ENERGY EFFICIENT TECHNOLOGIES AND ENERGY SAVING POTENTIAL FOR COLD ROOMS

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ABSTRACT

Food processing demands a considerable and continuous energy supply and the rise in the price of electricity in South Africa has put much pressure on the industry. This has forced a re-think and development of alternative energy efficiency technology.

In South Africa's cold storage chain the entire refrigeration system is among the most energy-intensive areas, but also offers opportunity for short and long term saving. It also provides an opportunity for enhancement of sustainable development and cold chain management.

This paper presents a combination of three efficient technologies in those areas:

(1) Airflow pattern optimisation through a computer assisted simulation model in which overall energy efficiency of cooling facilities is dependent not only on the energy generation efficiency of the refrigeration system, but also utilisation efficiency of all cooling facilities. Optimal airflow pattern of a cold room would move heat effectively to a refrigeration system, hence increasing both energy efficiency and refrigeration distribution.

(2) Variable speed drive (VSDs) technology on evaporator fans motors: VSDs reduce motor electricity consumption by 30-60%; other benefits include prolonging equipment life through motor speed adjustments according to load.

(3) Minimising heat transmission load by heat conduction transfer - coloured and shaded external walls being a major factor.

Such technologies saved energy, thus reducing cold chain facilities' demand. The system was also cost-efficient and, inter-alia, research detailed in this paper contributed towards alleviating South Africa's energy problems.

1. INTRODUCTION

Renewable, efficient energy sources are said to be the twin pillars of a worldwide sustainable energy policy. In many countries industrial and agricultural sectors contributed significantly to national development, but simultaneously creating higher energy demand. Thus energy efficiency was vital to not only reduce demand, but to provide viable production and services, while playing an important role in nurturing the environment and insisting on sustainable development.

For developing countries undergoing rapid economic growth and surging energy consumption, efficient design and management offered cost-effective control of power costs surges. Unless seriously considered, excessive power costs would adversely impact on the viability of power itself - rising costs of future energy imports to meet domestic demand by industry - leading to health and the environment being seriously affected. In 1994 the US Department of Energy (DoE) began working with industry to develop a consensus approach to measuring and verifying investment to overcome existing barriers to efficiency in that area [1].

Improved energy efficiency is usually achieved through adoption of a more efficient technological or production process. There are various motivation options to enhance energy efficiency. Moreover, any viable, low-cost scheme to implement the cutting of energy usage meant saving to be passed on to consumers.

Throughout commerce refrigeration is an integral part of the perishable foodstuffs chain. It is, however, beset with temperature control problems, the effect of which has a detriment effect on shelf-life [2]. To maintain top quality and the freshness of agro-foods a cold chain must observe required temperature levels. The initial cooling, processing and subsequent cold storage of fruit and vegetables are the most energy-intensive sections, but provide the greatest potential for energy efficiency improvement.

Refrigeration gobbles more than 50% of food industry energy consumption, which, globally, stood at about 15-17% of total electrical energy produced [2].

Generally, energy consumption was classified into residential, commercial, industrial, transport and agriculture sectors. South African consumers used about 10% of energy produced; commercial and agriculture sectors about 6%; the industrial sector remains largest, consuming 45%. Transport 20%, non-energy 17% and others 2%, complete the picture; (SA Energy Association (Sanea), 2003); [3].

In Britain, the food industry was responsible for 12% of industrial energy consumption, using in excess of 4 500 GWh/y - 99% of energy used in refrigeration was electric [4].

SA's, four biggest municipal supermarkets provide about 75-80% of foods sales nationwide; Tshwane Market employed 55 cooling units (cold rooms) for the ripening of bananas.

The literature review disclosed many investigations focused on development of the computational fluid dynamic model (CFD) system for decrypting foods and fruits cold storage or boxes; upon airflow patterns and stacking arrangement, heat transfer processes and use of Navier–Stokes equations.

Throughout the studies, however, no one examined impact of airflow efficiency or stacking style on the rate of energy consumption by evaporator fans motors (EFMs). One study suggested optimal airflow pattern in a quick-freezer saved energy and improved efficiency by about 18-28% without increasing initial investment [5].

This paper presents three efficient technologies combined, (1) airflow pattern and stacking method by computed simulation. (2) VSD technology on evaporator fans and (3) minimising transmission heat load. Colouring and shading technology of external walls and roofs reduced evaporator fan demand when partially or fully loaded and improved overall efficiency, particularly for fruit cold rooms.

Nomenclature

P	Pressure, kpa
μ	Dynamic viscosity, kg/ms
u	Velocity vector, m/s
kc	Resistance coefficient, m
mr	Resistance coefficient, kg $s^{(b-2)}m^{(b+1)}$
O	Vent hole ratio, %
ρ	Density, kg/m^3
β	Forchheinner drag coefficient, l/m
d	Constant
b	Resistance exponent
G	Production rate of quick-freezer, kgh^{-1}
Hi	Enthalpy of foods at the entrance of quick-freezer (J kg^{-1})
Ho	Enthalpy of food at the exit of quick-freezer (J k^{-1})
Wicompressor	Input power of compressor (kW)
Wifan	Input power of fan (kW)
η_e	Efficiency energy

2. ENERGY CONSUMPTION IN COLD ROOMS AND COST SAVING TECHNOLOGY

A cold room maintains a low temperature environment to minimise deterioration, and pollution of harvested products.

2.1 ENERGY CONSUMPTION

Table 1 published on cold store energy consumption by [6], report energy consumption of between 370-560 kWh per m^2 annually and 8-12 kWh per cubic/m annually for cold stores of between 900~2500m²; the dimensions of cold rooms is also an important consideration.

Table 1: Energy consumption for different sizes of cold stores

Room size (m3)	Energy consumption (kWh/m3.Year)
10 000	100
1000	200
100	600
10	1500

Electricity is used to power a wide variety of machinery required to maintain pre-cooling, palletised and containerised consignments of fruit and vegetables for transportation.

Energy efficiency improvement is required primarily in management practices and the control of major refrigeration units such as compressors, condensers and fans. To fully understand operational systems, a simple schematic of chilled water is presented in Figure 1; Chilled water leaves at about 5.5˚C, travels to cooling units, where its temperature rises because of heat load impacting from the evaporator coil and from transportation through the main pipe line. The water returns to the chilling machines, now at an average temperature of 11˚C – usually during summer. Where condenser water leaves at 22.5˚C, it is cooled 6.4˚C, then returned to the condenser.

Cold rooms' energy consumption is directly related to air circulation, evaporator fan coil; cold water circulation and the refrigeration system. It is well known that to cool a horticultural product air is forced through the container box, pallet and stored product. However, flow resistance induced by the box, bulk or the product in cold rooms affects cooling efficiency' energy consumption increases throughout EFMs and any cooling system

This research involves computing a fluid dynamic (CFD) modelling airflow system through random stacking of horticultural in vented boxes. The objective was to develop a valid numerical modelling methodology that took into account product geometrical properties, box design and random product stacking. Prediction studies of air flow through box stacks containing agricultural and horticultural products found flow resistance was affected by confinement ratio, product size, porosity, box vent hole ratio, but much less from random filling. The air inside the stack was heterogeneous and the low resistance of the flow through the bulk and vented box could be expressed either in the form of Darcy-Forchheimer with reasonable accuracy for the flow through a vented box with products or a bulk. [7]

$$(\Delta p = -\frac{\mu}{kc}u - \rho\beta \square O^{-d}u^2) \qquad (1)$$

or Ramsin power law equations

$$(\Delta p = -m_r O^{-d}u^b) \qquad (2)$$

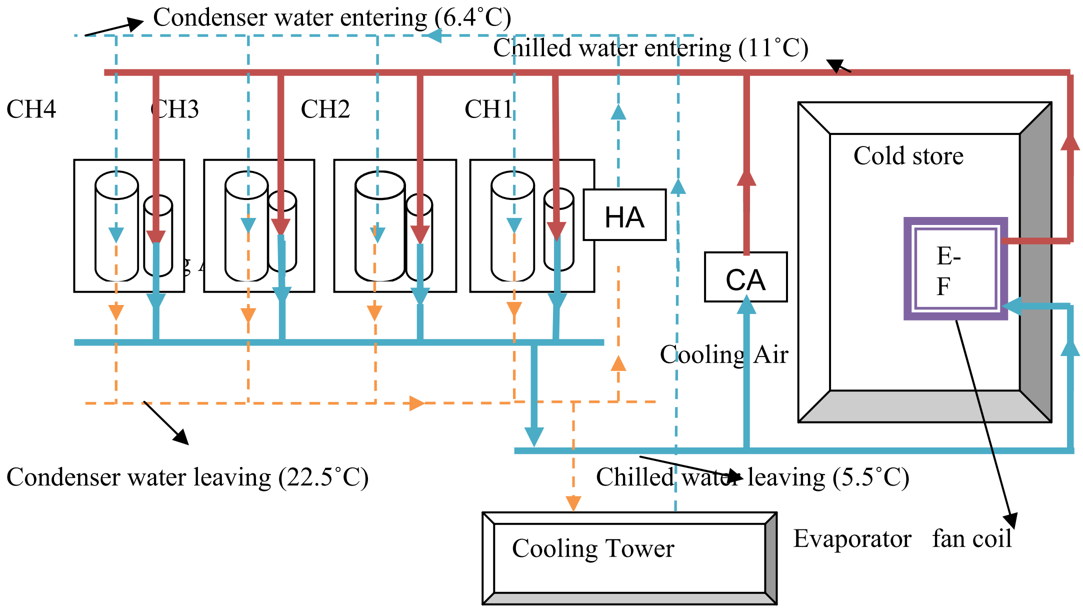

Figure 1: Schematic of water chilled system and condenser water system

2.2 SAVINGS TECHNOLOGY

Three technologies are presented which optimise efficiency and energy saving for cold rooms.

(1) Airflow pattern optimisation by simulation from computational methods: The overall energy efficiency of the cooling facilities was dependant not only on the energy generation efficiency of the refrigeration system, but also the utilisation efficiency of the cooling facilities. The optimal airflow pattern of the cold room would move heat effectively to the refrigeration system, thus increasing energy efficiency of the refrigeration generation and its utilisation.

(2) VSDs technology on evaporator fans: The existing cooling facilities of Tshwane Market fans still use conventional electrical driver motors VSDs reduced electricity consumption by 30-60%. Other VSDs benefits included prolonging equipment life through adjustable motor speeds to suit load requirements. Not only were there considerable cost saving, but vitally a reduction in greenhouse gas emission.

(3) Minimising transmission heat load through shading and colouring of building envelope and increased thermal resistance of external walls and roofs: This reduced much of the energy demand from evaporator fans, either when partially or fully laden. Previous and improved energy consumption is being recorded; all measurements effected by simulation.

3. CASE STUDY

According to this paper's case study, an energy audit benchmark had been defined for Tshwane Market's cold chain. This type of benchmarking is applied to the rate of electricity consumption and a rating provided for each section. These indicate where energy saving opportunities is presented.

Table2: Energy audit in the banana ripening section

Item Description	Rating(W)	Quantity	Total Wattage
High Mast (Mercury Vapour)	500W	106	53000
Mercury Vapour	500W	28	7000
Double Fluorescent Lamp	60W	306	11016
Fan	60W	39	2340
Quad Fluorescent Lamp	72W	13	936
Incandescent Bulb	100W	4	400
Fluorescent	18W	1	18
Stove	2500W	2	5000
Geyser	850W	1	850
Arc Welding Machine	2400W	1	2400
Bench Grinder	750W	2	1500
Drilling Machine	910W	2	1820
Extraction Fan	35W	12	420
Angle Gas Generator	1800W	1	1800
Ethelene Gas Generator	400W	55	22000
Urn(Boiler)	3000W	1	3000
Pump Electrical Motor	5500W	8	44000
Cfl	14W	4	56
Compressor Input	90000W	(Chillers Machines)	90000
Cooling Capacity	357000W	(55cold Rooms)	357000
Air Con	3500W	6	21000
Roll-Up Door Motor	500W	60	30000
Off-Loading Platform (Lift)	1500W	8	12000
Computer	220W	4	880
TOTAL			**668436W**
			668.436KW

An energy utilisation points system serves as a standard measurement tool to create the benchmark and provide a baseline from which to track and compare future energy usage. There are surprisingly large differences in energy consumption from cold room to cold room, but in all consumption is high.

Based on the energy audit in this case study, the cooling capacity for banana ripening units at Tshwane indicate intensive energy consumption cooling units and compressors - 53% and 13% respectively of total wattage used. True energy savings were evident in cooling rooms units and in refrigeration systems.

Cold storage

For a cold storage, energy consumption, measured in kWh/ton-day is seen in the graphs plotted in Figures 3 and 4, obtained from data on site. The variation of energy consumption is per day and month respectively;

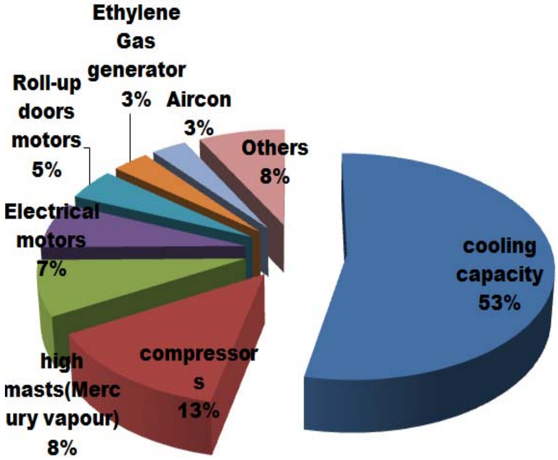

Figure 2: Total rating power per section in the banana ripening process

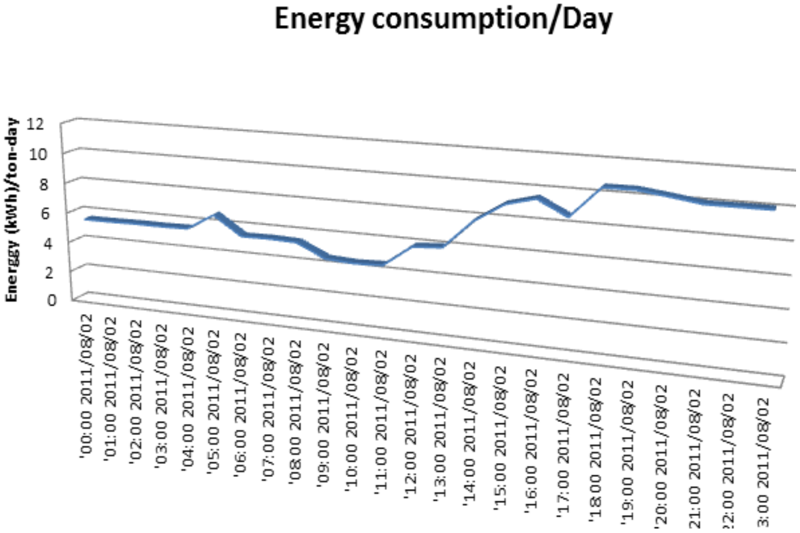

Figure3: Energy consumption/ton-day

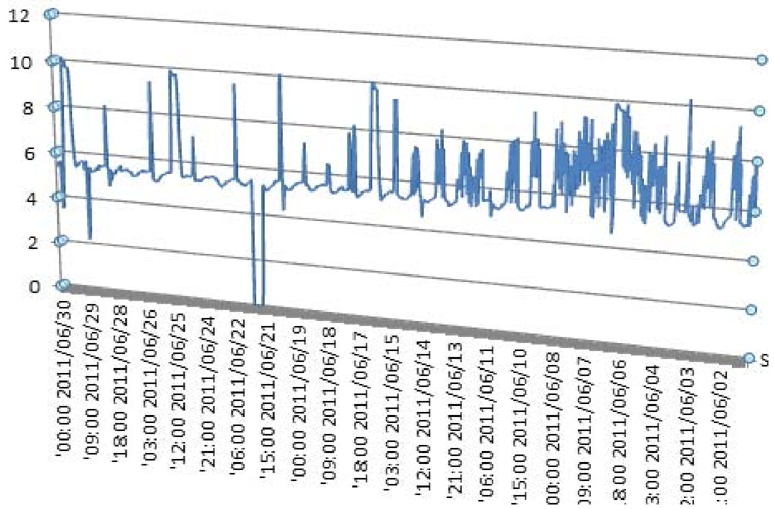

Figure 4: Energy consumption/month

Results indicate an average of between 5kWh/ton-day and 10 kWh/ton-day of energy consumption recorded during a day. Many reasons contribute to the variations and is must be understood the most obvious are not always the true causes. Regarding the ambient temperature and the removal of field heat, results indicate such factors as not significant to the variation, but rather that operation practices played a far bigger role than anticipated. A benchmark (See Figure 5) inside a cold room shows the most intensive energy consumption by EFMs which consumed three-quarter of total energy.

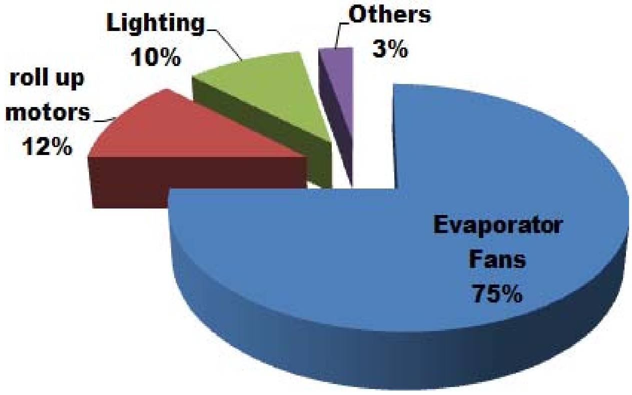

Figure.5: Benchmark cold room energy use

Refrigeration equipment in an industrial application was complex with many variables to control when seeking and optimum solution. Important aspect included balance between different units in refrigeration and cooling plants and employees were well trained and regularly supplied with the latest information on energy conservation. As each unit influenced one another any sub-optimum setting affected energy consumption, resulting in inefficient procedure.

(1): Airflow optimisation

It is well to note that in a cold store, while the cooling process's main objective is removal of total heat load, reduction in source load was vital. Fan efficiency - is the ratio between power transferred to the airflow and power used by the fan - was generally independent of air density. Optimal airflow cold room patterns moved heat effectively to the refrigeration system, increasing the energy efficiency of the refrigeration generation and efficiency utilisation. By example in the quick freezer it has been shown low efficiency of airflow organisation corresponded to low energy utilisation efficiency and vice-versa as the input power of the compressor fan does not change significantly.

In energy efficiency technology from Eq (3) relative energy efficiency can be calculated the efficiency [8].

$$\eta_e = \frac{G(Hi - Ho)}{Wicompressor + Wifan} \quad (3)$$

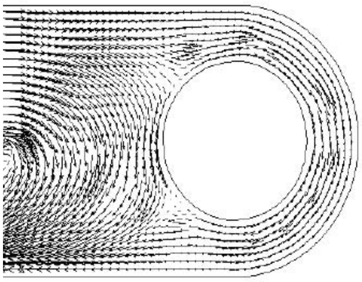

Figure 6:: Airflow with blockage board 0mm width

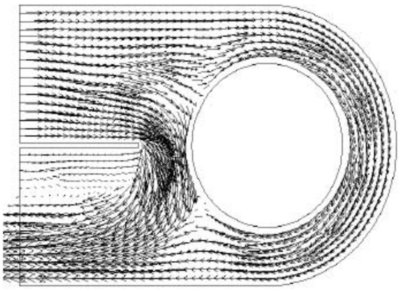

Figure 7:: Airflow with blockage board of 550mm

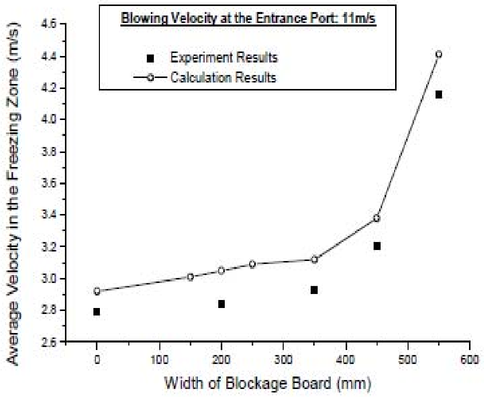

Figure 8: Average air velocity with blockage board

Previous studies show airflow patterns should be organised by use of airflow blockage and guide technology. But this paper shows by optimising the airflow blockage and guide boards average air velocity in the freezing zone would enhance 2.5-2.7 times compared to original design. Correspondingly freezing time was shortened to 78-85% and the energy efficiency and production rate increased by 18-28% (for the studied case [8]). But it well to note that, in practice, improvements might be less where products moved successively through zones of low and high velocities.

(2): Saving through VSDs technology on EFMs

Based on Tshwane cooling facilities, conventional electric motors are still used for evaporator fans; measurement of energy consumption remains uncertain. During 30 days' inspection on site, the evaporator fans in cooling units were set unnecessarily to run 24/7 at constant speed, either partially or fully loaded It makes for good business sense that VSD technology has advantages resulting in substantial energy saving. It important to remember when analysing VSDs' relationship with evaporator fans that:

- Airflow is proportional to fan speed. (cubic cm per metre proportional to rotation per minute);
- fan heat and fan energy was proportional to the third power, or “cube”, of rotational per minute;
- evaporator capacity was proportional to fan speed and,
- airflow was proportional to fit speed.

The VSD on evaporator fans also reduced electric fan motor heat load expended from mechanical losses. In the same manner the feeling of airflow throughout all bulk was evident.

Figure 9 indicates a small change in motor speed using VSD systems provided an opportunity to save about 15-40% of energy and extend equipment lifetime by allowing gentle start-up and shutdown [9].

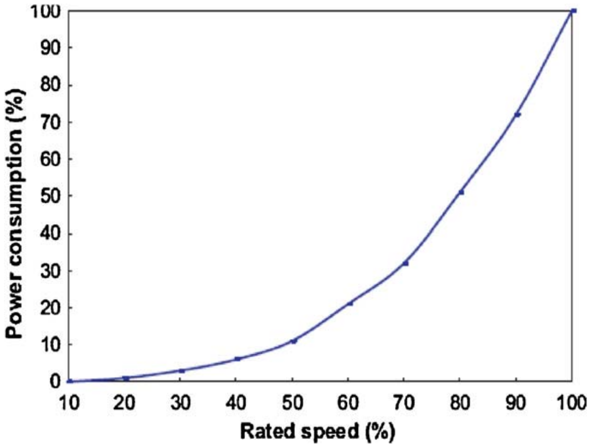

Figure 9: Relationship between motor power reduction and rated speed

VSD speed reduction should not be used unless long-throw nozzles are used on evaporator fans, to increase airflow throughout a cold room. It is also found that correct bin spacing from front and back walls and between required constant palletising. if inadequate space was allowed, even 100% fan speed and nozzles were insufficient to permit adequate airflow through the bins into the store. When applied to the fans’ evaporative motor, as load decreased, so the fans’ speeds should be decreased.

(3) Colouring and Shading technology

Cold room heat loads were comprised internally from lighting, evaporative motors and externally from sunlight. Many cold rooms are designed to be beneath a building envelope, yet still cannot handle total heat gain. Colouring and shading technology on external walls remained important to increase walls’ thermal resistance; white paint provided the best remedy..

4. CONCLUSIONS

An improvement in energy efficiency is often achieved by adopting a more efficient technology or production process. The technologies presented in this paper indicate optimisation of airflow pattern and correct pallet stacking style in cold storage significantly improved the scenario. Achieving improved circulation control permits air extraction by means of high pressure bulk evaporator fans, removing both internal heat and external heat gain and using it effectively in the refrigeration system. It is evident airflow efficiency might increase energy efficiency by 18-28%. Thus the VSDs technology remains a suitable option.

Small fan speed adjustments obtained 15-40% in energy saving; others advantages such as total heat load and maintenance cost reduction meant the same. Colouring and shading technology to increase thermal resistance, thus lowering heat gain from sunlight conduction, plus improvement in fans’ evaporative motors energy efficiency were prime factors to be considered..

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