3. MODELLING METHODOLOGY

3.1 INTRODUCTION

Correctly predicting alterations to the process of HVAC (energy utilisation, operating schedules etc.) resulting in energy efficient solutions solely depends on an abstraction that completely describes the system and the processes involved. According to Rose [43, p. 1] such an abstraction of a real world process is called a mathematical model i.e. any process or system described in mathematical terms is called a mathematical model. Since the study focuses on energy related models, they will be of the energy conversion form, and are thus more aptly called *energy conversion models*.

Broadly speaking, the purpose of this chapter is to present a methodology for the development of energy conversion models relating the energy utilisation of the air-conditioning equipment to energy costs. In so doing provide a DSM tool that will enable cost effective energy configuration, schedules and tariffs. The methodology will ensure that the models are developed in such a manner that they represent the processes with acceptable accuracy without being too complicated.

3.2 CONTEXT OF MODEL DEVELOPMENT

According to Delport [30, p. 1], energy conversion models represent the energy engineer's view and understanding of the real world system. It is thus clear that the models that describe the processes or systems need to be as accurate as possible, so as to provide a realistic approximation of the actual real world. For this to be possible, the development of the models needs to be kept within the context of the real world, which they are to represent. For this purpose figure 3.1 on the next page graphically represents the operational hierarchy of the context of energy models.

In terms of this study, the *system* would be the HVAC plant installed in an exchange and the *processes* would be the activities needed to control the internal environment, more specifically temperature levels. The interaction and interdependence between these two elements of the hierarchy can be defined as *operational performance* (i.e. maintaining the environment within specifications). Energy usage values are outputs of the *system* and inputs to the *plant*, which in this case would collectively represent a telecommunications exchange. The uppermost element in the hierarchy is the *organization*, which is comprised of all the *plants* (exchanges) situated around the country. For the purpose of the study this element is concerned only with managerial considerations and for this reason the interdependence with the *plant* is primarily monetarily based i.e. *energy costs*, the reduction of which is the fundamental objective.

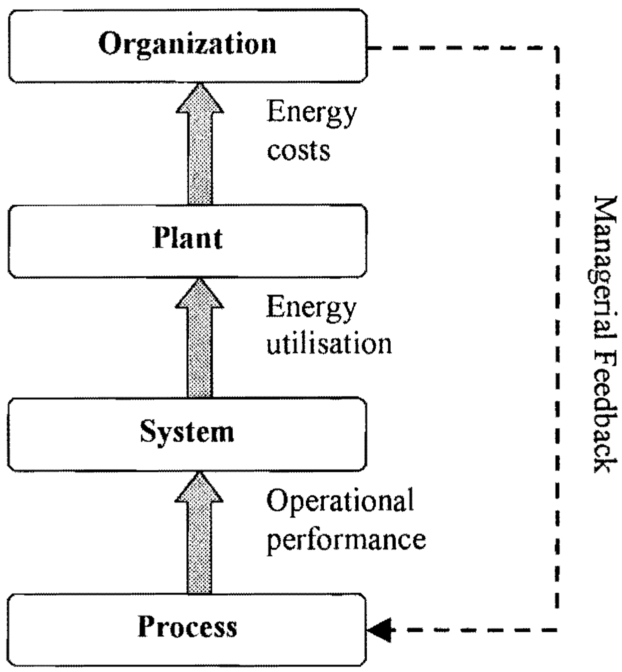

Figure 3.1 Modelling Context

The primary objective of any organization is to maximise profits, for this reason there needs to be continual feedback from the upper organisational hierarchy to the lower elements of operation. Thus, in terms of the organization's energy policy, decisions are based in terms of performance and profit margins. In this context, it is easy to understand that an evaluation tool is needed to aid this decision-making process. That is, a model that can completely describe the relationship between the respective processes and the organization as a whole is needed.

3.3 IMPACT OF OPERATIONAL PERFORMANCE ON ENERGY COSTS

3.3.1 Energy Costs Versus Operational Performance

Since the primary objective of the study is to lower the energy costs of HVAC through DSM, the models are to represent the operational performance relationship with economic aspects of the cooling process. From the modelling context, such a relationship will in fact form the pivotal point for the development of the models. The relationship between the operational performances of the *processes* and the energy costs of the *organization* can be collectively described by the energy conversion models as shown in figure 3.2.

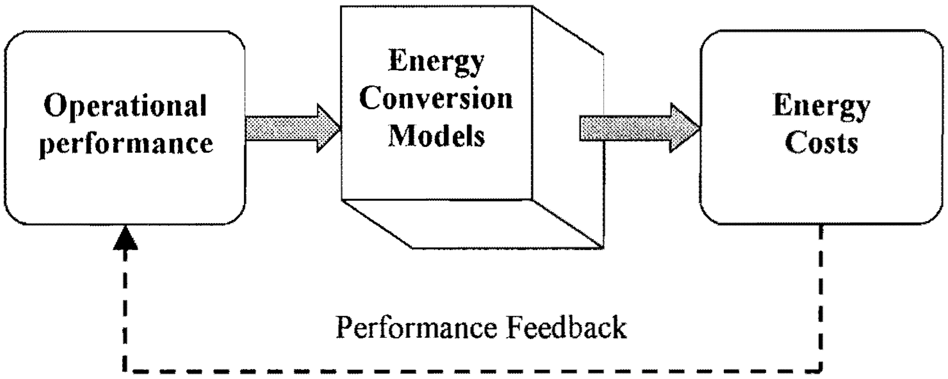

Figure 3.2 The interdependence between operational performance and energy costs

It is easy to understand that a strong relationship between operational performances and energy expenditure exists. Since there is this interdependence, a mathematical abstraction in the form of energy conversion models can be constructed to closely approximate this relationship. Changes in operational performances, such as altering temperature set points, have a direct influence on the air-conditioning equipment's energy consumption, and hence energy costs. These alterations can obviously have a negative or positive influence on the energy costs, and thus on the organization's profit margins. For this reason there needs to be continual feedback ensuring only positive influences are induced.

This relationship between the operational performance and energy cost can be modelled in a number of ways i.e. Murphy and Groncki [44, p. 91] suggest that because there is a definite relationship between energy and cost, such models can be modelled in one of the following two ways:

- *Capturing Energy-Economy Interactions*: this is the complete capturing of the full general equilibrium interactions between energy and economy in a single set of complex models.
- *Linking Energy Models*: this is the building of individual models for the energy and economic relationships separately. As such the outputs of the one set of models forms the input to the other.

For the purpose of this study the latter option was chosen for the sake of conforming to a modular approach, which will be discussed in detail in paragraph 3.5. Following this methodology also allows experts to focus on their field of expertise i.e. they are able to concentrate only on the models relevant to their specific needs.

3.3.2 Minimising Energy Costs

Figure 3.3 was drawn up to provide a visual understanding of how energy costs are to be minimised. For the sake of simplicity, the operational performances (which will be discussed during and after the development of the models in chapter 4) that are to influence the energy costs are merely represented as "*inputs*" for the moment. Of importance here, is the methodology followed ensuring energy cost savings are incurred. For the sake of clarity, note that the figure represents the interdependence of the *systems* level with the *organisational* level in figure 3.1; and as such it explains the relationship between the energy utilisation and energy costs.

The implementation of demand-side management requires that a complete understanding of the energy utilisation be known. This necessitates the understanding of energy consumption levels, rate of energy consumption (power levels), and load profiles. Hence, the outputs of the energy conversion models need to be energy and power values.

Dictating the energy costs at the end of every month is a specified billing tariff. Paragraph 2.2.2 discussed numerous such tariffs, each of which has its own billing structure. This provides a practical means of reducing the energy costs – by manipulating the energy utilisation (energy and power consumptions, and load profiles) through various demand-side management activities, and selecting the most appropriate tariff structure, maximum energy cost savings can be realised.

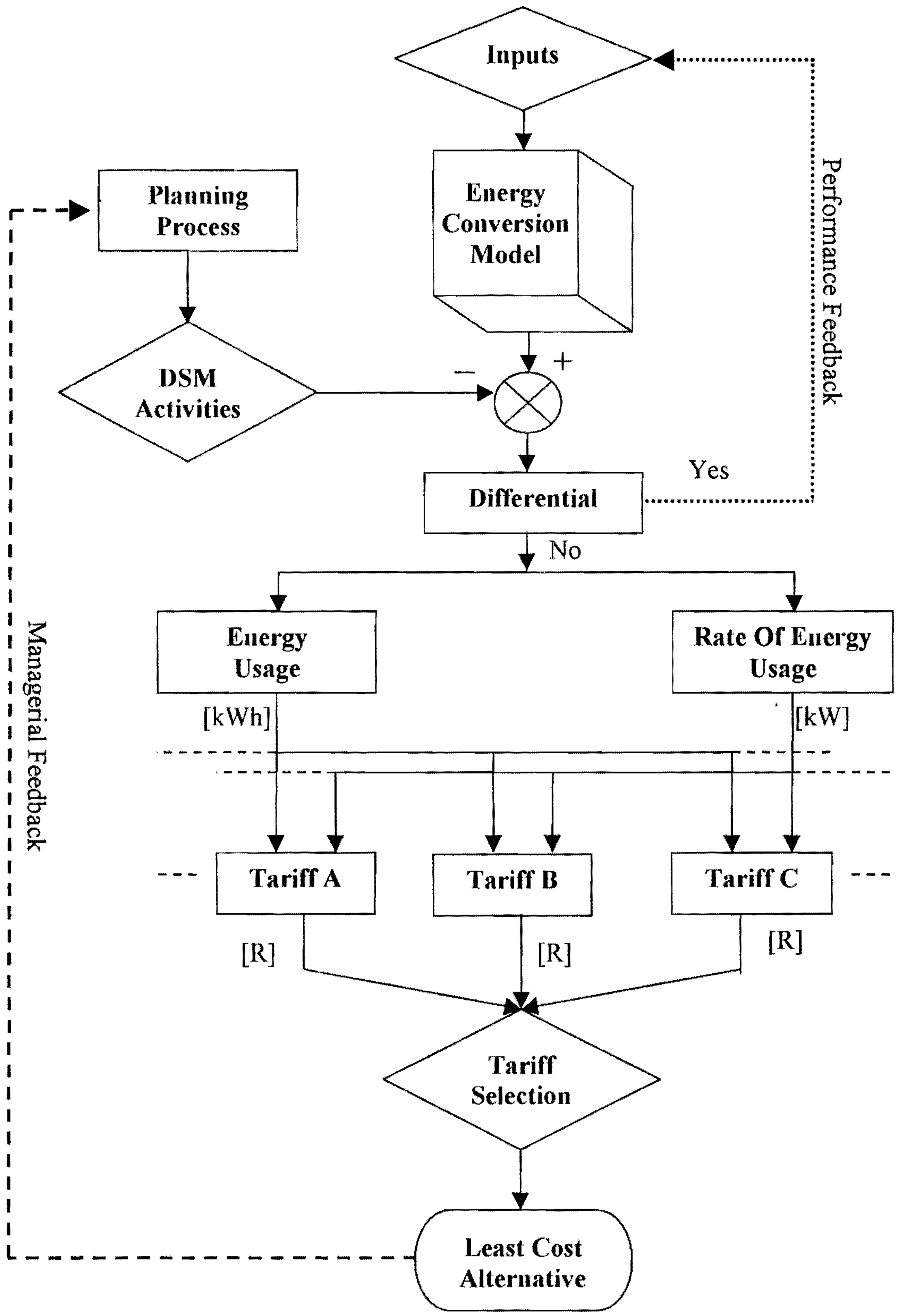

Figure 3.3 Finding the least cost alternative

The problem is, there needs to be a way of predicting if the applicable DSM activities will indeed result in savings. The function of the energy conversion models is precisely this – various variables (i.e. *operational performances*) can be used as inputs to the models and the outputs observed. If these theoretical outputs concur with what is required by the DSM activities, the appropriate tariff structure can be selected using these outputs to ensure maximum energy cost savings. However, if the outputs do not agree with the suggested DSM activities, the operational performances need to be reconsidered until they are in agreement; this explains the "*performance feedback*" illustrated in the figure (note this feedback is the same as that shown in figure 3.2).

3.4 SYSTEM BOUNDARIES AND CONSTRAINTS

According to Murray [45, p. 28], in order to keep a clear perspective of the system being modelled, finite system boundaries must be identified. Any system, which is being modelled has certain inputs, which are obviously part of or relevant to the system. He goes on to mention that these inputs are either internal to a direct system boundary, having a direct influence on the processes, or to an ultimate system boundary, which would mainly consist of environmental factors and indirect influences such as managerial constraints on the specific system.

3.4.1 Boundaries and Constraints

To clarify where these boundaries exist in context of the models it will be poignant to describe them in terms of figure 3.1. Figure 3.4 on the next page demonstrates the direct and indirect system boundaries, as well as the environmental influences for the modelling at hand in terms of system context. It is important to note that the boundaries may vary if different objectives are required, such as if the processes themselves rather than the system are modelled, in which case the direct system boundary would be at the *process-level* and the ultimate boundary would either be at the *plant* or *organization-level*. For the modelling at hand however, which requires the models to describe the system (e.g. air-conditioning system) rather than processes, the direct system boundary and ultimate system boundary are defined at the *system* and *organization-level* respectively.

3.4.2 Modelling Inputs and Outputs

The *direct inputs* are defined as those influences which are within the direct system boundary, and which have immediate effect on the model outputs i.e. they are essentially the 'operational performances' mentioned in paragraph 3.3. The *indirect inputs* are process and system limitations, and system specifications. *Environmental influences* are the "outside" influences affecting the model outputs, and which there is no control over. These are aspects such as managerial constraints and limitations.

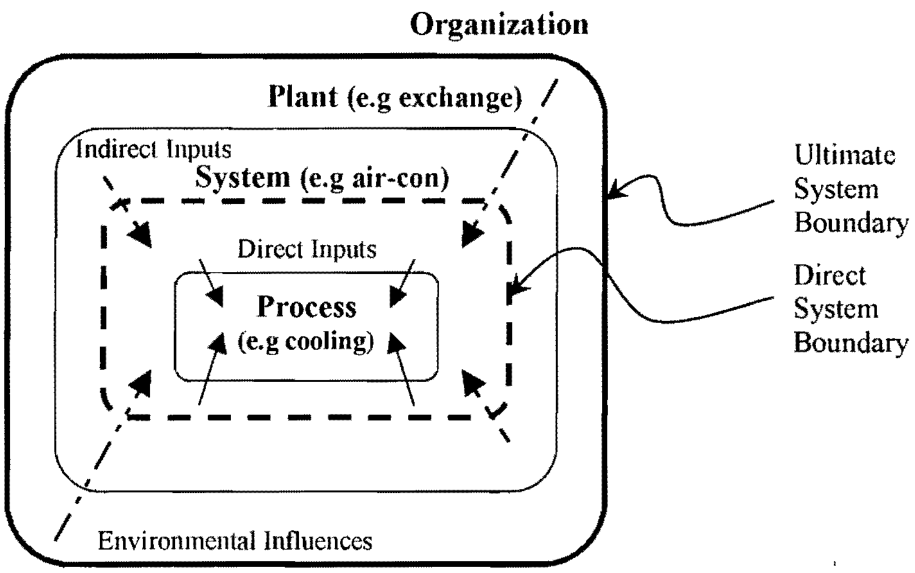

Figure 3.4 System boundaries and inputs

3.5 CONSTRUCTING ENERGY CONVERSION MODELS

3.5.1 Introduction

Hogan and Weyant [46, p. 4] suggest that the development of energy conversion models should posses the following set of criteria: (1) they should be based on a *consistent theory*, for the development and use thereof; (2) to simplify acquisition and application of the data, they should follow the *natural organization* of the data; (3) a very desirable quality, is that they should by *modular in form* to ensure system integrity when individual components are considered; (4) they should be *decentralised* enabling experts to concentrate on their own field of expertise; (5) they should *promote efficient* computation in both development and application.

3.5.2 The Building Block Approach

In keeping with these criteria, Delport [30, pp. 10 – 14] provides a holistic approach to developing energy conversion models using the "Building Block" approach. This methodology enables the development of the models to be modular in nature and thus have immense applicability when considering different systems with many processes – considering figure 3.1, it allows the *processes* to be modelled individually, yet at the same time enable them to be integrated with others to describe the *system*. Similarly, because of the modular nature, various *systems* can be integrated with each other to represent a *plant*, which can then also be used to describe the *organization*.

The approach states that each identifiable process of a particular system can be modelled as a building block consisting of a specified *storage buffer* and a *process*. As an example, consider figure 3.5 modelling a centralised water-cooled air-conditioner's ability to lower the temperature of an exchange. The storage buffer in this case would be the amount of cold water contained in the chiller's storage tanks; the process would be the actual process of lowering the exchanges temperature.

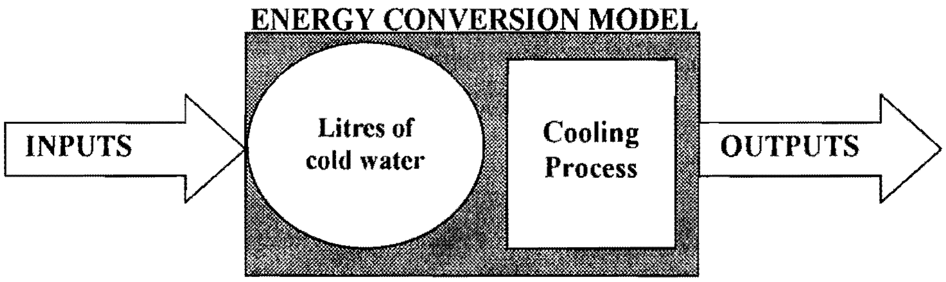

Figure 3.5 Example of modelling an air-conditioner's ability to cool an exchange using the Building Block approach [3, p. 8]

In the above example, if a DX (Direct Expansion) air-conditioner that uses CFC's is modelled instead of a water-cooled system, the buffer in figure 3.5 is equated to zero i.e. a *zero-buffer*. In a DX system there is no storage mechanism of any kind – once the air-conditioner is switched on, the process of cooling begins, there is no thermal storage of any kind. Thus in the 'building block' only a process would be included, and no buffer.

A crucial factor governing the development of any such modules (models) is that they need to be completely compatible with each other, in any configuration i.e. the inputs and outputs of each individual module must conform to a specified standard established for the entire system.

From the discussions above it is clear that using this methodology to develop energy conversion models adheres to all the criteria pointed out in paragraph 3.5.1. For this reason this approach will be followed in chapter 4 where the development of the required models are undertaken.

3.5.3 Acquisition and Processing of Data

Figure 3.6 on the next page presents a flow chart of how models are to be developed using this methodology [45, p. 24]. The graphical representation illustrates that the development stage of the model requires a number of inputs, namely theoretical knowledge, manipulated real world data, and a refining input from previous model trials. The output is of course the actual model.

In the development of the model, it is necessary to obtain theoretical knowledge as well as real world data for the processes involved. That is, all scientific information pertaining to existance, operation and limitations need to be gathered and interpreted in conjunction with real world data. This includes basic physics and applied theory for which ever process the model is being developed.

Models will in general be developed from a theoretical standpoint, but cannot be totally independent from the real world. Knowledge of permissible values such as limitations, efficiencies and managerial aspects all need to be taken into account. Once all information has been interpreted and related to the physical process, a relationship between input and output can be established from which an explicit model is developed.

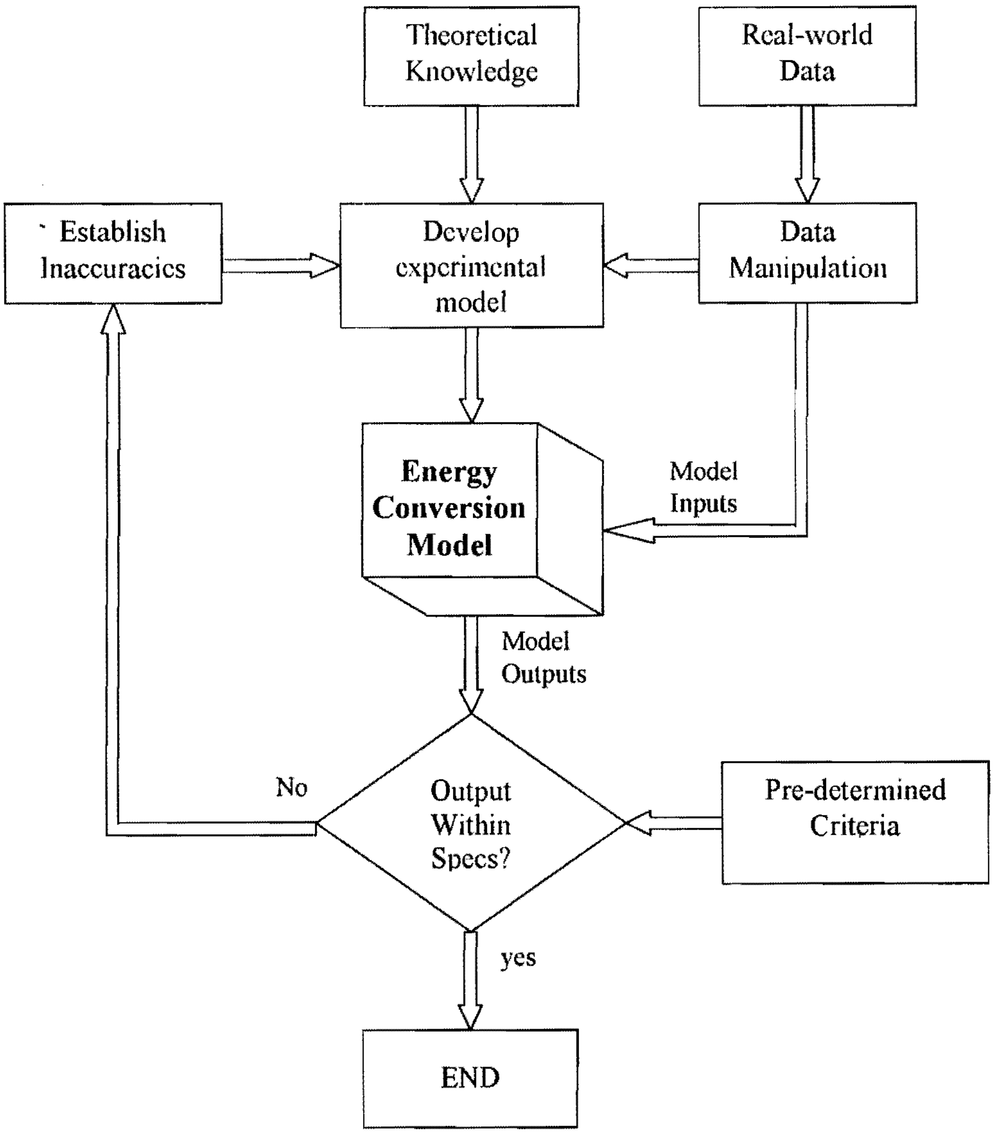

Figure 3.6 Model development flow chart [45, p. 24]

Once the model has been developed, it needs to be verified and tested. Since the model represents a relationship between input and output of a real-world process, it needs to be tested in the real world to confirm that the relationship is valid. Usually it is not possible to include each and every process in the model, it is either impossible to identify all the processes, or the model will be too complex. As a result, there will always be a slight discrepancy between the model outputs and the real world process.

3.6 SUMMARY

The chapter provided a detailed modelling methodology for the development of the energy conversion models pertaining to the cooling process of exchanges. It illustrated how the models fall into the context of the organisational hierarchy, and as such explained the relevance of the models to describe the operational performance/energy costs relationship. A flow diagram was presented that illustrated how maximum energy cost savings can be incurred as a result of DSM and correct tariff selection. In so doing it laid out the methodology to be followed to ensure the most cost effective manner to operate the air-conditioning equipment.

Thereafter the methodology for the development of the actual energy conversion models was presented. The "Building Block" approach, described by Delport [30], was selected for the development of the models. This approach ensures that the models conform to the criteria provided in paragraph 3.5.1.

Now that the methodologies have been completely described, the following chapter delves into the development of the models according to the method. As will be explained, the models consist of three modules that will completely describe the air-conditioning equipment and the processes involved; enabling the energy cost reduction of this end-user through DSM activities.