise with a helpline at 7% / 5 min

3.1 A method to recognize peak periods

A traffic forecaster based on fuzzy logic, originally developed to recognize traffic patterns in a real-time control system, can be applied to the problem at hand [3]. Fuzzy logic allows classification of a continuous range of values between zero and one by descriptive terms [8]. For example, given a proportion of a traffic component, fuzzy logic infers whether the proportion is *Low*, *Medium* or *High*. Specific rules first convert the descriptive proportions into more generic types such as *Incoming*, *Outgoing*, *Two-way*, and *Mixed* traffic. It is worth noticing the duplicated use of terms incoming and outgoing: in this context, they mean generic traffic type, not traffic components as parts of a traffic mix. Second, fuzzy logic identifies passenger demand to be *Light*, *Normal*, *Heavy*, or *Intense* with respect to the peak five-minute demand of the prevailing peak period.

During morning uppeak periods, the proportion of incoming traffic follows the same pattern in both rises as shown in Fig. 3. Traffic mixes exhibit significant proportions of incoming traffic already after 7:15 in both rises but that does not necessarily designate early beginning of uppeak period. Indeed, the traffic forecaster interprets passenger demands light until 7:30 in the Low-rise and until 8:30 in the High-rise. As shown in Fig. 4, passenger demand exceeds 5% of population per five minutes during the interval of 7:30-7:45 for the Low-rise and 8:30-8:45 for the High-rise. Traffic patterns during these intervals are then classified as normal incoming traffic, which marks the beginning of uppeak period. Uppeak period ends in the Low-rise at 9:30 since the traffic forecaster interprets the traffic mix between 9:30 and 9:45 as Two-way. This follows from the proportions of incoming and outgoing traffic, 56.7% and 43.3%, respectively, which are on Medium level according to the fuzzy membership functions used by the traffic forecaster. On the other hand, traffic in the High-rise is still detected as Normal Incoming between 9:30 and 9:45 since 59.0% of incoming traffic is classified as Medium but 29.0% of outgoing and 12.0% of interfloor traffic as Low.

In the beginning of lunchtime, say, before 12 o'clock, the proportion of outgoing traffic is more than 50% in both rises. After 12:00, the proportion of outgoing traffic decreases steadily while the proportion of incoming traffic increases reaching 50% at about 13:00. As shown in Fig. 4, passenger demand is high throughout the lunch-peak period. The Low-rise demonstrates a clear peak only at the end of the period but the High-rise during both the outgoing and the incoming phase. Hence, peak detection is not necessarily as clear as it is in the case of morning uppeak. The lunch-peak is defined to begin when the traffic forecaster classifies 15-minute traffic pattern as Outgoing with at least Normal intensity, which results in start times of 11:15 and 11:30 for the Low- and the High-rise, respectively. The outgoing phase continues as long as a 15-minute traffic pattern remains either predominantly Outgoing or Two-way with a proportion of at least 50% of outgoing traffic component. In a similar manner, the incoming phase of the lunch-peak can be detected when two-way traffic contains more than 50% of incoming traffic or the traffic pattern is recognized as Normal Incoming. With these definitions, the lunch-peak in the Low-rise lasts until 15:00 while it ends in the High-rise at 14:30.

In the afternoon, the proportion of outgoing traffic exceeds 50% in the Low-rise already at 15:30 (Fig. 3). After the initial peak, the proportion of outgoing traffic decreases below 50% just to return above 50% between 16:15 and 16:30. Furthermore, passenger demand in the Low-rise drops to a low level just before 17:00 while the highest five-minute peak demand occurs just after 17:00 as can also be seen in Fig. 4. On the other hand, the proportion of outgoing traffic in the High-rise rises above 50% at 17:30, but the traffic forecaster recognizes a traffic mix consisting of 29% incoming, 48% outgoing and 23% interfloor traffic between 16:00 and 16:15 as predominantly Outgoing. Since passenger demand during that period is rather high, downpeak is found to start at 16:00 in the High-rise even though the highest peak demand occurs after 18:00. Thus, both rises exhibit a pattern of recurring and relatively short peak periods. To detect the highest peaks, all periods satisfying downpeak criteria need be included in the overall evening downpeak period.

3.2 Peak traffic patterns

Once the beginning and the end of peak periods have been determined, it is time to define peak traffic patterns. Table 1 and 2 show passenger demands as well as traffic mixes aggregated for different period lengths for the Low- and the High-rise, respectively. Average passenger demands across the entire peak periods are clearly lower than the demands in shorter periods as can be expected. The 15-minute average peak demands clearly flatten the highest five-minute peak demands showing extreme values.

Even though five-minute demands are somewhat affected by randomness, they well describe worst-case passenger demands. Regardless of the differences, the rises seem to indicate similar timing of the most intense peaks, which may reflect the culture and way of life in Singapore. In the morning, passenger demand peaks just after 09:00, midday outgoing traffic peaks are around 12:00, and evening downpeak around 18:00. Peak demands during morning uppeak conform well with the known design criteria for multi- and single-tenant offices being 11.1% of population per five minutes for the Low-rise and 13.4% for the High-rise. Typical to office buildings, the highest demand peaks during lunch traffic clearly exceed the uppeak demands and occur during the incoming phase: 14.7% in the Low-rise and 18.9% in the High-rise. Interestingly, the highest five-minute demand of the day in the Low-rise occurs during downpeak at 17:00 and reaches as high as 15.4%. Clearly, this peak as well as the other extreme downpeak demand occurring at 18:00 show that a significant amount of office workers end their days exactly on the hour. On the other hand, downpeak demands in the High-rise are clearly on a lower level compared to other peak periods, remaining at 11.0% at 18:00.

Table 1 Low-rise peak traffic patterns aggregated for different period lengths

Peak	Period	Demand [% / 5 mins]	Incoming [%]	Outgoing [%]	Interfloor [%]
Uppeak	7:30-9:30	6.7	76.6	22.8	0.6
	9:00-9:15	10.4	76.0	24.0	0.0
	9:05-9:10	11.1	71.0	29.0	0.0
Lunch-peak outgoing	11:15-13:15	9.4	37.2	62.5	0.3
	11:30-11:45	9.8	36.8	63.2	0.0
	11:40-11:45	14.3	32.5	67.5	0.0
Lunch-peak incoming	13:15-15:00	9.1	59.6	37.8	2.6
	13:45-14:00	13.7	61.3	38.7	0.0
	13:50-13:55	14.7	68.3	31.7	0.0
Downpeak	15:30-18:45	8.0	34.6	64.2	1.2
	17:00-17:15	10.2	38.1	61.9	0.0
	17:00-17:05	15.4	34.9	65.1	0.0

Table 2 High-rise peak traffic patterns aggregated for different period lengths

Peak	Period	Demand [% / 5 mins]	Incoming [%]	Outgoing [%]	Interfloor [%]
Uppeak	8:30-9:45	8.1	75.3	17.3	7.4
	9:00-9:15	11.5	79.5	9.3	11.1
	9:05-9:10	13.4	85.9	14.1	0.0
Lunch-peak outgoing	11:30-13:00	9.0	25.4	66.3	8.2
	12:00-12:15	12.1	17.9	68.0	14.1
	12:00-12:05	12.9	26.8	61.0	12.1
Lunch-peak incoming	13:00-14:30	13.3	51.0	28.1	20.9
	13:45-14:00	15.5	56.4	19.9	23.7
	13:45-13:50	18.9	48.3	24.2	27.5
Downpeak	16:00-18:45	7.0	28.1	55.0	17.0
	18:00-18:15	7.9	18.0	72.4	9.7
	18:05-18:10	11.0	21.4	78.6	0.0

Peak traffic patterns are characterized by specific traffic mixes that represent typical traffic conditions during the periods. The proportion of incoming traffic is surprisingly low, only about 75%, for the whole uppeak period in both rises. As already indicated by Figs. 2 and 3, the Low-rise does not have significant amounts of interfloor traffic even during lunch-peak. The High-rise, on the other hand, has interfloor traffic throughout the day end even more than 20% during the period of the most intense lunch-peak.

4 PEAK TRAFFIC PATTERNS IN HIGH-RISE OFFICE BUILDINGS

Measurements with the temporary sensor devices were conducted in 25 high-rise offices from 2018 to 2020 in different regions. Data was collected before pandemic-related restrictions in the respective cities and countries. The sample includes 12 cases from Asia, two from Australia, eight from Europe and three from North America. The European cases include buildings from different parts of Europe: the Netherlands, Poland, Spain, Serbia, and Turkey. All the Asian cases are from Southeast Asia: Singapore, Thailand, Malaysia, and the Philippines. North American cases are from different parts of the USA.

From each building, a random measurement day was chosen. It does not necessarily present the most typical day nor the busiest day of the building. Buildings that had relatively low peak demands during measurement days might have higher peaks on other days, and vice versa. The only reason for rejecting a measurement day was missing data. In such a case, another day was chosen. Late evening hours after evening downpeak are not critical, but the morning hours are: if recording was started too late or if some sensor missed early morning, population would be estimated lower than in reality and, consequently, percentage passenger demand higher than in reality would be observed.

As shown in Section 3, lunch-peak may nicely split into downpeak and uppeak phases. However, it turns out that, in only half of the cases, these phases are clear. In the rest of the cases, either the phases are not recognisable, or they repeat due to lunch shifts. As a result, the detection of lunch-peak period became non-trivial, and the highest peaks could not clearly be determined. Therefore, the following analysis considers lunch-peaks as continuous peak periods rather than in phases.

4.1 Office categorization based on lunch-peak interfloor traffic proportion

Often offices can be recognized as single or multi-tenant offices based on peak passenger demands and proportions of interfloor traffic. Well known examples are Siikonen profiles [3]. By using only measurement data but no a priori knowledge of the studied offices, peak demands did not show any clear trend. Therefore, buildings are categorised into offices with low, medium, and high interfloor traffic, where the proportion of interfloor traffic during lunch-peak was less than 15%, between 15% and 30%, and more than 30%, respectively. The interfloor category does not directly indicate office type, but buildings with low interfloor proportion are probably multi-tenant offices. Buildings with medium interfloor proportion are often single-tenant offices, but some of them can also be multi-tenant offices. Buildings with high interfloor proportion have either a transfer or an attraction floor with, e.g., cafeterias, restaurants, meeting rooms, conference facilities, or social space, among populated floors. Such buildings cannot automatically be identified as a single- or a multi-tenant office. Table 3 shows the number of measured offices for each region and interfloor category.

Table 3 The number of measured offices for different regions and interfloor categories

Interfloor category	Asia	Australia	Europe	North America	Total
Low (<15 %)	5	2	2	1	10
Medium (15…30 %)	5	0	1	2	8
High (≥30 %)	2	0	5	0	7
Total	12	2	8	3	25

Table 4 shows average interfloor proportions for different peak periods as well as the upper bounds of their 95% confidence intervals. The averages for lunch-peak follow the above categorisation: 8.6% for the low, 21.9% for the medium, and 41.0% for the high interfloor category. The upper bounds of 95% confidence intervals interestingly show how high the proportion of interfloor traffic can be, the most distinguished case being the lunch-peak of the high category with as much as 50% interfloor traffic. Offices in the low category also had low interfloor proportion during morning uppeak and evening downpeak. The buildings in the medium and high category had a lot of interfloor traffic during uppeak and downpeak, slightly more than 20%. In general, the proportion of interfloor traffic was about the same during all peak periods within an interfloor category. As an exception, lunch-peak interfloor traffic proportion in the high category was about double compared to other peak periods. In a couple of cases, interfloor traffic was almost non-existent all day: both Australian cases and the example Low-rise from Singapore.

Table 4 Peak period interfloor traffic proportion per interfloor category

	Average interfloor proportion (%)				95% CI UB interfloor proportion (%)			
Peak period	**Low**	**Medium**	**High**	**All**	**Low**	**Medium**	**High**	**All**
Uppeak	7.6%	23.2%	20.2%	16.2%	11.3%	29.4%	29.6%	20.4%
Lunch-peak	8.6%	21.9%	41.0%	21.9%	12.0%	25.3%	49.6%	28.0%
Downpeak	10.3%	21.6%	22.2%	17.2%	15.0%	25.7%	32.1%	21.1%

The analysis of regional differences would also have been interesting but is omitted here. The offices are unevenly distributed among different interfloor categories within the regions. This entails a risk that, e.g., single-tenant offices from one area are compared to multi-tenant offices from another. Therefore, with this sample, results based on regions would be misleading. With a larger sample of office buildings from each region, the analysis could be expanded to cover regional differences within an interfloor category.

4.2 Peak demands in offices

Table 5 shows statistics for the highest peak demands across the studied buildings. Minimums, maximums, averages and 95% confidence intervals are given for each peak period and interfloor category separately. Generally, in 72% of measured offices, the highest peak occurred during lunch-peak, in 12% of the cases during morning uppeak, and in 16% of the cases during downpeak. Minimums and maximums well demonstrate the wide range of observed values. Furthermore, maximum demands, while possibly being random events, reveal the extremes that lift installations may encounter: 15.3% of population per five minutes in morning uppeak, 23.2% in midday lunch-peak and 19.0% in evening downpeak.

The averages and the upper bounds of 95% confidence intervals are more important than the extremes when contrasting the actual peak demands to the requirements in design standards. The average of highest morning uppeak demands was 10.7% of population per five minutes, which seems similar to peak demands in the Peters major office and in the Siikonen multi-tenant office measurement [2,3]. The upper bounds of 95% confidence interval exceed these measurements but matches quite well with the highest uppeak demand in the Siikonen single-tenant office measurement.

The most intense five-minute demand during lunch time was on average 12.8% and its 95% confidence interval upper bound was 14.2%. These values match well with the corresponding peak demands in the Peters major office and Siikonen single-tenant office. However, one Southeast Asian case had very high peak demand, 23.2% / 5 mins. Furthermore, it was not the only case with very high demand. The second highest lunch-peak demand in Southeast Asian offices was 18.9%. The same buildings that had the highest lunch time peaks had also the highest morning peaks, although the morning peaks were closer to the expectations.

Table 5 Five-minute peak demand statistics for peak periods and interfloor categories

Peak period	Interfloor category	Percentage passenger demand (% of pop / 5 min)			
		Min	Max	Average	95% CI
Uppeak	All	7.3	15.3	10.7	[9.9, 11.6]
	Low	8.6	15.3	11.4	[10.1, 12.7]
	Medium	7.9	13.4	10.4	[8.7, 12.1]
	High	7.3	13.9	10.2	[8.1, 12.3]
Lunch-peak	All	8.3	23.2	12.8	[11.4, 14.2]
	Low	9.7	16.8	13.3	[11.6, 15.1]
	Medium	8.3	18.9	12.4	[9.6, 15.2]
	High	8.9	23.2	12.6	[8.0, 17.1]
Downpeak	All	5.4	19.0	10.3	[8.9, 11.8]
	Low	6.6	15.4	11.5	[9.4, 13.6]
	Medium	6.8	16.4	9.6	[7.1, 12.1]
	High	5.4	19.0	9.5	[5.2, 13.8]

Evening downpeak is not considered in the current requirements of design standards [5,6,7]. In the previous measurements, evening downpeak demands were less sharp and clearly lower than morning uppeak and lunch-peak demands [2,3]. Therefore, downpeak has not been seen as a critical peak period in offices. From this perspective, most of the measured offices in this study resemble the earlier results where downpeak demands were clearly lower than uppeak demands. However, the highest measured evening downpeak demand was 19% per five minutes, which indicates that evening downpeaks can be intense as evidenced in early observations [1]. Average peak demand and the upper bound of its 95% confidence interval were almost the same as in uppeak, 10.3% and 11.8%, respectively, which are clearly affected by a few extremely high downpeak demands. Generally, offices in Europe had the lowest downpeak demands except for Turkish cases.

4.3 Traffic mixes in offices during peak periods

Peak period average traffic mixes are presented in Table 6 for each interfloor category. In the studied buildings, the proportion of incoming traffic in the morning was rather low, from 60% to 70% depending on the interfloor category. Generally, average traffic mixes in the interfloor category *low* closely correspond to the traffic mix of Siikonen multi-tenant office measurement [3]. For such cases, a traffic mix consisting of 70% incoming, 20% outgoing and 10% interfloor traffic could represent a typical office. However, buildings in the interfloor categories *medium* and *high* had as much as 20% interfloor traffic in the morning resembling Siikonen single-tenant office measurement. All the observed proportions of interfloor traffic clearly exceed the ones in Peters major office measurement [2].

During lunch traffic, the proportions of incoming and outgoing traffic were almost equal with respect to each other, but the proportion of interfloor traffic varied depending on the interfloor category. In the buildings in the low and the medium interfloor category, average lunch traffic mixes were close to the ones found in earlier measurements: 45% incoming, 45% outgoing and 10% interfloor traffic, or, 40% incoming, 40% outgoing and 20% interfloor traffic [2,3]. The buildings in the high interfloor category had about 40% of interfloor traffic, which is similar to Siikonen single-tenant office measurement.

Table 6 Average traffic mixes for peak periods and interfloor categories

Peak period	Interfloor category	Proportion of traffic component (%)		
		Incoming	Outgoing	Interfloor
Uppeak	All	66.7	17.1	16.2
	Low	71.3	21.0	7.6
	Medium	59.9	16.9	23.2
	High	68.0	11.7	20.2
Lunch-peak	All	39.9	38.2	21.9
	Low	47.5	43.9	8.6
	Medium	40.6	37.5	21.9
	High	28.3	30.7	41.0
Downpeak	All	21.2	61.5	17.2
	Low	25.7	64.1	10.3
	Medium	21.8	56.6	21.6
	High	14.3	63.5	22.2

As was the case with uppeak incoming traffic proportion, downpeak contains surprisingly low amount of outgoing traffic, only about 60%. The proportion of interfloor traffic correlates with the categories, i.e., low amount of interfloor traffic during lunch-peak implies low interfloor traffic during downpeak. Average downpeak traffic mix across all cases resembles Siikonen multi-tenant office down peak components, 20% incoming, 60% outgoing and 20% interfloor traffic [3].

5 DISCUSSION

Peak traffic patterns varied a lot between the studied buildings or rises. Generally, the highest peak demands and proportions of interfloor traffic occur during lunch time while morning uppeak and evening downpeak seem similar in both respects on average. The buildings were categorised based on the proportion of interfloor traffic during lunch-peak, which allowed to differentiate typical peak traffic patterns.

Average five-minute peak demand in the morning varied around 11% of population per five minutes depending on the interfloor category while the upper bound of 95% confidence interval varied around 12% per five minutes. Thus, the well-known required handling capacity of 12% per five minutes for uppeak seems a good value for standard designs [5,6,7]. In the studied buildings, the proportion of incoming traffic in the morning was surprisingly low compared to uppeak traffic mixes assumed in the design standards. While pure uppeak with 100% of incoming traffic is useful for determining handling capacity as a historical reference, a traffic mix of 85% incoming, 10% outgoing and 5% interfloor traffic has been used as an alternative [5,6,7]. To accommodate higher proportions of outgoing and interfloor traffic as found in this study, design simulations could be conducted with a traffic mix consisting of 70% incoming, 20% outgoing and 10% interfloor traffic.

During lunch time, average peak demands of around 13% per five minutes were observed. The averages are at the higher end of the current requirements for standard designs, which vary from 11%

to 13% per five minutes [5,6,7]. However, both the upper bounds of 95% confidence intervals and maximums clearly exceed these requirements. Hence, required handling capacity for lunch traffic could be increased, e.g., to 14-15% per five minutes especially in Southeast Asia. In the buildings in the low and the medium interfloor category, average lunch traffic mixes were close to the ones currently used in design simulations. However, the buildings with an attraction or transfer floor among the populated floors demonstrate the need for an alternative lunch traffic mix to be simulated: 30% incoming, 30% outgoing and 40% interfloor traffic. In some rare cases, the observed lunch traffic was pure two-way traffic without any interfloor traffic, which could be an option for simulations if local practices allow it.

Nowadays evening downpeak is not seen as a critical peak period for lift service as design standards do not set any requirements on it. Based on the measurements, peak demands in the evening follow peak demands in the morning on average. As lift groups are known to have a downpeak handling capacity of at least equal to uppeak handling capacity, the measurements do not indicate a need for adding the consideration of downpeak to design standards [3]. If desired, required handling capacity in downpeak could be defined 12% of population per five minutes, i.e., equal to the typical uppeak requirement, while traffic mix for design simulations could consist of 20% incoming, 60% outgoing and 20% interfloor traffic. Alternatively, pure downpeak with 100% outgoing traffic could be simulated to determine handling capacity in the cases where the whole building needs to be emptied at once.

In some of the measured buildings, peak demands remained well below handling capacities required by the design standards and, in some other buildings, greatly exceeded them during measurement days. Thus, variation seems to make peak demands unpredictable. The design standards should direct the selection of lift configurations into such that can handle peak demands in most of the buildings. However, exceptional cases, where peak demands exceed the required as well as the actual handling capacity, may occur. Therefore, handling capacities higher than required by the current standards could be considered, especially if local experience or building usage indicates very high demands during any of the peak periods. It is worth noticing that higher-than-standard handling capacities may not only target at satisfying peak demands but also at providing more spacious user experience and more robust service with respect to exceptional situations.

6 CONCLUSION

In this paper, new evidence on lift passenger demands was collected from 25 high-rise office buildings. To handle such a large amount of data, an algorithm analysing people flow data derived from automated passenger counts was developed to recognize typical peak periods known to occur in office buildings. Then, peak traffic patterns in the measured offices were studied statistically. The results indicate that the current requirements in design standards match quite well with the observed peak demands and traffic mixes.

However, some modifications or additions to the design standards could be considered. Required handling capacity for lunch traffic may need to be increased especially for Asian countries, where extremely high peak demands were observed in some cases. In addition, traffic mixes with higher proportions of interfloor traffic could be simulated for both uppeak and lunch traffic.

Due to high variation, people flow in each building appears rather unique reflecting the habits of the country and/or the tenant. To find stronger evidence on trends between different geographical areas or office types, a larger data set would be needed.

Peak demands in this study are scaled to the observed population of daily lift users including also absenteeism and visitors. Hence, research on actual occupancy rates would be needed to refine the estimation of design population. Knowledge of occupancy rates have become ever more important since the COVID-19 pandemic, which may have permanently influenced occupancy rates.

REFERENCES

[1] G.R. Strakosch, *Vertical Transportation: Elevators and Escalators, 2nd Edition*. John Wiley, New York (1983).

[2] R. Peters, R. Smith, and E. Evans, "The appraisal of lift passenger demand in modern office buildings". *Building Services Engineering Research and Technology*, Vol. 32, No. 2, 159-170 (2011).

[3] M-L. Siikonen, "Planning and control models for elevators in high-rise buildings". *Ph.D. thesis*, Helsinki University of Technology, Systems Analysis Laboratory (1997).

[4] D. Batey, and M. Kontturi, "Traffic analysis for high rise buildings to be modernized". *Elevator Technology 21 – Proceedings of Elevcon 2016*, IAAE, 26-35 (2016).

[5] ISO, *ISO 8100-32:2020 – Lifts for the transportation of persons and goods – Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings*. International Organization for Standardization, Switzerland (2020).

[6] BCO, *BCO Guide to Specification 2019*. British Council for Offices, UK (2019).

[7] PCA, *A Guide to Office Building Quality: Third Edition*. The Property Council of Australia, Australia (2019).

[8] L.A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning - I". *Information Sciences*, Vol. 8, No. 3, 199-249 (1975).

BIOGRAPHICAL DETAILS

Janne Sorsa, D.Sc. (Tech.) in operations research, heads the People Flow Planning team for KONE Major Projects and has played a key role in establishing and further developing the KONE network of People Flow Planning experts. He joined KONE in 2001 to develop dispatching algorithms for double-deck lifts and has successfully improved the performance of KONE double-deck destination control. He has published over 30 articles on people flow planning, optimization, and simulation. Sorsa also acts as the convenor of ISO/TC 178/WG 6/SG 5 and the project lead for the ISO 8100-32 standard on planning and selection of passenger lifts. Additionally, he actively participates in the work of ISO/TC 178/WG 6/SG 4 on writing the requirements for lifts used to assist in building evacuation.

Tiina Laine is a senior expert in People Flow Planning team and has been working for KONE Major Projects since 2008. In her role, she analyses people flow in high-rise buildings and other complex buildings. In addition, she trains the KONE network of People Flow Planning experts and advises them in challenging building projects to find optimal people flow solutions for customers. Laine holds a Master of Science (Tech.) degree from the Helsinki University of Technology, Department of Mechanical engineering.