ENERGY CONSUMPTION IN A PHARMACEUTICAL FACTORY AND PROPOSALS FOR A REDUCTION IN RUNNING COSTS

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A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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ABSTRACT

An investigation was carried out on a pharmaceutical factory which is still in the construction stage to quantify all the sources of energy usage. The major energy consumers were investigated and comparisons carried out with international standards to see if improvements are required.

The Performance Indicator of the building was determined as 1,666 GJ/m^2 per operating year by simulating energy consumption.

A correlation between ambient dry bulb and building cooling electrical demand were established.

A monitoring and targeting instrumentation schedule was proposed after defining a targeting philosophy.

The proposed building services were analysed and possible energy cost saving investments were identified and analysed by different costing models to see the effect of the costing model on the type of proposal.

The two proposals which showed financial viability are firstly, the removal of dehumidifier heat with evaporation which showed an electrical energy saving of 965,76 MJ p.a. and a payback period of 2,9 years and secondly, the installation of high efficiency lights which showed a electrical energy saving of 76 MJ p.a. and a payback period of 0,62 years.

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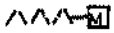
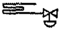
LIST OF SYMBOLS

	AIR FLOW SENSOR
	MOTORISED OPPOSED BLADE DAMPER
	MODULATING STEAM HEATING COIL
	COOLING COIL (CHILLED WATER)
	FAN
	FAN WITH VORTEX DAMPER
	VOKES SUPERVEE PANEL FILTER
	VOKES 22 MA ABSOLUTE FILTER
	VOKES UNIVEE 3.FINE BAG FILTER
	DRYING WHEEL OF ROTAIRE M10 000 DEHUMIDIFIER
	THERMOSTAT
	PRESSURE SENSOR
	HUMIDISTAT
	ELECTRIC HEATER
	VARIABLE VOLUME AIR SUPPLY OUTLET
	NON RETURN DAMPER
	FAN
	ENTHALPY SENSOR
	CONTROLLER
	VOKES UNIVEE 2 FINE BAG FILTER

CHAPTER 1

INTRODUCTION

A considerable amount of time is spent throughout the Western World on minimising the consumption of energy. This tendency started during the OPEC cartel price fixing of the mid-seventies and continued with more or less vigour as the oil price fluctuated. The art of managing energy turned into an autonomous field of activity and is now known as Energy Management.[1)]

The main aim of energy management is not to minimize the consumption of energy, but the minimization or optimization of expenditure on energy. This anomaly can be illustrated by the rules of buying energy i.e. tariffs. In South Africa electrical energy is generally paid for in terms of a maximum demand measured over a period of one month, six months or even one year, plus the cost of units of energy consumed generally on a monthly basis. In Great Britain, for instance, some electrical tariffs are based solely on units of energy consumed. An anomaly therefore exists with the present structure that payment is not effected for the use of non-renewable energy. It is evident that the aim of energy management is to optimise energy costs per unit of production.

The above then implies that the Energy Manager should exploit the various methods of paying less money for energy, firstly by studying the tariff structures open to him, secondly by conserving energy, thirdly by recovering waste energy and fourthly by relaxing process and comfort environmental conditions to consume less energy.

In South Africa due to the very low cost of coal, the unofficial condonement of the use of coal (very low key official action against environmental pollution) and the availability of coal as an indigenous energy resource has made most energy consumers pay only lip service to energy conservation, energy recovery, and where it does not affect production costs, energy management. On the other hand efficiently run organizations have spent a lot of time, effort and money to minimize energy costs to keep their competitive edge in the market place. However, the cost of primary energy is still so low that energy reclaim is only applied whenever a great abundance of energy in the right form is available.

Due to the steady and regular increase of the cost of energy, even the cheap energy sources like coal, a greater awareness of energy conservation, optimization of energy costs and energy reclamation is starting to occur in South Africa. In the nineteen seventies and early eighties, with the economic boom, very little time and effort was spent on anything but producing enough. Today many plant operators are taking a hard look at every avenue available of minimizing production costs. The present economic climate and the creeping costs of energy is forcing everybody to take a hard look at opportunities to cut costs. In future years the tendency will escalate because conservation must become way of life. This is a logical conclusion if the limited reserves of coal, the prohibitive cost of nuclear power, the limited reserves of oil which has b discovered and the capital limitations of South Africa to further thermal power stations is considered.

As South Africa emerges from being a third world nation and more technical people become available to operate the technologically more intricate plants the reliability and therefore the acceptability of the mc complex plants will improve and become more commonplace. This t. hnology is available either from overseas or from specialised South African institutions like the Chamber of Mines Research Laboratories, the CSIR or in house research facilities. The concept is not foreign to South Africa, but the combination of history and inertia to change has sunk many a good proposal.

When the opportunity arose to design a pharmaceutical plant for Messrs Reckitt and Colman in Durban all indications were that this plant will be a large energy consumer. Specialised buildings, environmental requirements, electrical requirements and process requirements made the integration and optimisation of energy consumption an interesting proposal.

In the design brief a definite upper limit of money available was imposed on the project and the whole design team had to keep this objective in mind. This monetary restraint made the ultimate in design out of the question and, within the scope of the installation, energy management sometimes had to take secondary importance.

The aim of this report is to analyse the present installation and see to which norms the air conditioning design complies with. The design will be analysed on the following aspects :

Building process
Manufacturing process
Environmental requirements
Air conditioning installation

In order to do this the following steps are desireable. Estimate energy consumption of the building services on a monthly basis, identify and quantify the users of energy and compile an energy performance indicator.

Opportunities where energy could be saved should be identified and quantified to see the amount of energy that could be saved on a yearly basis.

Opportunities to save money on energy consumption and energy consumption patterns should be investigated by defining the electrical costing structure. Then, by applying different financial costing models to determine which of the energy saving proposals are cost beneficial the relative advantage of each of the proposals may be determined.

A monitoring and targeting schedule of instruments and plan of action should be drawn up to be able to institute a positive energy consumption feedback and targeting management system.

CHAPTER 2

BUILDING REQUIREMENTS

2.1 BUILDING ENVELOPE

The building envelope has a decisive influence on air conditioning cooling and heating capacities[2] and therefore on plant size i.e. capital costs and running costs.

No South African national directive exists on acceptable construction standards for conservation of energy. The information available on construction standards are the National Building Regulations[3] which cover the aspect of structural strength for public safety, ventilation openings for occupant health, sewer standards for hygiene etc, but no insulation values or construction standards for energy conservation.

Typical standards used in this country for the design of an office building are as follows :

Windows	20% of facade area	good
	40% of facade area	average
	0,3 shading coefficient	good
	0,8 shading coefficient	average
Walls	U value 1,8 W/m^2 ^{o}C	good
	U value 2,8 W/m^2 ^{o}C	average
Roof	U value 0,7 W/m^2 ^{o}C	good
	U value 1,5 W/m^2 ^{o}C	average

The above is not really applicable to factories, because process requirements do have an influence in the design of fenestration for a factory and even the Factories' Act[4] makes provision for a windowless factory if a process demands no daylight, although for normal factories the window area must be equal to 15% of the floor area. This value is a standard requirement.

The leading acceptable practice for construction of buildings is the ASHRAE STANDARD 90.[5] Although other codes are also in existence [6] [7] [8] this code of practice was drawn up after the oil price increases of 1973. The first recommendations were published in 1977 with updates till 1984. Being a United States of America standard it is not altogether applicable to South African conditions, but it gives a good indication of what is an acceptable standard. A comparison of how our building envelope compares to this standard gives a good indication of how this building compares to American buildings. The standard makes use of a degree day method[9] to determine insulation values.

According to the ASHRAE Standard the building must comply with the following values

Walls	U value	=	2,2 $W/m^2\ ^oC$
Roof	U value	=	0,57 $W/m^2\ ^oC$

The actual values for the building considered in this report are as follows

Walls	U value	=	1,5 $W/m^2\ ^oC$
Roof	U value	=	0,6 $W/m^2\ ^oC$
Window to facade ratio		=	7%

These values compare well with, and on walls exceed, the ASHRAE Standard 90 prescribed values. From a thermal point of view the building envelope can be considered to be in the South African state of the art category.

The difference between American and South African values can be attributed to the South African climate, because overseas building insulation has evolved from the heating of buildings and not from the cooling of buildings. Due to our short winters heating has never been a cost factor to the extent experienced in the United States of America and therefore has not influenced building designs to the extent that it has in America and Europe.

2.2 MANUFACTURING PROCESSES

The production facility has been planned to manufacture the following products:

Gaviscon powder in sachets
Gavison tablets in bottles or sachets
Gaviscon liquid in bottles or tubes
Fybogel powder in sachets
Fybogel tablets in bottles
Disprin tablets in bottles or sachets
Disprin X tablets in bottles
Codis tablets in bottles
Senokot tablets in bottles

The above products all consist of a chemically active ingredient stabilized or tabletised with large quantities of inert material, sweetener or preservative. The chemically active ingredient in Disprin is Acetylsalicylic Acid for example. These ingredients are made in laboratories under special conditions and arrive at the factory pre-packed, tested and lot numbered. Although this is the pharmacologically active ingredient, the production facility receives these material as a final product to be further processed for human consumption.

The reasons why these two processes are separated is firstly to prevent any contamination from one facility to the other. Secondly the active ingredient is a small portion of the finished product and therefore the quantities required for a production run can be produced under laboratory conditions. Thirdly, quality assurance before dispatch is much more easily controlled, because no uncontrolled movement of material is possible. Of secondary importance is the completely different type of manufacturing processes between fine chemistry and tablet production.

The additives to the chemically active ingredients are pharmacologically inert substances, or preserving substances to ensure chemical stability of the active ingredient. Some of the substances are used to flavour the product. The bulk of the material handled is starch, saccharine, chalk, citric acid and calcium carbonate, and the only requirement of these ingredients is that it reaches the production facility without contamination, and at an acceptable level of purity for human consumption.

The production facility has been designed to produce powders in one area, liquids in another area and Senokot in a completely seperated area. The isolation of Senokot is necessary, because senna powder is yellow and a natural laxative and contamination of other product lines can be a serious problem.

The production facility is also designed to operate on a batch production principle. The batching of production is necessary and each tablet, sachet or tube must be traceable to ingredient batch numbers according to the inspection authority of the Department of Health. This requirement first of all requires a very intricate and thorough system of production tagging, checking and inspection, but it also implies that many inspection stations must be operated in the production line to carry out the necessary inspections.

Due to the above, the whole production facility has been designed around bins, hoppers, buckets and pallets which implies substantial internal transport by forklift, machine and human power. The advantage of this system is flexibility in the production of different types of products or changing production mixes or products.

The first major operation is the weighing and homogenation of ingredients. This is carried out by dispensing big volumes of inert material in tote bins, sieving the material to ensure homogenity and then restoring it to a tote bin for processing. The inert and chemically active material are still in separate tote bins after dispensing, the first sieving operation being only to establish homogenity.

The manufacturing processes then separate into different type of production processes, mainly due to different environmental requirements of the various products. The general sequence of production is then to blend the ingredients, mix thoroughly with a high energy mixer, add binding agent, tabletize and finally pack either in bottles or seal in foil.

2.3 PROCESS REQUIREMENTS

The different production lines have very distinct environmental requirements for each line, as well as for some processes of each line.

The most important environmental requirem[illegible] all processes is that no contamination occurs [illegible]ient conditions. This requirement is met by filtering all ambient air (i.e. fresh air) and return air from the production facilities through filters with the required arrestance and dustholding capacity. Generally these filter banks consist of pre-filters, medium class bag filters and then high efficiency particulate air (HEPA) filters. The aim is to filter to 5 micron particle size. The pre-filters and bag filters are to protect the HEPA filters, because HEPA filter, although an excellent arresting medium, has a very poor dustholding capacity.

The building is also overpressurised to allow leakage out of the building, but not into the building. If any of the processes were toxic the pressure differential would have been reversed to allow the inflow of air. The over-pressurisation is for the prevention of the inflow of contaminated air.

Another general environmental requirement is control of the air velocity in areas where the powders are exposed to ambient conditions. The powder, whether in component form or final product form before tableting, is extremely fine and very light, and the product particles become airborne at extremely low air velocities. The contamination of this powder with other products is one serious problem; the deposits of powder on walls, ceilings and machinery is another problem and the ingestion of airborne product by the operators is one of the more serious problems in a plant of this nature. Dust supression, closed powder storage and transfer and dust extraction are major portions of the production equipment. Where powder is dispensed in open hoppers extreme care is taken to have the correct air velocity across the hopper mouth otherwise the abovementioned problems may impair production or the health of the production workers.

The main production line of this facility is for the production of Disprin. Disprin is an effervescent tablet which when dropped into water emits carbon dioxide. For the production of Disprin it must be kept in an area with low relative humidity from the moment the calcium carbonate is dehydrated. The standard has been set at 20% relative humidity because it has been found that Disprin packed in foil absorbs water through the foil at a fixed rate[10]. If the tablet is started off at a relative humidity of 20% the shelf life of the tablet is approximately two years. If the tablet is started off at a higher relative humidity the shelf life reduces linearly. A shelf life of two years was determined as being acceptable, because lesser periods may require periodic re-calling of old stock of Disprin in foil.

The liquids and ointments production area requires no special environmental conditions and are therefore treated only to ensure human comfort.

The Senokot area, being separated from the other lines because of contamination requirements, also requires no special environmental conditions except for the treatment of exhaust air from this area to minimise contamination probabilities. The environmental conditions are designed to satisfy human comfort conditions.

The total plant requirements are low relative humidity in certain areas and for the rest there are no process requirements; but human comfort is required for optimal working conditions.

CHAPTER 3

AIR CONDITIONING INSTALLATION

The function of the air conditioning installation is to provide the process environmental requirements as stated in the previous chapter as well as providing acceptable thermal working conditions where production people are working.

3.1 THERMAL CONSIDERATIONS

The process requirements were specified as 20 $\pm$ 5% relative humidity and 20 $\pm$ 1 °C dry bulb space temperature in the low relative humidity area, and no special requirements except human comfort in any other area.

The above design values were used to determine the cooling and heating plant capacities for the process areas where no fluctuation of ambient temperatures outside the control tolerance were to be allowed. Where no special process takes place, ambient conditions must satisfy only human comfort and legal requirements and are taken into consideration as determined below.

Human comfort and human performance[11)] depends on the independent variables of clothing level, metabolic rate, air velocity, radiant temperature and air temperature. In the factory the clothing level is rigidly fixed for external clothing due to hygene requirements. Each operator has to wear a full cover overall, shoe protectors, gloves and a cap. In summer conditions with no other clothes than those specified above the clothing level has a minimum value of 0,66 clo. The metabolic rate for the type of work done in the factory is approximately equivalent to 2 mets. (Medium activity). The air velocity is kept as low as possible i.e. below 0,15 m/s to minimize dust entrainment. To nullify radiant energy it is assumed that the wall temperature will be identical to the room temperature which is a good approximation for this building. From the above parameters the optimium operative temperature will be 20 °C and the maximum acceptable operative temperature will be 26 °C[12]. This value may be compared to the old Factories' Act Regulation of the maximum permissible indoor temperature of 27 °C Effective Temperature when 80% of the workers would complain if this maximum indoor effective temperature of 27 °C were maintained.

The choice of which design value to use is usually left to the designer. The Factories' Act Regulation specified indoor temperature is only applicable under normal ambient conditions. This implies that the regulation can be exceeded under abnormal ambient conditions. It is common to assume an arbitrary design criteria of 10%, 5% or 2,5% probability level as a design criteria. The probability level determines the number of days in a year the design ambient conditions can be exceeded. The design ambient condition has a direct relationship with plant capacity and therefore capital costs. Due to this being a manufacturing plant the client selected the 2,5% probability level as the design criterion[13].

This criteria theoretically allows 2,5% or 9 days per year to exceed the design temperature. If only working days are considered this figure reduces to approximately 6,5 days per year. *If an annual closing period between Christmas and New* Year is considered the 6,5 days statistically reduces even more, because this time of the year is part of the maximum ambient temperature cycle. However, it is difficult to quantify this period of time in a specific number of days per year.

The temperature distribution of a 2,5% probability design day indicates that the design value may be exceeded for a period of only 1,5 hours per day.

Ambient temperature, solar heat gain, insulation and building mass are the main external parameters having an effect on cooling loads[14]. This building, with its small fenestration and excellent building insulation materials for the building envelope, tends to lessen the ambient temperature effect i.e. to time delay the external heat gain with a function which is dependent on thermal inertia. Thermal inertia is primarily a function of building mass and insulation.

With the above consideration, the total excess of design temperature period may reduce to say 1 hour per day. To determine the exact time a computer simulation programme taking all relevant parameters in consideration must be used. A number of these programmes exist[15], but have seldom been used in South Africa because of the massive amount of input that must be processed to arrive at a meaningful answer.

During the six hours per year the design temperature may be exceeded the client has decided to stop production, or to curtail production to lessen heat generation from production machines. The above philosophy is what is proposed in the new Factories' Act to be implemented. The proposed act evaluates comfort with a single value expressed as a Wet Bulb Globe Temperature Index (WBGT) which is a combination of air temperature, humidity, air movement and radiant heat as one value. If the reading exceeds certain values dependent on type of work carried out in the building production is halted to prevent heat stress[16].

For comfort considerations the only two values under consideration are therefore the legal value of 27 °C effective temperature and the optimum 20 °C operative temperature value. The decision was made to deliberately undersize the capacity of the cooling plant to allow temperature swings to occur between 22 °C dry bulb and 27 °C dry bulb (cooling mode) and 18 °C and 22 °C dry bulb (heating mode) under the various outdoor climatic conditions.

Optimum plant capacity was determined by progressively changing ambient temperatures between the 2,5% probability and 10% probability level and then simulating the cooling load capacity of the building. The difference between 2,5% probability and 5% probability on ambient air conditions had a 10% influence on total plant cooling capacity, while the influence between the 5% and 10% probability levels had a 2% effect on plant capacity. Ambient temperatures lower than the 10% probability level influenced the plant capacity even less and design values of just below the 10% probability level were used as an optimum value. A total saving of approximately 11,2% in plant capacity were effected by deliberately relaxing design ambient conditions. Unfortunately plant cost is not directly linear with plant capacity and a capital cost saving of approximately 6% were envisaged.

3.2 ACCEPTABLE INDOOR AIR QUALITY

Another very important function of the air conditioning installation is to provide enough fresh air to replenish air that leaks out of the building or is consumed by the process. This air is also used to overpressure the building and to ensure an acceptable indoor air quality.

Air quality is dependent on human odour, building materials emitting gasses and process contamination. The method to combat unacceptable indoor air quality is to introduce either the correct amount of fresh air into the air conditioned area or to cleanse the existing air in the air conditioned areas.

The introduction of fresh air into an air conditioned area is a well-known method to control air quality. Because of the low relative humidity requirements in some areas the uncontrolled introduction of fresh air is a costly process. To dehumidify 10 000 m^3/h of ambient air from 83% relative humidity to 20% relative humidity requires a dehumidifier costing approximately R50 000 in January 1984.

Air conditioning plant capacity is also dependent on cooling coil entering conditions. Air flowing to the coil is made up of return air and fresh air and under design conditions the enthalphy of the fresh air is much higher than that of the return air[17]. Therefore, to minimise plant capacity it is very important to limit the fresh air quantity to the absolute minimum acceptable levels.

When the enthalpy of the outside ambient air is more beneficial than the return air which will be used as supply air to the cooling coil, a method of saving running costs is to use the "free cooling" concept of fresh air instead of cooling return air. This will be discussed at a later stage.

Local gas cleaning devices were considered to cut down on ambient air as a cleansing medium. Devices available are mechanical filters, electrostatic filters, cyclones, scrubbers and adsorbents. Cyclones and scrubbers are usually too bulky to be effective inside a production area while electrostatic filters tend to generate undesirable quantities of ozone. Filters were used to prevent contamination, but are not suitable for removal of odours or gasses and can therefore not be used instead of introducing fresh air. Indoor adsorbents are usually for gaseous contaminants and are ineffective gainst airborne particles, which in this case is the major source of dangerous contaminants[18].

Determination of optimum fresh air quantity is dependent on the usage, the level of contaminants, human odour and indoor freshness required. Because this value is a value determined experimentally ASHRAE standard 62-1981 were consulted. This indicates a requirement of 5 litres per second per person for non smoking, medium activity workers in industrial facilities[19], while the Factories' Act[4] regulations require a fresh air supply of 8,3 litres per second per person or 1,6 litres per second per m^2 of floor area.

The criterion laid down by the Regulations of the Factories' Act were the only legally enforceable standard in South Africa at the time the factory was built, and because these requirements are more stringent than that of the ASHRAE standard 62-1981 these values had to be accepted and were therefore implemented.

Considerable thought was spent on the aspect of fresh air quantity because the effect the ambient air had on the capacities of the dehumidifiers. Even now the illegal downturn of fresh air quantity is being considered because of the running costs of the dehumidifer. The monitoring of air quality with infrared light sensors[20] were investigated, but were discarded as being too sophisticated for this type of application. An additional complication was that this method of gas control is not in compliance with the regulation of the Factories' Act.

3.3 AIR CONDITIONING INSTALLATION-GENERAL

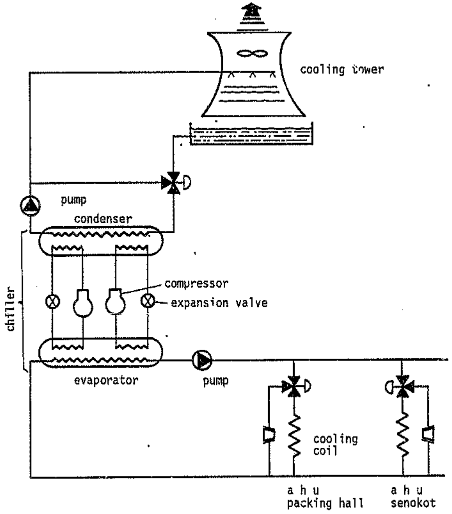
An initial decision was made to separate each low humidity production area into its own self contained autonomous plant installation. This decision had the advantage of creating good control over running costs because a plant can be switched off when the production area is not in use. It also had the least effect on production capacity if only one plant is out of service due to maintenance. Unfortunately, the capital costs of dehumidifer plant is not a linear function between cost and air capacity, but becomes progressively more expensive for low capacity plant. This lead to a compromise where two plants were combined and served by one air conditioning installation.

The comfort air conditioning is divided into the Packing Hall area, the Fybogel/Senogel area, the Senokot area, the Dispensary area and the Granulation/Liquids area. The division of the areas in the above plant is done because of the following reasons :

Packing Hall	:	This area operates 100% of the time and operates longer hours than any of the other production facilities
Fybogel/Senogel	:	This is an independent production area which will be used intermittently and can be stopped when not in use.
Senokot	:	Apart due to contamination problems.
Dispensary	:	Independent production area and will only be used intermittently.
Granulation/Liquids	:	Independent production area which will be used intermittently.

Cold water is generated in a central chiller plant and distributed throughout the building with a pump and piping system. The chiller is a dual circuit i.e. a twin independent refrigeration circuit machine giving 50% capacity with one refrigeration circuit out of commission. Two steps of capacity unloading per compressor gives a total of 4 capacity steps each step being 25% of total chiller cooling capacity. The number of capacity steps is indicative of fine control of leaving water temperature and limits hunting of compressor capacity.

Two methods of heat rejection exist, namely, directly to ambient air or through an evaporation device (cooling tower) to ambient air. The dry cooler rejects heat to atmosphere above dry bulb temperatures and therefore the condensing temperatures is in excess of dry bulb temperature. The cooling tower evaporates water and therefore rejects heat to



WATER CIRCUIT

FIG 1

atmosphere above wet bulb temperature. Because of the difference between wet and dry bulb temperatures the condensing temperature for cooling towers is at least lower by the amount of the difference between dry and wet bulb temperatures. The result is a higher coefficient of performance (C.O.P.)[21] for a chiller operating with a cooling tower. The chiller with the cooling tower therefore uses less energy, to produce the same amount of cooling, than an air cooled chiller.

The disadvantage of a cooling tower is the maintenance required, the cost of the chemicals for the water treatment installation and the cost of water. If, as in this case, the client has cooling tower installations in use the choice is much in favour of a cooling tower installation because the client knows what to expect and what to do to ensure satisfactory cooling tower performance. The choice therefore was in favour of a cooling tower instead of an air cooled condenser. The capital costs favoured the cooling tower installation as well.

The function of the chiller plant is to supply cold water to each air handling plant for cooling and dehumidification. The water temperature entering the coil has an influence on running as well as capital costs. If the chiller leaving water temperature is high (in the region of 8 °C to 10 °C) the C.O.P. of the chiller is higher than when the water temperature is in the region of 2 °C to 4 °C.

The C.O.P. of the chiller is a direct indication of running costs and with a lower C.O.P. more electrical energy is consumed than with a higher C.O.P. On capital costs the lower the water temperature entering the cooling coil the less the number of rows required to maintain identical coil leaving conditions. If the coil is manufactured from copper, as is in this case, an appreciable amount of money is involved in the selection of the optimum chiller water leaving temperature. The correct method to determine the optimum condition is to carry out life cycle costing exercises, because pump running costs are also involved in the costing structure. Coil selections are carried out by suppliers and computer selections for various water entering and leaving conditions can be obtained.

The chiller has been specified as a standard item from a supplier and no additional energy saving devices were specified on the chiller refrigeration circuit. Capacity control is by means of compressor cylinder unloading and switching off of one refrigerant circuit when capacity is less than 50% of full load. Intercooling or multiple compression stages is not usual in this size of compressor and has not been specified.

The air distribution has been designed to be a low pressure low velocity system. This design saved on complexity and the capital cost of terminal boxes[22)] because enough space for installation was available in the ceiling void.

3.4 AIR CONDITIONING PACKING HALL

The air conditioning system designated Packing Hall serves the Packing Hall, Bin Feed and Dust Extract Area, Store, Servery and Canteen.

The system is a variable air volume terminal reheat system. When in the cooling mode the fan supplies the designed amount of air to each zone. As the cooling requirement diminish the room undercools if heat is not added to the supply air or if the quantity of supply air is not reduced. The air quantity reduction continues till the air quantity is 33% of the design value. To maintain room temperature after capacity reduction the reheater is then switched on. This is a classical variable air volume installation saving on reheating costs by reducing supply air volume[23)].

The energy saving device fitted to this system is an enthalpy controller comparing the enthalpy of the return air with the enthalpy of the ambient supply air. If the ambient air enthalpy is more suitable than the return air the return air is exhausted and 100% ambient air is used. A refinement to this system is to compare enthalpies and adjust to the source with the more advantageous enthalpy and then adjust dampers to optimise the enthalpy of the air mixture to the cooling coil. *This energy saving system is called* an economy cycle and it ensures that no valuable air is exhausted (apart from statutory fresh air required) when its enthalpy is better than the ambient air enthalpy or returned when entalpy is worse than ambient air. The system is particularly useful during the intermediate seasons of autumn and spring. During these periods ambient air temperatures are low and can be utilized with considerable energy savings. The maximum energy of waste air still occurs under design ambient conditions, because the fresh air amount must be introduced into the air conditioned space although the maximum design difference between fresh air and return air enthalpy occurs at this point.

In classical VAV (Variable Air Volume) systems the supply air temperature from the coil is kept constant regardless of ambient temperatures. This is done to control humidity. It also implies that under heating conditions the air must be cooled before being reheated by the terminal reheaters. If the fine control of humidity is not that critical it can be advantageous to adjust the cooling coil outlet conditions to vary with ambient temperature. By resetting the cooling coil outlet conditions with ambient air conditions the implication is that the amount of cooling needed to keep space temperature constant varies with ambient conditions. This statement is partially true, because heat transmission gains do reduce with lowering of ambient temperature, but when high internal cooling loads or big solar cooling loads are present the situation is somewhat different. The system being installed is usually fully adjustable and after the

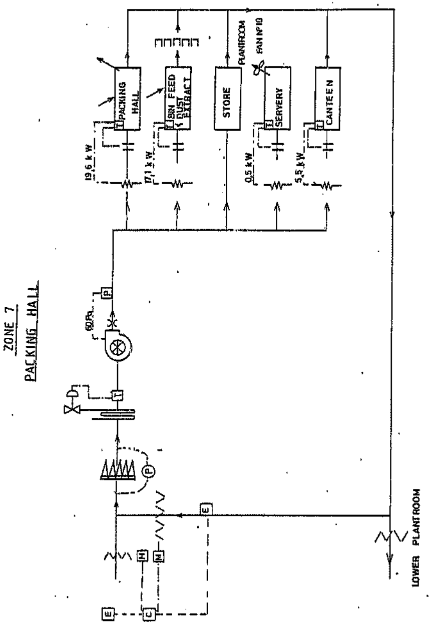
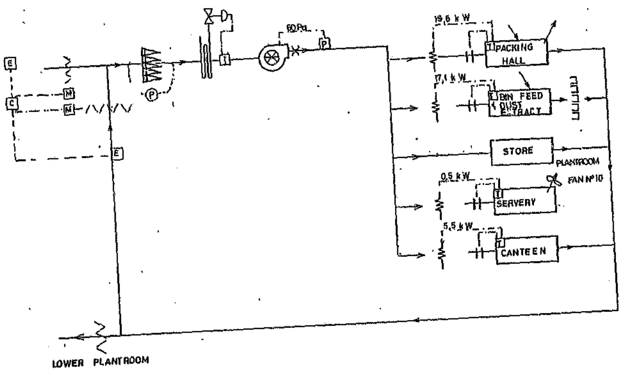

ZONE 7
PACKING HALL
PACKING HALL
BIN FEED & DUST EXTRACT
STORE
SERVERY
CANTEEN
PLANTROOM
19.6 kW
17.1 kW
0.5 kW
5.5 kW
60Pa
LOWER PLANTROOM

FIGURE 2

ZONE 7

PACKING HALL



plant is put in operation final adjustments to the various parameters are carried out. This control system is called a coil reset controller[24)] and the aim of the system is to minimise reheater energy consumption under minimum and intermediate ambient temperatures.

3.5 AIR CONDITIONING FYBOGEL SENOGEL

The air conditioning system serving the Fybogel Senogel area is a constant volume terminal reheat system.

The system is fitted with an economy cycle, but due to the fact that it is a single zone area it does not require a coil reset controller because the temperature sensor controls exactly in the same way as a coil reset controller. No humidity control is required.

No energy saving is possible by making the system a variable volume system.

3.6 AIR CONDITIONING SENOKOT

The air conditioning system serving the Senokot area is a constant volume terminal reheat system.

The system is fitted with an economy cycle and as above has not been fitted with a coil reset controller.

The system is a constant volume system for the same reasons as the Fybogel/Senogel area.

3.7 AIR CONDITIONING DISPENSARY

The air conditioning system serving the Dispensary is a variable air volume terminal reheat system.

ZONE 1
FYBOGEL SENOGEL

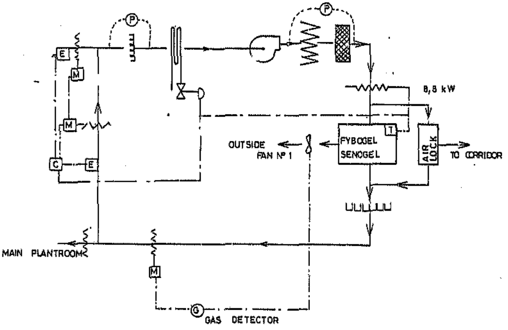


FIGURE 3

ZONE 2

SENOKOT

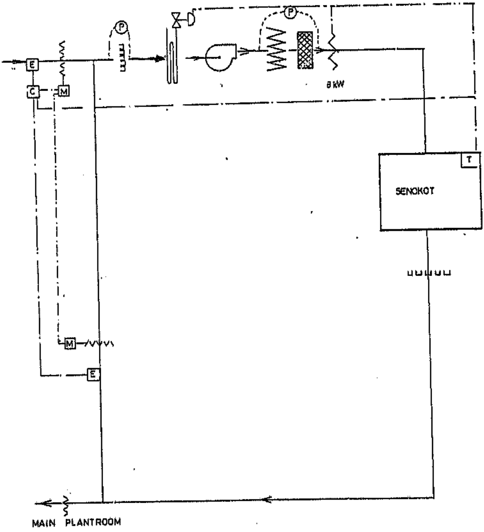


FIGURE 4

ZONE 3
DISPENSARY

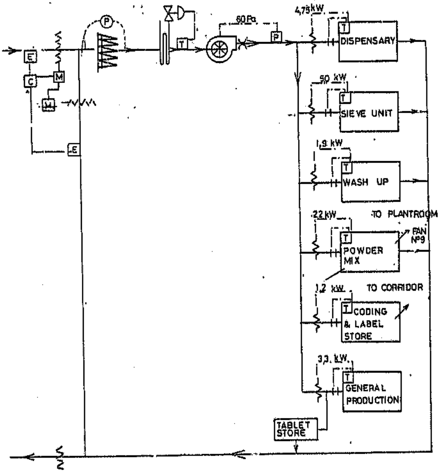


FIGURE 5

The system is fitted with an economy cycle as well as a coil reset controller.

The system is a variable air volume system because it serves six individually controlled production areas.

3.8 AIR CONDITIONING PROTECTED FILLING AND TABLET COMPRESSING

Although the air conditioning installations for the protected filling and the tablet compressing areas are two independent systems, they are identical and can be discussed simultaneously.

These systems serve the low relative humidity (20% relative humidity) and 20 °C ambient temperature areas.

Due to the fact that the relative humidity is 20% dehumidification of supply air could not be done by the conventional method of dehumidification by cooling coil. The conventional method of dehumidification is to condense the water out of the supply air stream by selecting a coil which will cool the air far enough below dew point. When air is cooled below dew point condensation of water occurs and the humidity ratio of the air decreases.

The usual way to achieve this effect is to select the cold water temperature to the coil approximately 5 °C lower than the temperature of the air leaving the coil. This temperature difference ensures enough temperature difference to economically dehumidify the air passing through the coil.

Trying to do the same for a low relative humidity area is impossible, because if the same allowance is made with a 5 °C water temperature drop and with a unity sensible heat factor the temperature of the water to the coil must be approximately -10 °C. Supply water (in this case a glycol/water mixture) of -10 °C is a possibility, but the

C.O.P. of the chiller will be extremly low, a specialised refrigerant must be used and the chiller would have to be specially designed to supply water temperature of -10 °C. This is a technical possibility and is commercially available in an ice storage system, but expensive.

The alternative option was to use a dehumidifier. The dehumidifier works on a process which absorbs water by means of a chemical substance (in this case lithium chloride) and then, when it is saturated with water, to dry it out by means of heating the lithium chloride. This process can be carried out in a batch process whereby one cell is absorbing water while the other cell is being regenerated or by a continuous process whereby the lithium chloride is coated on a wheel. The wheel revolves through to the air to be dried out and then revolves into the regeneration area where the moisture is driven off from the lithium chloride with hot air.

As can be seen the heat of regeneration must be enough to evaporate the water absorbed in the dehumidification process. The choice was made to heat this air with steam because of the favourable cost of steam energy versus electrical energy.

One peculiarity of the dehumidifier is that it is a constant air volume machine i.e. it can only dehumidify a constant volume of air. Although the air may vary in moisture content the volume flow may not change. A reason for this is the drying wheel revolves at a constant speed and this fixes the water absorption rate at a constant value. With both inlet air volume and inlet air humidity as variables and the above constant water absorbtion rate the controls reduces into a two independent variable control problem which, under conditions of less than maximum air flow or maximum air humidity, results in a solution with an infinite number of air flow versus dehumidity control settings which satisfy the required outlet humidity. This is not a feasible control system and therefore the air flow rate is fixed at a constant amount and the variable being the humidity of the air.

This results in the fact that the dehumidifiers are only available in specific sizes e.g. 3 500 m^3/h, 10 000 m^3/h and 15 000 m^3/h models. They can be used at intermediate air volumes, but the bigger size of unit must be used when intermediate quantities of air must be dehumidified.

To design the system as a constant volume terminal reheat system would have had the effect of installing a dehumidifier capable of handling the total amount of supply air (for maximum conditions) and then cooling the air down to the required cooling coil leaving temperature (again for maximum conditions) and then to reheat the air for each production area which does not require the design cooling load.

The effect of this would have been :

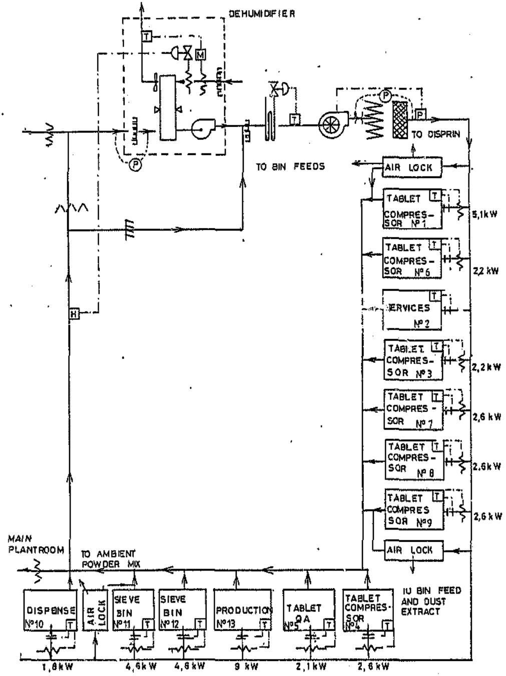
1) The dehumidifier would have been selected to operate at full capacity for 6 hours per year.

2) The dehumidifier would have been selected to dehumidify at approximately 70% of dehumifier water rejection capacity because supply air through the unit is the governing criterion.

3) Reheaters would have been in operation for a period of the full production year minus the six hours at maximum ambient conditions.

The above design is an energy inefficient and capital [illegible]ive solution and was rejected.

The design was refined to have a constant volume loop in



ZONE 4

TABLET COMPRESSING

FIGURE 6

ZONE 6

PROTECTED FILLING

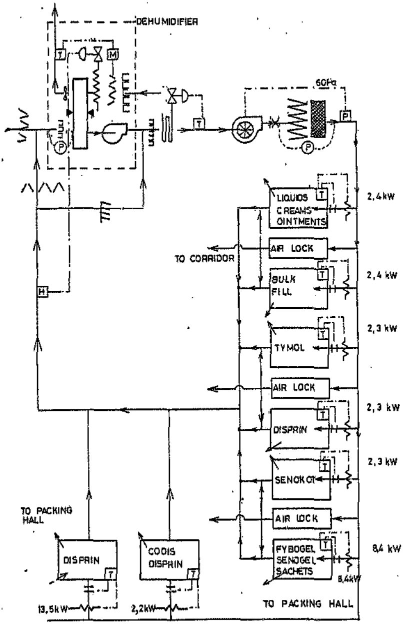


FIGURE 7

which the dehumidifer is installed and a variable volume loop which supplies the required amount of air to the production area.

The advantages of this system is :

1) The dehumidifier is sized for dehumidification as well as air volume.

2) The dehumidifier is operating in a constant volume system for which it is designed.

3) The dehumidifier operates much nearer to 100% capacity and for longer durations of time.

4) Terminal reheat is reduced by introducing less air into the production areas under heating conditions.

Unfortunately the variable air volume concept could not be used to its full advantage, because enough air for the dehumidifier (being a constant volume device) had to be introduced. The air quantity required to satisfy maximum load conditions are more than the dehumidifier requires. However, under heating conditions less air is introduced to save on reheating capacity but the dehumidifier required more than acceptable minium quantities. This resulted that the turndown ratio had to increase from the normal 1 to 0,33 to 1 to 0,82 in the Tablet Compression area and 1 to 0,55 in the Protected Filling area. An appreciable amount of capital costs were saved, but on reheating capacity less than 50% of the normal savings were realised.

The characteristics of the dehumidifier is that the exhaust air is at a dry bulb temperature of 43 °C and a relative humidity of 10%. The air must be cooled down to 12,7 °C before being introduced into the production areas. Thus up to 198 kW (both systems) of low grade heat is available for heat regain. Again, this value will vary as ambient conditions vary.

The constant volume loop supplies the dehumidifier with return air and ambient air mixed in the correct volume, but at varying moisture content. This amount of air is *continually* supplied to the system.

The variable volume loop bypasses the dehumidifier and is introduced with the air from the dehumidifier into the cooling coil. The volume of this bypass air may vary from 0% to 100%. Nil bypass will happen during the heating cycle while 100% will bypass during the maximum cooling cycle. The maximum energy saved by using the variable volume loop is 30 kW in heating capacity. The capital cost saved by not installing bigger dehumidifiers is approximately R15 000 per unit.

CHAPTER 4

ELECTRICAL INSTALLATION

The electrical installation supplies power to the bulk of the installation i.e. the production machinery, the lighting installation and the air conditioning installation. The installation in itself is a fairly conventional system which connects to the 11 kV supply of the Durban Corporation, is transformed down to 400 Volts and then distributed through the main distribution board to motor control centres and lighting distribution boards. Adequate fault level protection and metering is installed to make the installation safe and controlable. Power factor correction equipment was installed and the system is designed to have a power factor of 0,95 [25].

The energy management available on this system is the main area where cost savings can be utilised and a careful study of the tariff structure of the Durban Corporation is necessary to optimise savings.

Five possible tariff contracts with the Durban Corporation are available :

Two Part Bulk Low Voltage
Three Part Bulk Low Voltage
Two Part Bulk High Voltage
Three Part Bulk High Voltage
Business and General

The LV (Low Voltage) and HV (High Voltage) tariff structure is identical, the metering for the HV is done before the transformer while the LV metering is done after the transformer. The LV rates are approximately 3% more expensive which would account for transformer losses due to the position which the metering is carried out in the distribution system.

The definition of terms used by the Durban Corporation are as follows :

kVA - *Maximum demand:*	This is the highest kVA demand per running half hour period during the billing month
kWhr - Energy consumed:	This is the actual energy consumed by the user
kVA - Restricted demand:	This is the highest kVA *demand* during the hours 16h30 to 18h30 in a billing month. (The Durban Corporation would give a discount for savings on maximum demand made during these hours)
Notified demand:	Demand registered on which *calculation is carried out*

The tariff structure is as follows [1984 values]

4.1 2 Part Bulk Low Voltage

kVA - maximum demand	R7,70	
kWhr - *consumed*	*first* 5 000 units	6,95c/unit
	next 10 000 units	4,45c/unit
	remaining units	2,75c/unit

Minimum kVA demand charge 70% of maximum notified demand.

4.2 3 Part Bulk Low Voltage

kVA - maximum demand	R12,00
kWhr - consumed	1,8c/unit
kVA - restricted demand	R2,35

Minimum kVA demand charge 70% of maximum notified demand.

The tariff structure *is peculiar in the fact that* an agreement is signed whereby the consumer agrees to a notified demand. This is the basis for calculation of minimum kVA charges. However, if the actual demand exceeds the notified demand then the highest actual demand becomes the *notified demand*. The consumer has the option to reduce his notified demand once per year and if this option is not exercised the notified demand may be based on maximum demand figures a few years old.

As indicated before the High Tension metering tariffs are in accordance with the Low Tension tariff except that transformer losses had been disregarded. The minimum charge is based on a maximum demand of 1 000 kVA (this automatically becomes the minimum notified demand) and is therefore aimed at the bigger users of electricity.

The Business and General tariff structure is as follows :

kW-hr consumed 7,45c/unit

This tariff structure is aimed at general business and household consumers and is not applicable for industrial electrical consumption, being much too expensive.

It is immediately apparent that the tariff structure itself is complicated and to make the right choice between tariff structures can have a significant bearing on energy costs. The additional charges e.g. regional surcharges, general surcharges, coal adjustment charges and service charges have been ignored, because they have no bearing on the structure of how the charges have been compiled and how to choose the correct tariff structure.

To consider the choice between 2 Part and 3 Part Bulk Low Voltage a load factor must be determined. Assume a user with a maximum demand of 1 000 kVA with unit power factor. If he is a consumer operating his plant 24-hours per day then the maximum number of units that can be consumed is

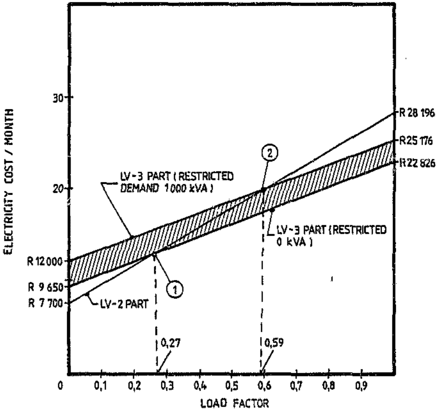
24 hours/day x 30,5 days/month x 1 000 kVA x 1 = 732 000 kWh/month.

A user consuming only half of the possible 732 000 kWh would have a load factor of 0,5. Although maximum demand is automatically fixed as notified demand the load factor comparison is valid for any maximum demand.

The cost of electricity could be read from this graph if the load factor is known. The shaded area indicates the savings possible with a three part bulk low voltage tariff agreement exploiting the possible savings with restricted demand. The lower boundary indicates the maximum saving during restricted hours; the upper boundary is when no advantage of the restricted demand tariff is made.

The break even points 1 and 2 between the different tariffs indicate the economical point to change from one tariff structure to the other. Thus, if no savings is made within the restricted demand timespan, it would be more economical to go on a three part bulk low voltage tariff at a duty factor of 0,59 and higher. With increase of savings of maximum demand during the restricted hours the duty factor reduced to a minimum of 0,27 when maximum saving must take place in the restricted demand time.

To determine the correct tariff structure the duty factor and restricted demand values must be determined after the full plant is in operation to be able to make an intelligent decision. If a table of the sensitivity of the tariff structure is analysed the following electrical costs will be payable each month. (The quoted figures are based on the 1984 tariff structure when the plant was in construction)



MONTHLY ELECTRICAL CHARGES VERSUS LOAD FACTOR

FIG 8

DUTY FACTOR	LV2 PART	LV 3 PART		
		RESTRICTED DEMAND UTILISATION		
		100%	50%	0%
0,1	R 9 600	R10 000	R11 800	R13 300
0,3	R13 800	R13 500	R15 000	R16 600
0,5	R[illegible]	R16 600	R17 500	R18 300
0,7	R22 200	R18 300	R19 600	R21 200
0,9	R26 800	R21 200	R22 500	R24 200
1,0	R28 196	R22 826	R24 000	R25 176

Table 1

From the above table it is clear that whatever tariff structure is considered the maximum saving that can be realised is between LV2 part and 100% restricted demand LV3 part. If the duty factor were unity, the difference would be 23%, - in real terms is R5 370 per month or a total of R64 440 per year. (Assuming the notified demand is 1 000 kVA which is the size of the transformer for this factory).

If a more realistic restricted demand is taken i.e. 50% and the duty factor comes down to a more realistic 0,7 (say) the difference now total 14,8% or in real terms R2 900 per month or a total of R34 800 per year.

If the influence of maximum demand is investigated it is R12,00/kVA (LV3 part) or R7,70 kVA (LV2 part). Once this maximum demand has been registered the cost of one kVA is R104,4 p.a. (LV3 part) or R66,99 p.a. (LV2 part).

The influence of duty factors is also of interest, because the complete tariff structure is aimed at penalising consumers with a low duty factor. To increase the duty factor i.e. to have a steady continuous demand at all times is advantageous both to the consumer, by paying the minimum amount of money for energy consumed, and the utility company by utilising the distribution network to its full steady state capacity. The network then runs at the most economical state with no excess capacity required to cater for demand peaks.

The full exploitation of restricted demand on the 3 part tariff brings about a saving in monthly charge of between 33% (duty factor 0,1) to 10% (duty factor 1,0). This is also an aspect where savings can be made, but the full implication of having a 100% restricted demand means switching off the complete factory between 16h30 and 18h30 each and every day per month. One day operation between those hours negates all the savings made on all the other days that month. Savings expressed in monetary terms are between R3 300 per month and R2 350 per month which must make this option a very carefully considered option.

To fully exploit the tariff structure the options open are:

1) Choose correct tariff structure
2) Reduce duty factor
3) Reduce maximum demand
4) Optimize restricted demand

The interesting point is that a consumer is not encouraged to save energy as such, because the LV2 Part has a backup sliding scale making energy savings less and less advantageous and the absolute cost of energy under the LV3 Part structure of 1,8c/kWhr is so small it is hardly worth conserving.

The above again illustrates the dilemma of energy conservation in South Africa. Although the Durban Corporation has a difficult tariff structure to optimise it again proves the point that saving on maximum demand charges is much more advantageous than saving on the consumption of irreplaceable energy. The commment is made without even applying any financial model to see if the above is correct; the magnitude of the figures above is a clear indication of the dilemma.

In this plant as stated above money can be saved as follows :

1) Choose the correct tariff structure. When the actual load pattern becomes available the choice of the correct tariff structure is made according to fig 2 and application for the most advantageous tariff structure solves the problem.

2) Reduce the duty factor. The improvement of the duty factor is, in effect, equivalent to controlling maximum demand and forms part of the next point.

3) Reduce maximum demand. Maximum demand can be reduced employing the following techniques:

   i) Measure kVA on the same basis as the Durban Corporation. This ensures the same information is used by both parties to calculate costs according to tariff structure.
   ii) Control startup in morning to ensure that the target peak demand is not exceeded.
   iii) Shedding load when maximum demand exceeds target peak demand if possible.
   iv) Optimise time to get building on temperature.

v) Interlock plant to prevent systems working together and thereby exceeding maximum demand.

vi) Store energy in a useable form during off peak periods to raise the load factor.

4) Optimise restricted demand. Taking advantage of this discount may be feasible, but since it has a direct link with production it is not a strategy that can be used without affecting production and production periods. Cognisance of this must be taken with production scheduling in mind.

CHAPTER 5

ENERGY CONSUMPTION

In Chapter 1 the argument was made that savings can only be effected by analysing the pricing structure of the various forms of energy *and then optimising on those components which can realise* the biggest return on investment. This is true, but it is also true that non renewable energy costs money and by saving this energy a saving in overall energy costs are also achieved.

If a speculation about the structure of future energy costs can be ventured it is conceivable that once the overall demand of the national grid is satisfied the pricing structure of electricity may change. This change will be in the relative charges between maximum demand, which determines the generation capacity of the national grid, and units consumed, which is a reflection of the running costs of a power station. If the generation capacity is satisfied then emphasis from maximum demand will tend to shift to energy consumption and therefore a tendency to more expensive energy can be foreseen.

It is also a declared policy of ESCOM to put a high priority on the conservation of non renewable energy.

For the economic life of this factory it is therefore imperative that energy consumption is identified and quantified and that the same is done for all energy conservation opportunities.

5.1 ENERGY CONSUMPTION

The three main sources of energy available for this factory are electricity, which is brought from the Durban Corporation, steam, which is generated on site and compressed air, which is also generated on site. The steam is used for dehumidification and process cleaning requirements, the compressed air is used for production machinery and the electrical installation is used for production machinery, lighting, heating and air conditioning.

To determine the energy consumption of the factory each user of energy must be analysed. The major user of energy is the air conditioning installation and must therefore be analysed in detail.

The building thermal energy behaviour was simulated using the HCC III cooling load calculation program. This program simulates a building cooling load by taking in account external ambient conditions, internal conditions, the building envelope and the type of air conditioning system, to arrive at hourly thermal energy requirements to maintain specified indoor requirements.

The cooling loads of the comfort and low humidity areas were simulated independently, because the temperatures in the comfort areas were allowed to drift within comfort conditions, while the low relative humidity areas were simulated at a fixed indoor temperature and humidity. For both cases a system analysis (variable volume or constant volume system) were included in the analysis. The dehumidifier of the low relative humidity systems were simulated on an hourly basis by taking in account the air entering volume, temperature and absolute humidity to obtain air leaving temperatures and absolute humidity. This was done on an hourly basis by hand, because the computer programme was incapable of simulating a dehumidifier.

MONTH	HOUR	7	8	9	10	11	12	13	14	15	16	17	18	DAILY kW-h	MONTHLY kW-h
JANUARY	TEMP F	76.0	78.0	80.0	81.0	82.0	82.0	82.0	82.0	82.0	81.0	80.0	79.0		
	TEMP C	24.4	25.6	26.7	27.2	27.8	27.8	27.8	27.9	27.8	27.2	26.7	26.1		
	CONDENSING T	33.4	34.6	35.7	36.2	36.8	36.8	36.8	36.8	36.8	36.2	35.7	35.1		
	LOW RH	115.3	153.5	160.4	164.3	165.8	163.9	162.8	162.1	160.2	157.6	154.6	154.6	1565.8	31315.6
	COMFORT	280.5	316.5	316.5	316.5	316.5	316.5	316.5	316.5	316.5	316.5	316.5	154.6	3128.5	62570.4
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	457.4	531.6	538.5	542.5	544.0	542.1	541.0	540.3	538.3	535.8	532.7	370.9	5311.4	106228.0
	CHILLER KW	104.9	127.7	129.4	138.[illegible]	138.5	138.0	137.6	137.6	137.0	132.0	131.5	89.1	1325.8	26516.0
	COS FI	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8		
	CHILLER KVA	129.3	146.8	148.7	158.7	159.2	158.6	158.2	158.2	157.5	151.7	151.1	108.7		
FEBRUARY	TEMP F	64.0	67.0	70.0	71.0	75.0	76.0	77.0	78.0	70.0	78.0	77.0	75.0		
	TEMP C	17.8	19.4	21.1	21.7	23.9	24.4	25.0	25.6	23.6	25.6	25.0	23.9		
	CONDENSING T	26.8	28.4	30.1	30.7	32.9	33.4	34.0	34.6	34.6	34.6	34.0	32.9		
	LOW RH	97.6	140.5	146.9	136.9	155.6	156.0	154.6	154.2	152.7	150.8	146.9	118.0	1445.8	28915.6
	COMFORT	104.7	137.3	160.7	176.5	192.8	200.8	206.1	208.8	206.4	202.4	195.4	136.4	1796.4	35928.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	264.0	339.4	369.3	375.2	410.2	418.5	422.4	424.8	420.8	414.8	404.0	316.1	3859.3	7[illegible]
	CHILLER KW	56.5	72.5	78.9	80.2	91.9	96.9	101.5	102.1	101.2	99.7	93.6	70.8	881.4	1[illegible]
	COS FI	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.8		
	CHILLER KVA	70.6	88.4	96.2	96.6	109.4	114.0	119.4	120.1	119.1	117.3	111.4	86.3		
MARCH	TEMP F	59.0	62.0	66.0	68.0	71.0	73.0	73.0	74.0	74.0	74.0	72.0	70.0		
	TEMP C	15.0	16.7	18.9	20.0	21.7	22.8	22.8	23.3	23.3	23.3	22.2	21.1		
	CONDENSING T	24.0	25.7	27.9	29.0	30.7	31.8	31.8	32.3	32.3	32.3	31.2	30.1		
	LOW RH	90.0	127.1	133.4	139.6	145.4	148.1	146.4	146.4	145.1	143.9	139.3	109.3	1355.3	27105.6
	COMFORT	89.3	115.6	136.2	153.7	166.4	176.3	181.1	184.4	181.9	177.7	168.2	109.2	1562.6	31252.4
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	231.1	304.4	331.3	355.3	373.5	386.1	389.3	392.4	388.8	383.3	369.2	280.2	3535.0	70700.0
	CHILLER KW	49.4	65.1	70.8	75.9	79.8	82.6	83.2	87.9	87.1	85.9	78.9	59.9	767.7	15354.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8		
	CHILLER KVA	62.2	81.4	87.4	92.6	97.3	99.5	100.2	105.9	104.9	103.5	96.2	74.0		
APRIL	TEMP F	51.0	56.0	60.0	63.0	66.0	68.0	68.0	69.0	69.0	68.0	66.0	62.0		
	TEMP C	10.6	13.3	15.6	17.2	18.9	20.0	20.0	20.6	20.6	20.0	18.9	16.7		
	CONDENSING T	19.6	22.3	24.6	26.2	27.9	29.0	29.0	29.6	29.6	29.0	27.9	25.7		
	LOW RH	65.5	108.6	117.0	123.7	128.8	131.0	130.3	129.3	127.8	125.9	122.1	92.0	1188.1	23762.8
	COMFORT	65.3	90.5	107.0	123.3	136.1	146.2	151.1	154.1	151.5	145.3	135.6	80.5	1270.3	25405.8
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	192.5	260.8	285.7	308.7	326.6	339.0	343.1	345.3	341.0	332.9	319.3	234.2	3075.5	61510.6
	CHILLER KW	41.2	55.8	61.1	66.0	69.8	72.5	73.4	73.9	72.9	71.2	68.3	50.1	657.7	13154.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	52.8	70.6	76.4	82.5	86.2	89.5	90.6	91.1	90.0	87.9	85.4	63.4		
MAY	TEMP F	42.0	47.0	52.0	56.0	58.0	60.0	62.0	62.0	62.0	61.0	59.0	58.0		
	TEMP C	5.6	8.3	11.1	13.3	14.4	15.6	16.7	16.7	16.7	16.1	15.0	14.4		
	CONDENSING T	14.6	17.3	20.1	22.3	23.4	24.6	25.7	25.7	25.7	25.1	24.0	23.4		
	LOW RH	51.0	89.8	100.7	107.8	112.1	114.0	114.1	112.6	110.4	108.0	104.9	74.6	1020.5	20409.8
	COMFORT	-10.9	26.0	46.3	65.1	77.8	89.5	94.1	98.5	94.2	87.9	76.9	17.5	670.5	13410.4
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	101.9	177.5	208.7	234.6	251.6	265.2	272.0	272.8	266.3	257.6	243.4	153.8	2308.1	46162.2
	CHILLER KW	21.6	37.6	44.3	49.8	53.4	56.3	57.7	57.9	56.5	54.7	51.7	32.6	489.8	9796.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	28.8	49.5	56.8	63.0	67.6	71.3	73.0	73.3	71.5	69.2	65.4	43.5		
JUNE	TEMP F	42.0	46.0	50.0	53.0	55.0	56.0	57.0	57.0	57.0	56.0	52.0	47.0		
	TEMP C	5.6	7.8	10.0	11.7	12.8	13.3	13.9	13.9	13.9	13.3	11.1	8.3		
	CONDENSING T	14.6	16.8	19.0	20.7	21.8	22.3	22.9	22.9	22.9	22.3	20.1	17.3		
	LOW RH	41.0	78.7	89.7	97.0	102.0	104.2	104.5	103.7	101.5	99.1	95.5	65.5	921.3	18426.8
	COMFORT	-60.2	-38.6	-14.3	6.9	19.5	32.8	41.1	42.9	37.0	30.5	18.2	-45.5	97.5	1949.2
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	42.5	101.9	137.1	165.6	183.2	198.7	207.3	208.3	200.2	191.3	175.4	81.7	1635.9	32718.0
	CHILLER KW	9.1	21.8	29.3	35.4	39.2	42.5	44.3	44.5	42.8	40.9	37.5	17.5	349.8	6995.8
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	12.1	29.1	39.1	46.6	51.6	54.5	56.8	57.1	55.4	53.8	49.3	23.3		

HOURLY CHILLER ELECTRICAL DEMAND

TABLE 2

HOUR / MONTH		7	8	9	10	11	12	13	14	15	16	17	18	DAILY kW-h	MONTHLY kW-h
JULY	TEMP F	43.0	46.0	51.0	55.0	57.0	57.0	58.0	58.0	57.0	56.0	54.0	52.0		
	TEMP C	6.1	7.8	10.6	12.8	13.9	13.9	14.4	14.4	13.9	13.3	12.2	11.1		
	CONDENSING T	15.1	16.8	19.6	21.8	22.9	22.9	23.4	23.4	22.9	22.3	21.2	20.1		
	LOW RH	41.0	78.7	89.7	97.0	102.0	104.2	104.5	103.7	101.5	99.1	95.5	65.5	921.3	18426.8
	COMFORT	61.1	39.1	15.2	5.8	18.4	31.8	40.5	42.1	36.4	29.8	17.2	-46.2	320.2	6404.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	163.8	179.5	166.6	164.5	182.1	197.7	206.7	207.5	199.6	190.6	174.4	81.0	1858.6	37172.8
	CHILLER KW	7.1	20.1	25.8	33.5	37.0	39.0	41.1	42.0	41.0	39.8	37.5	17.5	326.4	6528.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	9.5	26.8	34.4	44.1	48.7	50.0	52.7	53.8	53.2	52.4	49.3	23.3		
AUGUST	TEMP F	45.0	49.0	54.0	56.0	57.0	58.0	58.0	58.0	58.0	57.0	55.0	54.0		
	TEMP C	7.2	9.4	12.2	13.3	13.9	14.4	14.4	14.4	14.4	13.9	12.8	12.2		
	CONDENSING T	16.2	18.4	21.2	22.3	22.9	23.4	23.4	23.4	23.4	22.9	21.8	21.2		
	LOW RH	51.0	89.8	100.7	107.8	112.1	114.0	114.1	112.6	110.4	108.0	104.9	74.6	1020.5	23762.8
	COMFORT	-15.7	24.0	45.2	63.1	75.8	85.9	95.9	97.1	93.1	84.8	74.9	17.4	649.2	24988.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	[illegible]	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	97.0	175.5	207.6	232.6	249.6	261.6	271.8	271.4	265.2	254.5	241.5	153.7	2286.8	61092.8
	CHILLER KW	20.1	[illegible]	43.8	47.2	52.6	56.3	56.9	57.4	56.3	54.2	51.7	32.6	481.9	13362.0
	COS FI	[illegible]	[illegible]	[illegible]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	[illegible]	[illegible]	[illegible]	59.7	66.6	71.3	72.0	72.7	71.3	68.5	65.4	43.5		
SEPT	TEMP F	[illegible]	[illegible]	[illegible]	60.0	61.0	61.0	61.0	61.0	61.0	60.0	59.0	57.0		
	TEMP C	[illegible]	[illegible]	[illegible]	15.6	16.1	16.1	16.1	16.1	16.1	15.6	15.0	13.9		
	CONDENSING T	[illegible]	[illegible]	[illegible]	24.6	25.1	25.1	25.1	25.1	25.1	24.6	24.0	22.9		
	LOW RH	65.5	[illegible]	[illegible]	123.7	128.8	131.0	130.3	129.5	127.8	125.9	122.1	92.0	1188.1	23762.8
	COMFORT	64.8	89.4	105.1	121.1	134.1	144.2	148.2	151.3	148.4	142.8	132.6	78.9	1249.4	24988.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	192.0	259.8	283.8	306.5	324.6	336.9	340.2	342.5	337.9	330.5	316.4	232.6	3054.6	61092.8
	CHILLER KW	42.1	56.5	61.8	66.6	71.6	73.8	74.6	74.8	73.8	72.5	69.3	50.9	668.1	13362.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	54.0	71.5	77.2	83.2	88.4	91.1	92.1	92.3	91.1	89.5	86.6	64.4		
OCTOBER	TEMP F	59.0	61.0	63.0	64.0	65.0	65.0	65.0	65.0	64.0	63.0	62.0	62.0		
	TEMP C	15.0	16.1	17.2	17.8	18.3	18.3	18.3	18.3	17.8	17.2	16.7	16.7		
	CONDENSING T	24.0	25.1	26.2	26.8	27.3	27.3	27.3	27.3	26.8	26.2	25.7	25.7		
	LOW RH	80.0	127.1	133.4	139.6	145.4	148.1	146.4	146.4	145.1	143.9	139.3	109.3	1355.3	27105.6
	COMFORT	85.0	114.0	130.5	151.2	165.4	174.2	177.2	180.5	178.4	174.8	164.1	105.4	1531.2	30624.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	226.7	302.8	325.6	352.5	372.5	384.0	385.3	388.6	385.3	380.4	365.1	276.5	3503.6	70071.6
	CHILLER KW	40.2	64.2	69.1	75.9	79.7	81.2	82.6	84.8	84.5	84.0	78.1	58.0	754.2	15084.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		
	CHILLER KVA	61.0	80.3	85.3	92.6	97.2	97.8	99.5	102.2	101.8	101.2	95.2	71.6		
NOVEMBER	TEMP F	65.0	67.0	68.0	69.0	70.0	70.0	70.0	70.0	69.0	68.0	67.0	66.0		
	TEMP C	18.3	19.4	20.0	20.6	21.1	21.1	21.1	21.1	20.6	20.0	19.4	18.9		
	CONDENSING T	27.3	28.4	29.0	29.6	30.1	30.1	30.1	30.1	29.6	29.0	28.4	27.9		
	LOW RH	97.6	140.5	146.9	136.9	155.6	156.0	154.2	154.2	152.7	150.8	146.9	118.0	1445.8	28915.6
	COMFORT	104.7	137.3	160.7	170.5	183.6	192.4	200.8	201.6	200.0	195.0	185.0	130.0	1748.5	34970.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	264.0	339.4	369.3	369.2	402.9	410.1	417.1	417.5	414.4	407.5	393.6	309.8	3811.4	76227.6
	CHILLER KW	53.1	72.5	74.9	77.5	85.2	94.2	99.3	99.4	99.5	98.5	92.1	69.5	854.1	17082.0
	COS FI	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.8		
	CHILLER KVA	66.4	88.4	91.3	93.4	101.4	110.8	116.8	116.9	117.1	115.9	109.6	84.8		
DECEMBER	TEMP F	70.0	72.0	73.0	74.0	74.0	75.0	75.0	74.0	74.0	73.0	72.0	71.0		
	TEMP C	21.1	22.2	22.8	23.3	23.3	23.9	23.9	23.3	23.3	22.8	22.2	21.7		
	CONDENSING T	30.1	31.2	31.8	32.3	32.3	32.9	32.9	32.3	32.3	31.8	31.2	30.7		
	LOW RH	115.3	153.5	160.4	164.3	164.9	163.9	162.8	162.1	160.2	157.6	154.6	154.6	1564.9	31297.0
	COMFORT	270.5	300.5	302.0	310.0	312.0	316.5	316.5	316.5	310.2	308.2	305.4	154.6	3062.8	61255.0
	PROCESS	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	61.7	617.1	12342.0
	TOTAL	447.5	515.7	524.1	536.0	538.6	542.1	541.0	540.3	532.1	527.5	521.7	370.9	5244.7	104894.0
	CHILLER KW	105.3	120.1	122.1	125.4	126.0	130.0	132.2	132.5	132.0	127.2	128.5	86.0	1252.8	25056.0
	COS FI	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8		
	CHILLER KVA	123.9	138.0	140.3	144.1	144.8	149.4	152.0	152.3	151.7	146.2	147.7	104.9		

HOURLY CHILLER ELECTRICAL DEMAND (CONTINUED)

TABLE 2 (CONTINUED)

Simulations of one design day of each month of the year was carried out over the period the air conditioning system will be in operation. The hourly thermal energy of the different systems plus the process thermal energy requirements were totalled on the same basis as set out above to obtain an hourly cooling load requirement.

To determine the electrical energy consumption from the cooling load requirements the chiller was manually simulated on an hourly basis to obtain the electrical consumption figure [26]. The chiller performance is dependent on condensing temperatures which again is dependent on cooling tower performance. If the chilled water outlet temperature is constant the above can be determined with the wet bulb ambient temperature and the chiller performance curves to obtain the electrical energy consumption on an hourly basis.

Table 2 represents the design day cooling requirments on an hourly basis indicating ambient temperature, condensing temperature, cooling load requirements, chiller kW requirements, the power factor of the electric motor of the chiller and the chiller kVA requirement. These figures are totalled to give a daily consumption and also a monthly consumption.

To obtain a yearly electrical, steam and compressed air energy consumption it was assumed that the production tempo will be 100 % of capacity throughout the production year. Because production batches and durations of machine operation for each process cycle are not known a 100 % duty cycle was assumed as a first approximation. The process thermal requirements were therefore taken as a constant load.

The pumps for the condenser water and chilled water systems were also considered as having constant loads, because both systems use 3-way diverting valves instead of 2-way throttling valves to control temperatures. The fan loads for the variable volume systems were analysed and part load performance were calculated. Delumidifier steam consumption was analysed on part load performance to determine the yearly energy consumption for the complete factory.

The yearly energy consumption figure for the factory consist of the following :

Fan and pump loads	438,84 GJ
Lighting load	503,71 GJ
Production machinery load	1 728,00 GJ
Steam consumption for dehumidification	225,84 GJ
Air conditioning load	1 846,43 GJ
Compressed air consumption	0,86 GJ
TOTAL	4 743,68 GJ

PERFORMANCE INDICATOR[27)] 1,666 GJ/m^2 per operating year

The above performance indicator is a ratio of yearly energy consumption per unit floor area and includes all the electrical, steam and compressed air consumption for the operation of the factory. It does not include steam usage for production utensils cleaning, because this is a manual operation and is dependent on the operator and therefore cannot be quantified.

5.2 ENERGY CONSUMPTION PREDICTION

To determine the theorectical energy consumption of a building in the design phase the building envelope has to be defined, the interior ambient conditions and all the energy consumers in the building must be defined and quantified. With the above information an estimate of the energy consumption of a building can be made using the following methods :

5.2.1 Degree day method

The definition of number of degree days assigned to a

24-hour period is the difference between the 24-hour mean outside temperature and an arbitrarily selected base temperature.

The method implies that if a building consumes a specified amount of energy with a defined difference between the base temperature and the average daily ambient temperature it will consume twice the amount of energy if the temperature difference doubles.

The above assumption of energy consumption against temperature difference has been developed to calculate heating energy requirement especially during winter and night time periods. The assumption becomes questionable when the solar influence on a building with a big glass facade is analysed during daylight periods.

To analyse a building for cooling energy consumption this method is also questionable due to the influence of building mass, thermal storage, solar influence, the dependency of a chiller C.O.P. on ambient wet bulb temperature and system configuration like free cooling.

The one major limitation of this method is the fact that the 24-hour average temperature is used instead of the average temperature over the period the plant will be in operation. During the cool period of the night the air conditioning system of a commercial building usually does not operate and therefore the degree day will indicate a too low energy consumption for air conditioning installations in operation during day time hours and conversely a too high energy consumption for heating systems only in operation during day time hours. For a system running 24-hours per day this method will give reasonable answers especially for heating systems independent of system configuration like a chiller or a cooling tower.

5.2.2 Bin Method

The bin method is an improvement on the degree day method because instead of giving one degree day figure a frequency distribution of the ambient dry bulb temperature is given in 2,8°C (5°F) increments or bins. The information is given in the form that a specific amount of the yearly time is attributed to a specific temperature bin.

This method is essentially the same as the degree day method except that with the bin information temperature dependent equipment, for example, a water to air heat pump can be simulated which cannot be done using the degree day method.

The major limitation of the bin system is identical to the degree day method because it is representative of a 24-hour day and the simulation of an 8-hour plant operation is not possible.

5.2.3 Modified bin method

The bin method has been extended to circumvent the above limitation by giving the bin information in three 8-hour periods of one day i.e. the temperature duration has been made time dependent. This information is now adequate to simulate the energy requirements of a building operating in any one specific 8-hour period. Longer operational hours can be accommodated by careful extrapolation.

The method does not simulate an air conditioning system, because again chiller performance and free cooling cannot be incorporated in this method.

To carry out a simulation approximately 10 to 15 bins must be analysed to cover the full variation in temperature. This analysis must be carried out for each system installed in the building and then totalled to give a yearly energy consumption figure.

5.2.4 Computer simulation

Quite a number of computer programs exist which can calculate the energy requirements of a building on an hourly basis for a design year.

Two types of programs exist namely programs which simulate energy requirements for keeping indoor temperatures constant i.e. cooling/heating simulations and the more powerful programs which takes the building mass storage capabilities, the energy flow between inside and outside conditions with a system simulation in consideration when calculating energy requirements.

The simple program requires enough input to define the building envelope while the energy program needs the above plus input on systems and system control tolerances to be able to simulate energy requirements.

The computer simulation is the most powerful method of simulating energy requirements. Energy requirements are calculated on an hourly basis and, depending on the degree of sophistication of the program, simulation of air conditioning systems and chiller performance can be calculated and summed automatically. Indoor changes of occupancy levels, lighting levels and other variables can also be accommodated. This method is much more accurate, but also much more time consuming than the degree day, bin or modified bin method.

5.2.5 Design Information

In the four methods described above the quantification of the building envelope in thermal resistance values etc is straightforward. The information which is very difficult to obtain is data for South African ambient temperature *conditions.* Data are available giving the following information:

1) Monthly average and maximum temperatures[28)]
2) *Monthly and hourly average temperatures*[28)]
3) Degree days for 4 stations (not one is a commercial centre which can be used) for various base temperatures[13)]
4) Cooling/Heating hourly temperatures for different probability levels[13)].

The above, except the degree day information, are available for all the major centres in South Africa.

From the above information it is possible to compile degree day, bin and modified bin data, but only on average temperatures. To simulate a building on a specific probability level for a specific month is not possible, because the probability level information is only available for maximum and minimum conditions.

An attempt was made to create modified bin data from average ambient temperatures and normal distributions[30)] of weather *patterns, but it seems as if the model* which has been used is only applicable to the weather patterns of the United States of America and not to South African weather patterns. Either published data on modified bin information or an adaption of the model to be able to predict modified bin data for any centre in South Africa is required, because this information is not freely available.

5.2.6 The Energy consumption of the building

The building was analysed on an hourly basis for the hours the plant will be in operation. The hourly analysis were simulated for the design day of each month of the year. Energy consumption figures were determined from the simulations for a 20 working day month for the 12 months of the year to arrive at a monthly and a yearly energy consumption figure.

To be able to use this information as input for management the monthly electrical energy consumption for the air conditioning installation is plotted in fig. 9 for each month of the year.

The simulation was carried out using the 2,5% probability ambient temperature levels for the production area and the 10% probability ambient temperature levels for comfort areas during maximum temperature conditions and 2,5% probability levels during the rest of the year for both areas. For non maximum conditions the 2,5% probability levels were adjusted by monthly average temperature differences.

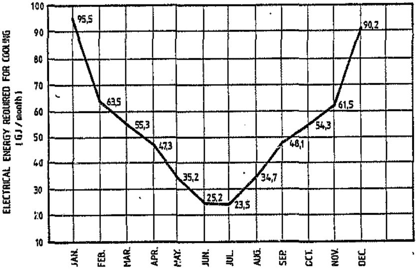
An attempt was made to relate ambient temperature to cooling electrical energy consumption to be able to predict energy consumption using a single parameter i.e. dry bulb temperature. Ambient dry bulb temperatures and electrical energy consumption required for cooling were correlated using the least squares fit technique and with 120 sample points as shown in figure 10 a correlation co-efficient of 0,94 were obtained. This is a significant correlation[31].

If an attempt is made to explain this correlation it can be attributed to

1) The relative small influence of direct incident solar energy
2) The good building envelope insulation values
3) The insensitiveness of the dehumidifier air outlet conditions to air entering conditions (i.e. there are constant cooling loads on the coils of the low relative humidity systems)

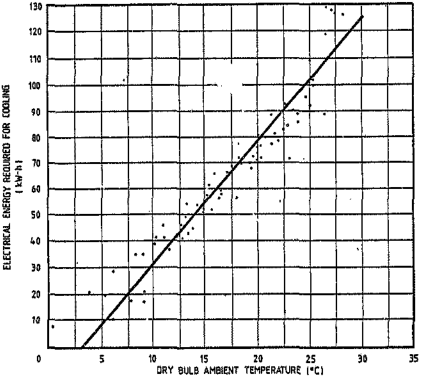
The system, for a major portion of the installation, is a low relative humidity installation and one would expect that ambient wet bulb temperatures should have a much greater influence on energy consumption than ambient dry bulb temperatures. Because dry bulb temperature is much easier to measure than wet bulb temperature and with the good correlation between energy consumption and any bulb temperature - it seems if it is the easiest way to determine energy consumption.

The above simulation was carried out assuming full production capacity for all the production hours. Simulation with 75%, 50%, 25% production capacity should be carried out to be able to determine air conditioning energy consumption at various production levels



MONTHLY ENERGY CONSUMPTION FOR COOLING

FIG 9



COOLING ELECTRICAL ENERGY REQUIREMENTS VERSUS TEMP

FIG 10

CHAPTER 6

ENERGY CONSERVATION OPPORTUNITIES

The energy conservation opportunities are part of the cost savings opportunities as shown later in the report, but the following are the energy conservation possibilities considered and analysed:

6.1 Minimising of solar energy entering the building through windows

By installing solar reflective windows with a glass shading co-efficient of 0,59 i.e. Solar Shield 20/20 or by sticking reflecting film on existing windows the solar incident energy will reduce over a period of one operating year as follows :

Incident energy at present	122,027	GJ
Reduced incident energy	71,996	GJ
Saving in energy	50,031	GJ

If the C.O.P. of the chiller is conservatively taken as 4 a saving of 12,51 GJ in electrical energy is possible.

6.2 Lights

If high efficiency fluorescent lights instead of conventional lights are used the electrical requirements are 58 Watt per tube instead of 65 Watt per tube i.e. a saving of 12% can be realised for the same lighting output. If this is applied to the whole factory a saving of 7,036kW can be made. This represents a 60,792 GJ electrical energy saving per operating year plus a saving in air conditioning running costs of 15,2 GJ electrical energy per year.

6.3 People

If people not actuall) working in the area are told to leave a saving of 178 Watt per person can be realised. If the equivalent of one person is prohibited from loitering in the air conditioned area an energy saving of 1,54 GJ per year is possible on the air conditioning system or in total a saving of 0,385 GJ per person per year in electrical energy is possible.

6.4 Volume control and speed control on fans

The two types of air conditioning systems employed are constant volume and variable volume systems. One of the characteristics of a constant volume system is that, as the name implies, a constant amount of air is delivered to the air conditioned area. This characteristic is true if the system pressure drop does not change. If the pressure reduces for instance when an outside door is opened more air will be delivered to the area.

Conversely less air will be delivered when the system resistance increases. A normal increase in system resistance can only happen when the filters becomes dirty. A filter installation usually has an initial pressure drop of 80 Pa and a cleanout pressure drop of 250 Pa. If HEPA filters are required to obtain very high filtration efficiencies it is customary to use a bag filter and a HEPA filter in combination. This combined filter has an initial pressure drop of 300 Pa and a cleanout pressure drop of 750 Pa.

If this pressure drop is related to fan sizing and volume delivery to the air conditioned area the system must be over sized to be able to deliver the required amount of air at maximum system resistance i.e. at filter cleanout pressure drop. This means that the system delivers more air than required for the majority of the time which, in effect, means the system is oversized and wasting of fan energy takes place. If the amount of fresh air is set as a constant percentage of supply air it means that when over supply of air occurs the same happens to the fresh air. In a conventional system the system pressure increase is approximately 170 Pa. If a hypothetical system with an identical amount of air as a typical system in this factory is analised the increase in air quantity is 12,5%. If an engineering approach is taken whereby the specified air delivery is never reached with a dirty filter by selecting the fan to cater for system resistance plus a 70% dirty air filter the increase now reduces to approximately 8%. This increase is, with the accuracy which air can be measured in a ducted system, within design tolerance and is a very common approach in commercial air conditioning systems. This approach for a production facility must be carefully considered because of the high production machinery load in comparison to what is happening in a commercial installation.

Areas with a constant volume system and HEPA filters have the above situation plus an additional pressure drop of 450 Pa which must be added to the system resistance for dirty filters. This means an air volume increase of 23,6% with a favourable fan selection and if an oversized fan is used the increase can be as high as 90%.

The increase in absorbed fan power is approximately 3 kW for this size of installation and therefore a saving in energy to power the fan can be made by installing a device which controls supply air at design volume with a change in system resistance.

Air volume can be controlled by controlling the airflow to the fan by means of a damper, or by having a variable inlet vane control, or by regulating the speed of the fan. The variable inlet vane control is essentially the same as a damper, but by altering the air entering velocity to the eye of the fan a more energy effective method of fan capacity control is achieved.

If the most effective method is analysed, namely the regulation of fan speed, the average saving will be the average of the difference between the initial and cleanout absorbed fan power i.e. 1,5 kW if a 100% efficient system is used. This is virtually the case with a thyristor type of speed control device and a saving of 12,96 GJ/year per system is possible. Variable volume systems take care of this aspect automatically and no additional savings are possible. The total savings therefore will be 25,92 GJ/year because two of the systems of nearby identical air volume can be converted.

If the supply air can be kept constant the fresh air, which in this case is approximately 10,5% of supply air, will also be kept constant. The absolute amount of fresh air is not controlled, but the percentage of fresh air of the total supply air is set and the absolute amount of fresh air will vary with the amount of supply air. If the volume increase is 23,6% of what is required an increase of 3,01 kW is added to the cooling and dehumidification load (under maximum conditions). To determine the total contribution the time of year the filters are clean or dirty must be known, but if an average is taken and the total effect on the refrigeration load is calculated a nett saving of 7,407 GJ/year can be realised. It is a fact that the cleanout cycle of these filters are about 9-months, but averaged over a few years the above nett saving is possible.

The above saving is in building refrigeration load, but if a chiller C.O.P. of 4 is assumed an electrical energy saving of 1,8518 GJ/annum is possible.

At the present the variable air volume systems are fitted with v[illegible] guide vane inlet control. If the volume con[illegible] fans are changed to variable speed control t[illegible] savings are possible: In January the average fan [illegible]me required for the design day from 07h00 to 17h00 is 0,919 of the maximum design air volume. If the same calculation is carried out for the design day of each month and totalled for the number of production days a saving in electrical energy of 110,7 GJ/annum is possible.

If the savings on fan energy and excess fresh air is totalled the net savings in electrical energy are as follows:

Constant volume systems

Constant volume systems	
Fan energy (2 systems)	25,92 GJ/annum
Fresh air (2 systems)	1,85 GJ/annum
Variable volume systems	110,70 GJ/annum
TOTAL	138,47 GJ/annum

6.5 Duct Leakage

Duct leakage can be an invisible waster of energy. In the code of practise for duct installation [32] the maximum permissible leakage is defined as:

$$\frac{V_1}{V} \times \frac{nQ}{100} \cdot m^3/s$$

where V_1 = Volume of section under test (m^3)
V = Volume of total duct system (m^3)
Q = Total maximum system design flow rate (m^3/s)
n = Value equivalent to 8 for low pressure ducting

When the whole system is considered $\frac{V_1}{V} = 1$ and the equation then becomes:

$$\frac{nQ}{100} \quad m^3/s$$

and with n substituted the leakage rate is therefore 8% of the total maximum system design flow rate. This test must be carried out at 150Pa or 1,5 times normal static pressure. The normal static pressure in the systems varies from 63 Pa to 40 Pa and an average of 150 Pa as the test pressure will not be unappropriate for this discussion.

To relate the maximum losses at prescribed test pressures to normal operating pressures according to Bernoulli and ignoring compressibility of gasses

$$Q_2 = Q_1\sqrt{\frac{\Delta P_2}{\Delta P_1}}$$

which in this instance gives a delivery of 64,8% of test requirements or a leakage rate of 5,18% of maximum design air flow. In both t[illegible] . able volume and constant volume systems this value [illegible] .ain constant.

Two sources of energy is required to offset this loss; additional treated air to offset the treated air which is lost in the ceiling void (this air is not leaked in air conditioned spaces) and additional fan energy to offset the transportation of this additional amount of air.

From the fan laws :

$$kW_b = \left(\frac{\text{Total pressure b}}{\text{Total pressure a}}\right)^{1,5} kW_a$$

where [illegible] and b refers to situation without leakage and situation with leakage respectively and kW refers to fan energy [illegible]ired.

For [illegible] specific installation $kW_b = 1,1509\ kW_a$ or an incre[illegible] of 15,09%. On the total fan power this represents 8,75kW or for the total operating year an electrical energy requirement of 75,619 GJ/annum.

The electrical energy required to cool and dehumidify the additional 5,18% of air lies between 8,34 GJ/annum and 2,60 GJ/annum depending whether enough return air is available to satisfy the requirement or whether outdoor air will be required. If the smallest value i.e. 2,6 GJ/annum is added to the fan requirements a total of 78,219 GJ/annum is wasted in this manner. It is obviously very difficult to get a system completely air tight, but if standards are raised to say a 4% leakage rate at test pressure the electrical energy savings are 41,09 GJ/annum on the figure of 78,219 GJ/annum for a 8% leakage rate.

6.6 Chiller optimal starting sequence

A device is available which senses both outdoor and indoor ambient conditions. From these two temperatures an optimal plant start time is established by measuring time elapsed from starting to getting the building on temperature. The *elapsed time and the combination of indoor and outdoor* temperatures are stored in the memory of the optimal start up device and within a period of six months a file of indoor outdoor combinations plus time from starting to getting the building on temperature is established.

This system can be of great help to commercial buildings, because temperature and not humidity is the operative criterion. The relationship between indoor and outdoor dry bulb temperatures does not describe indoor relative humidity and therefore as the controller is marketed today it is not the correct application for this installation.

If outdoor temperature and indoor humidity can be the input parameters this system is worth considering. It is extremely difficult to attach a specific energy saving to this method, because building mass, permeability and porosity of building materials now control the start-up time.

6.7 Energy Reclaim

Various energy savings opportunities are available in this category. It is true that this energy is reclaimable, but usually it is in the wrong form (i.e. the temperature is too low), it is available at the wrong time of the day or it is very uneconomical to reclaim, store and reuse at a later date.

6.7.1 Building heat reclaim

The biggest amount of energy that can be reclaimed is the heat rejected from the building. The amount of heat available is 2840,44 GJ/annum. This heat if recovered through a heat reclaim chiller is available at a maximum temperature of 50°C but only when cooling is required.

6.7.2 Condensate reclaim

The condensate from the steam supply which is used to dry the dehumidifier wheel is not reclaimed, but dumped in the drain. The maximum steam use is 308 kg/hr which occurs under maximum wet bulb ambient conditions. The steam demand will follow the building cooling demand and therefore the yearly use of steam will be 409 140 kg/year. If the condensate from this steam is available at 90°C and it can be returned to the boiler instead of using cold boiler feed water at 10°C a saving of 136,817 GJ/annum can be realised. An additional saving, although not in energy, is in the cost of treating raw water instead of returning treated water.

6.7.3 Exhaust air

The statutory amount of fresh air implies that the same amount of conditioned air must be exhausted to atmosphere. A total amount of 11 300m^3/hr is continually exhausted to atmosphere. The total yearly amount of energy involved is -1,373 GJ in sensible cooling and 4,5558 GJ in latent cooling. The sensible cooling can be reclaimed with a heat wheel, but the latent cooling is a change of state which cannot be recovered with a sensible heat reclaim device. The positive amount of energy that can be reclaimed is 0,4889 GJ/annum sensible and 4,6102 GJ/annum latent.

6.7.4 Dehumidifying process

The dehumidifier when dehumidifying the air heats the air. The supply air temperature rise at full capacity is 22°C and at minimum capacity 18°C. If the simulation is carried out to determine this amount of heat on an hourly basis the amount of heat reclaimable is 965,76 GJ/annum (if a 100% recovery is possible). This heat, however is available at 43°C maximum.

If this heat is extracted by an evaporative cooling device instead of a refrigeration device a saving in electrical energy is possible. If this heat is rejected to atmosphere in a cooling tower with a cooling coil/cooling tower arrangement the air temperature leaving the coil can conservatively be brought down to 4°C above wet bulb temperature without undue capital costs. The cooling tower and circulation pump energy must be deducted and if a conservative C.O.P. of 4 is assumed for the chiller a saving of 295,82 MJ/annum (electrical energy) or 1183,28 MJ/annum in rejected heat can be achieved.

CHAPTER 7

MONITORING AND TARGETING INSTRUMENTATION

The philosophy behind monitoring and targeting systems, and therefore instrumentation, will follow the management by exception strategy. This strategy is to monitor only one parameter namely energy consumption and to see whether a system will meet its projected target or whether a system will overrun its projected target. If at any point in time a diagnosis of an overrun can be made it is also assumed that one or more systems are malfunctioning. An investigation in the system, sub system or individual components is then carried out to find the malfunctioning component. Consumption monitoring is not the only method to monitor plant malfunctioning. If for instance, space temperature is unacceptable or a plant breakdown occurs it is obvious that something is wrong and must be repaired to keep plant operating at design parameters.

7.1 GLOBAL MONITORING AND TARGETING

To be able to tie energy consumption to energy billing it is necessary to measure the inflow of all energy to the factory in exactly the same way as the billing authority measures their energy. Ultimately energy can be related to costs, and to have a discrepancy in information can lead to making the wrong decision.

To be able to manage energy consumption it is necessary to quantify the projected energy use for a defined period. Usually this period is one month, because it then synchronises energy use and energy costs.

When energy use is quantified it must be divided into production days. The actual energy use each day is then compared to the targeted energy use and if a running total is kept it is possible to see deviations very quickly. The problem arises when energy consumption is not only dependent on production rate, but also on external factors like ambient temperature.

To budget the amount of energy that will be used, the relationship between dry bulb and energy consumed (fig. 10) can be used. The monthly average temperature is available and with this figure energy consumption for the air conditioning installation can be determined. To check daily consumption it is necessary to integrate ambient dry bulb temperature over the production day to be able to determine the projected usage against actual usage. If the average ambient temperature of that specific month is higher than the long term average it will automatically show from the temperature records, but it will still be possible to detect differences between actual usage and targeted usage.

When the actual consumption figures become available and knowing that the plant has been in good running order an actual energy consumption versus ambient temperature relationship can be found. This relationshipbeing measured instead of calculated should have a higher correlation than fig 10.

7.2 MONITORING

Monitoring is the process of providing a method to identify if a system or component is not performing to required performance.

To be able to monitor effectively the monitoring system should be structured in such a way that it is possible to immediately identify a fault situation and where the fault is situated. The strategy to identify functional groups of equipment working together and to monitor only one parameter to assess whether the group as a whole is functioning correctly is the management by exception strategy as previously defined.

In the air conditioning system the chiller/cooling tower/chilled water system is a funcional group and each air system is another functional group.

The production machinery is more difficult to identify, because of the batch type operation of the process installation, but again a batch or a production line can be identified as a functional group.

7.2.1 <u>Chilled water generation equipment</u>

The chilled water generation functional group consist of the chiller, cooling tower, condenser water circuit and the chilled water circuit. By monitoring chilled supply water temperature to the cooling coils an effective monitoring system for the whole group of equipment is instituted. If at any time the chilled water supply temperature deviates from set point [illegible] immediately obvious that something is amis and that [illegible] pection of the individual components are required.

However, this monitoring strategy does not indicate if the prime energy consumer, the chiller, is working to its required efficiency target. To produce chilled water at the correct temperature may consume much more energy than optimally required and individual performance monitoring of equipment which can perform, but not at optimum performance, is required.

The chiller is the main consumer of electricity in the air conditioning system and therefore needs special monitoring. A chiller consists of three sytems namely a refrigeration circuit, a condenser and an evaporator.

In the refrigeration system the following have an influence on efficiency :

1) Mechanical parts e.g. valves, valve springs, strainers, driers expansion valves and piping.
2) Oil contamination in the heat exchangers.
3) Internal gas leakage and overall loss of gas.
4) Presence of non condensible gas.

In the condenser and evaporator the main influence on efficient heat transfer is fouling. Fouling of the evaporator is a long term occurrence, but fouling of the condenser can happen much faster, because the condenser water ci...uit is an open system.

To be able to determine the efficiency of a chiller it is necessary to monitor the following parameters :

1) Suction pressure
2) Discharge pressure.
3) Pressure drop through evaporator and condenser at design flows.
4) Temperature of the water in and out of the condenser and evaporator.
5) Electrical consumption (kW-h) and demand (kVA).
6) Ambient dry bulb temperature.
7) Ambient wet bulb temperature.
8) Refrigerant flow.

From the above measurements the following can be determined (the reasons for determining the specific parameters follows):

1) Suction pressure, discharge pressure and refrigerant flow:

    1.1 The refrigeration effect of the refrigerant system
    1.2 Fouling of condenser and evaporator surfaces

2) Pressure drop through evaporator and condenser :

   2.1 Fouling of heat exchange surfaces
   2.2 Flow conditions

3) Temperature of chilled and condenser water :

   3.1 Heat rejection performance
   3.2 With 2.2 the total heat transfer
   3.3 Part load conditions

4) Electrical input

   4.1 With 3.2 the C.O.P. of the chiller

These systems monitor the net effect of the refrigeration system versus electrical input. No monitoring of mechanical parts are carried out and if the above is according to specification an assumption is made that the mechanical equipment is working to specification.

To narrow the above down to the practicable minimum and still to be able to monitor the chiller performance a simultaneous recording of the following parameters are required :

1) Suction pressure
2) Discharge pressure
3) Dry bulb and wet bulb temperatures
4) Flow and temperature of the inlet water and outlet water of the evaporator

The measurement is necessary for the following reasons :

1) Suction and discharge pressures : To determine actual performance of the refrigeration circuit

2) Ambient temperatures : To determine condensing temperature and to be able to compare to discharge temperatures to see if something is amiss in the heat rejection circuit.
3) Flow and temperatures of incoming and outgoing water of evaporator : To determine actual performance and therefore part load performance of the chiller

To effectively carry out the above measurements temperatures (dry and wet bulb), pressures, flows and cooling medium temperatures must be recorded and then analysed with an elaborate method to arrive at a meaningful answer.

The measurements of wet bulb temperature needs a distilled water source and a minimum air velocity on the sensing element. This is very seldom found in commercial installations.

Because small differences in temperatures, pressures, flow etc. can affect the efficiency of the chiller recording of these quantities must be carried to great accuracy to be of any use in the diagnostic process.

The measurement of pressure and temperature is achievable by selecting sensors of the required accuracy. Measurement of flow may be made by venturi tube, orifice plate, vortex flowmeter or annubar. But the accuracy of such a device is typically $\pm$ 2% which is not really accurate enough for the early prediction of set point changes, drift or other malfunctions and therefore is a problem without an elegant solution.

Integration of flow, temperature, pressure etc is not a feasible solution to obtain energy usage, because piston compressors first unload and then switch off as loads diminish.

An indirect way of monitoring chiller performance is to relate electrical consumption to loading of the chiller. To do this with a piston compressor is only feasible at the moment a capacity change has taken place, because it can be assumed that it was or is now working at full capacity. Therefore, by sensing capacity changes and electrical consumption it is possible to compare to a predetermined value at that point in time and if the electrical consumption is more than the reference value it can be assumed to be a fault situation.

This indirect monitoring method requires a predetermined norm to compare with. This value is determined when the installation is new and can therefore be assumed to be the norm for the specific chiller installation.

The inherent possible misinterpretations of this method is :

1) If an incorrect set of values are taken for the norm the monitoring system is at fault
2) If a power dip occurs the energy inflow will be higher and a fault condition will be registered although everything may be correct
3) Ambient condensing condition affects the chiller performance

To overcome the last possible misinterpretation it is possible to compile a set of values for different condensing conditions, however, this is extremely difficult to do with a chiller in an actual installation.

The way chillers are checked for efficiency at present is to measure the various parameters as described on a monthly basis and plot the information on a graph. If there is a change or a change in trend it is assumed that the specific sub system is out of setpoint. The one aspect this method does not pick up is mechanical wear on valves, seats, etc.

The present method to check mechanical wear is to do a vibration analysis of the installation and to compare the analysis to the original vibration readings. Again, present vibration is compared to original vibration and differences indicate wear.

7.2.2 Air distribution and control equipment

The following has an influence on the efficiency of air distribution systems :

1) Pressure drop across filter
2) Duct supply pressure
3) Coil outlet conditions
4) Reheaters
5) Pressure drop across coil
6) Enthalpy control of free cooling

Different types of air distribution systems react differently on the above and each type of system will have to be analysed.

7.2.2.1 Constant volume systems

In a constant volume system the one aspect which can have a marked influence on efficiency is the simultaneous heating and cooling of the supply air. This situation is not easy to detect, because the room condition, which is a very good indicator of a malfunctioning system, can still be within design tolerance and does not indicate a fault condition.

To detect this situation it is necessary to sense :

1) Room temperature and humidity
2) Fresh air and return air mixture
3) Coil outlet temperature
4) Heating capacity in operation

From the above inputs it is again necessary to do a detailed study to see if the situation does occur. To monitor this automatically requires a control system with programmable steps which check the situation of simultaneous reheat and cooling and when it does occur, check further to see if it is admissable or not. If out of rule an alarm is raised.

As an example for the above scenario it is necessary to programme the controller as follows :

1) If heater is on is room temperature too low
2) If room temperature is too low situation is acceptable
3) If room temperature is on set point is humidity too high
4) If humidity is too high situation is acceptable
5) If humidity is on set point fault condition

The program logic can be extended to include 'l aspects of fault condition namely free cooling, enthalpy control, pressure drop across filter, the cooling cycle etc.

7.2.2.2 Variable volume systems

Variable volume systems compensates for heating requirements by throttling supply air to a predetermined minimum before activating the heater. This interlock is mechanical and therefore the above situation is much easier to control.

To develope a monitoring system for a variable volume system the following must be sensed :

1) Enthalpy of fresh air, return air and mixed air to determine if this sytem is operating correc'ly
2) Pressure drop across filters
3) Coil outlet condition
4) Duct static pressure

The most important parameters to check is duct static pressure and coil outlet conditions because if duct static pressure is too high too much air is delivered and if coil outlet conditions are too low unnecessary cooling is used.

When a supply air temperature reset sytem, which is controlled by ambient dry bulb temperature, is used to save energy under heating conditions this monitoring system becomes much more involved. Coil outlet conditions are now dependent on outside temperature and the set point of the free cooling system changes with the change in coil outlet temperature. This feature is only in use at low ambient conditions and if one assumes that this system works correctly the monitoring system can be disabled during the operation of this control cycle.

7.2.3 Control Systems

Control systems whether analogue, digital or pneumatic tend to drift from setpoint and needs re-calibration at least once a year.

It is not possible to automatically monitor a control system component by component, because when monitoring it requires a standard to compare against. This standard is typically an accurate potentiometer or resistance which is used in a measuring situation against a room thermostat or other sensing elements.

To monitor a control system it is possible to :

1) Check if room temperatures are within design tolerance
2) Monitor certain key variables to see that each specific value is within design tolerance
3) Monitor energy consumption to see if excessive energy is consumed to keep an area on temperature

Controls are usually checked and calibrated by hand twice a year. Control designers have gone to great lengths to make checking and calibrating easy by plug in modules and automatic testing machines. It still remains a manual operation, because sensors and controllers must be manually simulated and compared against a standard.

7.3 TARGETING INSTRUMENTATION

Ideally energy consumption of a production facility would be proportional to production rate. In practice energy consumption will decrease, although not linearly, in general agreement with production rate till the production ceases. At this point energy will still be consumed to maintain environmental conditions and illuminate the facility. The maintenance of conditions are ambient dependent.

To attempt a target of energy consumption either a prior knowledge of the energy consumption pattern of the facility is known, or an upper limit of money (and therefore energy) that can be absorbed by the costing structure of the product is known.

The first approach is the more positive one, because it tries to assume the optimum, regardless of what the costing structure indicates, and then tries to keep energy consumption at that level. The second approach is not a positive energy saving strategy, but only a method to determine upper limits of affordable energy consumption.

To target energy consumption the following variables must be quantified :

1) Production rate : therefore which machines are running
2) Environmental systems : which systems are running
3) Ambient conditions : time of day, month and ambient conditions

Once a target has been set from the above inputs a target monitoring system is required to determine whether this target will be met. To monitor it is necessary to measure and record :

1) Energy of electricty, steam, water and compressed air flowing into the factory
2) Production volumes
3) Ambient conditions

A first approximation will be to assume a linear relationship between production and machinery energy consumption. This relationship is reasonable for big production volumes, but it also assumed work in progress to be constant. which in a batch type production facility is not always correct.

The second assumption is that as production reduces the air conditioning energy consumption remain constant i.e. parts of the system is not switched off. This is in conflict with the initial design because the option to switch off production areas not in use is built into the system.

The target monitoring instrumentation will be incorporated in the overall targeting strategy which can be proposed as follows :

1) Determine production volumes for the production month and from this information draw up a production schedule per production day according to available production machines.
2) Determine the energy usage of the production machines at the required volume on a daily basis.
3) Predict with fig. 9 the energy the air conditioning and other services will use per production day. (This can be calculated from available average daily temperature tables).

4) Total all daily energy requirements and then on a daily basis monitor energy inflow to see if it is using the right amount of energy.

5) Where energy inflow is dependent on outside conditions it is necessary to check back with daily temperature to see if actual performance is on target.

To do the above the targeting instrumentation will consist of energy consumption meters on production machinery, air conditioning installation, steam flow and compressed air flow.

The strategy is broader than only to control on a daily basis, the strategy is to predict with available information what the actual monthly energy consumption will be. Therefore after one day of production the information will be very vague, but after three weeks a clear tendency will be evident and a target can be extrapolated from the available figures. The strategy is to try and determine as early as possible where problems may arise.

Energy targeting is energy conservation, but incorporates also fault detection. The concept is a team effort and takes a positive involvement to make it happen. Instrumentation to do the above are usually available in a typical factory and a plan must only be implemented to do energy targeting.

CHAPTER 8

ENERGY MANAGEMENT

Energy management is defined here as more efficient or effective use of energy. This definition implies both management of energy use and also management of the cost of energy usually per production unit or on a time basis.

As described use of energy is controlled by an energy targeting strategy which in effect monitor daily use against predicted use. Normally the time span of the monitoring period coincide with a billing month to coincide with energy accounts.

Cost of energy is controlled by optimisation of the tariff structure and exploiting every possibility available in the tariff structure. Tha tariff structure is made up of

1) Energy consumed
2) Maximum demand kVA
3) Maximum demand during restricted periods

Maximum demand is an integration of demand over a period of thirty minutes. The decision period to control maximum demand is therefore less than 30 minutes - typically 20 minutes at the most, because monitoring instruments usually need about 10-minutes to register a trend, extrapolate the trend to a maximum demand value in 30 minutes, compare it to a pre set target maximum demand and if it exceeds this value raise an alarm.

In a commercial building non essential loads e.g. chillers, fans, heaters, lights, lifts etc can be programmed to shed automatically in a predetermined sequence as the case may be.

In a production facility non essential loads form a very small portion of the overall demand, because the facility is designed and built for production purposes around process requirements. In this facility the shedding of complete production areas is feasible due to the batch type production process. This decision is dependent on producton programming and cannot be pre-programmed to happen automatically. A warning period of up to 20-minutes may be available and manual shedding of loads on an ad hoc basis is feasible.

The maximum energy demand management system can consist of a maximum demand monitor that raises an alarm if the targeted maximum demand is exceeded by the projected maximum demand. The maximum demand monitor must measure in exactly the same way as the maximum demand of the supply authority is recorded otherwise incorrect management of the demand may result.

During periods of restricted demand co-generation of own power by diesel generator may be a feasible solution. The potential revenue per production unit is not available in this period and it is therefore not possible to explore this possibility. At the moment the production day starts at 07h00 and ends at 16h00 - well clear of the restricted demand time.

8.1 Maximum demand

The demand of this installation is as follows :

Lights	61 kVA
Plant	211 kVA
Air conditioning (cooling mode only)	205 kVA
TOTAL	477 kVA

This electrical demand consists of a number of components which then build up to the total estimate and to be able to control the maximum demand it is necessary to be able to identify and quantify the components.

The heat load generated in the air conditioned space from production machinery and reflected in the air conditioning cooling load is 96 kW. This is a diversified load of the nameplate kW of the production machines. This load reflected back to chiller electrical maximum demand is 25 kVA with a conservative c.o.p. of nearly 4 for the chiller at maximum ambient conditions.

The total cooling load at maximum ambient conditions is 544 kW (thermal) and the chiller electrical maximum demand at this duty is 146 kVA which represents 71,2% of the air conditioning electrical demand. The remaining 59 kVA is utilised primarily to distribute air in the building, distribute cold water throughout the building and to reject the heat through the cooling tower.

The chiller electrical load constitutes of the following components :

1)	Process plant cooling	16,4%
2)	..resh air at maximum conditions	25,3%
3)	Lights	10,2%
4)	People	4,1%
5)	Proces. plant Chilled water requirement	11,1%
6)	Structural loads	32,9%
	TOTAL	100 %

The maximum demand of the air conditioning system expressed in kVA is compiled of the following :

Move air and reject heat	59 kVA
Plant cooling	24 kVA
Fresh air cooling	37 kVA
Lighting cooling	15 kVA
Personnel cooling	6 kVA
Process cooling	16 kVA
Structural cooling	48 kVA
TOTAL	205 kVA

To manage maximum demand, which at between R7-70 and R12-00/kVA, is one of the most critical tasks in keeping the energy costs at a minimum, a close control of the above parameters are required.

Table 3 indicates the chiller kVA demand on an hourly basis for the design day of each month of the year. To determine the other variables the maximum demand is made up as follows :

Lights	61 kVA
Producton machinery	211 kVA
Move air and reject heat	59 kVA
Chiller	146 kVA

The chiller demand is determined assuming a 100% production rate. The maximum demand of the chiller very considerably on a monthly basis even with the other parameters constant as illustrated in Fig. 11.

When production is not running at full capacity the following components of the heat load reduce :

1)	Plant cooling	24 kVA
2)	Personnel cooling	6 kVA
3)	Process cooling	16 kVA

The maximum demand of the production machinery will also reduce. This reduction has a cumulative effect as shown and if production areas which are not in use are switched off, a saving in maximum demand on the air movement and lighting components are possible.

8.2 <u>Tariff structure manipulation</u>

The rules of the tariff structure allows one change of notified demand per year. If a distinct peak of maximum

HOUR	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
JAN	115.7	134.4	136.2	145.4	145.8	145.3	144.8	144.8	144.2	138.9	138.4
FEB	59.5	76.3	83.1	84.4	96.7	102.0	106.8	107.5	106.5	104.9	98.5
MARCH	52.0	68.5	74.5	79.9	84.0	86.9	87.6	92.5	91.7	90.4	83.1
APRIL	43.4	58.7	64.3	69.5	73.5	76.3	77.3	77.7	76.7	74.9	71.9
MAY	22.7	39.6	46.6	52.4	56.2	59.3	60.7	60.9	59.5	57.6	54.4
JUN	9.6	22.9	30.8	37.3	41.3	44.7	46.6	46.8	45.1	43.0	39.5
JULY	7.5	21.2	27.2	35.3	38.9	41.1	43.3	44.2	43.2	41.9	39.5
AUG	21.2	39.1	46.1	49.7	55.4	59.3	59.9	60.4	59.3	57.1	54.4
SEPT	44.3	59.5	65.1	70.1	75.4	77.7	78.5	78.7	77.7	76.3	72.9
OCT	50.7	67.6	72.7	79.9	83.9	85.5	86.9	89.3	88.9	88.4	82.2
NOV	55.9	76.3	78.8	81.6	89.7	99.2	104.5	104.6	104.7	103.7	96.9
DEC	110.8	126.4	128.5	132.0	132.6	136.8	139.2	139.5	138.9	133.9	135.3

CHILLER MAXIMUM DEMAND (COS ϕ = 0,95)

<u>TABLE 3</u>

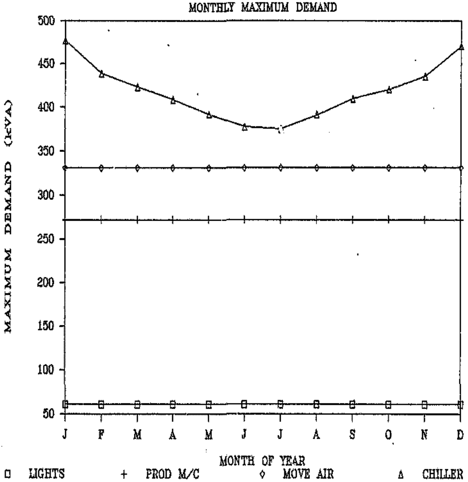

MONTHLY MAXIMUM DEMAND
MAXIMUM DEMAND (kVA)
500
450
400
350
300
250
200
150
100
50
J F M A M J J A S O N D
MONTH OF YEAR
LIGHTS
PROD M/C
MOVE AIR
CHILLER

FIG 11

demand occurs say in the summer as fig. 11 indicates for this factory it can be beneficial to apply for a new notified demand just after this peak has occurred. This strategy allows much lower minimum kVA demand charges for periods of low demand than if the actual maximum demand remains the notified demand. Unfortunately, if fig. 11 is analysed the maximum to minimum ratio of maximum demand is 0,78 and this strategy will not be beneficial for this specific factory.

The choice of tariff structure is also a controllable variable and the choice is between LV-2 Part, LV-3 Part and Business and General tariffs. The maximum demand for the factory is calculated to be 477 kVA with a monthly energy use of 276,6 GJ/month. The cost using LV-2part amounts to R 6 165-97 and with LV-3part amounts to R 7 107-10. Therefore, it is more advantageous to use the LV-2part tariff structure. The additional bonus is that no restricted demand tariff structure exists for LV-2part.

Another option is to use the Business and General tariff of 7,45c/unit with no maximum demand or power factor penalty. This option results in a monthly energy bill of R 5 724-51 which is the cheapest solution and should be implemented. The advantage of this tariff structure is that with this structure energy is bought on a fixed cost per unit of energy basis and if it is clearly spelled out that if a machine is not producing it should be switched off a very easily manageable energy management sytem can be instituted.

8.3 Power factor correction

The above kVA calculations have been carried out using a power factor of 0,95. The power factor correction equipment was installed by the client and did not form part of the installation. To increase power factor correction to 0,97, which is the accepted norm for a two year pay back on power factor equipment, reduces maximum demand by 10 kVA which represents a saving of R77/month on the LV-2 part tariff structure and R120/month on the LV-3 part tariff structure. No savings can be realised using the business and general tariff and therefore all the money spent on the power factor correction equipment can be saved if the latter tariff structure is used.

8.4 Monitoring

The maximum demand and energy consumption was calculated using a model and variances from the model can be expected. Close control of energy costs should be kept to see which tariff structure is the most beneficial. Here, the information favoured the Business and General tariff option. Actual consumption may indicate another structure. Cognisance of the fluctuations of energy due to seasonal influences must be taken in account. The fluctuations will definitely take the same shape as simulated, but the absolute values may differ.

CHAPTER 9

FINANCIAL ANALYSIS

9.1 COSTING MODELS

To determine whether a proposed system change is economically feasible an analysis between performance and economics must be evaluated on a rational basis[33,34].

The most rudimentary system to use as a criterion is the payback period. The savings are calculated and then divided into the costs to effect the savings. This then yields a payback period.

The advantages of the system is that it is easy to understand and easy to implement. The disadvantage of this system is that cost of capital and time related costs are not taken into account. The lifespan of equipment is also not considered.

The application of this type of model is when payback periods are relatively short i.e. one to two years and the economic life of a system is tenfold the payback period. When used as a comparison between various alternatives in a short payback period situation clear indications of which alternative is optimal can be determined quite easily.

When the payback period becomes longer and cost of capital, interest rates, taxes and equipment life must be taken in account a more elaborate costing model is required.

A life cycle cost model can be defined as an economic evaluation method for investment alternatives taking in account the total value of capital, running, maintenance and energy costs over the economic life of the proposed alternative. The advantage of a life cycle costing system is that it can point out if a proposed system will cost more than what it can save or which system saves the most out of different alternative proposed systems.

The technique in general use is to apply life cycle costing and calculate present worth. This value calculated is the present value of future payments in terms of present money values.

The evaluating techniques are :

<u>Life cycle costing of alternatives</u> : This is the method described above.
<u>Life cycle costing of savings</u> : The cost of an alternative are compared to the costs of an existing installation.
<u>Saving to investment ratio</u> : This is defined as the ratio of discounted cash value of savings to discount cash value investment. This ratio is a value which is a direct indication of economic efficiency of a proposal. A value greater than unity is a cost effective solution.
<u>Internal rate of return</u> : This represents the expected rate of return on an investment. The IRR (Internal Rate of Return) is the correct method to evaluate retrofitting of systems. Alternatives with an IRR higher than minimum acceptable rate of return on investments is cost effective.
<u>Discounted payback</u> : The time period necessary to pay back initial investment in discounted savings. When not discounted the method is exactly the simple payback period as described previously.

9.2 DETERMINATION OF FEASIBILITY OF ENERGY SAVINGS PROPOSALS

The majority of energy conservation opportunities have been listed and quantitified for potential savings in Chapter 6. To make an economic assessment initial, running and maintenance costs must be included to complete the picture.

The proposals discussed in Chapter 6 are listed in table 4 with a life cycle cost calculated in the right hand bottom corner. This figure is made up as follows:

Capital Costs :	If money must be spent it is shown as positive
Energy :	The energy savings is shown in the last line as positive, if there is a saving it is deducted from the capital and maintenance cost as a positive inflow of money.
Maintenance :	If money must be spent it is shown as positive
Life cycle cost:	If positive, money must be spent to carry proposal through economic life and is therefore not feasible. If negative, the inflow of money offset the outflow and is therefore a viable proposal.

The capital costs, energy costs, maintenance cost, life span of proposal, pre tax discount rate, escalation of energy costs and maintenance costs and tax rate is listed in the print out.

The proposals are as follows :

1) Solar reflection film : The removal of windows and replacement by Solarshield were not considered because of the disruption to production. The cost of the solar film is R35-50/m^2 and the installation is an additional cost.

   The payback period is $\frac{3577,75}{259,09}$ = 13, 8 years

   The life cycle cost is R 1 284,23

The life cycle cost is positive and therefore not viable.

2) Lights : The replacement of ordinary lights with high efficiency lights is part of normal maintenance and a very small amount of capital costs and yearly maintenance can be attributed to the proposal

The payment period is $\frac{1005}{1573,83}$ = 0,63 years

The life cycle cost is -R 5 593,62

Both financial models show a strong indication of viability and should be incorporated.

3) Speed control : The speed regulation of fans to regulate flow through filters and to improve efficiency at low turndown ratios for variable volume systems show the following results

The payback period is $\frac{35000}{2867,85}$ = 12,2 years

The life cycle cost is + R 10 346,89

If the capital cost of R35 000 reduces by R 10 346,89 the life cycle cost is zero and just viable.

The payback period then changes to $\frac{24653.11}{2867.85}$ = 8,6 years

4) People : To control the access of non working people to the air conditioned area will save R 70,58 per person over a period of 20 years.

5) Duct leakage : The capital cost that can be spent to make this proposal break even is R 7 533,24. To carry

out this proposal after the insulation has been installed is virtually impossible and should have been considered during construction stage. Retrospectively it is difficult to decide whether it could have been done for the amount of money shown above, but is seems questionable.

6) Condensate recovery : Intuitively the recovery of condensate feels as if it should be viable because most of the steam installations return condensate to the boiler.

The payback period is $\frac{6800}{122,74}$ = 55,4 years

The lifecycle cost is R 6 309,26. Both models show a very strong indication of unviability. The reason for this is the cost of energy and the expensive system required to return the condensate.

7) ejection of dehumidified heat : The proposal to reject heat with a cooling tower to temperatures just in excess of wet bulb ambient temperature seems a questionable proposal due to the 4 to 1 C.O.P. of the refrigeration systems.

The payback period is $\frac{18000}{6126.73}$ = 2,9 years

The life cycle cost is - R 21 021-15

At break even point the capital cost of the installation can be R 39 021-15.

This then gives a payback period of $\frac{39021.15}{6126.73}$ = 6,3 years

```
PROPOSAL  SOLAR REFL
******************************
                                        CAPITAL    ENERGY      MAINT          *LIFE CYCLE
CAPITAL CO    3577.75R                  3577.75                               *
ENERGY COS .     7.45c/kW-h                                                   *
TOTAL ENER    3477.78kW-h                                                     *
YEARLY ENE     259.09R                              259.09                    *
MAINTENANC       0.00R/YEAR                                      0.00         *
LIFESPAN O      20.00YEARS                                                    *
PRE TAX DI      12.50% PER ANNU                      84.00      31.69         *
AFTER TAX        6.25%PA                              0.21       0.46         *
ENERGY COS      17.00% PER ANNU                      17.70      14.67         *
REAL ENERG       5.00% PER ANNU                                               *
MAINTENANC      15.00% PER ANNU                                               *
REAL MAINT       3.00% PER ANNU                                               *
INFLATION       12.00% PER ANNU                                               *
TAX RATE        50.00%                                0.50       0.50         *
**************************************************************************************
                                        3577.75   2293.52        0.00         *   1284.23
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
PROPOSAL  LIGHTS
******************************
                                        CAPITAL    ENERGY      MAINT          *LIFE CYCLE
CAPITAL CO    1005.00           R       .005.00                               *
ENERGY COS       7.45      c/kW-h                                             *
TOTAL ENER   21125.22        kW-h                                             
YEARLY ENE    1573.83           R                  1573.83                    *
MAINTENANC    1000.00      R/YEAR                               1000.00       *
LIFESPAN O      20.00       YEARS                                             *
PRE TAX DI      12.50% PER ANNU                      84.00      31.69         *
AFTER TAX        6.25         %PA                     0.21       0.46         *
ENERGY COS      17.00% PER ANNU                      17.70      14.67         *
REAL ENERG       5.00% PER ANNU                                               *
MAINTENANC      15.90% PER ANNU                                               *
REAL MAINT       3.00% PER ANNU                                               *
INFLATION       12.00% PER ANNU                                               *
TAX RATE        50.00           %                     0.50       0.50         *
**************************************************************************************
                                        1005.00  1[illegible]731.63     7333.02         *  -5593.62
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
PROPOSAL  SPEED CONT
******************************
                                        CAPITAL    ENERGY      MAINT          *LIFE CYCLE
CAPITAL CO   35000.00           R      35000.00                               *
ENERGY COS       7.45      c/kW-h                                             *
TOTAL ENER   38494.66        kW-h                                             *
YEARLY ENE    2867.85           R                  2867.85                    *
MAINTENANC     100.00      R/YEAR                                100.00       *
LIFESPAN O      20.00       YEARS                                             *
PRE TAX DI      12.50% PER ANNU                      84.00      31.69         *
AFTER TAX        6.25         %PA                     0.21       0.46         *
ENERGY COS      17.00% PER ANNU                      17.70      14.67         *
REAL ENERG       5.00% PER ANNU                                               *
MAINTENANC      15.00% PER ANNU                                               *
REAL MAINT       3.00% PER ANNU                                               *
INFLATION       12.00% PER ANNU                                               *
TAX RATE        50.00           %                     0.50       0.50         *
**************************************************************************************
                                       35000.00  29386.41      733.30         *  10346.89
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
PROPOSAL  PEOPLE
******************************
                                        CAPITAL    ENERGY      MAINT          *LIFE CYCLE
CAPITAL CO       0.00           R          0.00                               *
ENERGY COS       7.45      c/kW-h                                             *
TOTAL ENER     107.03        kW-h                                             *
YEARLY ENE       7.97           R                     7.97                    *
MAINTENANC       0.00      R/YEAR                                0.00         *
LIFESPAN O      20.00       YEARS                                             *
PRE TAX DI      12.50% PER ANNU                      84.00      31.69         *
AFTER TAX        6.25         %PA                     0.21       0.46         *
ENERGY COS      17.00% PER ANNU                      17.70      14.67         *
REAL ENERG       5.00% PER ANNU                                               *
MAINTENANC      15.00% PER ANNU                                               *
REAL MAINT       3.00% PER ANNU                                               *
INFLATION       12.00% PER ANNU                                               *
TAX RATE        50.00           %                     0.50       0.50         *
**************************************************************************************
                                           0.00     70.58        0.00         *    -70.58
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

LIFE CYCLE PROPOSALS   TABLE 4

PROPOSAL DUCT LEAKA

			CAPITAL	ENERGY	MAINT	*LIFE CYCLE
CAPITAL CO	7500.00	R	7500.00			*
ENERGY COS	7.45	c/kW-h				*
TOTAL ENER	11423.02	kW-h				*
YEARLY ENE	851.01	R		851.01		*
MAINTENANC	0.00	R/YEAR			0.00	*
LIFESPAN O	20.00	YEARS				*
PRE TAX DI	12.50%	PER ANNU		84.00	31.69	*
AFTER TAX	6.25	%PA		0.21	0.46	*
ENERGY COS	17.00%	PER ANNU		17.70	14.67	*
REAL ENERG	5.00%	PER ANNU				*
MAINTENANC	15.00%	PER ANNU				*
REAL MAINT	3.00%	PER ANNU				*
INFLATION	12.00%	PER ANNU				*
TAX RATE	50.00	%		0.50	0.50	*
			7500.00	7533.24	0.00	* -33.24

PROPOSAL CONDENSATE

			CAPITAL	ENERGY	MAINT	*LIFE CYCLE
CAPITAL CO	6900.00	R	6800.00			*
ENERGY COS	0.00	c/KG				*
TOTAL ENER	409140.00	KG				*
YEARLY ENE	122.74	R		122.74		*
MAINTENANC	20.00	R/YEAR			20.60	*
LIFESPAN O	10.00	YEARS				*
PRE TAX DI	12.50%	PER ANNU		84.00	31.69	*
AFTER TAX	6.25	%PA		0.11	0.27	*
ENERGY COS	17.00%	PER ANNU		9.38	8.46	*
REAL ENERG	5.00%	PER ANNU				*
MAINTENANC	15.00%	PER ANNU				*
REAL MAINT	3.00%	PER ANNU				*
INFLATION	12.00%	PER ANNU				*
TAX RATE	50.00	%		0.50	0.50	*
			6800.00	575.37	84.63	* 6309.26

PROPOSAL DEHUMIDIFY

			CAPITAL	ENERGY	MAINT	*LIFE CYCLE
CAPITAL CO	18000.00	R	18000.00			*
ENERGY COS	7.45	c/kW-h				*
TOTAL ENER	82237.96	kW-h				*
YEARLY ENE	6126.73	R		6126.73		*
MAINTENANC	480.00	R/YEAR			480.00	*
LIFESPAN O	15.00	YEARS				*
PRE TAX DI	12.50%	PER ANNU		84.00	31.69	*
AFTER TAX	6.25	%PA		0.16	0.37	*
ENERGY COS	17.00%	PER ANNU		13.66	11.80	*
REAL ENERG	5.00%	PER ANNU				*
MAINTENANC	15.00%	PER ANNU				*
REAL MAINT	3.00%	PER ANNU				*
INFLATION	12.00%	PER ANNU				*
TAX RATE	50.00%			0.50	0.50	*
			18000.00	41854.32	2833.18	* -21021.15

LIFE CYCLE PROPOSALS (CONTINUED)

TABLE 4 (CONTINUED)

9.3 ENERGY STORAGE

9.3.1 Chilled Water Storage

To avoid maximum demand charges it is feasible to generate the cooling requirements during the night and store the cold water in a tank. In the day when the production processes start the chiller is stopped and the stored chilled water is used to cool the building. No energy is saved, in actual fact energy is wasted due to prolonged periods of time when conduction and other losses can take place.

The saving is made by reducing the maximum demand by not using the chiller and cooling towers when the production machinery is in operation.

Various alternatives exist to store the energy. The energy can be stored in the building structure or in a tank with water or in a tank where a phase change of cooling medium takes place.

The energy storage in building structure is of no commercial use for a production facility where exact constant temperatures must be maintained, because the storage in the building structure integrates over time and temperature drift occurs when the energy available becomes exhausted. This method is available for comfort cooling.

Chilled water storage can be carried out by having two storage tanks. The one tank will store the cold water, while the other tank will store the warm water. The temperature differential between the two tanks will be approximately 6 °C to 10 °C depending on cooling coil selections. In the morning the cold tank will be full, while the warm tank will be empty. As the day progresses the cold tank will become empty, while the warm tank will fill up. The disadvantage of this system is the cost of having in effect one empty tank at all times.

The hot and cold tanks can be combined by drawing off cold water at low level at the one end while returning hot water at high level at the other end. The method relies on the density difference of water between supply and return temperatures. Some mixing and therefore energy loss will happen at the interface of the cold and the hot water. One method of controlling this blending is to install baffles in the tank to make the interface area as small as possible. The system has been developed whereby a rubber membrane is installed between the interface and this membrane floats up and down as the cold or hot well increase or decrease.

If the hourly cooling load of the building is analysed 5311,4 kW cooling hours per day is needed to keep the building on temperature. If it is assumed that the building will be used 10 hours per day plus two hours which must be reserved for the limited demand period a total of thirteen hours per day remain for generating the cold water. A total of 5311,4 kW/hr cooling must be generated over a period of twelve hours. If a temperature drop of 7 °C is attainable over the cooling coils the tank must be able to hold 653,5 m^3 which, if a depth of 4,54 m is used, results in a tank with dimensions of 12,7 x 12,7 x 4,54 m. The chiller can be a little bit smaller, because it can generate the cold water over a period of 13 hours instead of 9 hours. The cooling load has been averaged out and the unit is therefore not sized on peak demand. The advantage of the system is that it is still a conventional chiller installation except for delivering cold water to the cooling coils it is delivering cold water to a big storage tank.

9.3.2 Ice Storage

In the early days of refrigeration plants where ice forming and later melting of the ice was extensively used it was applied because chiller plant capacity was too small to cope with refrigeration loads. When chiller plant improved and became smaller the concept disappeared because of the additional complexity and bulk of the plant.

The advantage of ice storage is that by utilizing the phase change between ice and water much smaller storage volumes are needed to store the ice. However, a few technical problems do exist. Ice can be produced in cubes, flakes or by forming an ice jacket around cooling pipes. During the day when the ice must give up its energy to the water the ice water mixture must produce cold water at the right temperature and at the correct rate. Ice in water tend to stick together so some sort of agitation must be employed to keep ice surface area open for heat transfer.

One commercial system is available which freezes a water spray in a sheet of ice on a plate heat exchanger. When the ice sheet is approximately 10 mm thick the coil is used in the defrost mode. The hot gas melts the surface between the plate condenser and the sheet of ice. The sheet of ice then drops in a reservoir from where by pumping water over the ice cold water can be drawn off. The forming of ice lumps is still a problem, but has been solved by breaking up of ice and the condition of the ice before it is put in the reservoir. The advantage of this system is that the C.O.P. is in the region of 3,3 which is better than the following system.

Another commercial system available forms ice around the condenser cooling pipes. This system is also commercially available, but a few disadvantages also exist. Ice is an insulator and to conduct cold through a layer of ice needs a big temperature difference and therefore very low suction temperatures. This results in a coefficient of performance which, for normal air conditioning applications is in the region of 4, drops to 2,2. The chiller plant in itself also becomes much bigger because of the increased differentials between suction and delivery pressures.

The ice plant is therefore not so practical and advantageous as it looked, but for saving on maximum demand charges it is a definite solution, because again, the cost of additional energy consumed is low.

For the specific choice of tariff structure i.e. business and general the shifting of maximum demand fom the chiller installation to night operation has no benefit, because maximum demand does not feature in the tariff structure. Where a maximum demand is part of the tariff structure this storage concept is a viable alternative with a payback period of 3-years.

At the moment an alternative to ice is being developed which is an ice solution in a transport medium which does not form big lumps of ice. Unfortunately this alternative is still being developed and very few technical details are available.

When more nuclear powered electricity generating stations come on stream the inability to reduce demand during night time will force ESCOM to subsidise energy storage systems to keep the minimum demand required on the nuclear power station.

This alternative although at first not a viable altenative may become a viable system in the future.

CHAPTER 10

CONCLUSIONS

The objective of this report is threefold:

1) Analyse the present factory design with regard to energy consumption

2) Investigate opportunities where energy could be saved and cost the energy saving opportunities for financial viability.

3) Optimise the energy tariff structure and propose an energy monitoring and targeting system as an input to an energy management system.

10.1 Present installation

The present installation includes the variables of the building envelope, the process, the process requirements and the building services.

1) Envelope

The factory has been designed to be energy efficient according to the South African perception of energy efficiency. The building surpasses the ASHRAE 90 requirements on the thermal resistance of the walls and are within 3 % of the requirement on the thermal resistance of the roof.

By improving the building insulation it is possible to save more energy. However, it is difficult to quantify the optimum insulation and when insulation values are within practical reach of international requirements other aspects, for example sun control of windows should be investigated to curtail external heat gain.

2) Process and Process Requirements

The pharmaceutical manufacturing process was obtained from Great Britain as a fully developed process package. Absolute adherence to this process requirements were observed at all times. No variations were investigated to accommodate local energy saving possibilities.

The process environmental requirements of air velocity, humidity, temperature and return air paths were also specified as rigid requirements and within the specified tolerances were strictly adhered to. HEPA filters are a standard requirement for the control of airborne contaminants in this type of plant and, although energy can be saved by omitting these filters, this was not investigated.

3) Building Services

The biggest user of energy is the air conditioning system. Separate air handling units have been installed to cater for areas with different and specialised environmental requirements. This was done to allow flexibility in production scheduling and to prevent unnecessary energy consumption when the properties of the supply air must be changed to suit the specific requirements of an area.

The other services, namely the electrical reticulation, the compressed air installation and the steam installation have been designed to current South African standards. Deliberate wasteage of energy takes place with the dumping of the steam condensate. A life cycle costing exercise has been carried out to determine whether it is economical to return this condensate to the boiler.

10.2 Energy Consumption

The energy consumption of this facilty was simulated at 100 % production capacity for an operating year. The simulation was carried out by computer using the HCC III air conditioning simulation programme. An analysis of a design month was repeated for twelve months of the year to arrive at the yeary cooling requirements.

Chiller performance at part and full load was determined by hand on an hourly basis. The dehumidifier performance was also determined by hand on an hourly basis, because being specialised equipment, was not incorporated in the computer programme.

The performance indicator for the complete factory is 1,666 GJ/m^2 per operating year and without production machinery amounts to 1,059 GJ/m^2 per operating year. The operating year has been calculated over 2 400 hours.

10.3 Energy conservation opportunities

Only energy conservation opportunities which do not disrupt production or affect the hygene conditions of the plant were investigated.

The opportunities investigated the savings, the payback periods and the life cycle costs are as follows:

PROPOSAL	ELECTRICAL ENERGY SAVING (GJ per year)	PAYBACK PERIOD (years)	LIFE CYCLE COST* (R)	VIABILITY
Solar film on external windows to reduce solar radiation	12,51	13,8	1 284,23	No
Fitting of energy efficient lights	76	0,62	-5 593,62	Yes

PROPOSAL	ELECTRICAL ENERGY SAVING (GJ per year)	PAYBACK PERIOD (years)	LIFE CYCLE COST* (R)	VIABILITY
Fan speed control	138,47	12,2	10 346,89	No
Duct leakage	78,219	8,8	-R33,24	Not as a retrofit
Condensate reclaim to boilerhouse	136,817	55,4	6 309,26	No
Dehumidifier heat removal with evaporation	965,76	2,9	-21 021,15	Yes

*) Negative LCC indicates financial viability.

Proposals also investigated, but which were unsuitable, are as follows:

PROPOSAL	WASTE ENERGY* (GJ PER YEAR)	REASON FOR UNSUITABILITY
Reclain of air conditioning rejected heat	2 840,40	Available as heat at 50 °C max and only when plant is running. Quantity diminish as ambient temperature reduce.
Reclaim of exhaust air heat	0,49 (sensible) 4,6102 (latent)	A very small amount and only available when the plant is running. Involves humidity which can not be sensibly reclaimed.
Reclaim of energy from heat wheel	965,76	Heat available at 43 °C max and only when plant is in operation.
Optimal starting time for chiller	not quantified	An optimal starting time device for the chiller is unsuitable for this factory, because moisture storage and not thermal st[illegible] is the governing [illegible]ameter.

PROPOSAL	WASTE ENERGY* (GJ PER YEAR)	REASON FOR UNSUITABILITY
Chilled water or ice storage	nil	Not investigated because the optimum electricity tariff proposed does not take maximum demand in consideration.

* Partially recoverable only

10.4 Optimal purchase of electrical energy

The theoretical calculated electrical energy consumption is 276,6 GJ/month and the maximum demand is 477 kVA. In terms of the 1984 tariffs the above tariffs are applied the monthly energy costs are:

2 Part Bulk Low Voltage	R6 165,97 p.m.
3 Part Bulk Low Voltage	R7 107,10 p.m.
Business and General	R5 724,51 p.m.

Therefore it has been recommended that the factory use the Business and General tariff structure. This tariff does not charge for maximum demand in kVA or restricted demand therefore no power factor correction or off peak generation of chilled water can be recommended.

10.5 Energy monitoring and targeting

The monitoring philosophy has been designed around a management by exception strategy.

To monitor individual systems for inefficient use of energy the following strategies could be used:

Functional Group	Monitoring Strategy
Chiller Cooling Tower	1) Obtain benchmark electrical consumption figures when installation is new and commissioned. 2) Compare actual electrical consumption to benchmark values when chiller is expected to deliver exactly the same amount of cooling capacity.
Constant volume air distribution system	1) Sense room temperature, humidity and if reheater is on. 2) If heater is on check if temperature is below setpoint or humidity is above setpoint. 3) If temperature is within setpoint range then humidity must be above setpoint range. 4) If humidity is within setpoint rang then a fault condition should be indicated.

Functional Group	Monitoring Strategy
Variable volume air distribution system	') Sense room temperature, duct static pressure and supply air temperature. 2) If any of the above is out of setpoint range then a fault condition should be indicated.

The monitoring of the chiller could be achieved by measuring refrigerant flow, suction pressure and condensing pressure, but a flow measurement device creates losses which wastes energy.

On line monitoring of air distribution systems, because of the simultaneous measurement of up to five parameters as indicated above needs programmable logic controllers or a computer to indicate a fault condition.

For effective targeting of energy consumption the following method has been proposed:

1) Energy consumption should be compiled on a monthly basis by totalling the energy consumption of the production days in that month. The energy consumption of a production day could be compiled from expected ambient temperatures using fig 10 p. 5-13.

2) On a daily basis an adjustment to the targeted figure should be made to compensate for actual ambient temperatures also using fig 10. When variances in production volumes occur an adjustment to the targeted figure should be made taking in account the energy consumption and the heat generation of the production machines not in use.

3) The actual daily energy consumption should then be compared to the targeted energy consumption to detect inefficient use of energy or malfunctioning of equipment.

The above targeting strategy has largely been based on the relationship found between ambient temperature and cooling electrical requirements which was derived from a theoretical simulation of cooling loads at 100 % production capacity. This relationship should be verified by comparing actual plant electrical consumption against ambient temperatures. Production volumes should also be quantified in terms of energy usage as an independent variable of the temperature versus electrical cooling requirement relationship.

CHAPTER 11

RECOMMENDATIONS FOR FURTHER STUDY

This report should he followed up by determining the Performance Indicator of other production facilities to build up a data bank of energy consumption figures for various types of production facilities.

Other plants should be researched in depth to determine energy conservation opportunities.

The need for more knowledge in energy consumption prediction exists and predictive relationships e.g. the relationship between ambient temperature and cooling electrical energy consumption or other relationships should be formulated.

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