5. APPLICABILITY OF MODELS

5.1 INTRODUCTION

Now that models, relating the cooling process to the energy utilisation have been developed and verified, it is necessary to explain how they can be used to reduce the related energy costs i.e. what becomes important now, is to demonstrate the applicability of the models through the use of examples and illustrations.

Finon [50, p. 155] provides an explanation of the validity of models such as those developed in chapter 4: "an energy model can aid the planning activity by providing help at three stages of the energy system:

- ☐ *System behaviour*: predict system response to various inputs ('what happens if?').
- ☐ *System controllability*: manoeuvrability of the system with reference to decision-making variables ('what can be done?')
- ☐ *Policy alternatives*: generate different policy alternatives with respect to system outputs ('what shall be done?')"

To explain this, let's recap on the energy conversion models developed in chapter 4. For the purpose of simplifying matters, figure 5.1 on the next page shows the inputs and output of the complete set of models i.e. models 4.12, 4.16 and 4.23 combined. The inputs can be divided into two groups: *operational performance* and *equipment specific*. The operational performance inputs are those explained in paragraph 3.3, and specified in paragraph 4.5 as the elements affecting the building heat load (e.g. outdoor temperature, wall type, number of people etc.). The equipment specific inputs are those factors which influence the energy utilisation directly, such as C.O.P and power factor. The output of the model-set is the actual energy utilisation of the air-conditioning equipment.

From this it is clear that the energy utilisation can be determined if the operational performance and equipment specific inputs are known. Thus, by specifying one of the inputs as a variable and holding the other inputs constants, the effects of manipulating this input on the energy utilisation can be observed enabling system behaviour and controllability to be forecast, as well as alternatives to be sought.

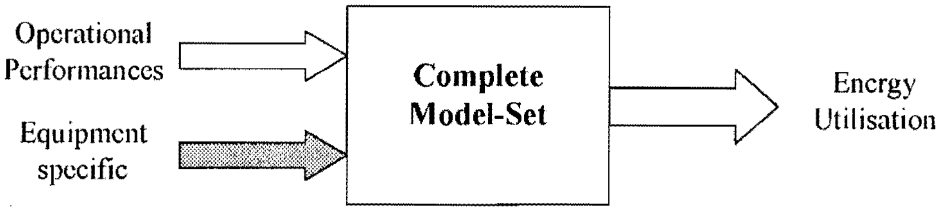

Figure 5.1 Inputs and output to the complete model-set

5.2 REQUIRED COOLING CAPACITY

Equations 4.12 and 4.16 provide the tool for calculating the cooling capacity required by an air-conditioning system to maintain a specified temperature set point. As such they enable the correct "size" air-conditioner to be calculated for a specific exchange. As an example consider Hillcrest exchange, with inputs as specified in table 4.1. The "total building heat load" (as specified by equation 4.12) is plotted in figure 5.2 below for a period of one day.

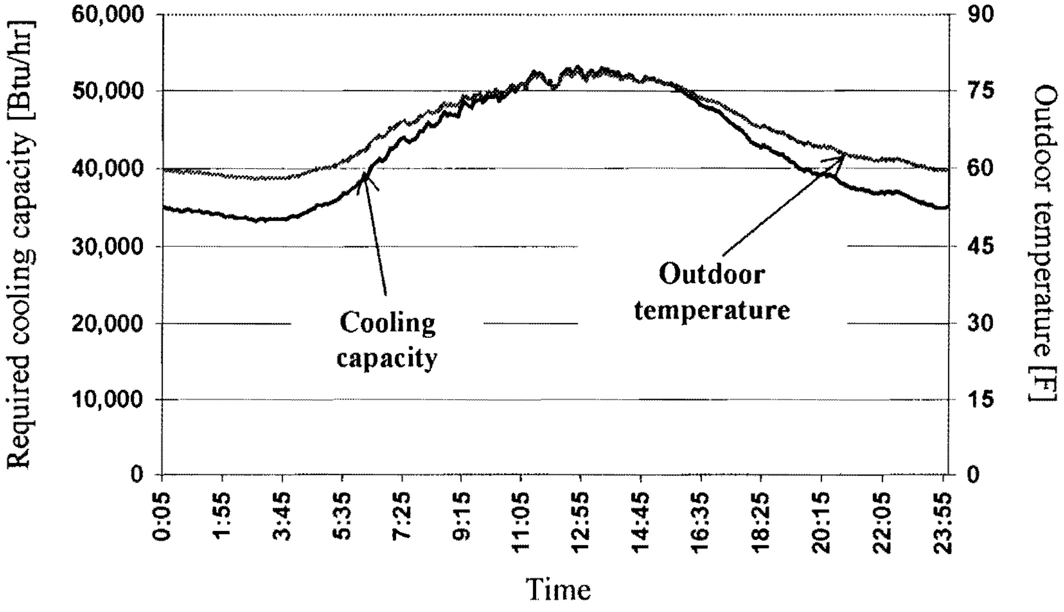

Figure 5.2 Required cooling capacity to maintain a constant temperature of 70 F (21 °C) at Hillcrest exchange for a period of one day

As a result of the ΔT term (which is the outdoor temperature (T_{Out}) minus the indoor temperature (T_{Exh})), the required cooling capacity follows the basic profile of the outdoor temperature. Since the indoor temperature is in fact the temperature set point (in this case 70 F) and is assumed to remain absolutely constant, and because the other terms in the equation are also fixed constants, it is clear that the cooling capacity will follow the outdoor temperature.

With the ability to plot graphs such as these, the applicability of the first two models becomes apparent – by specifying the required inputs to the models, the correct "size" air-conditioner can be determined by observing the maximum "required cooling capacity". That is, if an exchange is to be erected in a certain part of the country (with a particular climate), the required cooling capacity can be determined by specifying the appropriate inputs i.e. outdoor and set point temperature; number of installed telephone lines; number of lights; wall and ceiling type etc.

At this point it is important to qualify the phrase, "correct size air-conditioner", used above. That is, the air-conditioner's cooling capacity can be optimal for two very different objectives i.e. it can either be sized to meet operational specification, or to optimise energy costs. Finding the required cooling capacity for the former criteria is rather simple once graphs such as figure 5.2 can be plotted – by specifying the extreme conditions the exchange will be subject to, the peak "required cooling capacity" can be read off the graph, which in turn will be the required "size" to meet operational performance (i.e. temperature set point). In other words, this method calculates the absolute minimum "size" air-conditioner needed to maintain a specified temperature set point.

Calculating the cooling capacity for the latter criterion is not as simple. Sizing the equipment to optimise the energy costs involves a process known as TES (*Thermal Energy Storage*). This entails cooling the exchange below normal operating temperature during the cooler portions of the day (night and early morning). As a result, less cooling is need during the warms periods (daytime) since the air and equipment contained in the building, as well as the walls and floors, have "stored" this low temperature. This in turn enables reducing the air-conditioner's energy consumption during peak periods, and also lower maximum demand costs. Obviously, because lower temperatures are required, this type of cooling requires a larger cooling capacity than the previous scenario.

Thermal energy storage is however a large topic on its own and will not be focussed upon in this study, and as such will not form part of the literature to follow. It will be assumed that the air-conditioning equipment is "sized" to exactly meet operational specification.

5.3 INPUT MANIPULATION

Consider for the moment the effects of manipulating the exchange's temperature set point. If the set point is set as a variable and the other inputs to the models are held constant, the effects of altering the indoor temperature can be observed. This is accomplished by noting that the ΔT term in equation 4.12 is the outdoor temperature ($\mathbf{T_{Out}}$) minus the indoor temperature ($\mathbf{T_{Exh}}$), which is in fact the temperature set point.

Using equation 4.23, figure 5.3 on the next page shows load profiles of Hillcrest exchange's air-conditioning system for various set point values. Note that as the set point is increased, the power consumption decreases; this makes sense since the air-conditioners do not have to work as "hard". A value-added feature of these models is that they can also illustrate when heating instead of cooling is required – note that when the temperature set point is adjusted high enough, the power consumed becomes negative for certain times of the day (see before t_1 and after t_2). Although it is not possible for the air-conditioners to consume negative power, these "negative" regions do illustrate where heating instead of cooling is required.

This concept is easily conceptualised: if the temperature set point is set relatively low, the outdoor temperature is warm enough to enable ΔT to be positive for all times of the day. If the set point is now increased, there might be certain times of the day when the outdoor temperature is cooler than the indoor temperature; for these periods the ΔT term will be negative (implying heat is flowing out of the exchange). However, because of the additional terms in the equation (which are independent of temperature), this does not necessarily translate into a "negative power consumption". If the set point is now increased even further, the times when the outdoor temperature is cooler than the set point temperature will increase; this then carries more weight and as a result eventually causes the building heat load to be negative, which with the use of equation 4.23 translates into a "negative power consumption" for certain periods of the day.

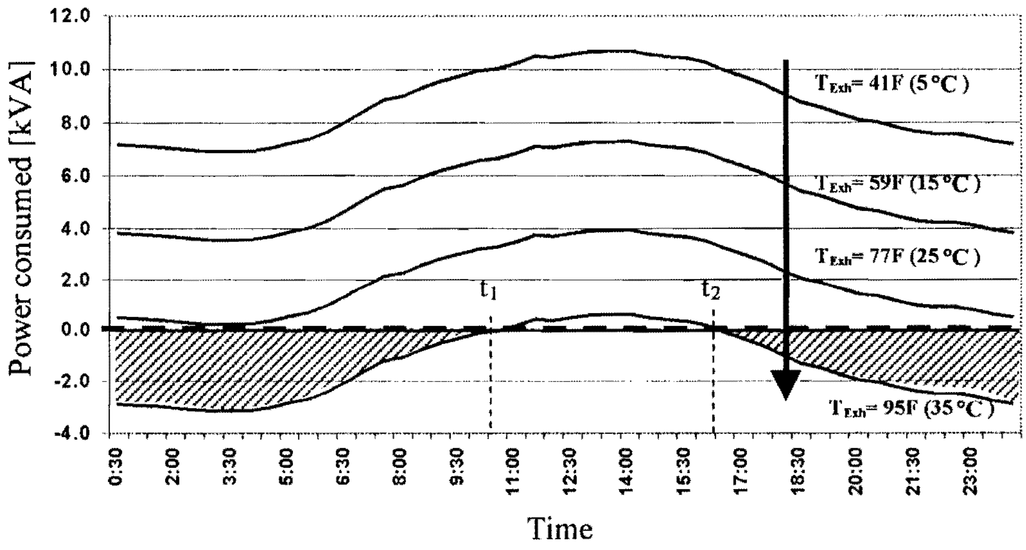

Figure 5.3 Load profile of the air-conditioning equipment versus temperature set point for a period of one day

By specifying other inputs (other than temperature set point) as variables, similar graphs as that shown above can be plotted. That is, load profiles for the air-conditioning equipment can be plotted as a function of inputs such as the number of people (personnel); power consumed for lighting; number of telephone lines; infiltration of air through doors and windows; wall and ceiling type, C.O.P, power factor etc.

It was mentioned in chapter 2 that two important quantities could be read from a load profile i.e. *energy consumption* and *maximum demand*. Thus from the load profiles that can be plotted using inputs as those mentioned above, the effects on the energy consumption can be observed. As an example consider figure 5.4 showing the air-conditioner's energy consumption versus the number of telephone lines installed in Hillcrest exchange. It was mentioned in the opening paragraphs and in the derivation of the models that most of the energy used by the telecommunication equipment is in fact converted directly into heat.

Hence, as the number of installed telephone lines is increased, so is the air-conditioner's energy consumption.

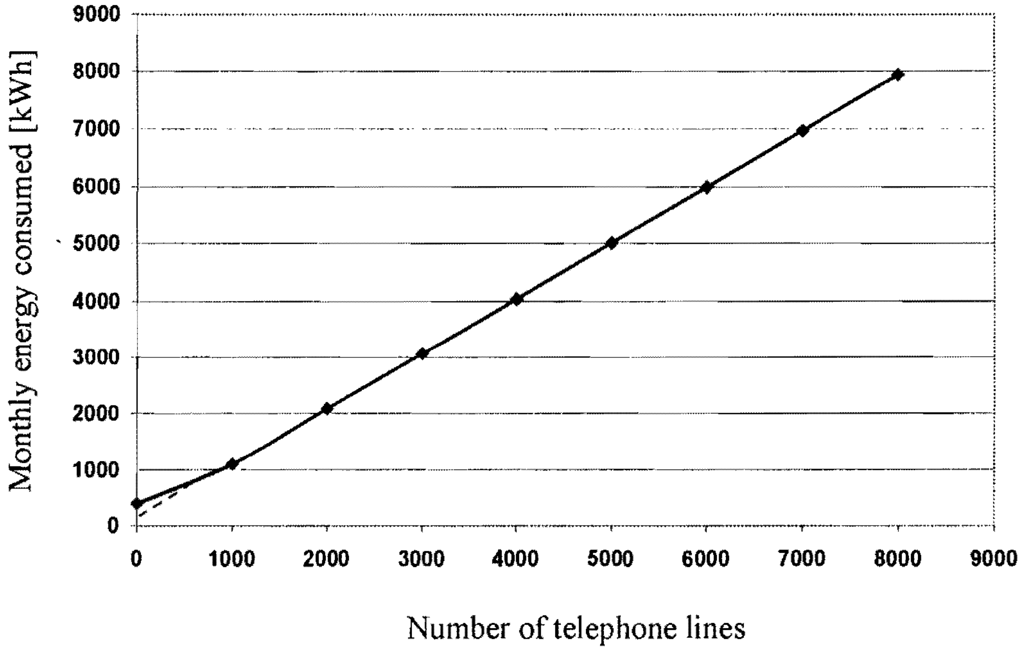

Figure 5.4 Monthly energy consumed by the air-conditioning equipment versus the number of installed telephone lines

Upon close inspection, it is noted that the gradient of the curve from 0 to 1000 lines, and 1000 to 8000 lines is different. The reason for this difference is that telephone lines contribute a large portion to the heat load; with less than 1000 installed lines a lot of heat is "lost" (as compared to 8000 lines) and when the outdoor temperature drops below the set point temperature at certain times of the day, insufficient heat is generated to maintain a constant indoor temperature. In this case additional heat needs to be generated by heating equipment. However the models do not take this equipment into account, and as a result the output of the models is equated to zero whenever there is a tendency for a "negative power consumption".

Graphs similar to figure 5.4 but with different input manipulations can be seen in addendum C. The reason for presenting them there is that there are far too many derivatives to be included in this study. Thus for the moment only the two examples provided above will suffice. None-the-less these do illustrate how the models can provide valuable information regarding the cooling of exchanges, but more importantly how manipulating certain key inputs can affect the air-conditioner's energy utilisation.

5.4 INTERACTION WITH TARIFFS

The most important aspect of having a tool such as the models presented in chapter 4 for energy management is that they can be used in economic analysis. With the aid of tariff structures the output of the model set (i.e. energy utilisation) can be translated into energy costs, and hence aid in the reduction of the electricity bill at the end of the month.

In paragraph 2.2.2 two tariffs structures were discussed, from these generic structures three derivatives have been implemented by Eskom (South Africa's utility supplier) i.e. *Nightsave*, *Miniflex*, and *Megaflex*. Due to specific criteria which have to be met, Telkom's exchanges can only be placed on either Nightsave or Miniflex. The costs associated with these tariffs are:

- Apart from a basic charge, monthly rental, voltage discount and transmission percentage surcharge, **Nightsave** charges customers for the total energy used per month, as well as a maximum demand charge for either kW or kVA integrated over a 30 minute period. The maximum demand charge for Nightsave is only applicable between 06:00 and 22:00 on weekdays.
- Customers using the **Miniflex** tariff are subject to a basic charge, monthly rental, reactive energy charge, voltage discount and transmission percentage surcharge. In addition they have to pay an active energy charge but no maximum demand (MD) charge. The main difference between Miniflex and Nightsave is that the energy cost varies on a daily time of use; these costs also vary according to two, yearly intervals i.e. *High Demand* (June – August) and *Low Demand* (September – May).

Using these tariffs it is possible to determine the air-conditioning system's monthly contribution towards the electricity bill by making use of the output of the model-set. That is, from the power versus time graphs (load profiles) that can be plotted (such as figure 5.3), it is possible to obtain the necessary information for the two tariffs i.e. active energy consumptions [kWh]; and the air-conditioner's contribution towards the maximum demand (MD) [kVA].

Consider for the moment the previous example explained in paragraph 5.3, where the number of telephone lines is adjusted. For this scenario, figure 5.5 below shows the air-conditioner's monthly contribution towards the electricity bill as a result of either Nightsave or Miniflex. **Note: all costs provided are exclusive of VAT, and are based on Eskom's 2001 tariff rates.*

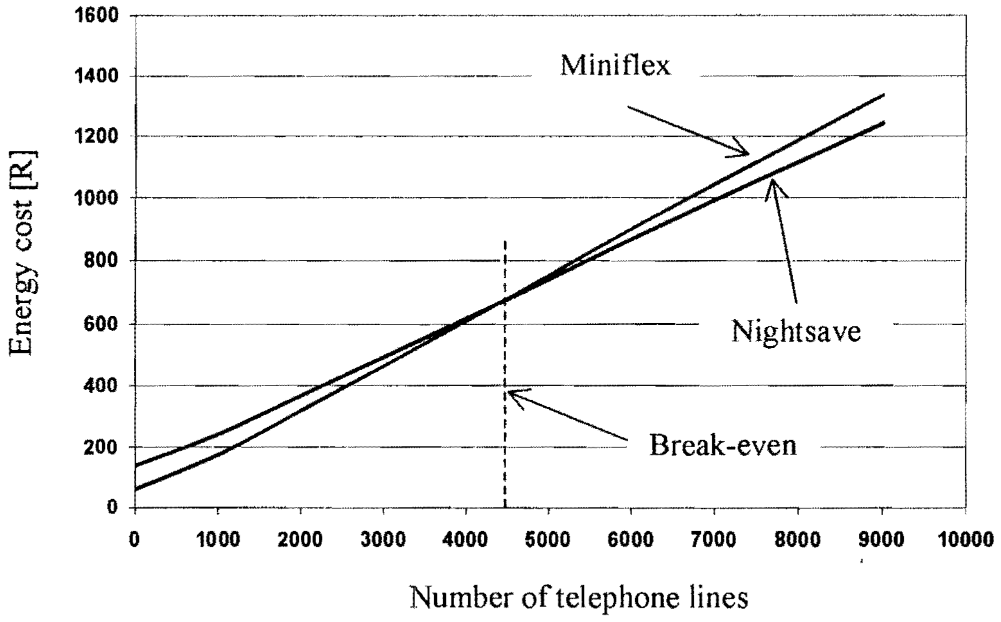

Figure 5.5 Air-conditioner's monthly energy cost contribution versus number of installed telephone lines

For illustrative purposes, a number of important aspects can be observed from a graph such as this. Firstly, it is clear that as more telephone lines are installed, the higher the energy cost will be as a result of the air-conditioner system having to work "harder". Secondly, the break-even point (if one exists) can be determined i.e. where the cost incurred as a result of Miniflex is the same as Nightsave. Thirdly, the rate at which the energy cost increases can be calculated for a specified billing tariff e.g. in this case it is R145 per additional one thousand lines per month on Miniflex, and R125 on Nightsave. Table 5.1 on the next page shows the rate at which energy cost increase as other operational performance inputs are increased.

	ENERGY COST RATE OF INCREASE PER MONTH							
	Hillcrest Exchange				**Bronberg Exchange**			
	Rand per Fahrenheit (T_{Exh})	**Rand per 1000 Lines**	**Rand per person**	**Rand per 1000W for lighting**	**Rand per Fahrenheit (T_{Exh})**	**Rand per 1000 Lines**	**Rand per person**	**Rand per 1000W for lighting**
Miniflex	-21	145	9	73	-75	135	12	67
Nightsave	-17	125	8	63	-76	136	12	68

Table 5.1 Energy cost rate of increase as a result of input manipulation

It is important to note that the '*Rand per person*' values are calculated assuming the exchanges are occupied 24 hours a day (this is the assumption used in the development of the models). Similarly, it is also assumed that the lights are on 24 hours a day. Note also that the '*Rand per Fahrenheit*' values have a negative sign because of the energy cost decreasing as the set point temperature is increased (see figure 5.3); all other values are positive because the cost increases as the variable is increased.

The above discussion was presented to explain the effects of manipulating the *operational performance* inputs, now for the first time the effects of manipulating the *equipment specific* inputs are discussed. Figure 5.6 on the next page illustrates how the monthly energy cost contribution is affected as the equipment's C.O.P is varied. In addition, figure 5.7 is presented to demonstrate how the system's power factor affects the energy cost.

Note that as the C.O.P of the air-conditioning equipment is decreased, the energy cost increases exponentially for both Miniflex and Nightsave. In terms of energy costs, it thus makes sense to have a system with a C.O.P as large as possible. Figure 5.7 illustrates that the energy cost is affected differently for Miniflex and Nightsave as the power factor is varied. This is because Nightsave, which has a MD charge, is strongly dependant on the apparent power (kVA's), and thus power factor i.e. as the power factor decreases, so the apparent power increases. Although Miniflex does not charge for MD, it still has a dependence on power factor in that the tariff imposes a *reactive energy charge*. This charges customers for the portion of the reactive energy (kvarh) consumed in excess of 30% of the active energy (kWh) consumed – this occurs at a power factor of 0.96. For both tariffs it is obvious that a power factor tending towards unity is desired.

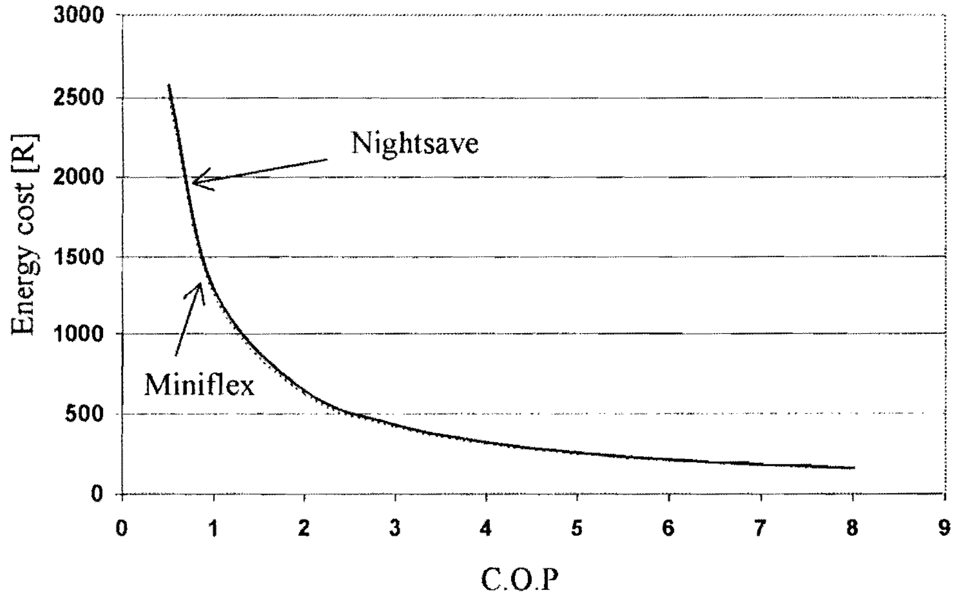

Figure 5.6 Energy cost versus C.O.P for Hillcrest exchange

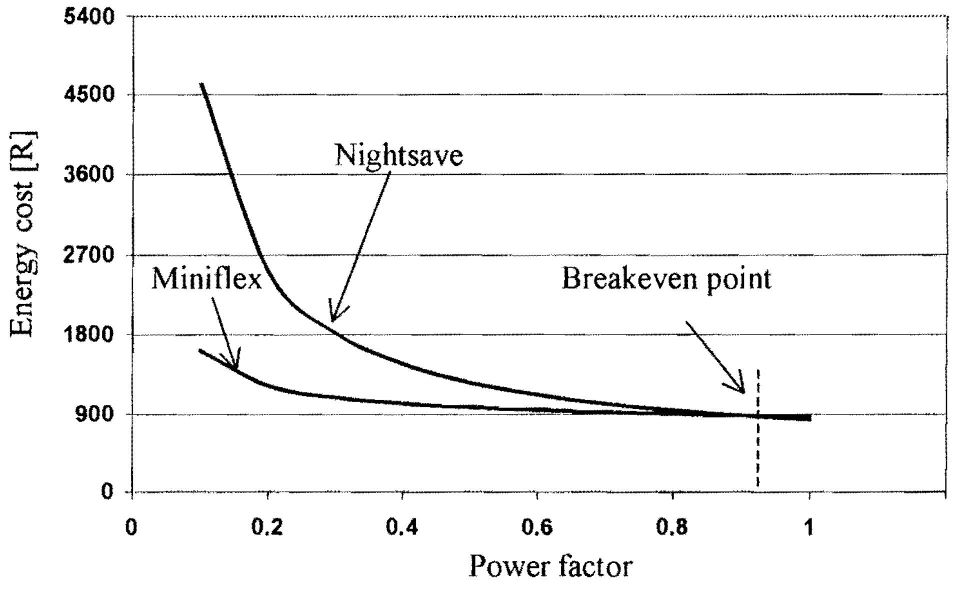

Figure 5.7 Energy cost versus power factor for Hillcrest exchange

5.5 ENERGY COST REDUCTION

The previous paragraphs explained how the energy utilisation and energy costs are affected by manipulating the operational performance and equipment specific inputs. However the discussions neglected to explicitly mention how energy cost savings could be implemented as a result. Cost savings can be realised in the following four ways: improved operational performance, improved equipment performance, correct tariff selection, and scheduling.

5.5.1 Operational Performance

From the examples presented previously, it is clear that energy costs savings can be forecasted by altering the operational performance inputs to the models. That is, by manipulating aspects such as temperature set point, wattage used for lighting, number of people, number of telephone lines, thermal insulation of walls and ceilings, and air infiltration through doors and windows, it is possible to arrive at a situation where maximum savings are realised.

As an example, consider the effects of personnel occupying Bronberg exchange. Assuming there are usually 40 employees working in the exchange, from table 5.1 it can be calculated that the air-conditioner's energy cost, as a result of people, is in the order of R480 per month. If a decision was made to relocate 20 of these employees out of the exchange, cost savings of approximately R240 could be realised. Although this does not seem much, if one considers that there are over 3600 exchanges situated countrywide, it is clear that this can translate into a rather large figure.

As another example, consider the temperature set point policy of the company – at present the guideline is to have the exchanges operate at 68 F (20°C). If however this is changed to say 95 F (35°C), which is still well within the ETSI 300-019-1-3 temperature specifications (see figure 1.2), Bronberg exchange can realise a cost saving of approximately R1 125 per month (which is approximately 3.2% of the electricity bill). Obviously, with the set point adjusted to this level, it would be impossible to have any personnel working in the exchange; meaning even more of a cost reduction can be realised (see previous example). If however mandatory work was needed (e.g. maintenance and/or repair), the set point could be lowered and thereafter raised again.

From the various operational performance inputs, it is clear that there are numerous ways of lowering the energy cost. Due to constraints however, only the above two examples will be discussed. These do however illustrate the applicability of the models for lowering the energy cost.

5.5.2 Equipment Specific

Large energy savings can also be achieved through improvement to the air-conditioning equipment itself. However, unlike the savings that can be realised through operational performance manipulation, this usually is accompanied by an initial capital outlay e.g. upgrading of equipment, improved maintenance etc. A financial decision thus has to be made as to the viability of the investment. Fortunately, a tool, in the form of the models presented in chapter 4 exists, which can provide great assistance in making a calculated decision.

For example, consider purchasing a new air-conditioning system for Bronberg exchange. The new system is to have an improved C.O.P of 2.00, as compared to the old system, which had a C.O.P of 1.62. An energy cost saving of R3,548 and R3,631 (roughly 10% of the electricity account) can be realised on Miniflex and Nightsave respectively. With this amount known, aspects such as payback period and cost budgeting can be calculated – providing valuable investment information. A similar discussion can be made when considering improving the system's power factor.

5.5.3 Tariff Selection

An additional way in which the models can be used to lower the energy cost is their ability to aid in the selection of an appropriate tariff structure. To completely understand this process recall figure 3.3 – once the operational performance and equipment specific inputs have been optimised through DSM activities, the tariff structure that will result in the least cost alternative can be selected.

To illustrate this concept, consider the effects of the number of installed telephone lines on the energy cost (figure 5.5). In the example a "break-even" point was illustrated – before and after this point the energy cost varied depending on the selected tariff. As a result, at certain points it would be more cost effective to be placed on a particular tariff i.e. in this example, at all points before the breakeven point it would be better be billed on Nightsave, all points after the breakeven point it would be financially more viable to be on Miniflex.

5.5.4 Scheduling

Massive energy cost savings can also be realised if TES (Thermal Energy Storage) is used. However, as mention in paragraph 5.2, because it is a new field and such a vast subject, an independent study needs to be conducted. None-the-less, a brief description of how this concept can be used to minimise energy costs is presented here.

For explanatory reasons a hypothetical time-line showing the various billing rates in a 24-hour day is presented in figure 5.8 on the next page. Included above this time-line is a diagram illustrating the process of TES and how the temperatures, and hence energy utilisation, are affected as a result. Note that, as mentioned before, TES requires that the building structure be cooled below "normal" operating temperature during the cooler periods of the day. Hence the air-conditioner is to operate (depending on its capacity) at full load. In terms of energy costs this does not matter because it is during the off-peak periods. Come peak periods (06h00 – 07h30 and 17h00 – 19h30), the air-conditioner can be completely switched off since the stored "cool energy" will keep the exchange within temperature specification (i.e. 41 F (5°C) to 113 F (45°C)). This then enables energy cost reductions to be realised through maximum demand (MD) reduction, and possible energy consumption reduction.

From this it is clear that there are two fundamental aspects that needed to determined in order to implement TES: (1) to what level should the temperature be dropped during the off-peak and standard periods, so as to prevent the temperature exceeding the upper bounds of the temperature specification when the air-conditioner is switched off during the peak periods, and (2) what will the optimal size air-conditioner be to implement TES successfully.

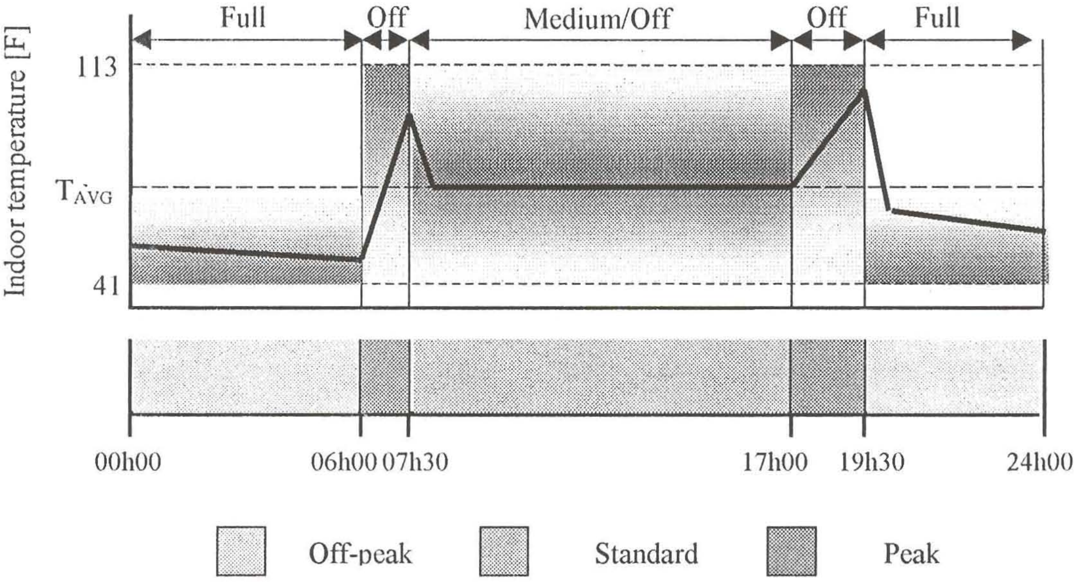

Figure 5.8 Reducing energy costs using TES

5.6 SUMMARY

The chapter was used for the purpose of illustrating the applicability of the energy conversion models developed in chapter 4. As such it described how the models could be used to (1) determine the required cooling capacity, and hence "size" air-conditioning equipment for a particular exchange, and (2) forecast energy requirements as well as the air-conditioner's monthly energy cost contributions towards the electricity bill.

In so doing, the chapter explained how energy cost reductions could be realised through manipulation of the operational performance and equipment specific inputs. For this to be explained it was necessary to discuss the two tariff structures available to Telkom i.e. Miniflex and Nightsave. These were then used in the energy cost savings analysis and hence quantified the effects of altering certain elements affecting the energy utilisation. Finally, specific target areas were discussed where energy costs savings could be realised i.e. operational performances, equipment specific, tariff selection, and scheduling.