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PUBLICATION

ENERGY-EFFICIENT ELEVATORS FOR TALL BUILDINGS

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This paper was presented at CTBUH (Council on Tall Buildings and Urban Habitat) 6th World Congress, Melbourne, Australia

ABSTRACT

According to elevator traffic studies, the traffic patterns in an office building, such as number of starts, round trips, and number of transported passengers, are repeated quite the same from day to day. In this study, the energy consumption of elevators in tall office buildings is studied by measurements and traffic simulations. A method using elevator load and travel distributions in calculating energy consumption is introduced. The simulation results are verified by measurements in a single-tenant office building. The proportions of savings gained by different drive systems and machinery as well as control systems are compared. A case study for yearly energy consumption in a tall building is presented.

1 INTRODUCTION

According to the GIBSE guide, elevators consume about 4–7 % of the total energy load in an office building [GIBSE]. In Finland, measurements were made in low-rise office buildings with 4-6 floors. In these buildings, the electricity consumption was somewhat lower, about 1-3 % of the total electricity load of the building. Most of the energy in prestige office buildings is consumed by the heating and hot water systems, lighting and office equipment, such as computers [Field]. The energy needed for space heating, ventilation, or air conditioning also depends on the outside temperature. Tall buildings vary in height and shape, and in their usage, as well as in elevator layout. In fact, there is no such thing as a typical high-rise building. Consequently, generalized statements about relative elevator energy consumption in tall buildings are difficult to formulate.

Owing to the uniqueness of tall buildings, this article concentrates on two specific office buildings, one in Finland and the other in Australia. The energy consumption of modern traction elevators and control systems is compared with technology that is about ten years old.

2 ELEVATOR TRAFFIC

Most offices are occupied for about ten hours a day, five days per week. A measurement of the passenger arrival rate in a single-tenant building with 18 floors was made in Finland (Fig. 1). The profile shows the numbers of passengers arriving at entrance floors (incoming traffic), travelling to entrance floors and exiting the building (outgoing traffic), and inter-floor traffic where passengers travel between the upper floors. The traffic profile was measured by the elevator control system using load information and photocell signals. In this building, passenger traffic is the most intense during the lunch hour, about 10 % of the population in five minutes. In the morning the traffic peak is not as sharp since the working hours are flexible. During normal times, passenger traffic intensity varies from four to 6% of the population in five minutes. The proportion of inter-floor traffic is greater in a single-tenant office building compared to a multi-tenant office building.

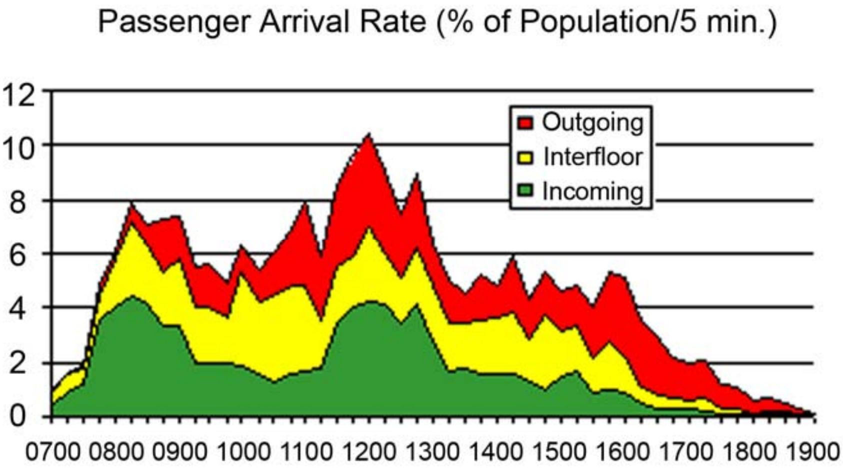

Figure 1. Passenger arrival profile measured in an office building in Finland

In this building, passengers are served by a group of six elevators with a car size of 16 persons. If the passenger traffic intensity exceeds a certain amount, e.g. 4–6% of the population in five minutes, the number of elevator starts and trips up and down (round trips) tends to reach the limit. The number of starts and round trips of one elevator in half-hour steps can be seen in Fig. 2. This measurement was made before the modernization in 1989. In the figure, the number of starts varies from 120 to 160 per hour, and the number of round trips reaches the limit of about 40 per hour. The maximum number of elevator starts within an hour is limited by the elevator performance. A typical measured value for an average cycle time from one elevator start to another is about 20–25 seconds. This time includes the elevator run from one floor to another, door opening and closing times, and passenger transfer times. With a typical cycle time, the maximum number of elevator starts varies from 145 to 180 within an hour.

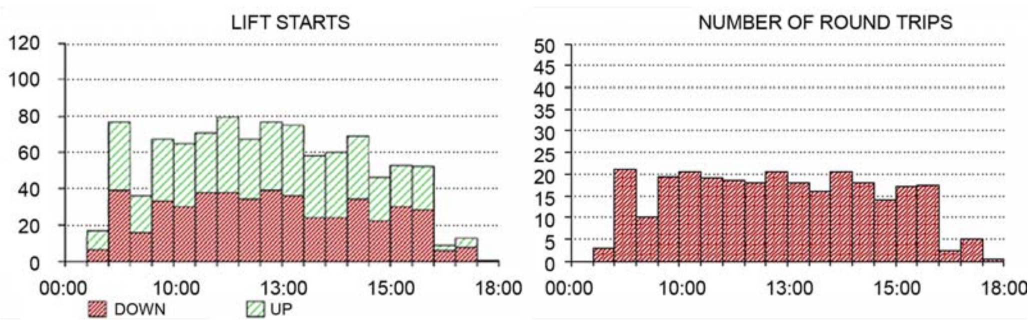

Figure 2. Number of starts (a), and number of round trips (b) of an elevator in a single-tenant office building

The simulated number of starts with different loads and running distances for the six cars is shown in Fig. 3. Figure 3a shows a theoretical up-peak situation, and Figure 3b a typical mixed traffic pattern from 9:00 to 11:00 o'clock, and from 13:00 to 16:00. During mixed traffic, about 25% of the starts are with empty load, and about 25% are for one-floor runs. Most of the measured starts during a day occur with a 10–20 % load factor and with a distance of 20—30% of the total. Exceptions are made if the elevator group has an express zone.

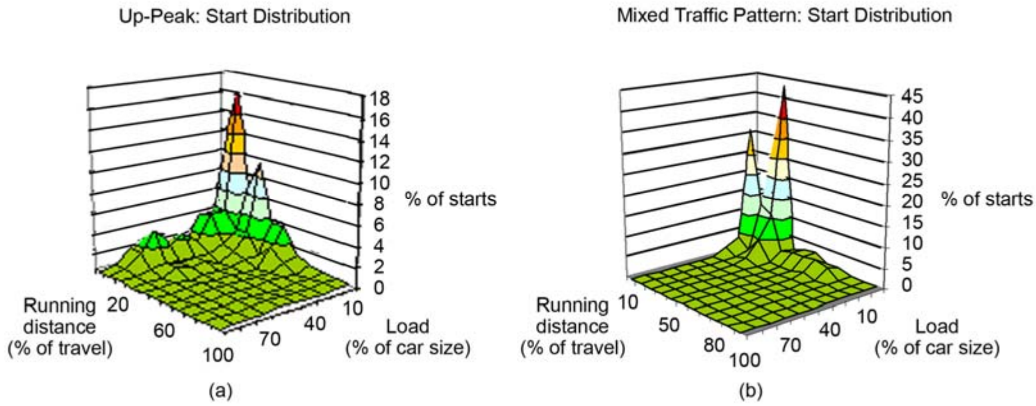

Figure 3. Distribution of starts according to passenger loads and running distances during up-peak (a), and daily mixed traffic (b)

3 ENERGY CALCULATION PRINCIPLE

In the procedure for calculating elevator energy consumption, elevator traffic is simulated for different times of day. The energy consumption is calculated for each elevator run. The direction of travel is considered for each run, as well as the loading of the car and the travel distance during each run.

There are many ways to estimate the energy consumption of an elevator or an elevator group. If only an idea of the magnitude of the energy bill is needed, the following principles can be used:

- The simplest way is to use only the motor power and number of starts with an experimental coefficient for different drive types.
- Another method is to estimate the lifted mass (E=kmgh), with an experimental coefficient. If the population and height of a building are known, an energy value can be calculated.

When comparing the savings gained by different technologies or traffic control principles, time-step simulation is the only accurate way. This method is used in this study. The simulation method consists of two parts:

- One-run energy is calculated for each load and travel distance and it is tabulated into a matrix corresponding to number of floors and number of passengers in the car (Tables 1 and 2).

- For each combination, the energy demand is calculated by an electro-mechanical simulation program (Fig. 4). The energy demands are calculated for both directions, but the actual location inside the building has not been taken into account in this study. This causes a small inaccuracy if the balancing is not perfect. For practical purposes this inaccuracy is negligible.

Table 1. Energy consumption in up direction (kWs)

Kg/ Persons	0/ 0	165/2	329/ 4	494/ 6	659/ 8	823/ 10	988/ 12	1152/ 14	1317/ 16	1482/ 18	Distance
Floors											(m)
3	16	30	45	62	80	99	120	143	167	193	11m
6	-18	12	44	78	114	153	193	236	280	327	21m
9	-57	-10	39	91	145	202	261	324	389	457	32m
12	-134	-58	22	106	193	284	380	479	582	690	43m
15	-193	-101	-6	94	198	307	421	539	662	789	54m
18	-252	-145	-33	83	204	330	462	599	741	889	64m
21	-310	-188	-61	71	209	353	503	659	821	988	75m
24	-369	-232	-89	59	214	376	545	719	900	1088	86m
27	-428	-275	-117	48	219	399	586	779	980	1187	96m
30	-486	-319	-144	36	224	422	627	840	1059	1287	107m
33	-545	-362	-172	25	230	445	668	900	1139	1387	118m
36	-604	-406	-200	13	235	468	710	960	1219	1486	128m
39	-662	-449	-228	1	240	491	751	1020	1298	1586	139m
42	-721	-493	-256	-10	245	514	790	1080	1378	1685	150m

Table 2. Energy consumption in down direction (kWs)

Kg/ Persons	0/ 0	165/ 2	329/ 4	494/ 6	659/ 8	823/ 10	988/ 12	1152/ 14	1317/ 16	1482/ 18	Distance
Floors											
3	195	171	148	127	108	90	73	58	44	32	11m
6	334	290	248	208	170	134	101	69	39	11	21m
9	468	404	343	284	228	175	124	75	29	-15	32m
12	711	610	512	418	327	240	157	78	2	-70	43m
15	821	699	582	468	359	254	154	58	-34	-122	54m
18	931	789	652	519	391	268	151	38	-70	-173	64m
21	1041	879	721	570	423	282	147	18	-105	-224	75m
24	1151	968	791	620	455	296	144	-1	-141	-276	86m
27	1261	1058	861	671	488	310	140	-21	-177	-327	96m
30	1371	1147	931	722	520	324	137	-41	-213	-378	107m
33	1481	1237	1001	773	552	338	134	-61	-249	-430	118m
36	1591	1327	1071	823	584	352	130	-81	-285	-481	128m
39	1701	1416	1141	874	616	366	127	-101	-320	-532	139m
42	1811	1506	1211	925	648	380	124	-121	-356	-583	150m

Electromechanical simulation is based on an elevator model, which takes into account both the mechanical and electrical parameters of the elevator system. The formulas are quasi-stationary, and no differential equations are used. The model uses the following mechanical parameters:

- Speed pattern with predetermined top speed, acceleration and jerk.

- Linear masses of car, counterweight, cables and ropes.

- Inertia of rotating parts like the traction sheave and other pulleys and the motor.

* Efficiency of roping, depending on guide-shoe type, number of bends in roping etc.

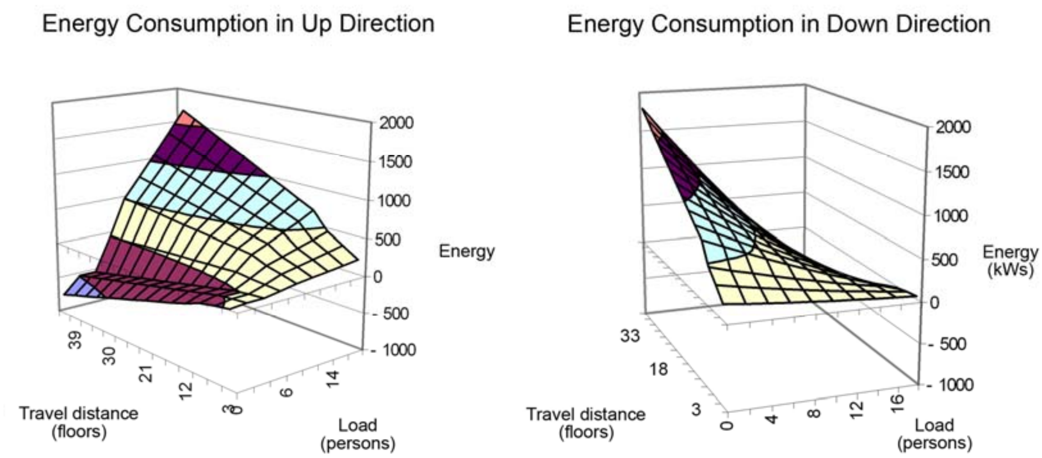

Figure 4. Energy consumption according to passenger loads and travel distances in up direction (a), and in down direction (b)

The electrical part of the model includes the following components:

* Copper and iron losses of the motor. Temperature rise of half of the maximum allowed has been assumed.

* Copper and silicon losses in the drive.

* Power of fans and brakes.

In one simulation step, the required torque is first calculated based on speed, load and acceleration. The corresponding motor current and voltage are then defined and finally the resulting line current. The line current comprises reactive power (small in the case of frequency converter) and true power, which is then used for integrating the energy.

Figure 5. Power and energy consumption, and the speed of an elevator during one run

An example of one simulation of an up/down cycle is shown in Fig. 5. The elevator design specification is 7 m/s and 1 564 kg. The solid line represents conventional technology with a motor efficiency of 80 %, and the dotted line is for MX-technology with a motor nominal efficiency of 90 %. The picture clearly shows the source of energy savings. Although the peak line power does not decrease more than 10 %, the energy of a total run decreases about 35 %. The reason is the energy savings accumulate over time in both directions.

4 EVALUATION OF THE ACCURACY OF SIMULATION

The accuracy of the simulation is compared with measured energy values in the same office building mentioned earlier. The building is an 18-floor office complex with DC-motors with a static converter. Energy consumption was measured for an elevator round trip from the bottom floor to the highest floor of the building with an empty car. The total energy consumption during the round trip was of the 124 Wh. Ten round trips were simulated with the same building. According to simulation results, the average energy consumption during a round trip was 118 Wh.

The accuracy of the simulation is about 5%. It has already been mentioned that the simulation does not take into account the actual location in the hoistway. This causes certain error, which depends on the balancing of the elevator. Other sources of error are:

- Temperature of the motor affects the energy losses, as well the brakes and other wound parts.

- Fans are controlled by thermostats, thus the actual running time is not known.

- Actual friction in the shaft is difficult to estimate, especially when sliding guide shoes are used.

5 TMS9900 GA™ CONTROL SYSTEM

Elevator group performance is traditionally measured in terms of interval, passenger waiting, ride and journey times and transportation capacity. Rarely has attention been paid to energy consumption when allocating landing calls to elevators.

The Optimum Routing Principle (ORP) in TMS9900 GATM (Genetic Algorithm) simultaneously optimizes several targets including energy consumption. In the multi-objective optimization the best routes for elevators to allocate landing calls are selected using a heuristic search method called Genetic Algorithm [Goldberg], [Tyni]. GA imitates 'Mother Nature' in its operation within a computer: route combinations with, e.g. shortest waiting times, are found by developing route alternatives from generation to generation. New generations are created from the selected routes with good properties using inheritance, mutation and crossover. The final combination of routes is a result of processing and evolving thousands of route alternatives. This evolutionary search method is the most powerful tool that has been seen in elevator call allocation problem so far.

Figure 6 shows the principle of the TMS9900 GATM system when optimizing both the passenger waiting times and energy consumption. The group control system uses feedback about the energy consumption regarding the elevator group in its decision making. The target for the service level, e.g. maintain the average waiting times to 20 seconds, is set externally. During the call allocation the GA search method considers the both targets when processing each route alternative. The energy consumption in elevators is asymmetric - less energy is consumed if elevators ascend with a smaller load and descend with a greater load. The route alternatives that best satisfy the target waiting time with the least energy consumption are selected and will be carried forwards to the next generation. As a final result, the route combination selected is the one that incurs the least energy consumption, and where the average passenger waiting times stay within the defined limit. During light and normal traffic ORP is able to route the elevator cars via more energy-efficient routes yet maintain good service level.

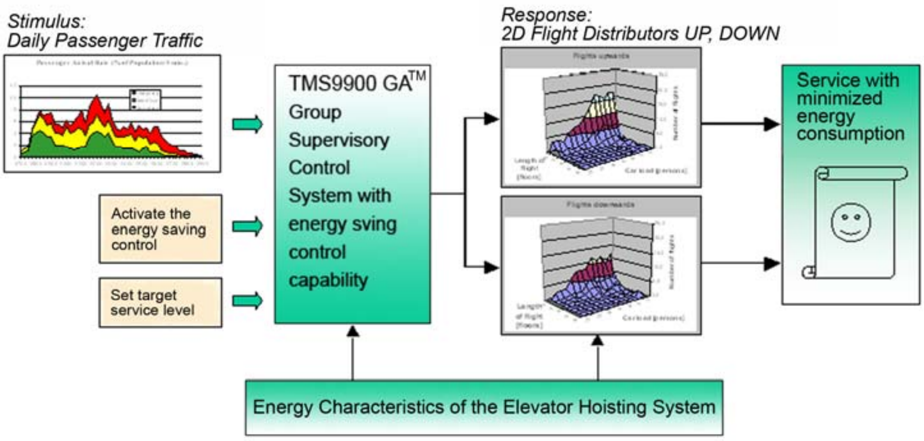

Figure 6. Elevator system with the TMS9900 GATM control system impacted with daily passenger traffic

5.1 CASE 1: Philip Street

A test of energy consumption was made for a high-rise office tower in Sydney, Australia. Totally there are 16 elevators three groups. The elevator groups serve floors as follows: the low-rise elevator group serves floors from 9 to 19, the mid-rise elevator group floors 20 to 29, and the high-rise elevator group 30 to 39. Each of the elevator groups has the entrance floor at street level.

The advanced lift traffic simulator (ALTS, Siikonen) was used to estimate the performance and the energy consumption of the elevator groups during active hours of the office building, i.e. from 7 a.m. until 7 p.m. In order to find out the differences between elevator supervisory controls, the traffic of the whole day was considered. The active hours of a typical working day are divided into six main phases (see Fig. 7a). When people arrive at work in the morning there is an incoming peak, which is followed by light mixed traffic before the lunch hour. The afternoon traffic resembles the traffic before the lunch hour. Later in the afternoon there is an intense outgoing peak after which the traffic lightens towards the evening.

Two different call allocation principles, TMS9000 AI with ESP (Enhanced Spacing Principle) and TMS9900 GA with ORP are compared. The ESP principle is an effective call allocation principle that was used during the last decade in TMS9000 control system. ESP optimizes passenger waiting times in all traffic situations and keeps the elevators evenly spaced in the building.

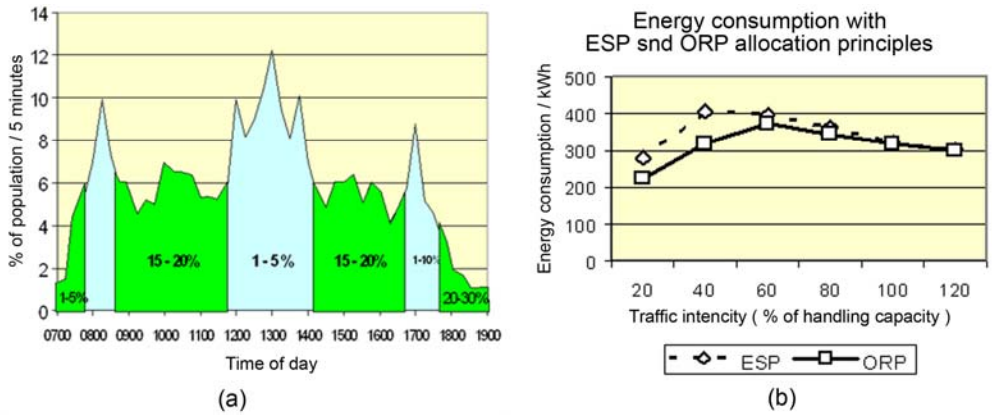

Figure 7. Energy savings gained with group control systems using ORP and ESP call allocation principles during mixed traffic (a), and during active hours of a day (b). The results apply to all the tested elevator groups

With ORP principle using the new energy saving control feature, about 15-20% of the consumed energy is saved before and after the lunch hour when the traffic intensity is not very high (7a). According to Figure 7b energy is saved especially during light traffic. In this simulation, waiting times were fixed to stay below 20 seconds with energy saving feature. According to simulation result, For the whole day traffic, about 15% energy saving with ORP is obtained compared to a control where energy consumption is disregarded.

Three different hoisting technologies, the SCD, V3F and MX technologies, are compared by simulating the daily traffic. SCD uses DC motors with static converter, and was used in traction elevators about ten years ago. V3F is a Variable Voltage Variable Frequency converter/inverter drive system that was used in AC elevators during the last decade. MX machinery is also known as EcoDisc™ and is used with the modern TMS9900 GA™ control system.

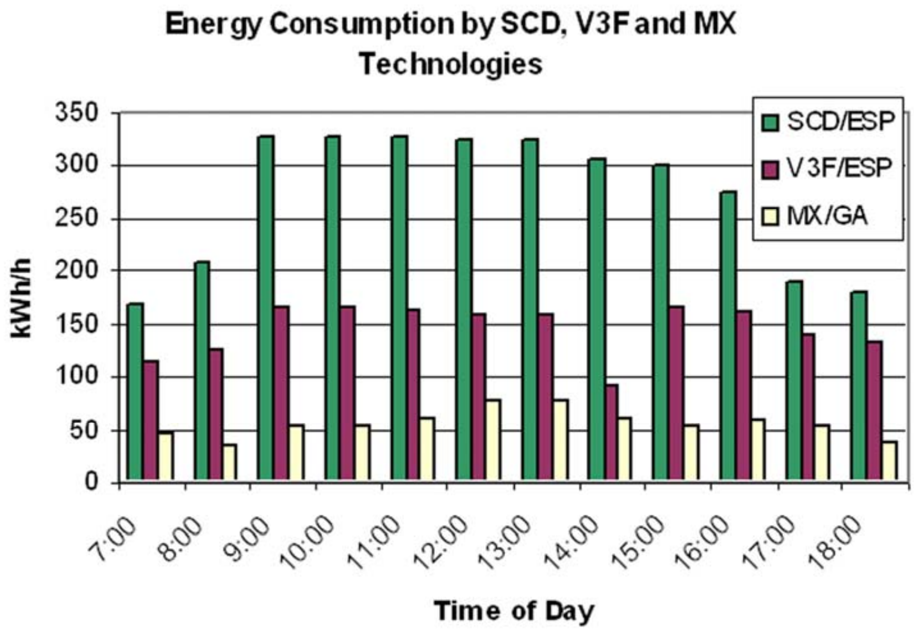

Figure 8. Simulated elevator energy consumption with SCD, V3F and MX technologies during the day in the example building

According to Figure 8, V3F saves 30-40% energy compared to the SCD technology. MX machinery with the TMS9900 GA™ control system consumes 65-75% less energy compared to the SCD technology in this building. If MX technology is compared with V3F drive system, MX saves energy 40-60% in this example case. In the calculations, feedback of the current to the network was taken into account. In this building, elevators with the SCD technology would consume about 700 MWh within a year, and 525 MWh with V3F. With the MX technology the energy consumption is only at minimum 200 MWh within a year.

CONCLUSION

Elevators consume 1-7% of the total energy load in a building. In this article, the energy consumption of different elevator technologies was studied. A simulation method to analyze energy consumption was introduced, and the method was verified by a measurement in an office building in Finland. The error with the simulation method stays in the range of 5%.

Using simulation, the effect of different machinery and drive systems, and group control systems were compared. The test was made for a 40-floor high-rise office building in Australia. According to the test case, during a typical day V3F drive system saves energy 30-40% compared to SCD system. With the MX machinery and TMS990 GA™ control system, energy savings are huge compared to both systems. About 40-75% less energy is consumed with MX technology compared with the old technology. Energy is saved also by control means, about 10–15% during a day compared to a control where energy consumption is not considered. According to this case study, the MX machinery with TMS9900 GA™ control system offers a real green elevator product for the most modern and demanding office buildings.

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