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Green Lift Control Strategies

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ABSTRACT

In general terms, green lifts are lifts with a low energy consumption. The energy consumption of a lift installation is a function of many variables ranging from the accessibility of the stairs to the type of lift drive selected. One variable is the strategies implemented by the lift control system, i.e. the choices the lift system makes in deciding how the lifts respond to passenger landing and car calls. This paper outlines various lift control strategies which result in a reduction in energy consumption. Improvements are measured using an object oriented lift simulation program which has been developed to test these strategies.

INTRODUCTION

Peters [1] has demonstrated that the dominating environmental burdens of lifts are the non-renewable resources depleted, the waste created and the emissions generated through the production of electricity for operation of the lifts while in use.

Buildings account for about a third of the energy we consume. Lifts are not the largest energy users in buildings, but they are significant enough (4% to 10% of electrical load) to warrant energy saving measures; a typical office four lift installation consumes in the region of 300kWh per working day. Each time someone takes a lift, they contribute to the generation of greenhouse gasses, which evidence suggests is leading to damaging environmental effects such global warming. If we can reduce the causes of these effects, we should do so. Apart from environmental concerns, the financial cost of the electricity used by lifts is a major incentive for adopting energy saving designs.

The energy consumption of a lift installation is a function of many variables ranging from the accessibility of the stairs to the type of lift drive selected. In this paper we discuss some of these variables. Having established the basis for a green lift installation, various lift control strategies are outlined which result in a further reduction in energy consumption.

Improvements in energy consumption achieved by the green lift control strategies are measured using an object oriented lift simulation program that has been developed to test the strategies. The program introduces passengers as they arrive at the lift lobby, then simulates the operation of the lifts and the energy consumption of the lift drives as the passengers are transported.

BASIS FOR GREEN LIFT INSTALLATION

There is limited value in developing green lift control strategies if other aspects of the installation are not specified with energy conservation in mind. The following issues need to be considered by the designer.

Lift drives

Hydraulic lifts are energy inefficient in comparison with electric lifts. In his site measurements, Doorlaard [2] concluded that *the energy consumption of hydraulic lifts travelling at the same nominal speed is over two times the consumption of conventional two-speed lifts*. Hydraulic lifts do have benefits (e.g. low structural building load, flexible motor room position, low capital cost). But they are not green.

Lift manufactures offer a wide range of electric lift drives ranging from single speed AC machines to variable speed AC and DC machines. A summary of these drives and their applications is given by Peters [3]. Their energy efficiencies vary significantly. The most efficient electric lift drives are the modern fully controlled static converter DC and variable voltage variable frequency AC drives (including vector control drives); the AC drives provide better power factor control.

Green lift drives should be regenerative, i.e. return power to the mains when delivering negative torque (braking). The alternative, dissipating the energy in resistors can be doubly wasteful, as the waste heat introduces an additional cooling load in an air conditioned building. Installation of regenerative systems should be co-ordinated with the electrical building services design engineer as additional protection and harmonic filtering may be required.

Other installation issues

The torque, and therefore the energy, required of a motor to accelerate a lift can be reduced if we minimise inertia and other resisting forces. All rotating components (gear, brake, sheaths, etc.) and travelling components (lift car, counterweight, finishes, ropes, etc.) contribute to the inertia and to resisting forces in the system. Compared with the conventional worm gear, significant reduction in inertia and higher efficiencies have been demonstrated by Zinke [4] for planetary gears, and by Stawinoga [5] for V-belt drives.

Lift car lighting should use efficient sources and be switched off automatically if a lift is not in use for long periods.

Planning issues

The total energy consumption of the installation is also dependant on planning issues. If stairs are accessible, attractive and adjacent to the lifts, there is likely to be a reduction in the use of lifts for short trips. It is also good to avoid over-sizing of lifts, as larger lifts result in greater inertia, larger motors and more energy use. While it is important to design spare handling capacity into a lift installation, over-sizing can be the result of:

- poor knowledge of probably traffic flows, leading to "safe" overestimates of required handling capacity.

- where traffic analysis suggests small lifts are acceptable, it is common to up-size the lifts selected. For instance, in a new office development where six, eight person lifts meet handling capacity and interval design criteria, ten or thirteen person lifts might be selected as larger lifts are perceived as prestigious.

LIFT SIMULATION PROGRAM

The lift simulation program, *Liftsim* has been developed as a design planning tool, and as development platform for green control strategies. The program has been written using Microsoft Visual C++ (for Windows 95 and Windows NT). C++ is a complex object oriented language, but it produces very fast programs, and easily reusable/portable code. The object oriented approach encourages the programmer to think in terms of objects (e.g. a lift, a person) rather than subroutines or procedures. This helps break down complex problems into manageable parts that are easy to work with as they represent familiar ideas or components.

The main simulation classes are as follows (a class defines the behaviour of an object):

> **building** defines the building in terms of number of stories and story heights.
>
> **motion** implements research by Peters [6] in ideal lift kinematics. Programs using the class can specify the journey distance, rated velocity, etc. and output the current distance travelled, velocity, etc. at any time, t since the journey began.
>
> **lift** defines a lift (rated speed, capacity, floors served, etc.) and its current status (position, speed, load, etc.). The motion class is applied to enable the lift to move according to the selected journey profile. The lift class includes algorithms to allow lifts to answer landing and car calls according to the principles of directional collective control. (Most lift control systems adopt a directional collective control strategy regardless of the complexities of the dispatcher algorithms.)
>
> **dispatcher** defines rules for allocating which lift serves which calls. For fair comparison of the green control strategies, the default dispatcher logic has been

based on conventional group control with dynamic sectoring as defined by Barney and Dos Santos [7].

person defines a person, what time they arrive at the landing station, where they want to go, their mass, etc. Once the journey is complete, the class provides details about passenger waiting, transit and journey times. Waiting time *is calculated as the actual time a prospective passenger waits after registering a landing call (or entering the waiting queue if a call has been registered) until the responding elevator doors begin to open.* This definition has been taken from the NEI Vertical Transportation Standards [8]. For continuity, transit time is calculated from *the time the responding elevator doors begin to open to the time the doors begin to open again at the passenger's destination*. Journey time is the sum of waiting and transit times.

motor defines the characteristics of the drive. The class calculates the energy consumption and other characteristics as per research by Peters [3] in motor modelling. The motor model is of a DC six pulse static converter drive. Motor simulation results by So [9] show that other regenerative drives have comparable power consumption profiles, thus it is reasonable to assume that the relative performance of green control strategies will be common to these drives.

The user can edit all the system parameters (No of lifts, speeds, floor heights, passenger traffic, choice of dispatcher algorithm, etc.) in Windows based tables/dialogue boxes. The program is a time slice simulation; it calculates the status (position, speed, etc.) of the lifts, increments the time, then re-calculates, and so on in a loop. On a Pentium PC, simulations run faster than real time using a time slice of 0.01 seconds.

GREEN CONTROL SYSTEMS

Definitions

Barney and Dos Santos [7] define a group supervisory control system as *a control mechanism to command a group of interconnected lift cars with the aim of improving lift system performance*. Conventionally this system performance has concerned maximising the handling capacity of the lift system, and minimising passenger waiting and transit times. So [10] provides a review of the increasing advanced control strategies applied by designers in order to realise improved performance in these terms.

It would be counterproductive to ignore conventional system performance criteria as excessive waiting for lifts is very frustrating for passengers. So let us define a green lift control system as a *group control system that considers conventional measures of system performance, as well as means to reduce energy consumption*. In the following subsections we shall consider three strategies that would be appropriate to a green lift control system.

Green strategy no.1 - control of kinematics

Conventionally lifts have the same maximum velocity, acceleration and jerk (rate of change of acceleration) for every trip. If the system does allow any variation, this is generally pre-set by the lift service engineer or building owner.

Research by Peters [6] in ideal lift kinematics has allowed us to generate, quickly and easily, motion profiles for any input of journey distance, velocity, acceleration and jerk. This allows us to consider control systems that vary all these parameters on line in lift system controllers.

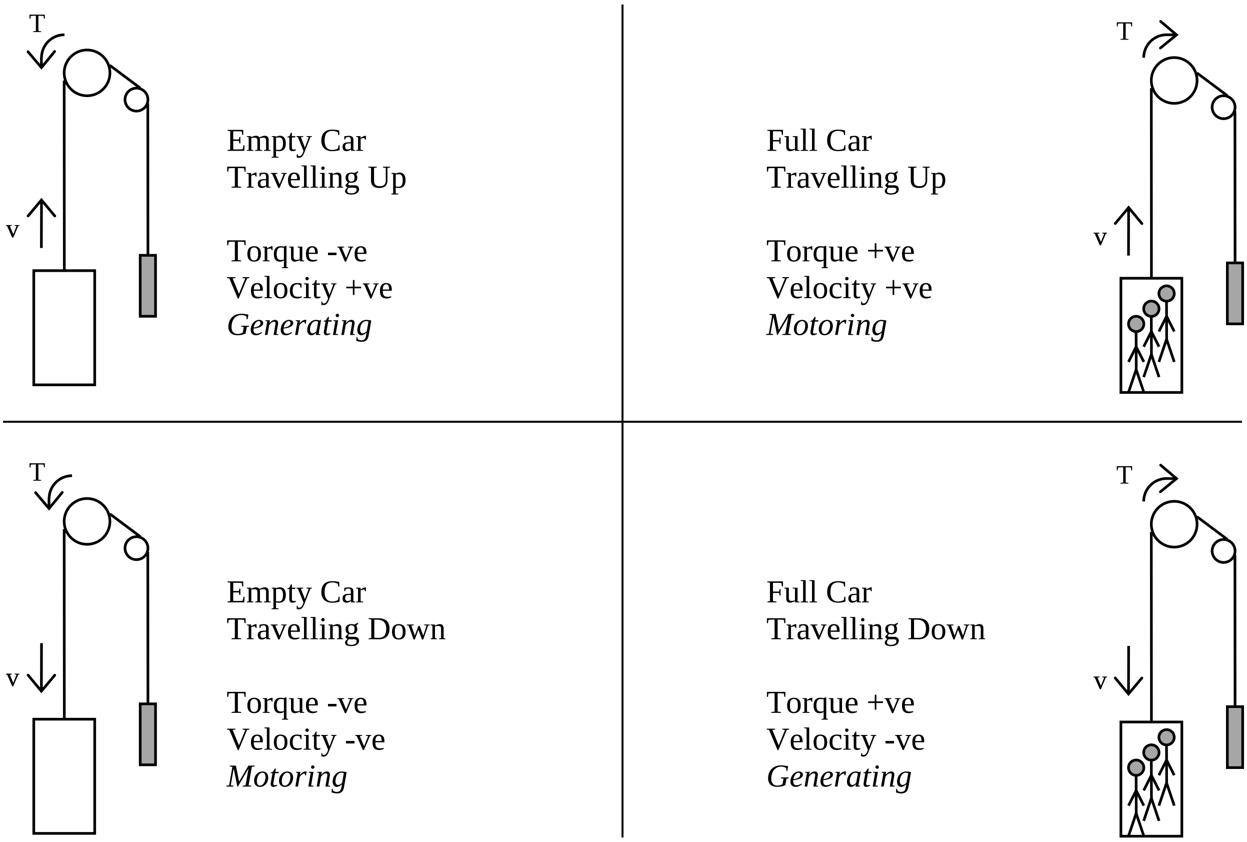

Figure 1 Four quadrant operation of lift drive

One reason for varying the lift kinematics could be for energy saving purposes. Indeed simulation results suggest that significant savings can be achieved without a significant overall reduction in performance from the passenger's prospective. To understand how these savings can be realised, consider:

When a lift leaves the ground floor full of passengers, it is motoring, requiring predominantly positive torque in a positive direction. As passengers are dropped off up the building, the counterweight becomes heavier than the lift, so the motor is providing predominantly negative torque in a positive direction. Similarly for a journey down the building, a negative direction, the motor can be required to deliver both positive and negative torque. Thus the lift motor is said to operate in "four quadrants", as represented graphically in Figure 1.

(This well known example of how a lift operates in four quadrants is not the whole story as the required motor torque is a function of not just the static load, but also of the angular acceleration and inertia of the system. Zhou [11] provides equations for calculating how the load torque varies over a lift trip.)

In general terms, reducing the performance of the lift when it is “motoring” will save energy; just as car driver who moderates his acceleration and breaking saves fuel. Likewise, increasing the performance of a lift when it is “generating” will regenerate additional energy. Consequently, we can gain energy in both instances, without an significant overall effect on passenger waiting and transit times.

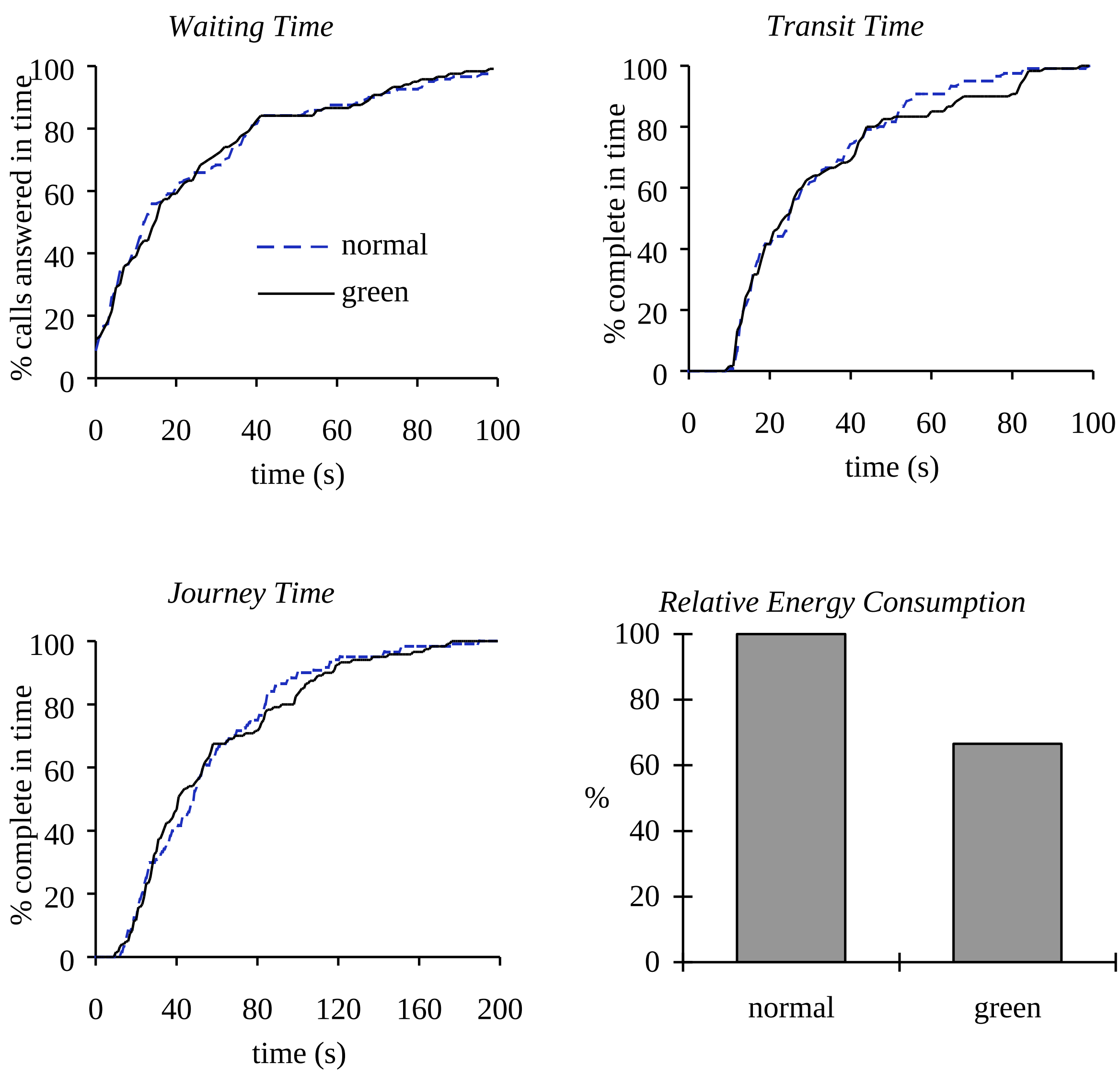

Figure 2 Simulation results for green strategy no.1 - control of kinematics

An algorithm has been developed that tests a range of velocity and acceleration options (ranging ± 20% from rated velocity and acceleration) before the start of each trip.

Figure 2 summarises the results of tests for a 10 storey building with 4 lifts. An inter-floor passenger traffic profile has been used.

Results show the % of calls answered or complete in a certain time, e.g. the waiting time graph shows that, for both normal and green systems, approximately 60% of calls are answered within 20 seconds, and 80% of calls are answered within 40 seconds.

In this analysis a 33.4% saving in energy consumption has been achieved using the green strategy. The average journey time has increased by just 1.3 seconds.

Green strategy no.2 - reducing the number of stops

Figure 3 demonstrates the energy consumed by a lift over a single trip (motoring), as presented by Peters[3]. The energy consumption peaks during the acceleration phase, and is relatively low once the lift reaches full speed. There is regeneration during the deceleration phase, but this is less in total than the energy expended during the acceleration phase. Thus it is reasonable to assume that there will be energy savings if we can transport the same number of passengers, with less stops, but without an increase in the overall distance travelled by the lifts.

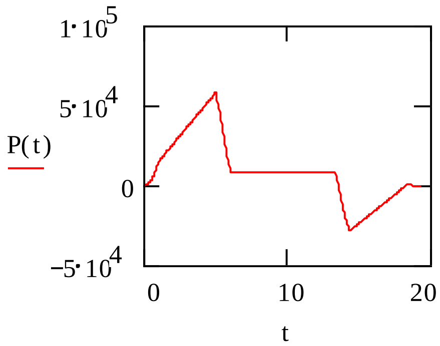

Figure 3 Energy consumed by a lift over a single trip (motoring)

One way to achieve this is by forcing the dispatcher to allocate a landing call to a lift when it is:

- already due to stop at that floor for a passenger's car call, and
- travelling in the right direction to serve the landing call.

This condition for a "forced" allocation may not occur for some time, e.g. it is unlikely during solely up peak traffic, or during light inter-floor traffic. But most lift systems are likely to benefit from the strategy at some time during their daily cycle.

Figure 4 records the results of a simulation of a 14 storey building with 6 lifts. The traffic profile is based on the beginning of the lunch period in an office building - down peak traffic to the ground floor, plus inter-floor traffic.

In this case, the "green" algorithm implementing the discussed strategy causes a 3.2% reduction in the number of motor starts, leading to a 6.2% reduction in the energy consumption. The waiting time distribution remains very similar, but there is a minor improvement in transit times. The improvement in transit time performance is explicable as the strategy will result in some passengers experiencing less intermediate stops during their journey.

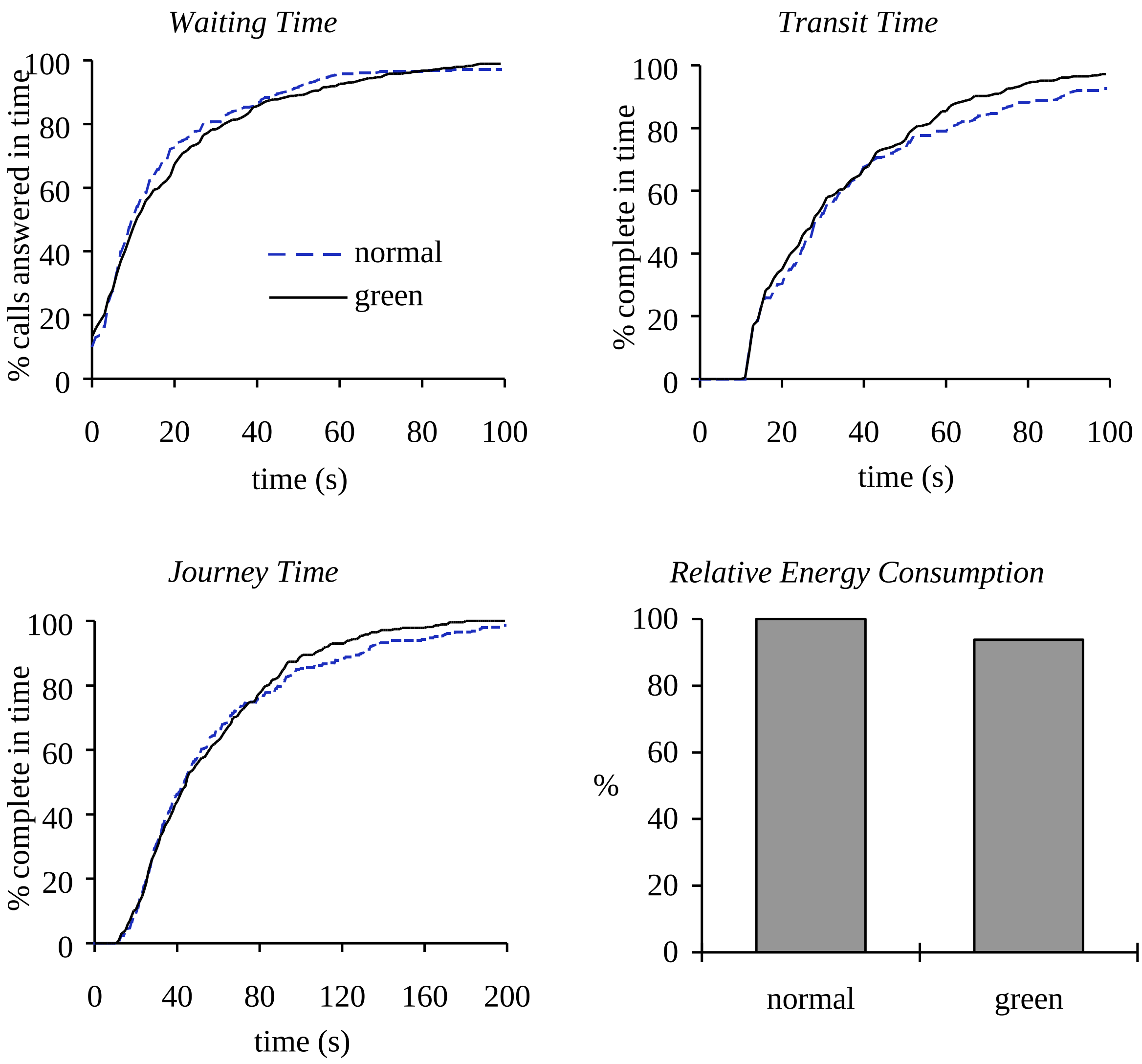

Figure 4 Simulation results for green strategy no.2 - reducing the number of stops

Reducing the number of stops is not a new goal for lift control systems. This is because reducing the number of stops reduces the round trip time, increasing the passenger handling capacity of the lift system, and sometimes the lift performance. Other systems that reduce the number of stops include:

- fixed zone systems where lifts are divided into zones to serve groups of floors, e.g. 4 lifts serving ground and levels 1 to 10, 4 lifts serving ground and levels 11 to 20.
- dynamic zoning systems, where the dispatcher indicates to the waiting passengers which floors a lift will be serving every round trip, e.g. Channelling as presented by Powell [12].

- call allocation systems, as described by Barney and Dos Santos [7], where passengers are required to register their destination (as opposed to direction of travel) at the landing.

While these systems do result in less stops, they do not necessarily result in an energy saving as:

- the overall distance travelled by the lifts is sometimes greater.
- the number, speed, capacity, etc. of the lifts will differ from a corresponding conventional, single zone design.

To assign credit for energy saving based on these methods, a designer would need to carry out a direct comparison of alternative schemes for the project in question.

Green strategy no.3 - selective parking policies

When a lift has answered all its calls and becomes free, it can be “parked” at the floor it last answered a call, or sent to another floor in anticipation of future calls. Barney & Dos Santos [7] describe how re-positioning a free car to a particular floor as part of a parking strategy can improve the overall performance of a lift system.

For instance, consider the morning up peak in an office building where the main passenger traffic flow is from the ground floor to upper floors. In this scenario, the dispatcher can improve system performance by returning free cars to the ground floor, and parking them with their doors closed. When a preceding lift departs from the ground floor, and another is needed, a free lift is available immediately rather than having first to be brought to the ground floor.

Similarly during off-peak traffic, answering a series of calls may leave free lifts poorly positioned to answer future calls. Consequently, lift control systems sometimes apply parking policies to improve performance in these scenarios as well.

From the energy saving viewpoint, we should apply parking policies selectively. Figure 5 summarises the results of the simulation of a fifteen storey building with very light inter-floor traffic. The simulation has been run with and without a parking policy that implements a parking strategy.

The results demonstrate that the parking policy improves performance. The question is whether the improvement in performance justifies that additional energy consumed; in this instance, probably not. Other scenarios will be less clear cut.

Green control systems should place parking calls selectively. This could be achieved by the dispatcher reviewing the potential contribution to system performance of parking calls before deciding whether or not they should be made.

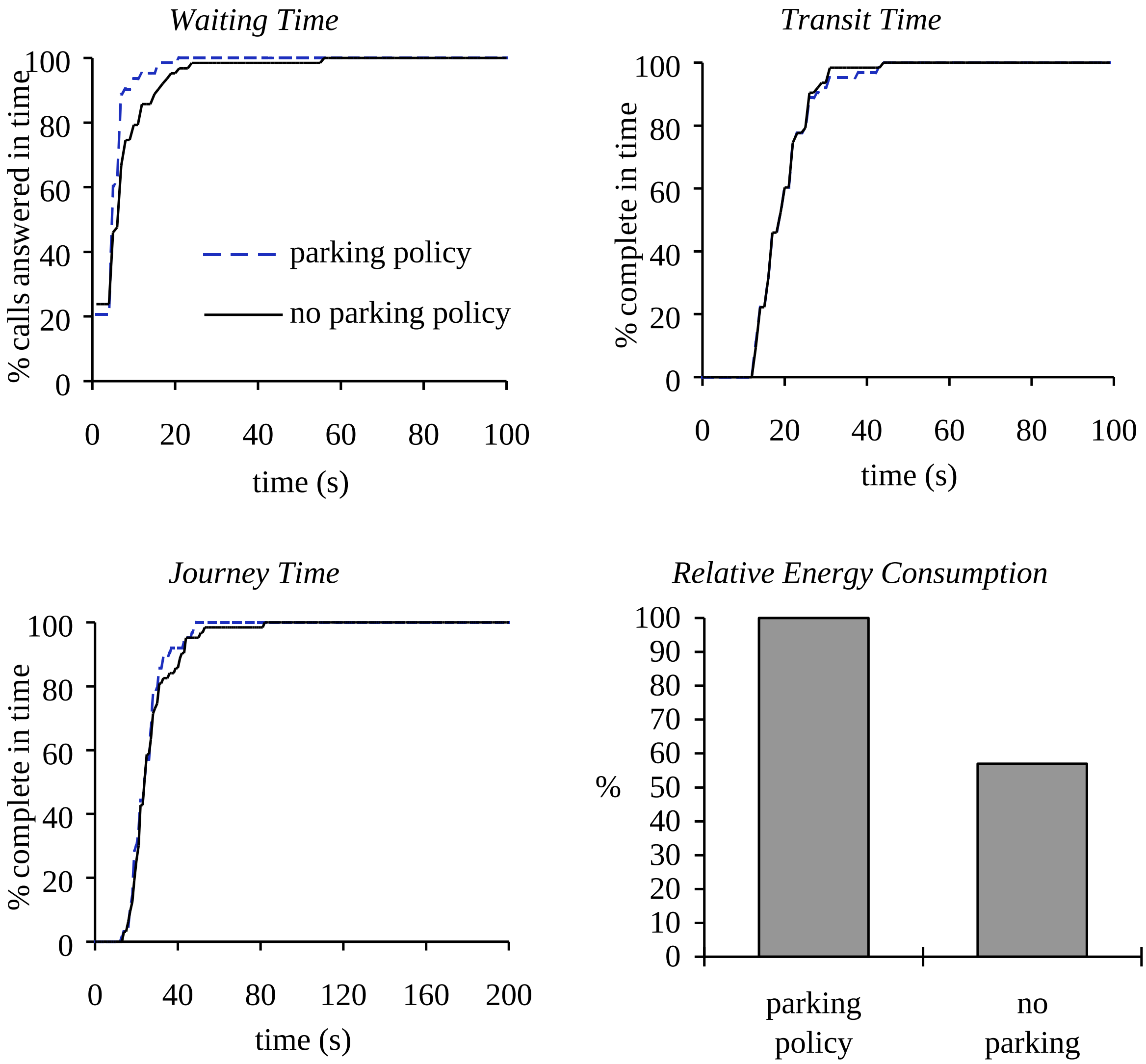

Figure 5 Simulation results for green strategy no.3 - selective parking policies

CONCLUSIONS

The use of electricity at current levels is unsustainable, and damaging to our environment. As responsible stewards of the earth, we should be reducing our energy consumption and seeking to develop sustainable energy sources. Lifts are not the largest energy users in building, but are significant enough to warrant energy saving measures. Apart from environmental concerns, the financial cost of the electricity used by lifts is a major incentive for adopting energy saving designs. Energy savings do not necessarily have to result in a significant loss in performance.

Before considering green, energy saving control strategies, there are other aspects of the installation that should be considered. For instance, there is limited value in implementing energy saving lift control strategies if an inappropriate drive is selected.

Given that there is an appropriate basis for a green lift installation, various control strategies can be adopted in order to reduce energy consumption further. In this paper we have discussed strategies involving control of kinematics, reducing number of lift stops, and selective parking policies.

Simulation has demonstrated that each of these strategies will allow green control systems to reduce energy consumption significantly. The magnitude of savings is a function of the installation and traffic flow, so cannot declared absolutely. However, simulation suggests that installations with regenerative drives could achieve additional savings in excess of 30% without a major impact on the overall system performance.

REFERENCES

1. Peters R D "Green lifts?" *Proceedings of CIBSE National Conference 1994* (The Chartered Institution of Building Services Engineers), Vol. 1, October 1994, pp. 312-321.
2. Doolaard D A "Energy consumption by different types of drive system" *Elevator Technology 4, Proceedings of ELEVCON'92* (The International Association of Elevator Engineers), Vol. 4, May 1992, pp. 77-85.
3. Peters R D "Mathematical modelling of lift drive motion and energy consumption" *Proceedings of CIBSE National Conference 1995* (The Chartered Institution of Building Services Engineers), loose leaf insert
4. Zinke W "Planetary gear and frequency inverter set new standards in lift drive efficiency" *Elevator World,* January 1996, pp. 132-135.
5. Stawinoga R "New Mechanical Solutions for High Efficiency Gears" *Elevator Technology 5, Proceedings of ELEVCON'93* (The International Association of Elevator Engineers), November 1993, pp. 193-202.
6. Peters R D "Ideal Lift Kinematics: Complete Equations for Plotting Optimum Motion" *Elevator Technology 6, Proceedings of ELEVCON'95* (The International Association of Elevator Engineers), March 1995, pp. 175-184.
7. Barney G C, Dos Santos S M *Elevator Traffic Analysis Design and Control,* Peter Peregrinus, London, 2nd edition, 1985.
8. National Elevator Industry Inc., *7th Edition Vertical Transportation Standards,* 1994 Supplement.
9. So A T P "Computer Simulation-based Analysis of Elevator Drive Systems", *HKIE Transactions,* Vol. 3, 1992, pp. 13-22.
10. So A T P, Liu S K "An Overall Review of Advances Elevator Technologies", *Elevator World,* June 1996, pp. 96-101.
11. Zhou T "Analysis of Motion Equations of Elevator Drive Systems", *Elevator Technology 4, Proceedings of ELEVCON'92* (The International Association of Elevator Engineers), May 1992, pp. 306-315.
12. Powell B A "Important Issues in Up Peak Traffic Handling" *Elevator Technology 4, Proceedings of ELEVCON'92* (The International Association of Elevator Engineers), May 1992, pp. 207-218.

BIOGRAPHICAL DETAILS

Richard Peters studied for a BSc in Electrical Engineering at Southampton University. After graduation he joined Ove Arup & Partners where he participated in and led the design of electrical services for a number of major, national and international construction projects. Richard has recently completed his Environmental Technology Engineering Doctorate in Vertical Transportation which was sponsored by Arup and CIBSE. He now runs his own engineering consultancy and software company.

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