# Heat pump water heaters for energy efficient water heating at centralized sanitary water heating systems

# A case study: Goldfields Kloof 8-shaft Industrial Change House


**Turnkey heat pump solutions provided by:**

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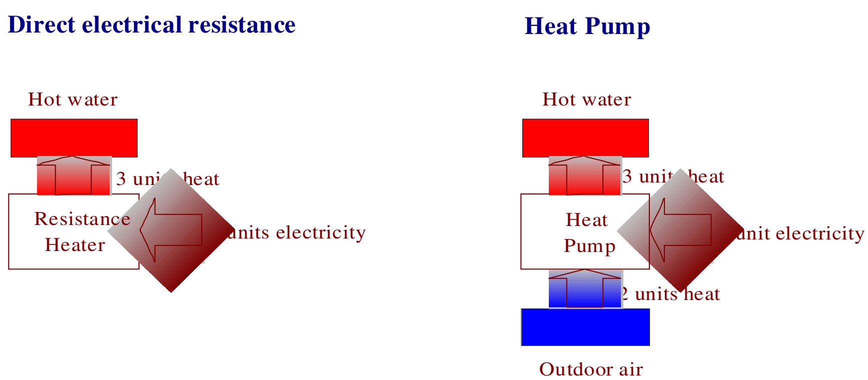
M-Tech industrial


ESKOM *eta* award winner in 2002 for energy efficiency

# Introduction

## Enerflow EH-MT Heat pumps for energy efficient water heating

The Enerflow EH-MT series external-air to water heat pumps recovers heat contained in the ambient air and transfers it to the water via a vapour compression cycle. Only a fraction of the total thermal energy output of the heat pump is consumed as electrical energy. Heat pumps therefore provide an energy efficient alternative to conventional heating plants that utilize pure electrical resistance heaters.




Heat pump performance is dependant on ambient air temperature, with a higher ambient air temperature leading to a better thermal performance of the heat pump. Heat pumps are therefore best suited to warmer climates, but can still operate efficiently at lower ambient temperatures above 3ºC.
In climatic regions where a large difference between summer and winter ambient temperatures exists, heat pumps can be combined with an electrical heater utilized as a backup heater. This combination optimizes energy efficient operation and hot water availability for a wide range of ambient air temperatures.

## Heat pumps vs. conventional sanitary water heating plants

Most conventional sanitary water heating systems utilize direct electrical resistance heating elements to heat water. These heating elements are usually installed inside the hot water storage tanks, according to ASHRAE guidelines.

Large amounts of sanitary hot water are typically required in hotels, hospitals, correctional services facilities and high density residences in the industrial sector. If this hot water requirement is provided by means of direct electrical heating, large amounts of electrical energy is consumed, and usually a significant demand contribution is also made by the water heating system towards overall building electric peak demand.

By comparison, heat pumps can reduce electrical energy consumption by 50% - 70% depending on implementation strategy. Furthermore the electrical demand of the plant can be reduced permanently; reducing sub station load and maximum demand contributions.

While heat pumps require routine maintenance and inspections to sustain reliable performance and energy savings, the labour intensity AND cost to maintain water heating systems are not increased.

# Case study: Goldfields Kloof 8-Shaft Industrial Change House

Heat pump performance and figures are now illustrated by means of an example plant. The Case study plant is an actual operational plant making use of heat pumps as primary heat sources. This plant provides sanitary hot water to 1600 mine workers at the Goldfields Kloof Division's No.8 Shaft Industrial Change House.

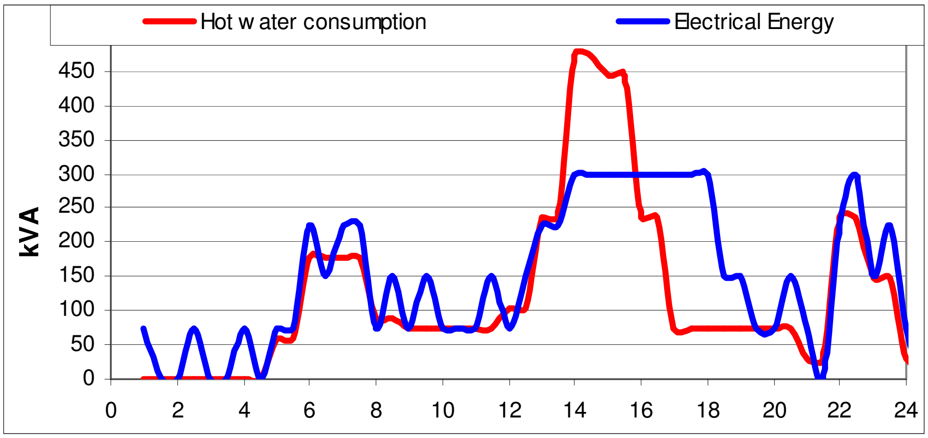
Typical hot water usage at an industrial change house is 35 – 42 liters per person per day at a normalized 60℃. The variation is a function of summer to winter variations in hot water usage. Cold water temperature at this site varies 12.5℃ – 17.2℃ winter to summer. Typical ambient temperatures conditions are 32℃ summer highest to -2℃ winter lowest.

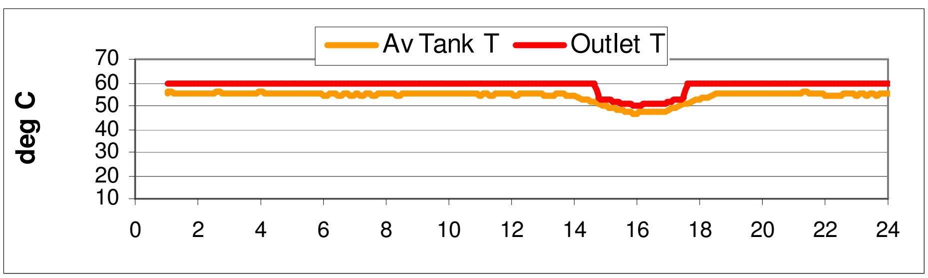
M-Tech Industrial designed and constructed the complete water heating system for Kloof Division, including inlet pressure reducing station, storage tanks, interconnecting pipe network, control panel and electrical reticulation network. Heat pump water heaters were proposed as an energy efficient option for water heating. Kloof Division eventually opted for the heat pump option as the economic feasibility of heat pumps, cost vs. savings, was very good. The case study below provides details on the economic analysis as mentioned.

M-Tech Industrial uses specialist simulation software to design water heating system solutions. This simulation model is able to simulate the current status of hot water systems and provide results of proposed retrofit changes. This simulation model has been developed in a Doctoral Study at the Northwest University. During this study, the simulation results have been verified extensively against measured results from actual plants. This simulation model gives M-Tech the knowledge base to size water heating systems for the optimum trade off between economic feasibility and energy efficiency.

Provided below are simulated results indicating the typical size requirements for a conventional heating plant able to serve 1600 users at an industrial change house. On the top graph the red line indicates hot water consumption during a 24-hour period, with a large early afternoon peak typical of shaft change houses. The blue line indicates heater operation. The bottom graph shows average storage temperature and importantly: Hot water supply temperature (Red line bottom graph).

As the graph indicates, a minimum of 300kW of conventional in-tank heater elements is required for this system. Lower heating capacity in this type of heating configuration could lead to an unwanted lowering of hot water supply temperature during peak shower periods.




M-Tech heaters and heat pumps however make use of technology that allows a so-called 'improved in-line heating methodology'. The methodology basically entails the following:

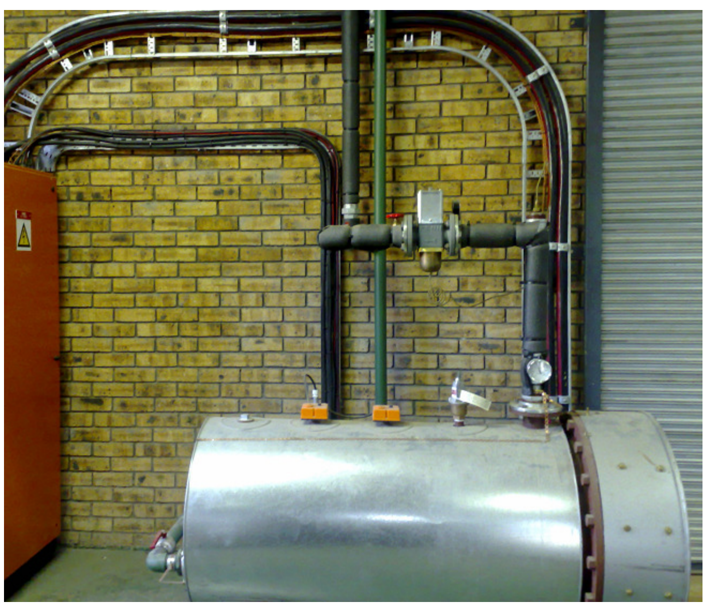
1. Outlet temperature of all heaters is controlled at 60℃ at all times, regardless of inlet water temperature (water inlet feed to the heater). This is achieved by either thermostatic flow control valves on the external 'non-storage' heater provided, or head pressure control valves on heat pump units.
2. Hot water from external heaters is then supplied to the top of the storage tank facility directly into the supply line feeding the change house with hot water. This configuration, combined with the outlet temperature control as mentioned in 1) ensures temperature stratification in the storage tanks.

The improved in-line heating methodology improves hot water supply availability and storage tank efficiency. This in turn allows heating capacity requirements per plant to be reduced slightly, as the heating load can be spread over longer periods in a day without hot water temperatures dropping too low.

M-Tech therefore proposed the use of the following heating equipment for this plant:

1. 2 x Enerflow EH70 heat pump units. These heat pumps provide 70kW of thermal energy each, whilst only consuming 23kW electrical energy each. These heaters are used a primary heaters, i.e. they are preferred heaters in the heating control algorithm.

2. An electrical in-line heater (This is an external heater fitted with heating elements, also known in industry as a non-storage heater) is also installed with a heating capacity of 180kW. This heater is configured to only be a backup heater. As can be seen from the photos below, a thermostatic flow control valve is installed on the heater outlet, to provide the outlet temperature control as mentioned.



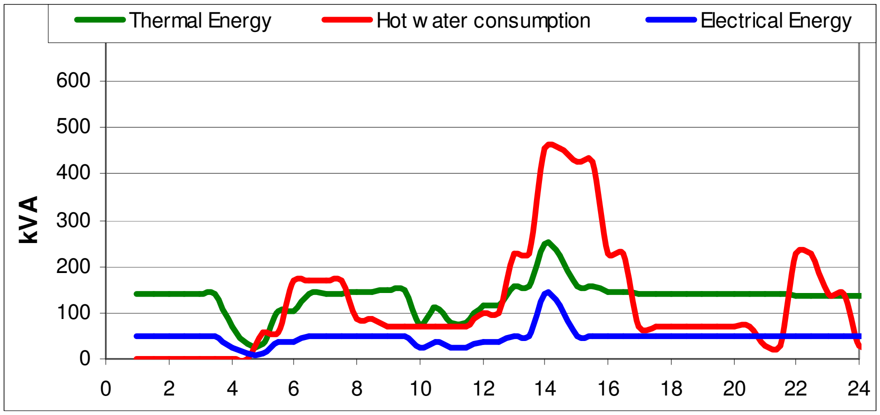
3. By combining the heat pumps with an electrical in-line heater as backup, the most economically feasible size of heat pumps can be used. Heat pumps are therefore sized to allow operation throughout the year of close of 24 hours per day. Remember, an energy efficient device only save you energy when

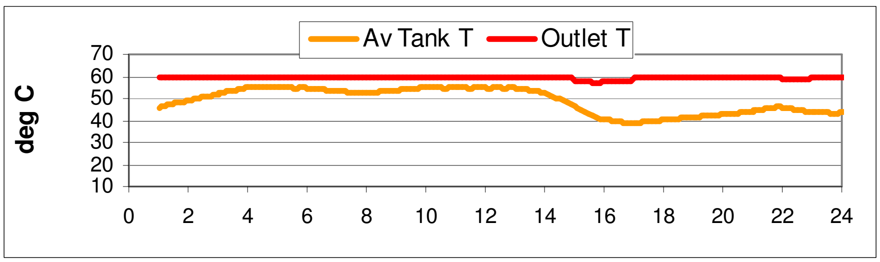
operational! Since heat pumps are designed for long operation periods throughout the year, it means during periods of higher than average hot water consumption (typically winter), the in-line backup heater will provide the rest of the hot water requirements per day.

4. The storage tanks of the system are sized to accommodate at least 60% of the daily hot water requirement. Sufficient storage capacity allows more recovery time for heaters, thereby allowing correctly sized heat pumps to operate for as close to 24 hours per day as possible. In this case 3 x 12000l storage tanks were used, all connected in series as required for the M-Tech improved in-line heating methodology.

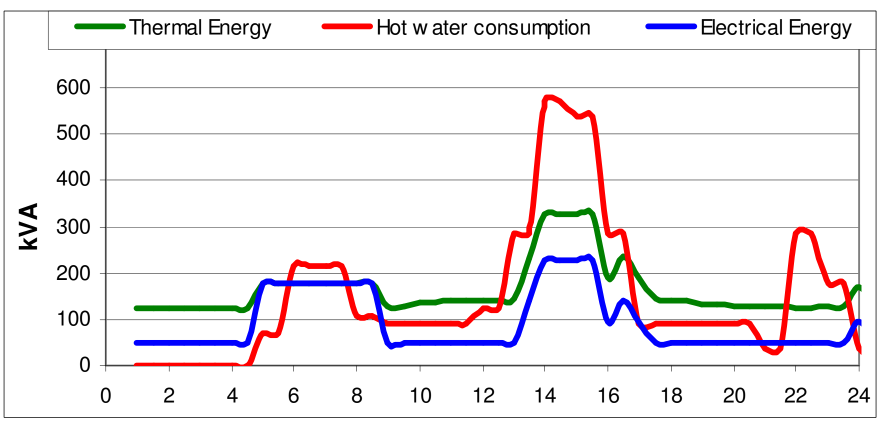
The following graph shows the performance of the heat pump based water heating system for typical summer operation. In the top graph the red- and blue lines refer to the same items as before, i.e. hot water consumption and electrical energy. The additional green line indicates the thermal energy that the heaters produce. When heat pumps are operational, the green line should be higher than the blue line as heat pumps produce about three times as much thermal energy than consumed in electrical energy, as illustrated on page 1 of the document.

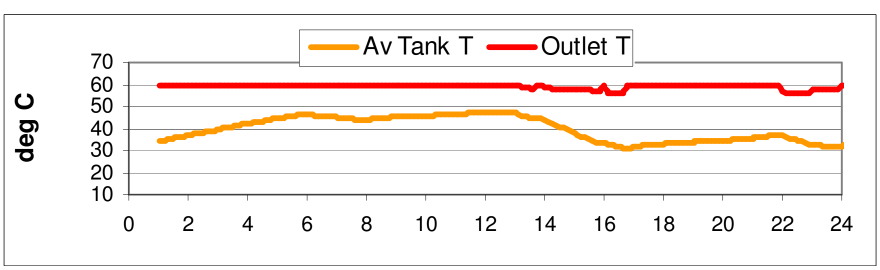
The bottom graph shows the outlet temperature and average tank temperature. Outlet temperature (red line bottom graph) stays close to 60℃ throughout the day, even though average tank temperature fluctuates significantly. This is the benefit of the improved in-line heating configuration; better utilization of the storage tanks without a reduction in hot water supply temperature throughout the day.




The second graph below shows the typical winter operation of the same system. Hot water consumption is higher (See red line top graph compared for the summer and winter graphs). The backup heater is now used more extensively during the afternoon peak shift. Additionally, the heat pump cannot operate on cold winter mornings (typically 04:30 – 08:30) with the backup heater also operational during those periods.



## Operational cost comparison

The table below shows the operational costs and energy consumption of a conventional electrical resistance heating system versus a heat pump based system for this specific 1600-user change house case study.

| | **Conventional electrical heating system** | **Heat pumps as primary heaters with ILH electrical backup** |
|---|---|---|
| **Main system specifications** | 300 kW electrical<br>36000 liter | 2 x EH70 heat pumps (140kW thermal, 46kW electrical)<br>180kW electrical<br>36000 liter |
| **Annual energy consumption** | 1,269,000 kWh | 476,000 kWh |
| **System Maximum Demand (Annual average)** | 291 kVA | 158 kVA |
| **Operational cost (Based on estimated '09 Megaflex)** | R397,800 | R144,200 |
| **Annual energy savings** | | 793,000 kWh |
| **Annual operational cost savings** | | R249,600 |

## Installation cost comparison

Typical pricing for the two types of water heating plants are as follows:

| | **Conventional electrical heating system** | **Heat pumps included** |
|---|---|---|
| **Total turnkey installation cost (Items incl. summarized below table)** | R945,000 Excl VAT [1] | R1,496,000 Excl VAT [2] |
| **'Extra-over' cost for heat pump installation** | | R551,000 Excl VAT |

[1] Cost as listed in the table is for a complete turnkey installed and commissioned water heating system. All engineering services are included, as well as all hardware (Pressure reducing station, storage tanks, electrical heaters, control panels, interconnecting piping electrical reticulation).

[2] Extra over costs for heat pump installation is the cost of heat pumps, additional piping and cabling to accommodate heat pumps, control and power distribution changes in the control panel to accommodate heat pumps, civil construction (concrete plinths and enclosure outside plant room for heat pumps).

The additional cost to include heat pumps in the water heating system is therefore estimated at R551,000 Excl VAT.

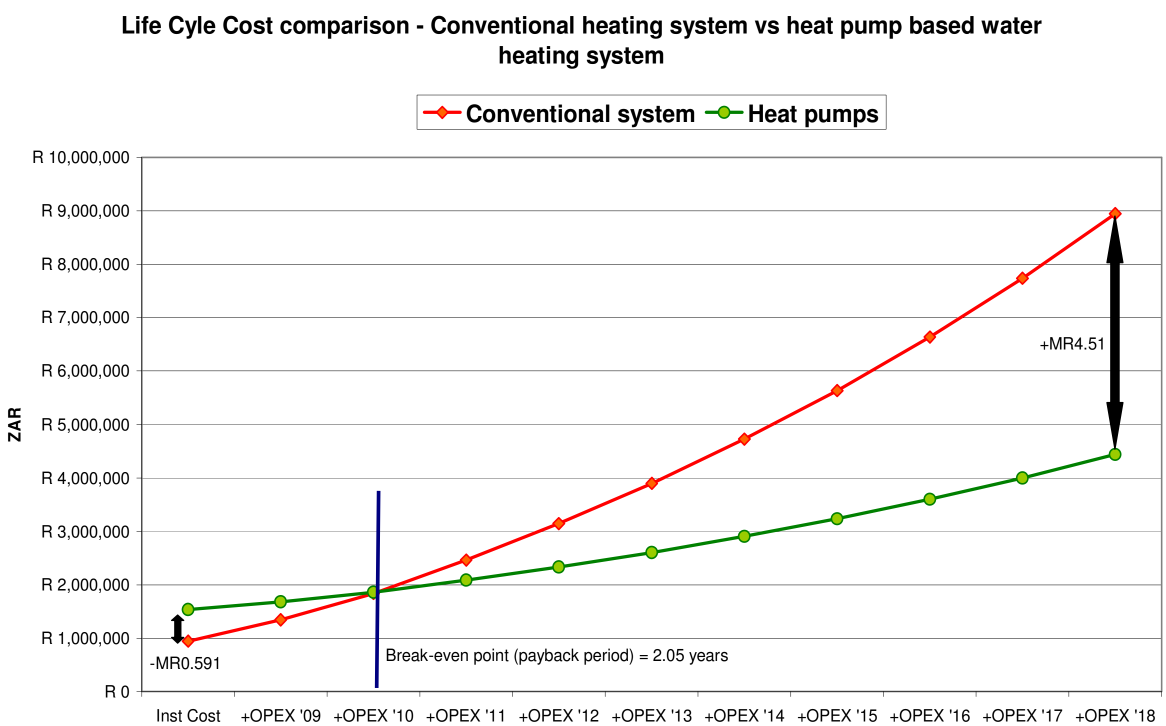
## Economic analysis

The graph below shows the estimated life cycle cost for both conventional system and heat pump based system. Estimated electrical tariff increases have been included as follows:

1. ESKOM Megaflex is used in the simulation program, including time-of-use tariffs, network demand charge, rate levies and taxes.
2. 25% tariff increases year-on-year is expected in 2009 – 2011, according to NERSA statements made in July 2008.
3. 10% tariff year-on-year increases is estimated for 2012 – 2018.

The following main observations can be made from the Life Cycle Cost graph.
1. Straight payback period for this type of project is shown to be slightly more than 2 years.
2. For a conservative 10-year life cycle (Heat pumps should last well beyond 10 years) the system life cycle cost is improved by R4,510,000 by fitting heat pumps.

Given the annual energy savings, operational cost savings and economic returns as illustrated by the case study, it is clear that heat pumps provide a viable option for energy efficient water heating.



## Logistical advantages of the heat pump in-line water heating approach.

The M-Tech heat pump and in-line water heater solutions also provide some additional logistical benefits during construction and maintenance activities.

Plant construction (New installations or retrofits).

1. Installation work is relatively easy and fast to complete. A complete water heating installation takes approximately 50 hours to complete (given that all equipment is ready to be delivered to site before commencing installation work). A retrofit installation can be completed in 8-16 hours. This is opposed to some competing technologies such as solar water heating (SWH) where installations can take significantly longer, especially on retrofit installations where plant availability during installation is a crucial issue.
2. Risk analysis of plant installations show that installation work is relatively 'low-risk' in nature and very little overhead work is required.

Maintenance activities:

1. Maintenance activities on heaters, such as replacement of heating elements or repairs on heat pump units do not impact on system availability. As long as hot water is stored in the storage tanks the plant remains available for usage by the change house. All heaters, i.e. heat pump units and in-line heaters, are fitted with shut-off valves meaning that heaters can be taken offline without impacting on system availability. All equipment such as heaters, pumps and control equipment are installed in series with flanges or unions meaning that replacement is a fast and simple task.
2. Replacement of heating elements in the in-line heater (if an in-line heater is used at a plant) is a quick task compared to the replacement of elements installed inside a storage tank as is conventionally found in most water heating installations. Only the volume of water inside the in-line heater (typically 150 -200 liters) needs to be drained and filled again after elements replacement. Elements are each installed on screwed bosses meaning individual replacement is possible.
3. Scale build up in tanks is a direct cause of the large temperature gradients in the water close to the heating elements. Since the heating elements are not installed in the storage tanks, very little scale build up will take place inside storage tanks. Storage tank life is significantly increased by this method.
4. Scale build up will however now occur in the in-line heater vessel where the elements are installed. The removal of scale build up in such a small vessel is however a significantly easier task compared to large storage tanks.
5. Additionally, should the in-line heater be replaced after many years of operation, it will be much less cost-intensive than the replacement of a storage tank. In-line heaters can also be removed and replaced easily at a plant without the utilization of riggers and possible structural work to the building when removing and replacing a storage tank.

As part of all turnkey projects, M-Tech provides a maintenance manual for all plants, as well as training to all site support personnel.

# M-Tech Industrial company profile

M-Tech Industrial (Pty.) Ltd. is an ISO9001 accredited engineering company based in Potchefstroom with a full-time technical staff of fifty graduate engineers. A number of lecturers from North-West University (Previously Potchefstroom University) also work on a part time basis in the company.

M-Tech was founded in 2000 by Dr. Gideon Greyvenstein and Dr. Pieter Rousseau, at the time both professors in mechanical engineering at Potchefstroom University. M-Tech Industrial grew out of an engineering consultancy known as M-Tech Mechanical that has existed since 1987.

M-Tech initially focused on consulting work in the fields of fluid mechanics and thermodynamics as well as the design of thermal-fluid systems. M-Tech also developed commercial thermal-fluid systems simulation software that is licensed internationally.

In 2005 M-Tech Industrial acquired Enerflow Technologies cc, a heat pump systems design and manufacturing company that was established in 1992. M-Tech therefore attained the technology and manufacturing expertise associated with a wide range of refrigeration and heat pump products.

M-Tech has close ties with the Engineering Faculty of North-West University, which acts as its research partner. The special relationship with North-West University contributes to the high-tech entrepreneurial culture of the company.

M-Tech is a Level 3 BBBEE contributor.