

# A PRELIMINARY INVESTIGATION INTO VENTILATION PROBLEMS IN THE MALELANE MILL PAN HOUSE

I SINGH<sup>1</sup> AND F SEED<sup>2</sup>

<sup>1</sup>*Transvaal Sugar Ltd, PO Box 47, Malelane, 1320, South Africa*

<sup>2</sup>*MIS Environmental (Pty) Ltd, PO Box 123832, Alrode, 1451, Gauteng, South Africa*

## Abstract

The Malelane mill is a 30 year old, medium size cane raw sugar factory with a back end refinery. By-product plants in close proximity to the sugar factory, as well as the factory's own cane off-loading, extraction and steam generation equipment, have contributed to an increase in the level of airborne dust in and around the sugar factory complex. In addition, modifications to the factory cladding to improve natural ventilation to alleviate operator thermal discomfort have aggravated the problem of ingress of airborne pollutants into the processing portion of the plant.

This paper reviews the sources of airborne contaminants and considers the closure of openings in the building cladding as a means of preventing contaminant ingress into the processing part of the factory. Forced draft filtered inlet air coupled with natural extraction ventilation is proposed to alleviate the problem of operator thermal discomfort.

## Introduction

Earlier work done to improve refined sugar quality (Moodley and Schorn, 1997) concentrated on sound carbonation and sulphitation technology, as well as practical steps that included the closure of open tanks and conveyors to reduce turbidity and suspended solids levels in refined sugar. However, intermittent refined sugar filterability problems persisted during the season.

Analysis of the residues from some clients' melted sugar filters have identified the main contaminant to be bagacillo. Investigation into the effectiveness of steps to close process tanks and sugar conveyors in the Malelane factory has revealed that these measures are adequate to prevent major pollution. However, because of high levels of airborne contaminants in the external environment, ample opportunity exists for their ingress into the factory and therefore some degree of contamination of refinery streams is inevitable.

Given this scenario, Malelane technical staff deemed it necessary to undertake a study into the environmental conditions existing within the quality sensitive areas in the processing plant. Early in the investigation it was realised that the ingress of contaminants and factory ventilation were inter-related problems. Superimposed on the ventilation problem was the issue of operator thermal comfort.

The objectives of the study were therefore to:

- determine the main sources of external and internal air pollution at Malelane;
- characterise the environmental conditions existing within the pan house building. This section of the factory had been chosen for the study since greatest opportunity for final product contamination and unfavourable operator thermal conditions existed in that area;
- provide a cost effective design for a system to ensure that airborne contaminants were kept out and that acceptable working conditions were achieved within the pan-house building.

## External sources of air pollution

### *Cane off-loading plant*

During the process of off-loading onto the cane feeder tables and subsequent transfer onto the main cane carrier, airborne cane trash and sand are entrained by the prevailing winds and settle out in and around the factory buildings, including the refinery.

### *Conveyor systems*

Lengthy conveyors transfer the bulk of the bagasse to the factory boilers, while the balance is conveyed to adjoining by-products plants. Long recovery conveyors transfer coal from a storage site to the factory boilers. All conveyors are generally inadequately covered and prone to spillage. This, coupled with a lack of extraction systems at the transfer points, results in a dusty atmosphere.

The lime and coal rail discharge facilities have no dust suppression systems and they contribute to airborne pollution in windy conditions.

The extent of these problems is evidenced by substantial coal dust and bagasse fibre build-up on roofs, on support structures and on the ground in the areas of these conveyor systems.

### *By-product plants*

An animal feeds plant using the separated bagasse pith, and a particle board plant using the residual fibre, have large dust cyclones to control dust emission from their processes. These cyclones are old and inefficient and result in a continual cloud of fine dust being expelled into the atmosphere on the prevailing windward side of the sugar boiling house. In

addition, the stockpile of uncovered bagasse fibre is a major dust source under windy conditions.

*Mill boilers*

Malelane mill is currently installing wet scrubbers in a phased programme on its old bagasse/coal fired boilers. This process is expected to take another three years. Although these boilers only produce about 25% of the factory's steam demand, the stack exhaust is in close proximity to the refinery and consequently fly-ash and flue dust are readily blown to the sugar boiling house complex when these units are in operation.

*Proximity of buildings*

The proximity of the sugar warehouses and packing station buildings to the main processing house has created a wind tunnel effect in the passageways between these buildings. On a typical day with a measured ambient wind speed of 0,3 to 0,5 m/s, the velocity through access ways between buildings was measured at 1,0 to 1,1 m/s. The higher velocity air

readily entrains any settled dust from the sources mentioned earlier.

The most efficient method of treating any pollution problem is to contain the pollution at its point of generation. However, due to the widespread nature of the air pollution generation it was evident that it would be extremely expensive, and that some of the solutions could only be implemented over a long period. The situation is compounded by the fact that the different plants fall under different responsibilities.

**Sources of air pollution within the pan house**

The pan house comprises a ground floor level for tanks and pumps; a raw and refined centrifugal and filter floor level; a raw and refined strike receiver/crystalliser level and a raw and refined sugar pan level. Attached to this structure is the extraction plant and the refinery decolourisation buildings, without any separation between them. The first is a source of airborne bagacillo and the latter entrains hot air into the pan house. The relative positions of the factory buildings are shown in Figure 1.

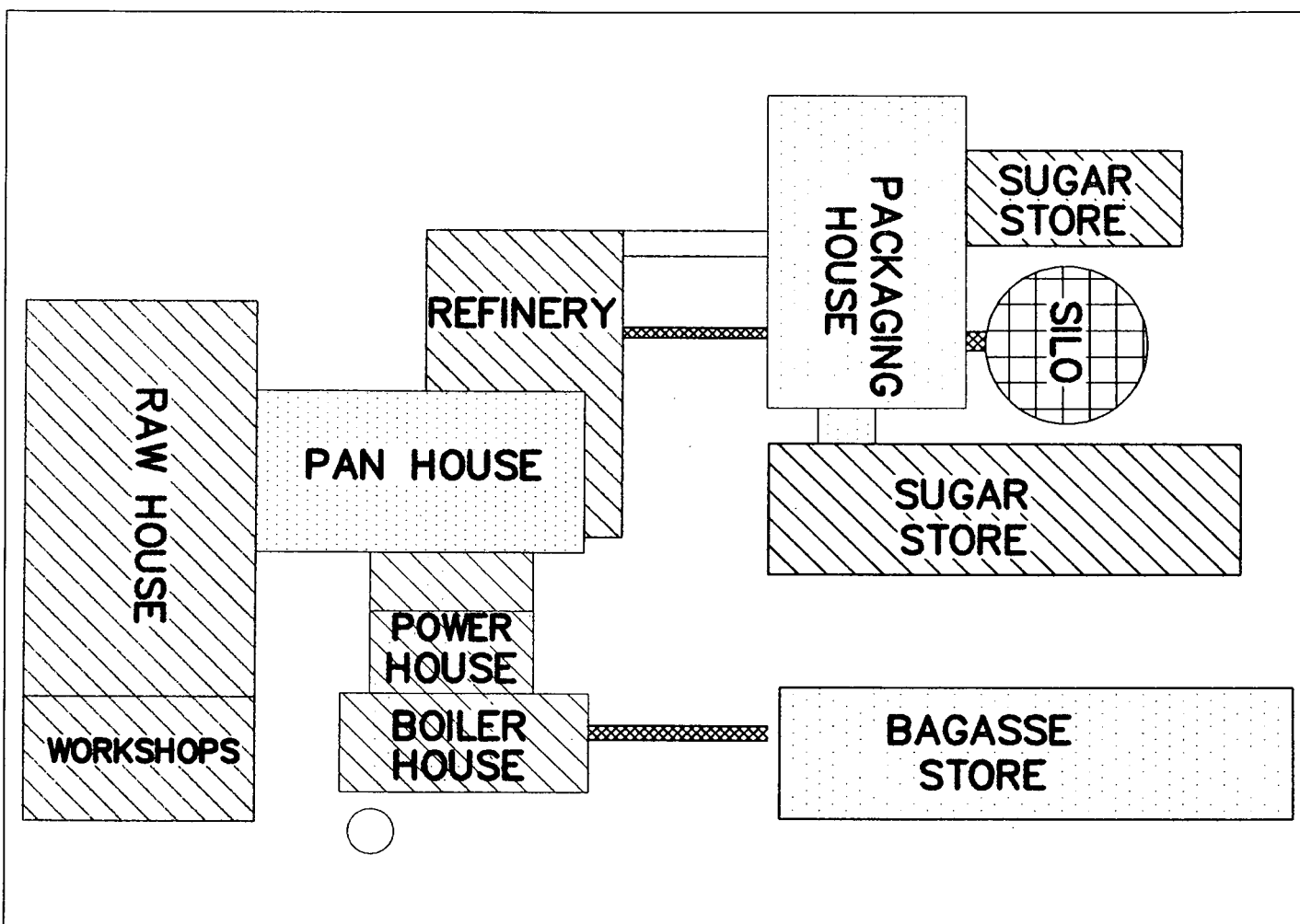


Figure 1. Site layout of pan house relative to other buildings.

The main form of pollution generated within the pan house is thermal. Insufficient or poor lagging and vapour venting within the building accounts for a substantial amount of the heat and humidity release. An example of this is the steaming out of the 15 batch pans comprising the pan station: approximately 0,5 to 0,75 tons of steam is discharged at the end of each three hour batch cycle directly within the pan house. This corresponds to three tons per hour of relatively high temperature vapour being released into the pan house building.

These conditions combine to create an extremely uncomfortable and unpleasant working environment, especially during summer conditions when temperatures in excess of 40°C have been recorded in the factory. In an effort to alleviate thermal stress created by these conditions, a number of modifications have been made to the factory buildings over the past few years.

Additional new openings have been installed at the eaves level all along the upper perimeter of the factory cladding to supplement the original ridge type ventilator openings at the apex of the roof. This is illustrated in Figure 2.

In addition the side cladding has been extensively modified to accommodate multiple off-sets to provide vertical side vents extending from the ground to the eaves. This is illustrated in Figure 2.

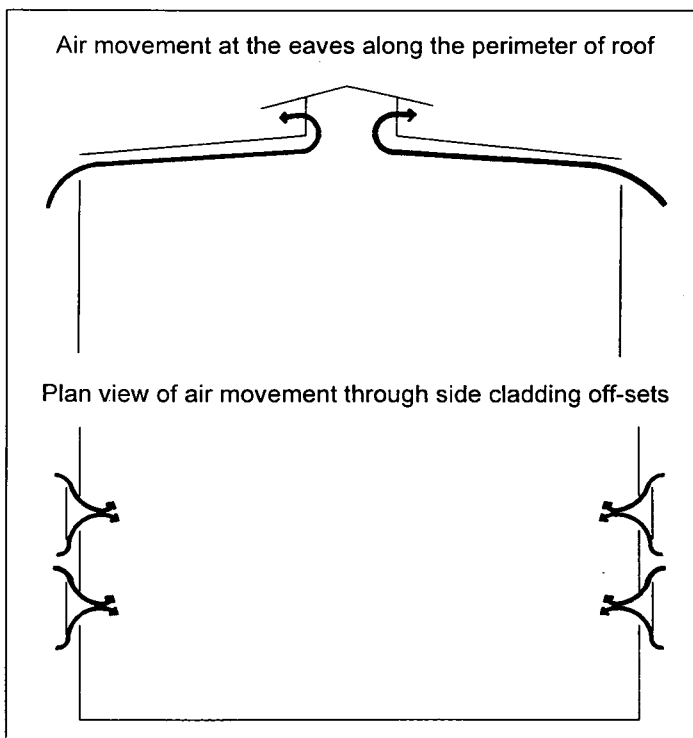


Figure 2. Openings in pan house at eaves level and at cladding off-sets.

To improve operator thermal comfort at the pan floor level, large sections of the cladding have been removed on the east and west sides. The intention has been to direct natural airflow to match the prevailing wind direction. These large cutouts in the factory cladding provide effective thermal relief

only when there is a strong breeze blowing across the building.

While these modifications appear to enhance the working environment, they have in fact been done with little or no scientific reasoning. Although large volumes of air enter through the openings referred to earlier, this ambient air does not reach the building interior. For example, the openings at the eaves make the thermal conditions worse by allowing natural draft to short circuit along the rafters and through the roof apex ventilator instead of entering at the ground floor level. Thermal discomfort is consequently greatest in these areas of poor air circulation. Any effort to seal off the cladding openings to prevent ingress of airborne contaminants will aggravate the situation unless an adequate volume of filtered air is introduced as ventilation.

**Design constraints for the pan house ventilation**

Retrofitting a ventilation system in an older building is constrained by the existing building design and the nature of the installed process equipment as well as its operation.

Uncomfortably high or low temperatures, a lack of fresh air movement and high humidity, impact negatively on operator productivity and increase the potential for accidents. Inefficient ventilation can cause worker efficiency to drop by up to 59% with a 15°C rise in temperature from ambient. (Anon, 1986). In addition, localised high humidity conditions lead to a reduction in the life of the building structure, and increased service costs. The authors have observed these conditions in several cane sugar factories in South Africa.

Operator thermal stress within a building is directly related to radiant heat and the wet bulb temperature.

The requirements set by the South African Department of Manpower for wet bulb/globe temperature (WBGT) indices are given in Table 1.

**Table 1. Maximum permissible WBGT index.**

Work/rest in each hour	Maximum permissible WBGT index °C	
	Light work	Heavy work
Continuous work	30	25
75% work : 25% rest	31	26
50% work : 50% rest	32	28
25% work : 75% rest	33	30

**Types of ventilation systems**

The following section of the paper provides a synopsis of good ventilation practice with the benefits and disadvantages of each system being outlined.

*Natural ventilation*

On heating, the density of air is reduced by expansion causing it to rise. The natural buoyancy of warmed air can therefore be used as the driving force of a natural ventilation system by providing openings in the building at both high and low

levels. The warm air will exhaust through the high level openings and will be replaced by cooler ambient air entering through the low level openings.

Another mechanism by which natural ventilation is achieved is by the action of wind blowing across a building. This creates pressure differences between the opposite sides of the building and induces airflow through any openings. The effect will vary and cannot therefore be relied on.

Natural ventilation airflow is affected by several factors, including:

- temperature difference between the air inside and the air outside the building
- difference in height between the air inlet and the exhaust vents
- convection currents rising from hot process equipment.
- rate at which heat is produced or released inside the building
- size, position and construction of the building
- wind speed and direction.

Thorough treatment of these factors is outside the scope of this paper.

The advantages of using natural ventilation are silence, low maintenance, no running costs and ease of installation. Also, no ducting is required. Extraction ventilators used with natural airflow systems are lightweight and thus can be distributed over a large area of roof. The nature of the design is such that these units are self regulating i.e. the airflow rate increases with heat load and *vice versa*.

Cane sugar factories in South Africa have historically favoured natural ventilation design because of simplicity and low cost. The main disadvantage of using natural ventilation is that it is dependent on wind direction and air pressure and therefore cannot always be used to give constant air movement at any work location or to provide a constant ventilation rate. Furthermore, due to the relatively small pressure differentials generated in a completely natural system this type cannot be utilised when filtered air is required. These aspects are significant in the case of Malelane mill, and hence the need to examine powered filtered ventilation as an alternative.

#### *Powered ventilation*

The use of forced draught has a number of advantages over natural ventilation. These are:

- Operation is independent of building height, thermal currents and wind pressure
- The system is normally weatherproof in operation
- Performance is predictable and repeatable
- The system can overcome the pressure drop of filters
- Fresh air can be ducted to localised hot spots at optimum velocity and temperature
- Filtering, heating, cooling and humidification can be provided where required.

The disadvantages of a powered system are:

- The system is not self-regulating, requiring sophisticated and expensive control systems
- The power and maintenance costs associated with fans are relatively high
- Control of noise emanating from fans is an added expense
- Extensive ducting may be required.

#### **Thermal and airflow survey methodology**

In order to calculate the volumetric airflow rate required and forecast temperatures within the pan house, the internal heat load within the building, the temperature gradients presently being experienced and the total airflow into the building have to be known.

Summarised thermal and airflow data captured during a three day site survey in mid-December is illustrated in Figure 3.

The sectional view through the pan house building shows the mass airflow entering the pan house, vertical flow velocity of the hot vitiated air and its temperature gradient.

These readings were determined as follows:

#### *Volumetric airflow into the pan house*

All the openings on the various levels were measured, and airflow readings were taken across the surface area of each of these openings, using a calibrated Vane anemometer. The volumetric flows for each opening were then determined and added together to determine the total volumetric airflow into or out of each level. Volumetric airflows were converted to mass flows to correct for density differences.

#### *Vertical flow velocity of the hot vitiated air*

These readings are an average of the vertical airflow readings recorded at the crystalliser level.

#### **Pan house thermal and airflow data analysis**

By analysing the summarised data, we can quantify the heat and humidity generation and pinpoint the worst sources.

The data portrayed in Figure 4 is a plot of the average dry bulb temperature for each level versus the height above ground level.

The mass flow of air entering pan floor operator level from the lower crystalliser level should be the accumulation of ambient air entering at the ground, centrifugal and crystalliser levels.

This measured value amounted to 368,7 kg/s and matches closely the density corrected mass flow figure of 360,5 kg/s for total amount of air entering the ground, centrifugal and crystalliser levels through the side cladding openings.

Warm air from the refinery decolourisation plant enters the pan house at the pan operator level at a flow rate of 37,8 m<sup>3</sup>/s and has a significant adverse effect on operator thermal comfort at this level. The airflow from the extraction plant into the adjoining pan house was found not to be significant.

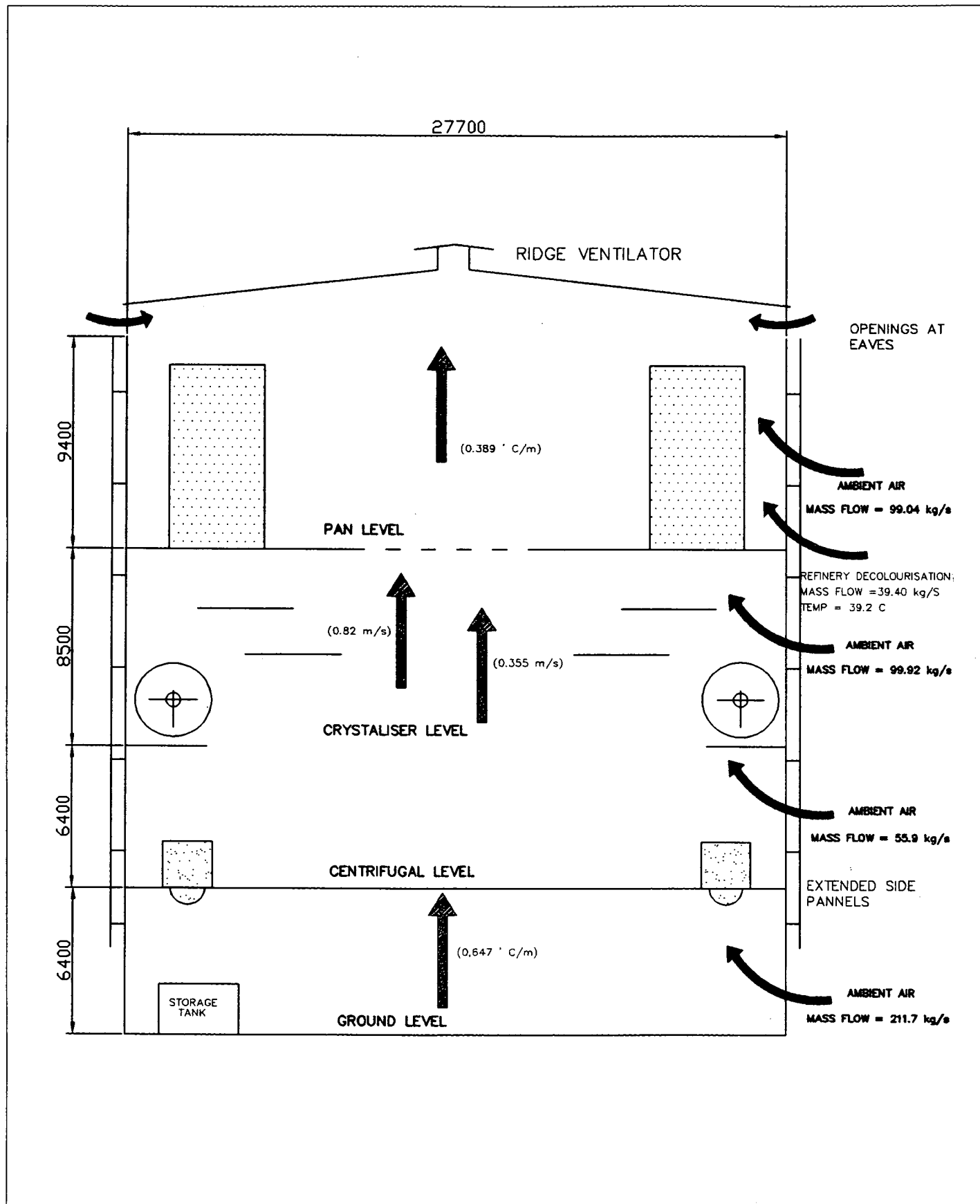


Figure 3. Section through Malelane pan house.

*WBGT measurements*

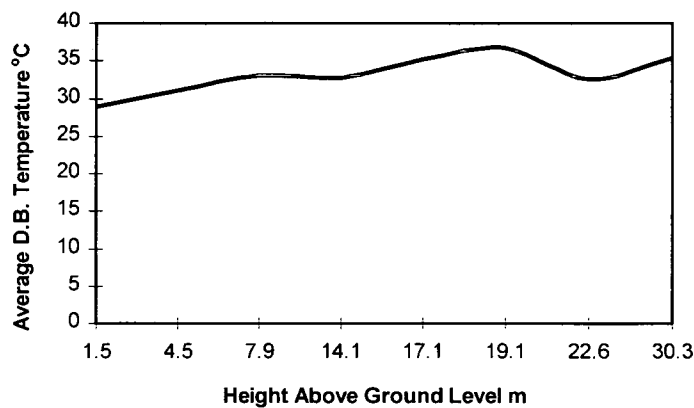
The maximum WBGT index readings taken within the pan house exceeded the criteria for light continuous work when the heat stress conditions were at a maximum. The measured values are shown in Table 2 and are typical of an average summer day in Malelane. These heat stress conditions can be alleviated with improved ventilation.

**Table 2. WBGT measurements within the pan house.**

Level	Max	Min	Average
Centrifugal	31,4	28,2	29,4
Crystalliser	30,1	29,1	29,6
Pan	30,5	27,1	28,7

*Heat load within the pan house*

The design objective for a ventilation system is to achieve a balance between internal heat production and heat dissipation to the environment and provide an acceptable working temperature. The two main sources of heat generation are process equipment and solar radiation acting on the pan house roof.



**Figure 4. Pan house thermal gradient.**

The process heat gain within the building is summarised in Table 3.

**Table 3. Heat gained within the building.**

Level	Heat gained (kW)
Basement/ground	851,00
Centrifugal	787,79
Crystalliser	1 414,60
Pan	892,50
Solar heat gain	182,30
Total	3 945,90

This data was computed from the mass flow of air for the various levels and the temperature rise of this air.

The pan floor level is the only level receiving heat from external sources, viz:

- Solar heat gain = 182 kW
- Adjoining refinery decolourisation building = 100 kW.

The solar gain of 182 kW was heat absorbed by the 2 100 m<sup>2</sup> area of the galvanised pan house roof.

Excluding the external sources above, 3 718 kW of heat is from process equipment within the pan house building.

*Natural ventilation exhaust vent area*

The next step is to determine the inlet airflows and the corresponding exhaust vent area. The calculations are based on a worst case ΔT of 15°C and for a slight over-pressure of 10%. The total heat load of 3 054 kW for the lower three levels is proportioned to the floor areas of these levels. The corresponding required inlet air volumes and vent areas per level are shown in Table 4.

**Table 4. Inlet airflows and area of ventilator required.**

Level	Inlet airflow required (m <sup>3</sup> /s)	Area of ventilator (m <sup>2</sup> )
Ground floor	61,89	36,29
Centrifugal	57,32	15,25
Crystalliser	103,41	36,29
Pan	65,12	25,40
Total	287,74	91,84

The total calculated roof vent area requirement of 92 m<sup>2</sup> will require an installation with 328 m<sup>2</sup>. The additional area is required to overcome the pressure drop across the vent.

**Ventilation options for the Malelane pan house**

Both powered and natural systems have qualities suited to the pan house ventilation duty.

Working on the premise that closure of the factory cladding is a necessity, the direction to pursue is to install a properly designed ventilation system to create the internal environment appropriate for personnel and at the same time maintain a partial positive pressure to prevent ingress of airborne material. Two systems that meet this requirement are:

*Powered air inlet/natural air extraction*

In this system, filtered air is introduced into the building in a positive manner such that reasonable control can be exercised over the air velocity and distribution, while at the same time air pressure within the building may be raised slightly above atmospheric, reducing unwanted air infiltration or draughts. The main disadvantage with the above system is that the velocity of air exiting the natural roof ventilators is significantly slower than for a powered extraction system and, under extreme external wind conditions, airborne dust particles may be blown back into the building.

### Powered air inlet/powered air extraction

This system provides the fullest control of ventilation by using fans for both air inlet and extraction. The inlet fans are generally rated to provide a slightly greater inflow than the extract fans to provide a degree of pressurisation to the ventilated space. As noted above, this reduces unwanted infiltration.

### Proposed ventilation system for the pan house building at Malelane

#### Separation of buildings

Partially screening the adjoining decolourisation and extraction stations from the pan house will assist in reducing the amount of ventilation required in the pan house building. The screen need only extend from the roof of the adjoining building to one metre below the pan house operator slab level to contain the airflows in respective buildings.

#### Cladding openings

The eaves openings as well as the off-set side cladding openings would have to be closed off. The large cut-outs in the cladding at the pan floor level need to be made good again.

Provision would have to be made for manually operated shutters that can be opened in the event of a power failure or during shutdowns.

#### Roof ventilators

Due to the inefficiency of the current apex ridge ventilator and the negative influence of wind on such a ventilator, it would be better to close it off and substitute low profile type unit ridge ventilators.

Roof ventilators with a total area of 328 m<sup>2</sup> would have to be installed uniformly over the entire pan house roof. The additional area is easily added with unit ridge vents, which are multiple modular units that can be installed to provide a series of slots across the length of the pan house roof in contrast to the traditional apex ridge ventilators which are custom built to provide a single slot along the length of the roof. Both types of roof ventilators are shown in Figure 5.

#### Air supply systems

When the pan house is isolated from the adjoining buildings each level should ideally be looked at separately and designed as a self contained area. However, due to the separating floor slabs between the various levels not being complete, and because of the significant size of the openings, it is better to model the airflows as an integrated system. Due to the fact that islands of operators exist at the pan and centrifugal levels only, it would not be necessary to ensure even distribution of air in the entire pan house but rather to achieve continuous ventilation only where required to alleviate thermal discomfort. A typical layout showing the powered filtered air units and ducting for each level is shown in Figure 6.

The option of using a powered system for air inlet and natural extraction for exhaust is the logical evolutionary route for the Malelane mill since both the initial capital outlay and running

costs will be lower. The powered extraction option, if necessary, can easily be added as a retrofit.

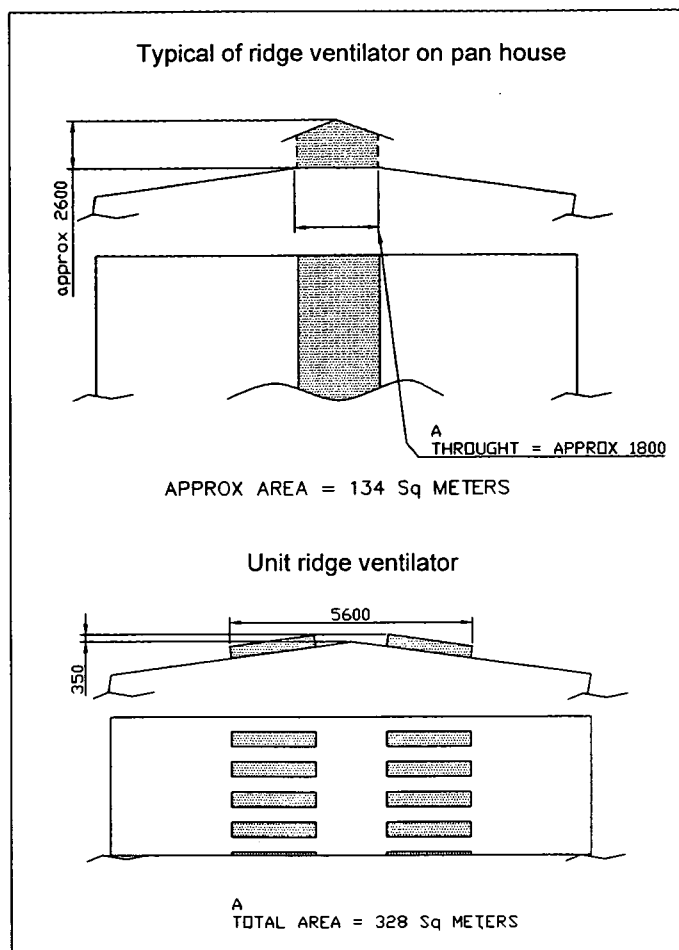


Figure 5. Apex ridge vent and modular unit ridge vent.

#### Reduction in heat load

The bulk of the heat load within the pan house comes from process equipment within the building. A conservative 30% reduction in heat load within the pan house is possible by implementing the following:

- Steam vents from vacuum pans need to be minimised and routed to outside the building.
- All unlagged steam, hot condensate and hot process piping needs to be adequately lagged.
- The pan steaming out technique needs to be changed.

With a lower quantity of heat being released into the pan house, the volume of replacement air would be less with concomitant reduction in fan and motor size. This translates to a reduction in capital and running costs.

#### Costs

The following cost estimates apply to the pan house building if the heat load remains unchanged. The ducting routes and filter plenums locations would have to be sited dependent on accessibility and where required.

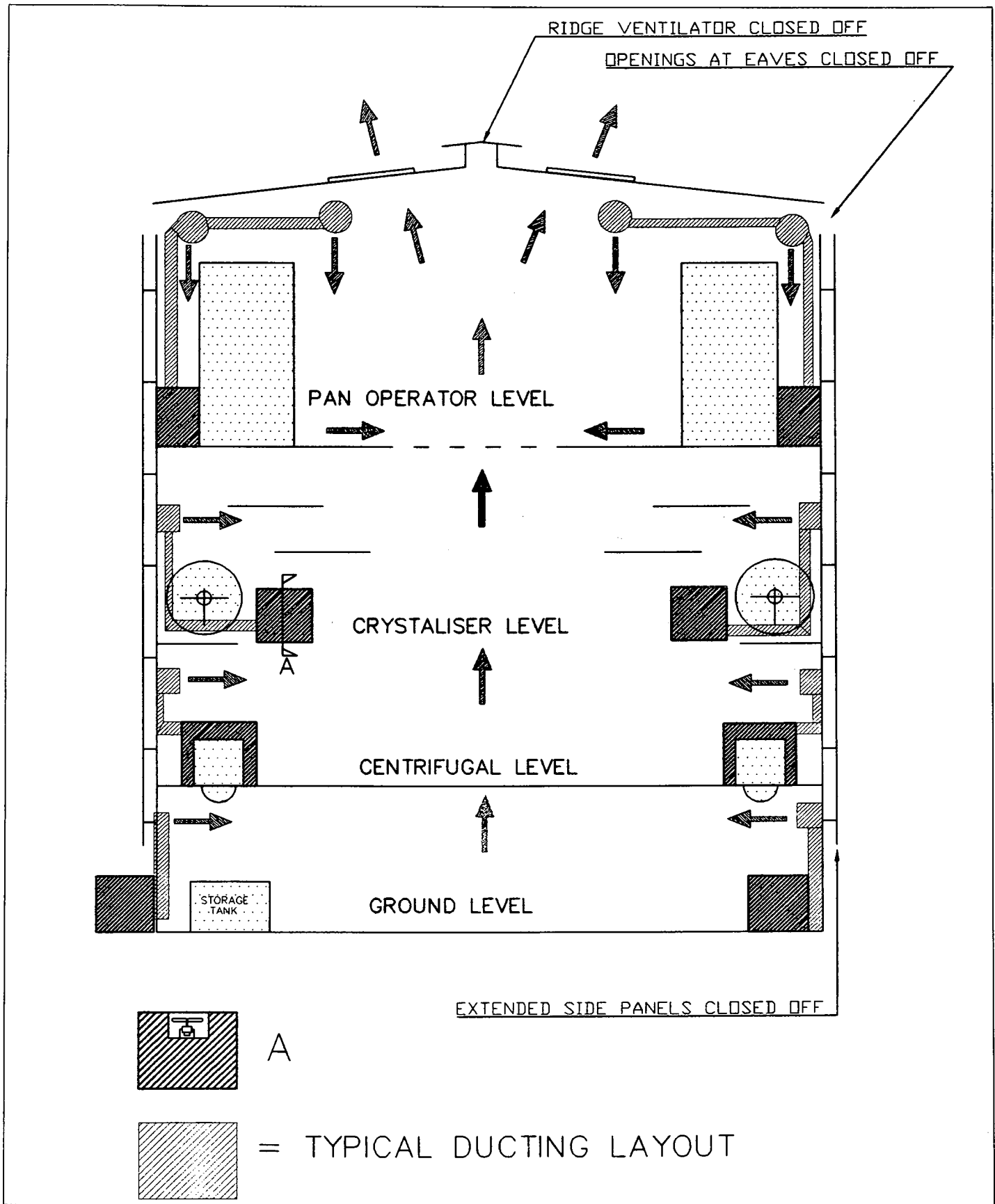


Figure 6. Typical installation showing filter unit and ducting.



**Capital cost**

Cost for the supply and installation of the filter and vent equipment.....	1 700 000
Repairs/modifications to cladding .....	<u>425 000</u>
Total	R2 125 000

**Operating cost**

Operating costs p/a for 300 kW of installed power* .....	300 000
Operating cost p/a for filter replacement .....	<u>75 000</u>
Total	R375 000

\*Cost estimate of mill generated power based on a typical value of R0,15/kWh.

If a 30% reduction in heat load is achieved the capital and power costs will reduce to R1 200 000 and R250 000 respectively. This scenario excludes the cost of lagging and process plant modifications. These latter costs will be offset to a great extent by the energy saving, which is estimated to be 1,5 t/h of low pressure steam.

**Conclusion**

Conventional cane sugar factory ventilation design has been based on natural ventilation, with limited integration of air pollution control and operator thermal comfort aspects. Market demands to further improve refined sugar filterability has necessitated the elimination of airborne contaminants from the processing plant. Superimposed on this problem is a new focus on means to alleviate operator thermal discomfort.

Sealing of the quality sensitive part of the factory building is proposed as a means of eliminating airborne contamination from refined sugar. The problem of the existing thermal discomfort, as well as the aggravated conditions resulting from closure of the cladding, can be adequately addressed by using powered filtered inlet air and natural extraction ventilation.

The recommended path for Malelane mill is to first reduce process heat load by sound engineering and sugar technology practice. In this way the sizing of powered air inlet units and roof vents can be minimised and a reduction in heat losses will benefit the factory's energy balance.

In addition a programme is needed to address external sources of airborne contamination.

**Acknowledgements**

The authors would like to thank their respective companies for permission to publish this paper.

**REFERENCES**

Anon (1986). CIBSE Guide. Published by the Chartered Institution of Building Services Engineers. Printed by Staples Printers Ltd.  
 Moodley, M and Schorn, PM (1997). Steps taken at Malelane Refinery to improve refined sugar quality. *Proc S Afr Sug Technol Ass* 71: 189-193.

**APPENDIX 1**

**Explanation of equations used**

*Equation 1*

$$v = 0,183 \cdot \sqrt{H_s} \cdot \Delta t$$

where v = velocity through ventilator, m/s

H<sub>s</sub> = Stack height, m

Δt = Design temperature difference ventilator, °C.

The equation is a derivation of equations given in BS 5925: 1991 and utilising STP conditions of air to arrive at the factor of 0,183 to simplify the process.

*Equation 2*

$$V = Q/C_p \cdot \Delta t$$

where V = Ventilation rate required, m<sup>3</sup>/s

C<sub>p</sub> = Specific heat at site conditions, kJ/kg °C

Q = Heat exchanged, kW.

This is derivation from the basic heat transfer equation which states that the heat absorbed or dissipated by a body is equal to it's mass times the specific heat value times the change in temperature. The equation is converted to volumetric flow by utilising air density.

*Equation 3*

$$\theta = A \cdot a \cdot e \cdot I$$

where θ = Solar heat gain in kW

A = Roof plan in m<sup>2</sup>

a = The portion of solar radiation (I) which is absorbed by the roof

e = Fractional part of the absorbed radiation which is transmitted to the inside of the building, depending on the 'u' value

I = Actual solar radiation striking the surface (this varies with latitude) in kW/m<sup>2</sup>.

NB: 'u' value is the transmittance coefficient of the roof structure in w/m<sup>2</sup> °C.

*Equation 4*

$$\text{Heat dissipated} = \frac{m \times C_p \times \Delta t}{1000}$$

where m = Mass flow of materials, kg/sec

C<sub>p</sub> = Specific heat capacity of material, kJ/kg °C

Δt = Temperature range, °C

1000 = To convert from J/sec to kJ/sec (i.e. kW).