

# Shower Tower, Miele Showroom, Johannesburg South Africa

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**ABSTRACT:** This paper presents the design and testing results of a prototype passive downdraft evaporative cooling tower PDEC installed and tested to guide the design of a permanent tower intended as a cost effective retrofit to the Miele Showroom at the South African head offices in Johannesburg.

The showroom forms a large part of the building which was completed 2 years ago. The building was designed without air conditioning but without quantifiable passive strategies. The occupants experience discomfort during the winter and summer extremes and air conditioning systems are being installed as a retrofit. The Tshwane University of Technology was approached to measure the performance of the building and to suggest interventions to improve the performance. Paul Carew was consulted for assistance and advice. One of the interventions suggested was a "shower tower" to temper the showroom during hotter periods.

This paper describes the space that is to be served by the tower, the tower itself and some lessons learnt during the construction of the tower and argues that the strategy is appropriate to the space and the climate. The prototype shower tower consists of a tube of elasticized fabric suspended from the roof structure with a metal hoop at the top and the bottom to hold the shape. Water is vaporised at the top of the tower using micronizer spray nozzles to produce an evaporative cooling effect. The tower is unusual from other towers in that it recycles air from the room and fresh air is not introduced directly via the tower. The fresh air change rate is unknown and thus it is difficult to calculate the rate of increase of humidity levels in the space.

Particularly 4 aspects are considered in the measurements; the effectiveness of the tower in cooling down and humidifying the air passing through the tower, the humidity build up in the space, the vertical stratification of temperature and humidity through the space and finally the extent of the tower's impact in the horizontal direction. The results of these are presented in this paper.

**Keywords:** Cooling, retrofit, shower tower, passive downdraft evaporative cooling tower

## 1. INTRODUCTION

The (1200m<sup>2</sup>) Miele South African Head Office was completed in 2004. The intent of the design was that comfort conditions would be provided passively. For a number of reasons not critical to this document the building has been deemed not to perform adequately with regards to thermal comfort. Interventions have been proposed and implemented in stages. The focus of this paper is on the evaluation of a prototype tower using passive downdraft evaporative cooling (PDEC) as a strategy for the main showroom. The main showroom becomes unsatisfactorily warm on hot days. It appears that the initial cross ventilation comfort cooling strategy has not been successful, again for reasons that would be too lengthy to explain in this short paper.

The intention is to provide comfort cooling for these peak days with a cost effective passive strategy that blends into the aesthetics of the showroom floor. Control of this strategy should be simple in order to

keep costs low with a number of on/off switches or valves controlled by the reception staff. The prototype is being used to guide the design of a final solution for the space.

## 2. THE SPACE BEING SERVED BY THE TOWER

### 2.1 Description

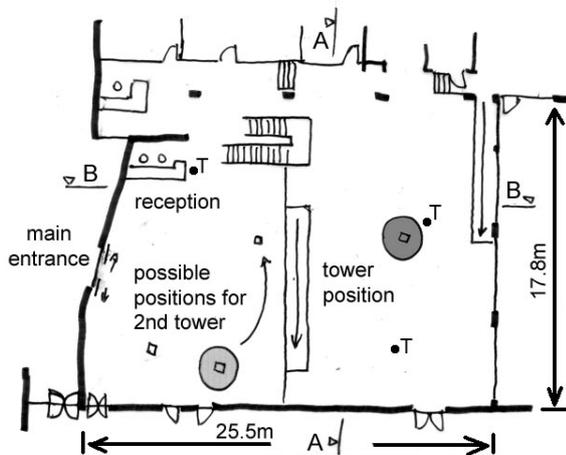
The showroom floor (425m<sup>2</sup>) also serves as the main reception to the building. The floor is rectangular in shape (figure 1) and has a stepped 0.7m change in level (figure 2) dividing the space into two sections. The entrance, reception, kitchen layout, extractor hoods, ovens and hobs are on display on the upper level. Fridges, washing machines and industrial and medical appliances are displayed on the lower floor where the prototype tower is tested.

Lighting consists of ambient and display lighting however, while natural light levels appear to be

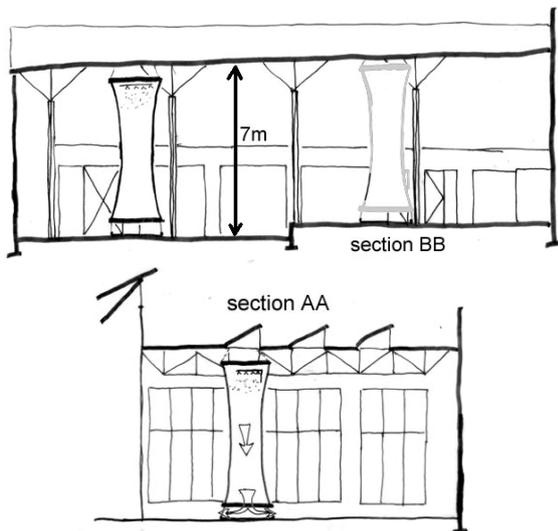
adequate there is no separate switching of ambient and display lighting and so all lighting remains on during occupation hours. Table 1 lists the surveyed internal loads of the space. The operating hours and occupation schedules are an estimation based on discussions with the staff.

**Table 1:** Table indicating the equipment loading of the space and the duration of operation.

	Load (W)	Load (W/m <sup>2</sup> )	Duration
lighting	3190	7.5	7:00-18:00
equipment	2815	6.6	7:00-18:00
people	1000	2.4	sporadic



**Figure 1:** Plan of showroom

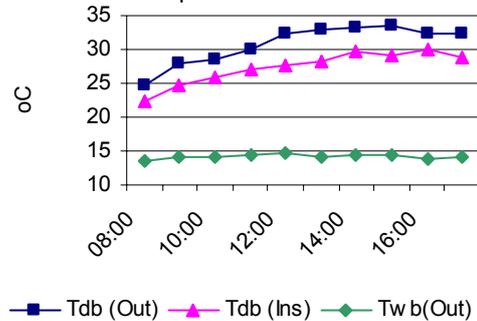


**Figure 2:** Section of showroom

The space has a saw tooth roof with south facing clerestory windows (keep in mind that this is located in the southern hemisphere) with permanently open louvers above the glazing. Un-insulated box gutters are situated between the roof sections. There is a relatively well shaded large west facing window with no openable sections. The automatic sliding doors of the main entrance are glazed. All rooms leading off the space have doors and walls separating them from the showroom space.

## 2.2 Measured conditions and staff comments on comfort

Temperatures were recorded at various points in the space during the initial investigations. Unfortunately time has not allowed for an entire year of readings to be taken and so it is difficult to determine the duration that the high temperatures occur. However, the data expressed in Figure 3 is an indication of the temperatures that can be experienced in the space.

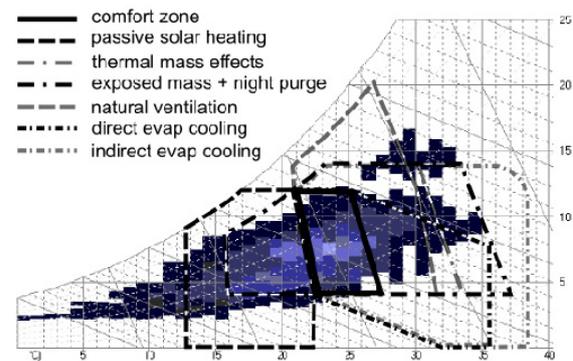


**Figure 3:** Typical temperature readings in the space (graph showing temperature readings from a typically hot day)

The initial strategy allowed for comfort ventilation with wind driven cross ventilation via the adjacent offices. The staff stated that very little air movement is experienced through the space. There are also many days when the temperature of the outdoor air would be too hot for a comfort ventilation strategy.

## 3. THE SHOWER TOWER DESIGN

### 3.1 Suitability to climate



**Figure 4:** Bioclimatic chart with Johannesburg weather data – the lighter areas indicate a higher concentration of hours when these conditions exist [1] [2]

Johannesburg is ideal for passive design strategies with an agreeable climate to many of the strategies available. (see figure 4.) The summer is the main rainfall period with late afternoon thundershowers typical. The hotter days occur after a number of days without a thunderstorm. Johannesburg (2362 cooling degree days, 1066 heating degree days [3]) is 500km from the ocean. While in the highveld climatic zone of South Africa [4] it has a particularly interesting microclimate influenced by the great number of trees and greenery

planted during the establishment of the city. This reduces the heat building up and assists in tempering the climate. Pretoria – 80 km north of Johannesburg has quite a different climate with 3238 cooling degree days and 639 heating degree days [3]

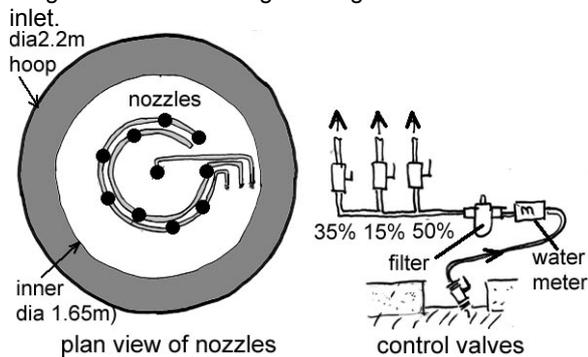
### 3.2 Suitability to the space

Evaporative cooling comes across as the easiest passive design strategy to retrofit to this space. The suitability of PDEC has been considered using the integrated design challenges as highlighted by Yoklic [5] for topics that have not been adequately addressed in past projects utilising PDEC.

### 3.4 Description of the shower tower prototype, initial observations and modifications

The requirement for the installation to be cost effective indicated that a simple tower structure with the tower walls having structural integrity was required. As it was intended to be a prototype tower the tower needed to be easily constructed and deconstructed without great adaptation to the building. It also had to appear not overly foreign and interfere too much with the space functioning as a showroom.

The prototype consists of a hanging tube of Spandex<sup>™</sup> material with a metal ring on either end giving shape to the inlet and outlet as well as being the fixing point via cables to the roof structure above. The material takes on an interesting shape under the weight of the metal ring forming a natural bellmouth inlet.



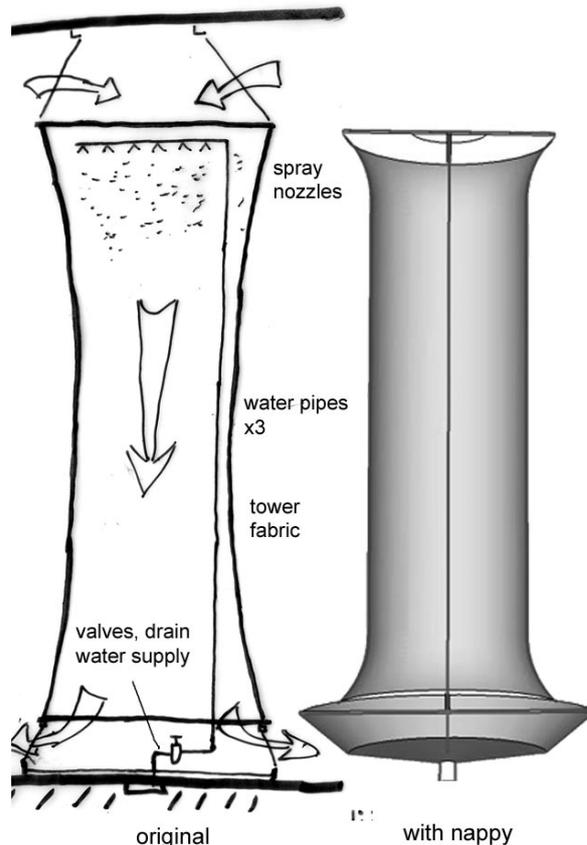
**Figure 5:** Nozzle configuration and water supply

The ring supports the header pipes containing the spray nozzles. HDPE piping runs up to the headers from a valve arrangement below. The valve arrangement includes a water meter and a filter. Water is supplied via a flexible hose connected to an outlet in the floor below the tower. 2 nozzle types are tested, a single high flow nozzle (Bete P-Series, 26L/h@4bar) with a large orifice and a pin to break up the water stream, and 9 nozzles (Amfog, 2.6L/hr@4bar) with the mist generated by the smallness of the orifice. The first has the advantage that it is less likely to clog with an outlet orifice of 1mm while the other nozzles seem to distribute the spray better. The nozzles are arranged so that water can be supplied in steps of 1, 3 or 6 nozzles and any addition of that number. See figure 5.

Initial dimensions were guided by calculations using equations from Yoklic [5] and Chen [6], however these are for a purely buoyancy driven tower

and does not take into consideration the induction effect of the spray nozzles.

Initially it was optimistically hoped that the all the mist would be evaporated in the tower. A temporary ring of plastic sheeting was placed directly under the tower to collect any droplets dripping from the pin on the larger nozzle. During the first test runs water droplets were observed forming on the floor up to 600mm outside the ring and creating a film of water. One could visibly see where the air was losing sufficient momentum to carry the water droplets where the mist could no longer be seen in the air.



**Figure 6:** Section of the original shower tower design and perspective section including the “nappy”

To overcome this, the tower was modified by fitting a “nappy” (or diaper) to the bottom which consisted of an inverted canvas dome (hung via cables running through the tower from the roof structure above.) This forces the air to change direction at the bottom of the tower and water droplets that have not evaporated are dropped out onto the canvas to drain via the floor drain adjacent to the water supply. The “nappy” was dimensioned to maintain the tower area to outlet rate of 1:1.5 as recommended by Yoklic [4.] Besides sweating on the metal rings, this seemed to prevent the wetting of the floor. From the temperature results (figure 8), the additional pressure losses do not seem to hinder the tower performance too much.



Figure 7: Photo of the shower tower and lower floor

#### 4. PROTOTYPE PERFORMANCE

##### 4.1 Measurement

Temperature, humidity and air flow was measured to record the performance of the tower. Temperature and humidity was measured in hourly intervals with the positions indicated in figure 1.

To gain an impression of the air flow through the tower, a hot wire anemometer was used to measure the velocity profile across the top of the tower. The measurements were taken for 10 seconds at predetermined positions for different water flow options. This was repeated 7 times. The wire anemometer probe was then fixed in a single point to log the air velocity at that point. The velocity profile across the tower was then used to estimate the air flow through the tower. Unfortunately this was only done after the measurements of 1<sup>st</sup> Feb 2006.

##### 4.2 Results

(Please note that January to March 2006 was a particularly rainy and cool summer. There were very few days in this period when the staff felt it was necessary to switch the tower on.) The results of the measurement exercise can be separated into 5 aspects; vertical temperature distribution, horizontal impact of the tower, effectiveness of evaporation, humidity build up in the space and air flow through the tower.

*Vertical temperature distribution* – figure 8 shows the measured vertical distribution through the space. This shows that the air distribution is behaving as a displacement type system. The small peak at 12

shows when all the nozzles were turned on (initially only the Amfog nozzles were on)

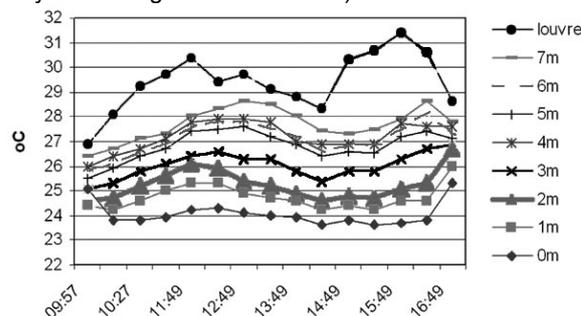


Figure 8 - Test day

*Horizontal impact of the tower* - the tower has a measured positive impact on the lower floor. However, in the first afternoon of measurement, the receptionists remarked that they felt that it was too humid where they sat. It was not expected that the prototype would be able to condition the entire space and two towers were envisaged for the final installation. Temperature and humidity sensors were placed below the working surface of the receptionists. Unfortunately the weather has been relatively cool then and the writing of this paper and there is only a single day when the receptionists felt it was warm enough to need the tower on. Figure 9 shows that when at 15:00 the tower was switched on there was only a small drop in temperature measured at the reception area while the absolute humidity increased relatively substantially. While a measurement taken on a hotter day would prove conclusively that a single tower is inadequate for the entire space, these results support the experience of the receptionist that the tower raises the humidity in this area of the showroom without adequately lowering the temperature.

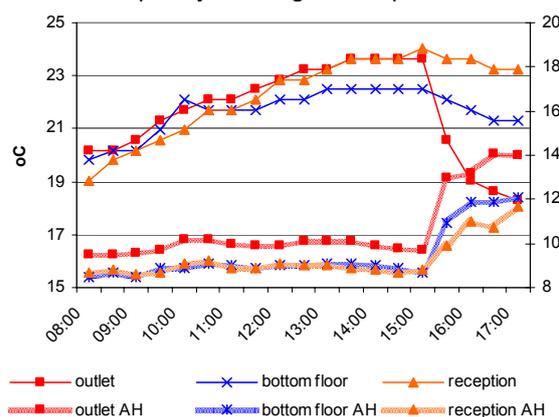


Figure 9: Horizontal distribution, Tdb (°C), AH (g) (4<sup>th</sup> April 06)

*Effectiveness of evaporation* – figures 10 to 12 shows the dry bulb and wet bulb temperatures at the tower inlet and at the bottom of the tower. The effectiveness calculated from these figures range from 55% for the Amfog nozzles to 70% for all the nozzles on. This is much lower than the 95% used in the estimations.

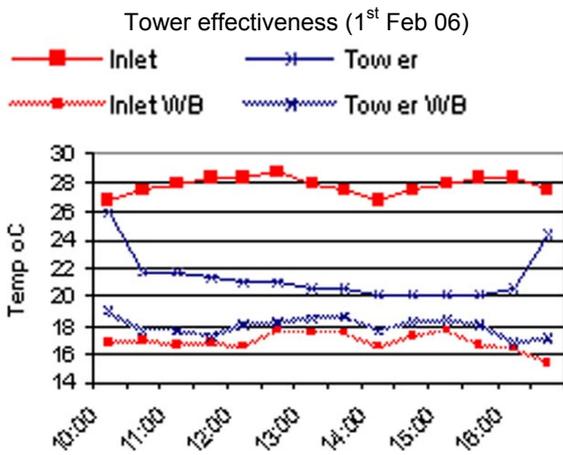


Figure 10: Tower Temperatures

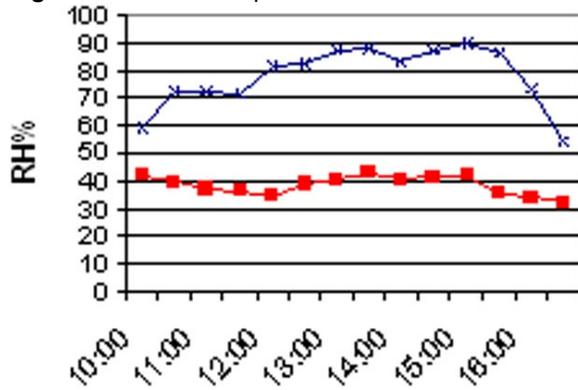


Figure 11: Tower RH

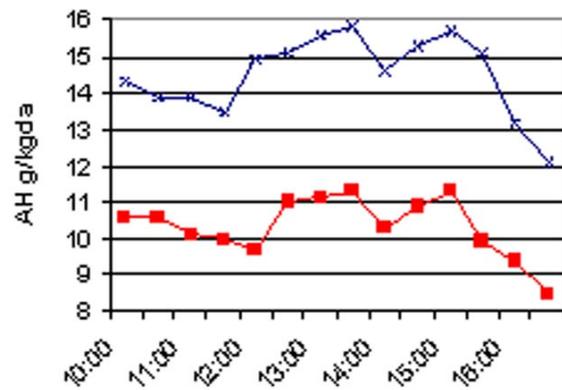


Figure 12: Tower AH

*Humidity build up* – the authors expected a humidity build up over time impacting on the performance of the tower. It was expected that the vapour permeance and the natural fresh air change would assist in lowering the rate of the build up.

Figures 13 to 15 indicate that while it appears that there is an increase in absolute humidity in the space it also has a vertical profile. The wet bulb temperature at the inlet to the tower does not rise above 18°C.

The absolute humidity (figure 14) appears to drop dramatically from near the floor where the supply air is running to 4m above the floor. The difference between the top and the middle of the space is very small. It is proposed the constant vapour pressure difference between the outside and the supply air

Vertical temperature/humidity distribution (1<sup>st</sup> Feb 06)

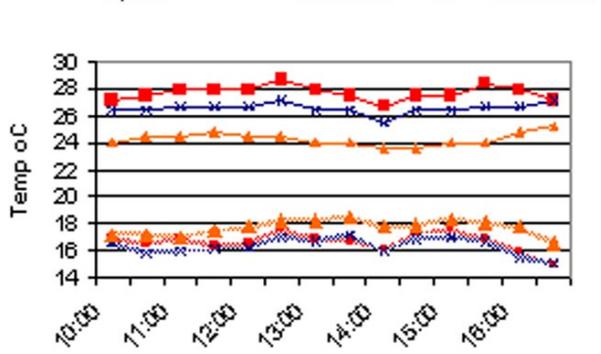


Figure 13: Space Temperatures

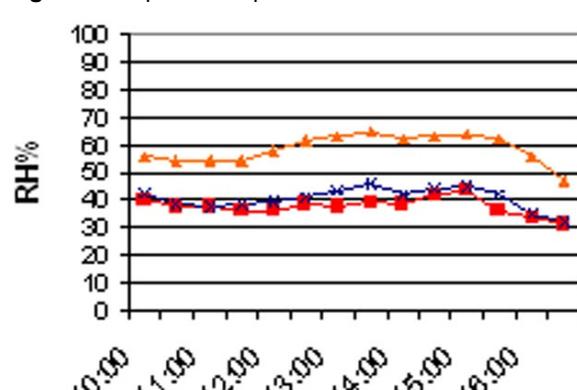


Figure 14: Space RH

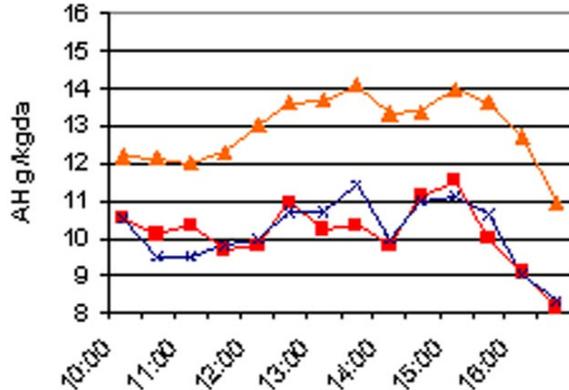


Figure 15: Space AH

running at floor level and the great vapour permeance of the building materials (brick walls and open louvers) reduces the impact of the evaporation on the humidity levels at the inlet of the tower, resulting in a lower impact on the performance than expect.

## 5. RECOMMENDATIONS FOR THE FINAL TOWERS

### 5.1 Further investigations

Further investigations are required into the effectiveness of the towers with attention placed on the nozzle type, spacing and pressure and flow available. The 'nappy' design needs to be rationalised

and reduced in diameter for aesthetic and space reasons. More data is required for higher load days to determine the variation in sensible cooling provided by the system. Possible improvements to the accuracy of the flow measurements needs to be considered with a focus on analysing the data.

#### 5.2 Air distribution

2 towers are required to be able to serve reception area too. Smaller towers should be considered to reduce the amount of show room floor area taken up.

#### 5.3 Water source

With the prototype, water not used goes to waste. The water consumption patterns require measurement for optimisation.

The box gutters and the positioning of the rainwater pipes on the same side of the building offer the possibility to collect rain water. Considering that summer is the rainy season, the water used by the system could be from a rain water collection tank and driven by a pump selected to optimise the nozzle performance. This would introduce electricity consumption to the system which needs to be considered.

#### 5.4 Investigate the costs

A detailed cost investigation and comparison for the final installation and conventional system should be made. The running and maintenance costs should be included. The cost of the prototype installation was 20,000ZAR (South African Rand), including the water tanking, pumps and two smaller towers, the cost of the final installation is expected to be 60,000ZAR. An conventional air conditioning system (constant volume DX rooftop package unit with mixing ventilation supply) would cost 500ZAR/m<sup>2</sup> = 212,500ZAR, 3.5 times the estimated cost of the towers)

#### 5.5 Determine performance equations

Yoklic's [5] equations require modification using the results of further performance measurement to take into account the induction of air by the nozzles.

## 6. CONCLUSION

The system behaves like a displacement system providing adequate cooling for days up to 28°C (Hotter days have not occurred during the test period.) The building seems adequately vapour permeable to use a recirculation system so that the humidity build-up does not impact on the performance of the tower. With the recommendations considered a permanent tower should prove to be an applicable and affordable solution to providing cooling to the space.

## ACKNOWLEDGEMENT

We would like to thank Miele South Africa for the financial support to this project and allowing the testing of what could be perceived as an untested technology in their main showroom.

## REFERENCES

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