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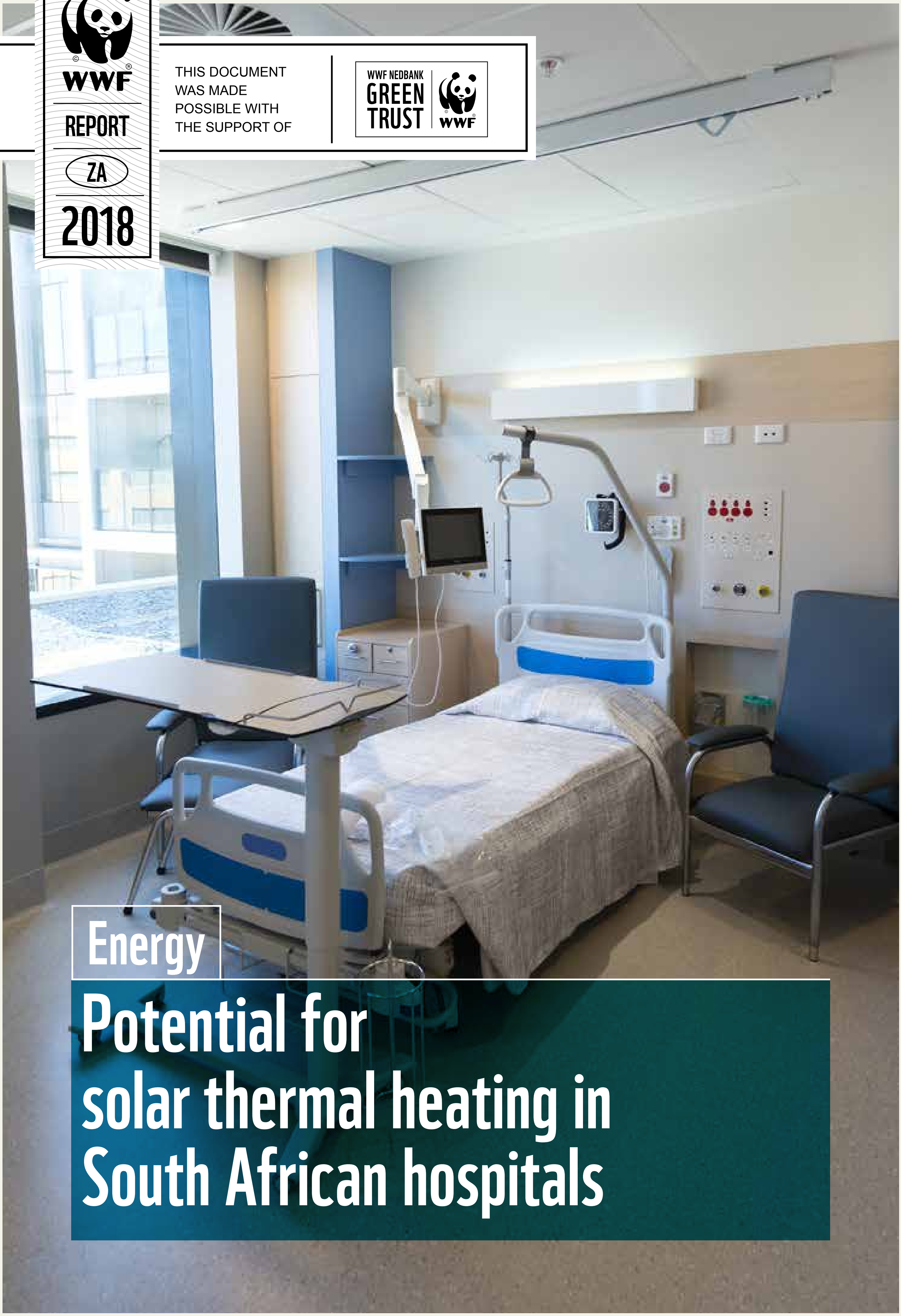

Energy

Potential for solar thermal heating in South African hospitals

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WWF South Africa's Policy and Futures Unit undertakes enquiry into the possibility of a new economy that advances a sustainable future. The unit convenes, investigates, demonstrates and articulates for policymakers, industry and other players the importance of lateral and long-term systemic thinking. The work of the unit is oriented towards solutions for the future of food, water, power and transport, against the backdrop of climate change, urbanisation and regional dynamics. The overarching aim is to promote and support a managed transition to a resilient future for South Africa's people and environment. The organisation also focuses on natural resources in the areas of marine, freshwater, land, species and agriculture.

This is one in a series of publications produced by WWF South Africa's Transport Low-Carbon Frameworks programme, which is a dimension of a broader mission around economic transitions towards economically, socially and environmentally sustainable futures. The transport project aims to provide a platform, expertise and perspectives to support labour, business and government in engaging with the challenges implicit in the shift to a low-carbon economy. We seek solutions that will lower greenhouse gas emissions and enable a flourishing South Africa, to deliver developmental outcomes and social equity in the context of South Africa's economic geography. Consideration is given to the three tiers of interventions that will be required to effect the transition of this sector, being to **reduce** movement of goods and people, **shift** to low-carbon modes of transport, from private to public and from road to rail, and **improve** mobility services, and energy and fuel efficiency.

CONTENTS

EXECUTIVE SUMMARY

In this framing paper, the potential for solar thermal heating technologies in South African hospitals is investigated. Low-temperature hot water at 60 °C is required for domestic purposes in hospitals, such as staff and patient ablutions. The study focuses on public and privately owned, large and smaller hospitals in the country. The database that was developed identified a total of 696 hospitals, with 126 490 beds in total, managed either by provincial health departments or privately owned companies such as Netcare, Mediclinic and Life Healthcare, or independently owned private hospitals affiliated with the National Hospital Network.

The study shows that most hospitals in the country are located in Gauteng (22%), the Western Cape (17%) and KwaZulu-Natal (17%). The total thermal energy requirements for producing domestic hot water was estimated to be in the range of 312 to 336 GWh/year using the building guidelines set out in South African National Standard (SANS) 10252-1. The study shows that the cold and hot water consumption of hopitals can vary significantly based on the type, size, geographical location and services offered by the hospital. This variation is accounted for using cold water measurements and available literature.

The study identified a total of 23 solar thermal systems at hospitals in South Africa, accounting for a total installed collector area of 1 333 m^2. Evacuated tube technologies are preferred to flat-plate collectors, with the former accounting for 68% of the total collectors installed at hospitals.

Currently heat pumps and electric boilers are the most common systems used in new and old hospitals, with a small number of larger and older public hospitals using coal boilers. The implementation of heat pumps is being driven by new building regulations in South Africa and the electricity savings it presents. Based on the data gathered throughout this study, it can be presumed that most private and public hospitals make use of heat pumps and electric boilers, or will do so in the future, while the implementation of solar thermal technologies, although low, is mostly seen within specific privately owned hospitals. A clear trend was identified, based on the type of renewable energy technology and private ownership: photovoltaic (PV) systems were preferred to solar thermal technologies as a renewable energy alternative to offset the hospital's energy dependence on conventional energy systems.

The study shows that the largest benefit for the implementation of solar thermal technologies will be achieved at public and private hospitals that still solely make use of conventional electric boiler technologies to produce hot water. A case study conducted at Paarl Provincial Hospital in the Western Cape showed that solar thermal system investments may exhibit a project internal rate of return (IRR) of 10% and a payback period of 12,3 years. Based on an exchange rate of R15,30/EURO, a levelised cost of heat (LCOH) of 4,05 EUROc/kWh (R0,62/kWh) is achievable with solar thermal systems installed at hospitals where heat pumps and electric boiler technologies are used.

Based on the findings of this study, it can be presumed that hospitals can feasibly increase their overall solar thermal capacity to compensate for 20 to 40% of their combined annual thermal energy needs by enhancing the performance of installed heat-pump systems and also reducing the industry's dependence on boilers and conventional fuel sources using solar thermal collectors. This would require the installation of approximately 73 972 to 147 944 m^2 of collector area throughout the 696 hospitals identified in South Africa. However, various challenges brought about by the high upfront capital cost of solar thermal systems, old infrastructure at hospitals and the collection and sharing of data and information, among other things, could hamper the large-scale implementation of solar water heaters in South Africa.

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ABBREVIATIONS AND ACRONYMS

CRSES	Centre for Renewable and Sustainable Energy Studies
CPC	Compound parabolic concentrator
CSP	Concentrated solar power
CWHC	Cold water for human consumption
DHW	Domestic hot water
DNI	Direct normal irradiance
GHI	Global horizontal irradiance
IRR	Internal rate of return
kWth	Kilowatt-thermal / thermal kilowatt
LCOH	Levelised cost of heat
MWth	Megawatt-thermal / thermal megawatt
PV	Photovoltaic
SABS	South African Bureau of Standards
SANS	South African National Standard
SF	Solar fraction
SG	Specific gains
SIC	Standard industrial classification
ST	Solar thermal
SU	Stellenbosch University
SWH	Solar water heater
WWF-SA	World Wide Fund for Nature – South Africa

INTRODUCTION

South Africa has some of the highest levels of solar irradiance in the world, yet is still highly reliant on fossil fuels for its energy needs. Although South Africa has a vast solar resource, it only has 1 055 MWth of solar thermal installations, which compares unfavourably to countries with limited solar resources, such as Germany (12 281 MWth) and Austria (3 541 MWth). Solar energy thus provides a key opportunity to decrease this reliance on fossil fuels and the attendant risks of price volatility, while also reducing greenhouse gas emissions.

Solar thermal technologies have great potential for supplying the thermal energy requirements of hospitals for low-temperature hot water at 60 °C. Replacing the present dependency of hospitals on electricity generated from fossil fuel will provide savings and reduce the carbon footprint of hospitals. At present only 0,4% of the total energy needs – estimated at 370 GWh – for producing hot water is generated by solar thermal collectors. This seems to indicate that there is enormous potential to increase the penetration of solar thermal installations in the industry.

This report serves as a framing paper for investigating the potential of solar thermal technologies at hospitals in South Africa, including the potential of the technologies to meet the hot water requirements of these hospitals. It also presents an overview of available technology, solar resources and the penetration of solar thermal systems in South African hospitals. A case study is presented to determine the feasibility of implementing a solar thermal system at a specific hospital in Paarl, Western Cape. The study was conducted by the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University (SU) in conjunction with the World Wide Fund for Nature – South Africa (WWF-SA) and funded by the WWF Nedbank Green Trust.

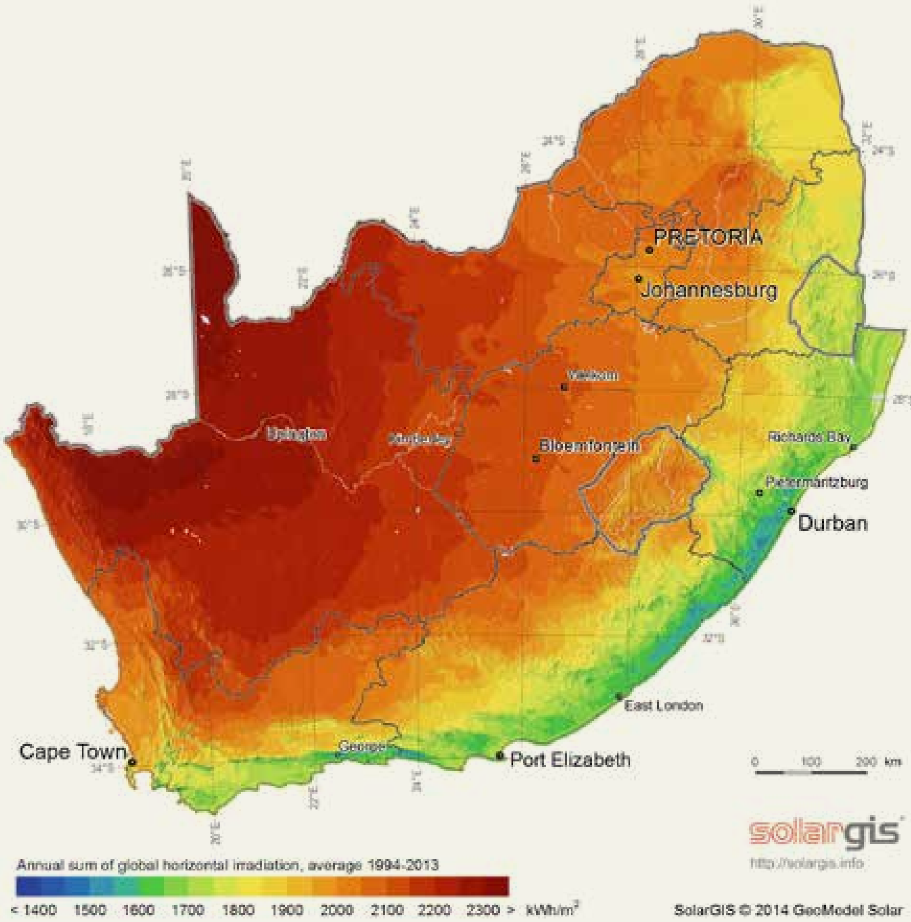
OVERVIEW OF HOSPITALS AND THE SOLAR RESOURCE

The study aims to identify the potential for industrial-scale solar thermal systems within the hospital industry in South Africa. This section of the study discusses the solar resource in South Africa and the relation it bears to the geographical location of hospitals in the country.

Solar resource in South Africa

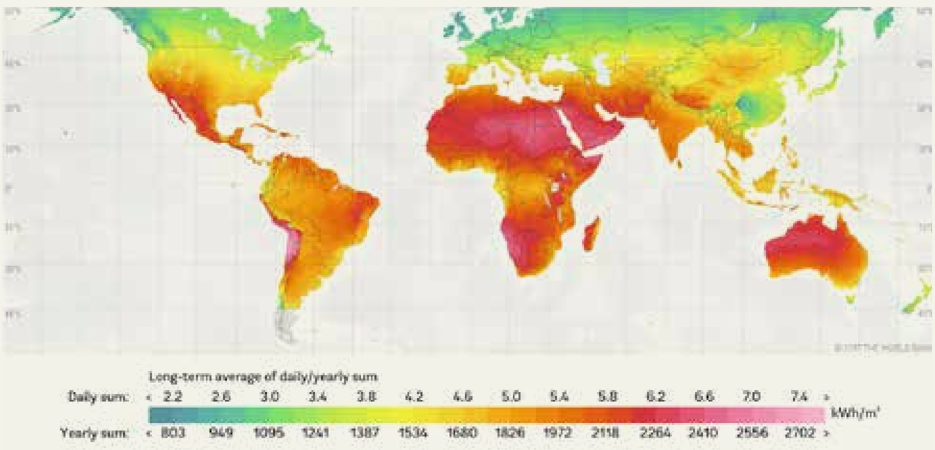
The potential for solar thermal systems varies across the world depending on the irradiation (sunlight) that falls on a specific location throughout the year. Figure 1 illustrates the distribution of the average annual sum of global horizontal irradiance (GHI) in South Africa. GHI is a combination of the direct normal irradiance (DNI) and the diffuse horizontal irradiance (DHI), where DNI is the light measured perpendicular to the light rays travelling in a straight line from the sun and DHI is the light that is scattered by molecules in the atmosphere (such as clouds). Therefore, tropical locations with a high rainfall experience lower direct irradiance and higher diffused irradiance than drier regions and thus have a lower annual GHI.

Figure 1: Map of South Africa showing the average annual sum of GHI



SOURCE: SOLARGIS, SOLARGIS.INFO

Figure 2: World map showing the average annual sum of GHI



SOURCE: SOLARGIS, SOLARGIS.INFO

South Africa experiences an abundance of solar irradiance and exhibits great potential for the application of large-scale solar thermal systems in industrial applications. It can be expected that the location of most of the hospitals in the country will be in regions with the highest population density, such as Cape Town, Johannesburg and Durban. Based on the data presented in Figure 1, most of these areas, excluding Durban, experience large amounts of annual solar irradiation greater than 1 800 kWh/m². These areas can be considered ideal for the installation of solar thermal technologies when compared to countries with a large number of solar thermal installations such as Austria, which has an average annual solar yield of less than 1 300 kWh/m², as seen in Figure 2. As one of the leading countries for installed solar collectors in the world, Austria had 430 kWth of solar water systems installed per 1 000 inhabitants in 2013 (Weiss et al, 2015). Table 1 lists cities in South Africa and the annual sum of GHI in each region.

Table 1: Annual sum of GHI in South African cities

Location	Annual sum of GHI (kWh/m²/year)
Upington	2 275
Bloemfontein	2 100
Johannesburg	1 990
Cape Town	1 890
Durban	1 650

SOURCE: PVPLANNER, SOLARGIS.INFO/PVPLANNER

Location of hospitals in South Africa

A database that identifies all public and privately owned hospitals in South Africa was developed by CRSES. This database identifies a total of 696 hospitals. As this study aims to investigate industrial-scale solar thermal application, this list excludes small clinics and healthcare facilities. The map in Figure 3 displays the geographical location of the listed hospitals.

As can be seen from Figure 3, a large number of hospitals are located in the densely populated areas of the country, such as Cape Town, Johannesburg and Durban. Compared to the rest of the country, Cape Town and Johannesburg have the highest likelihood of commissioning the installation of solar thermal technologies at hospitals, based on the number of hospitals and their geographical location with respect to solar irradiation.

The database was used to establish the number of hospitals, by province.
Figure 4 shows that most hospitals in the country are located in the Gauteng (22%), the Western Cape (17%) and KwaZulu-Natal (17%).

Figure 3: GIS map of geographical location of hospitals throughout South Africa

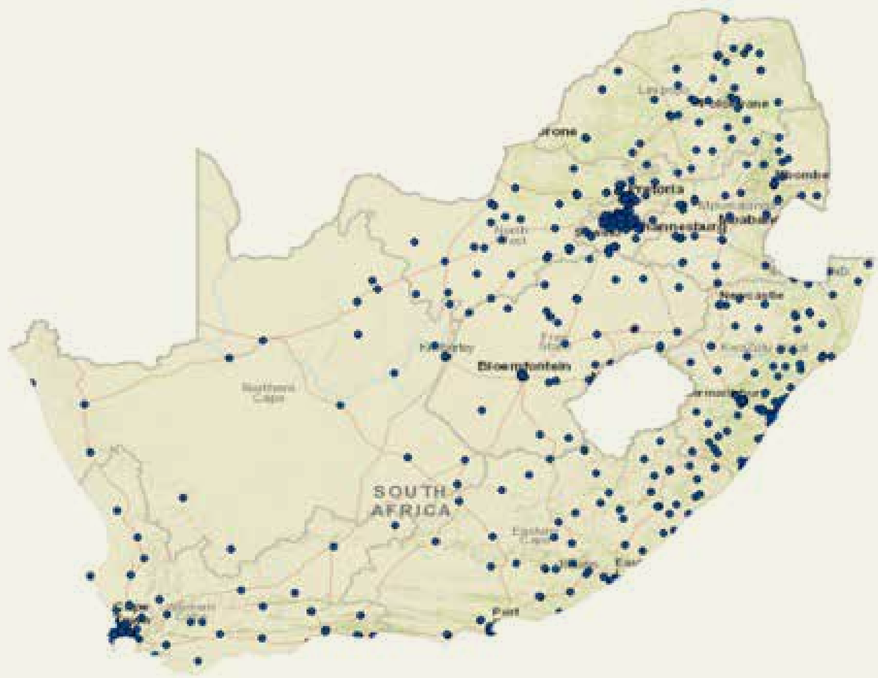
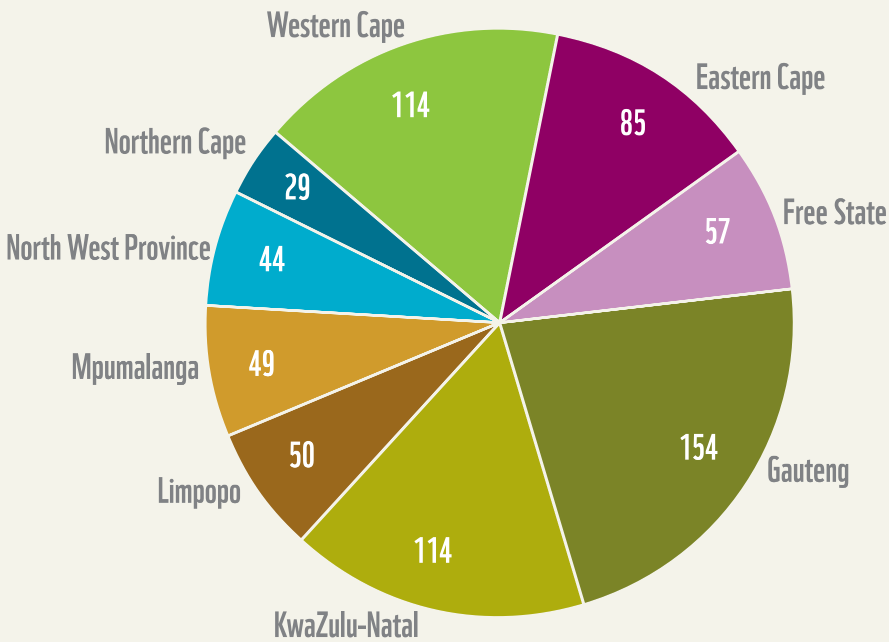


Figure 4: Number of hospitals per province in South Africa



OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

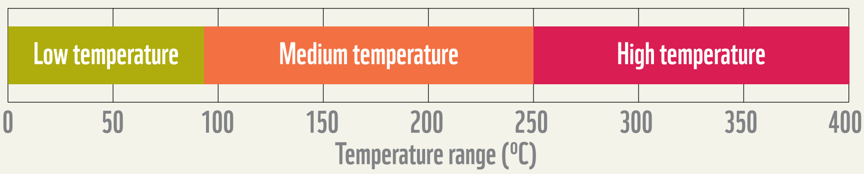
Energy from the sun is experienced as heat and light on the surface of our planet. Various technologies exist that utilise the energy from the sun for various purposes.

The most commonly known technology is photovoltaics (PV), which utilises photons (light) from the sun to generate electricity. Solar thermal technology absorbs radiation from the sun to heat up a medium such as water. Both these technologies can be purchased as modules or panels and can look very similar. However, it is important to differentiate them, since this report only considers solar thermal technologies for heating water to a desired temperature.

Solar thermal technologies

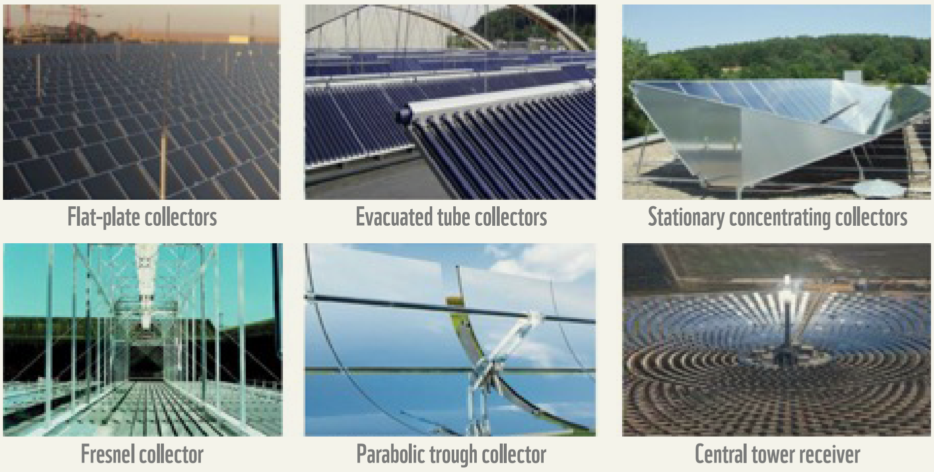
Solar thermal collectors convert solar radiation into useful heat. Solar thermal systems are classified into low, medium and high operational temperature ranges, as described in Figure 5. The most economical application of solar thermal technologies is for medium to low temperatures (less than 160 °C).

Figure 5: Classification of temperature ranges in solar thermal technologies



The solar thermal technologies available in the market are shown in Figure 6. Flat-plate and evacuated tube collectors are the only solar thermal technologies that do not use concentrated solar radiation. They are considered static collectors as they do not need to track the sun. The use of concentrated solar power (CSP) is typically only feasible on a megawatt scale, whereas flat-plate and evacuated tube systems are utilised on a smaller scale.

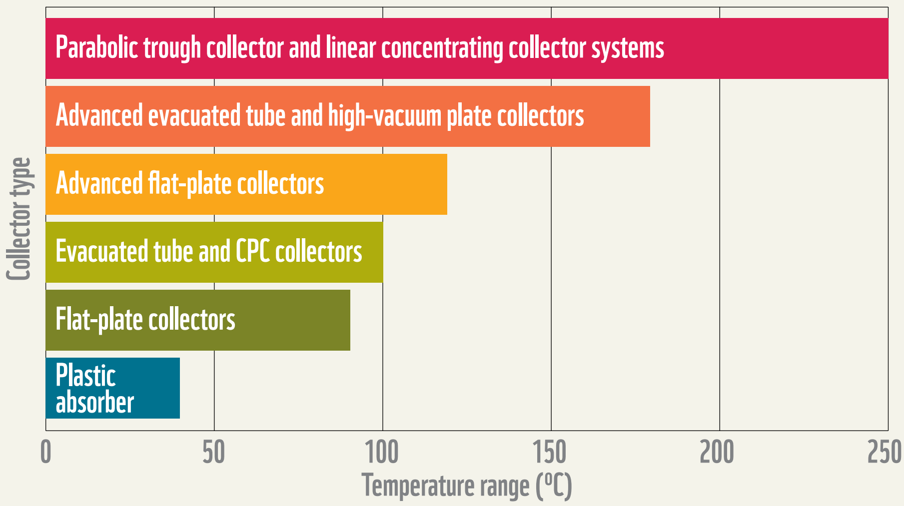
Figure 6: Various solar thermal technologies



SOURCES: WEISS, 2016; ESKOM, 2017

Hospitals typically use hot water for patient hygiene, kitchens and the cleaning of bed linen and dishes, usually at temperatures of up to 60 °C. Figure 7 illustrates the temperature ranges of the various solar thermal technologies. The efficiency and the cost of each technology increase proportionally to its operational temperature range. The most suitable technologies for hospital applications are flat-plate and evacuated tube collectors.

Figure 7: Temperature ranges applicable to specific solar thermal technologies



Solar thermal technologies for hospital applications

In order to differentiate between flat-plate collectors and evacuated tube collectors, a brief description is provided for each, along with the respective advantages.

Flat-plate collectors

Figure 8: Flat-plate collectors

SOURCE: VENAM, 2015

A glazed flat-plate collector is shown in Figure 8. The glazing is made of glass, which allows solar radiation that has a shorter wavelength to pass through into the collector, while preventing radiation with a longer wavelength from reradiating out of the collector, effectively trapping heat inside. A flat-plate collector includes copper piping to transport fluid through the collector to absorb heat. In higher-quality collectors, the copper is specifically coated or painted matte black, increasing its absorptivity and decreasing its emissivity and reflectivity. A direct system passes the water to be heated through the collector. However, indirect systems are more common for larger applications, making use of an anti-freeze fluid in a heat exchanger. Most large-scale industrial applications in South Africa use flat-plate collectors.

Advantages of flat-plate systems (Mangal et al, 2010) include the following:

- Flat-plate systems may be installed directly onto a rooftop, whereas evacuated tube systems require installation at a steeper angle, usually necessitating a support structure.

- Flat-plate systems cost less than evacuated tube systems owing to their simpler design.

- There is less risk of overheating in flat-plate systems compared to evacuated tube collectors.
- Flat-plate collectors are available in larger sizes as single units when compared to evacuated tube collectors.
- Flat-plate systems follow the gradient of the rooftop and are thus more aesthetically pleasing compared to evacuated tubes, which require a support structure.

Evacuated tube collectors

Figure 9: Evacuated tube collectors

SOURCE: TECHNOPRECISION.IN/SOLAR-WATER-HEATER-ACCESORIES.HTML

Figure 9 shows an evacuated tube solar thermal collector, which consists of copper heat pipes inside double-glazed tubes. A vacuum exists between two layers of strong glass that prevents the convection or conduction of heat through the glazing (Mangal et al, 2010). The system can either be direct, allowing the water being heated to flow through the evacuated tubes, or indirect. Indirect systems include heat pipes with a fluid that has a lower boiling temperature than water, and are more common for larger applications. Heat absorbed from solar radiation turns the fluid in the heat pipes into vapour, which rises to the top of the pipe where water passing over the pipes cools and condenses the fluid back into liquid. Evacuated tubes are installed at a higher angle than flat-plate collectors to allow for this process.

A typical problem with the tubes is that the vacuum can burst, letting air into the glazing. This is easily checked since the tubes that maintain a vacuum are cold to the touch while the tubes containing air in the glazing are noticeably warmer when exposed to sunlight owing to the conductive and convective heat loss.

Advantages of evacuated tube technologies (Mangal et al, 2010) include the following:

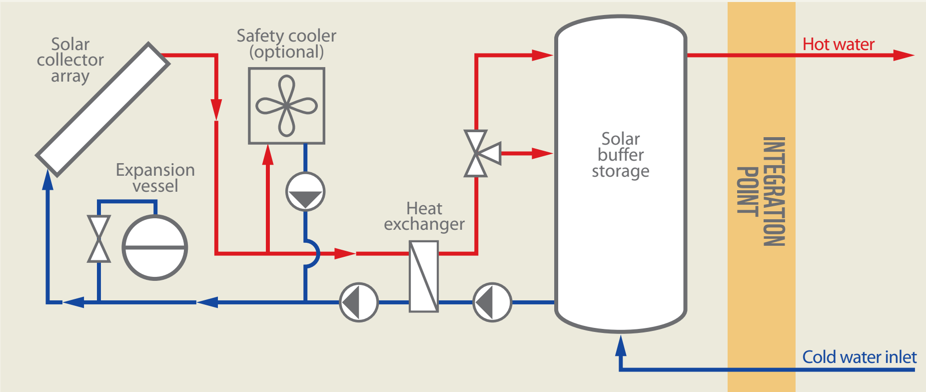
- If one or more tubes are damaged or broken, the system will still operate until the broken tubes are replaced. A flat-plate collector may still operate with damaged glass, but at a lower efficiency when compared to a broken tube in an evacuated tube system.
- The vacuum formed between the double-glazing is a better insulator than in air-filled flat-plate systems.
- The cylindrical shape of the tubes acts as a passive solar tracker.
- Evacuated tube collectors may be used in sub-zero environments because the vacuum prevents conduction or convection.
- Tubes may be replaced one at a time without the rest of the panel being affected.
- Evacuated tube systems perform better in overcast conditions than flat-plate systems.

Based on information gathered throughout this study, the type of technology used in the installation of solar thermal systems at hospitals is highly dependent on the appointed installer's expertise, recommendations and opinion of each technology. The choice of solar technology will also depend on the type of hospital, its geographical location, the number of people it serves and its heat demand. The use of each technology at South African hospitals is discussed under 'Solar thermal installations at hospitals in South Africa' on page 32.

Basic schematic of a solar thermal system in a hospital

A typical solar thermal collector process is illustrated in Figure 10. This schematic illustrates the function of a basic solar water-heating system. This may vary depending on the type of installation, specifically its application in larger hospitals, where its integration with existing technologies such as boilers and heat pumps would be included in the design to ensure the optimal performance of the hot water system.

Figure 10: Typical solar water-heating system



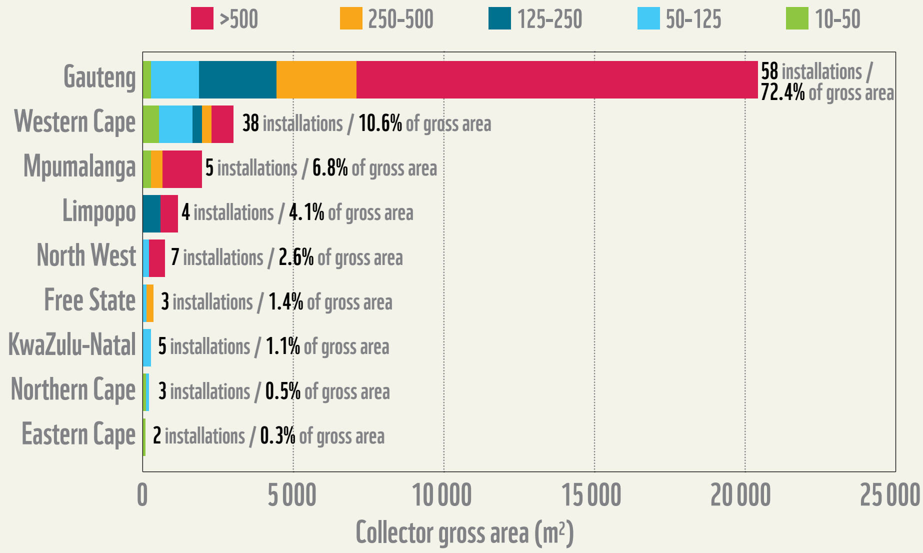
The collector loop utilises a heat collecting fluid such as a water-glycol mixture (Joubert et al, 2016). The collector fluid absorbs heat from solar radiation and heats water through a heat exchanger. A safety cooler may be used to reduce the risk of overheating. The hot water is stored until it is needed for the application process, which in the case of hospitals may be the washing of bed linen, showers for the patients, etc. The stored hot water is discharged and may be utilised directly or passed through another heat exchanger that integrates it with the conventional heating process. The conventional heating process is used to supplement the solar thermal system to ensure that hot water is always available. Typically, hospitals in South Africa use heat pumps and electric boilers as their conventional thermal technologies.

General statistics of solar thermal applications in South Africa

CRSES created, and is constantly updating, a database identifying large-scale solar thermal systems in South Africa. It should be noted that this database only accounts for large-scale solar thermal installations (>10 m²) and excludes small-scale residential systems below this gross area. The original database formed part of a study done by Joubert et al (2016) titled ‘Large-scale solar water heating in South Africa: Status, barriers and recommendations’ and has been expanded since.

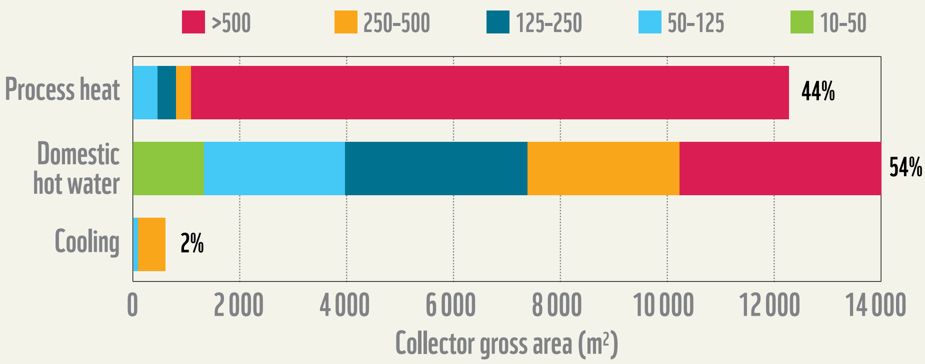
There are 125 systems listed in the database, amounting to a total collector area of 28 213 m², installed between 2002 and 2016. Figure 11, Figure 12 and Figure 13 categorise the individual systems based on a collector area range per province, per application and per industrial sector, respectively.

Figure 11: The total collector gross area of large-scale solar thermal systems installed per province in South Africa at the end of 2016



As can be seen in Figure 11, most large-scale solar thermal systems are in Gauteng, with 58 installations in total, accounting for 72,4% of the gross collector area installed throughout South Africa. Figure 12 shows the gross collector areas for the various applications that have solar thermal systems installed. The different applications for which the database is categorised include process heat, cooling and domestic purposes, which include hot water for staff ablutions in buildings.

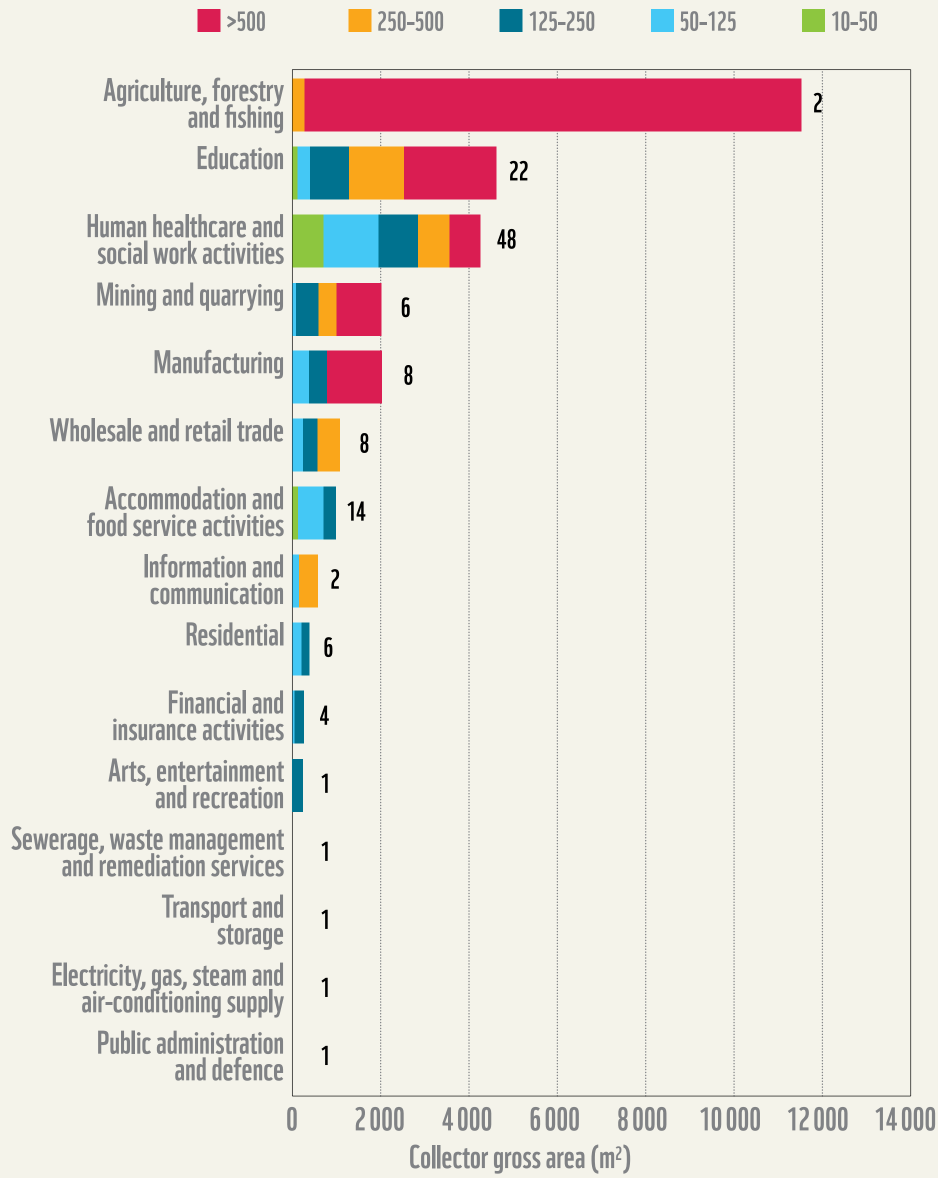
Figure 12: The total collector gross area of large-scale solar thermal systems installed in South Africa based on application at the end of 2016



As shown in Figure 12, 54% of installed collector areas in the country for large-scale applications are for domestic hot water purposes. The database characterises the application of solar thermal installations at hospitals for domestic hot water purposes, which entails the use of hot water for staff and patient ablutions and other functions in the hospitals. This forms part of the 54% as seen in Figure 12.

Figure 13 shows the distribution of the gross collector areas for the various industry applications in South Africa. The industry applications are based on the Standard Industrial Classification of all Economic Activities (SIC) Seventh Edition, October 2012 (StatsSA, 2012) ('SIC 2012'), excluding those identified as large-scale residential applications.

Figure 13: The total collector gross area installed in South Africa based on industry application at the end of 2016



It can be seen from Figure 13 that the industry sector categorised as ‘Human healthcare and social work activities’ has the largest number of solar thermal installations in South Africa, albeit with a smaller gross area, with a total installed collector area of 4 274 m^2 for the 48 systems installed. These installations include 23 large-scale solar thermal systems at hospitals in South Africa at the end of 2016, accounting for a gross collector area of 1 333 m^2. This is further discussed in under ‘Solar thermal installations at hospitals in South Africa’ on page 32.

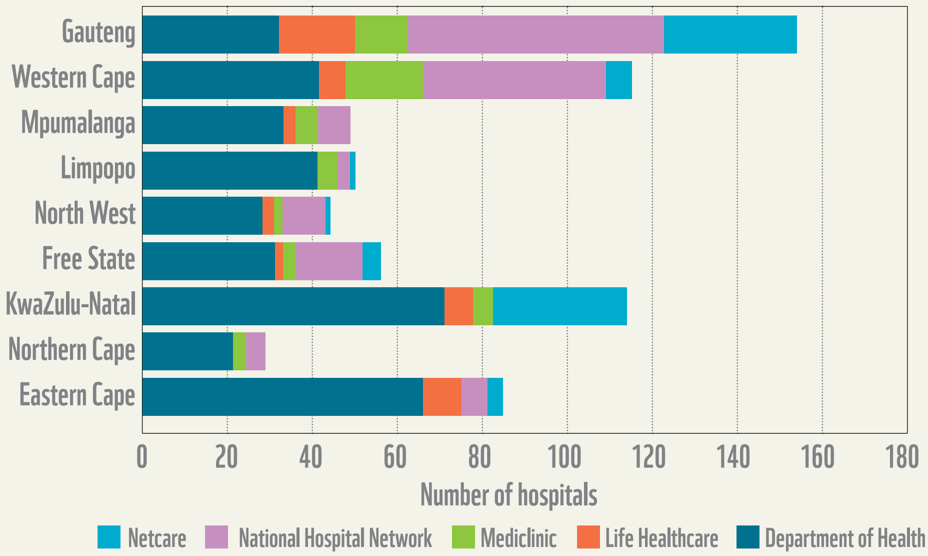
HOSPITALS IN SOUTH AFRICA AND HEAT DEMAND CHARACTERISATION

Hospitals in South Africa

The CRSES database that identifies all public and privately owned hospitals as well as large clinics in South Africa, lists 696 hospitals. These hospitals have approximately 126 490 beds in total, with a maximum bed count of 3 200 in a single hospital. It should be noted that the total number of beds is subject to error since the exact number could not be established for some hospitals and had to be approximated.

The hospitals presented in Figure 14 include large provincial hospitals that are managed by provincial health departments on a district level, as well as private hospitals owned by companies such as Netcare, Mediclinic, Life Healthcare and other hospital groups affiliated with the National Hospital Network. Figure 14 displays the total number of hospitals located in each province based on ownership, excluding smaller public and privately owned clinics.

Figure 14: Number of hospitals per province in South Africa based on management



Most hospitals throughout South Africa are owned and managed by the respective provincial health departments (Department of Health), as seen in Figure 14. Privately owned hospitals make up approximately 48% of the total hospitals in the country based on the data sourced, and form the majority of the hospitals in the Western Cape and Gauteng. Provincial hospitals are in the majority in other provinces of South Africa.

Characterisation of heat demand of hospitals

Annual heat demand

Large hospitals around the world require thermal energy for a variety of purposes, including central heating, staff and patient ablutions, and process steam in certain cases. Some larger and older public hospitals in South Africa make use of process steam, generated in larger-scale boilers, to operate autoclaves for sterilisation, provide humidification and heating, and generate hot water for domestic purposes. Most of the newly built public and private hospitals in the country do not depend on these steam cycles and make use of more efficient technologies and cycles. This section of the report focuses on the hot water demand in hospitals in South Africa for domestic applications, including staff and patient ablutions.

The South African Bureau of Standards (SABS) Standards Division acts as an arbiter in the development and maintenance of the South African National Standards (SANS). The SABS provides standards and conformity assessment services to industry with the aim of providing and promoting standardisation services in South Africa. *SANS 10252-1: 2012 – Water supply and drainage for buildings Part 1* establishes the general principles for the design, installation and testing of water installations for buildings.

SANS 10252-1 states that hospitals in South Africa can be expected to have a daily water demand of 450 ℓ/bed and 550 ℓ/bed based on design considerations. SANS 10252-1 provides guidelines to determine the hot water demand of different types of hospitals in the country. This guide is summarised and tabulated in Table 2 and is based on daily hot water demand, storage volume and heating power.

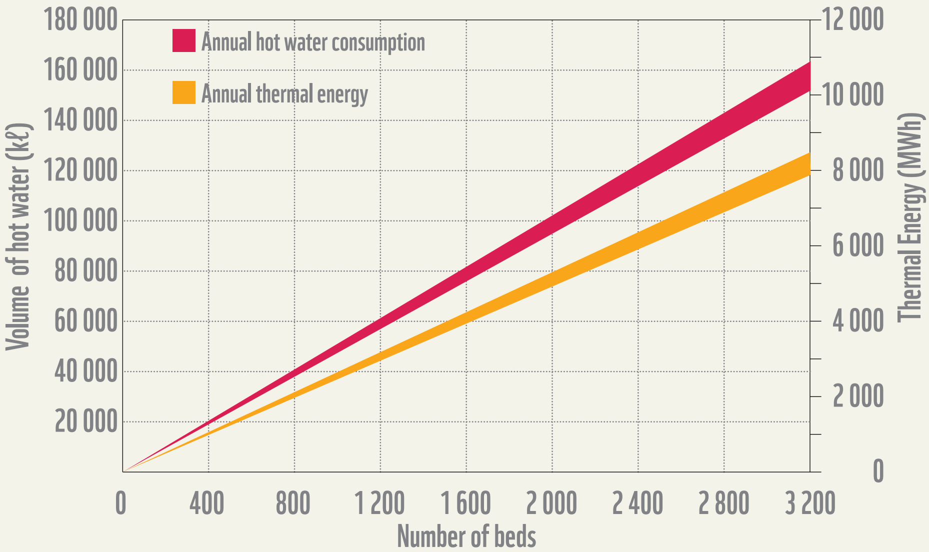
Table 2: SANS 10252-1 guidelines for hot water and cold water consumption based on hospital functions

Function of hospital	Total hot water demand	Storage volume at 60 °C	Heating power (direct electric heating elements only)
General	130–140 ℓ/bed/day	20–30 ℓ/bed/day	1–1.5 kW/bed
Infectious	220–230 ℓ/bed/day	40–50 ℓ/bed/day	1.5–2 kW/bed
Infirmaries	65–75 ℓ/capita/day	20–25 ℓ/capita/day	0.9–1.2 kW/capita/day
Infirmaries and laundry	85–95 ℓ/capita/day	25–30 ℓ/capita/day	1–1.4 kW/capita/day
Maternity	220–230 ℓ/bed/day	30–35 ℓ/bed/day	1.5–2 kW/bed
Mental	85–95 ℓ/capita/day	20–25 ℓ/capita/day	1–1.4 kW/capita/day
Nurses' homes	120–130 ℓ/capita/day	40–50 ℓ/capita/day	1–1.5 kW/bed

SOURCE: SANS 10252-1: 2012

Based on the SANS 10252-1 building standard guidelines, general hospitals are expected to consume 130 to 140 ℓ/bed of hot water per day. Considering the hot water temperature requirement of 60 °C for most hospitals in South Africa, general hospitals can be expected to have a thermal energy requirement of 6,77 to 7,29 kWh/bed/day. Figure 15 shows the annual hot water usage and heat demand range of general hospitals in South Africa based on the number of beds, adapted from the daily hot water consumption per bed as set out in SANS 10252-1.

Figure 15: Annual hot water usage and thermal energy requirement for hospitals based on the number of beds



The average daily hot water usage for hospitals in Europe and the United States of America (USA) ranges from 80 to 130 ℓ/bed and 100 to 150 ℓ/bed, respectively (Bujak, 2010). Based on this daily hot water consumption, it is expected that the energy consumption for heating the water to the required temperature is 4,17 to 6,94 kWh/bed/day for hospitals in Europe and 5,28 to 7,78 kWh/bed/day for hospitals in the USA (Bujak, 2010). The daily hot water consumption and thermal energy needed for heating this volume of water to the required temperature of hospitals in South Arica, the USA and Europe, based on the respective building standards, is displayed in Table 3.

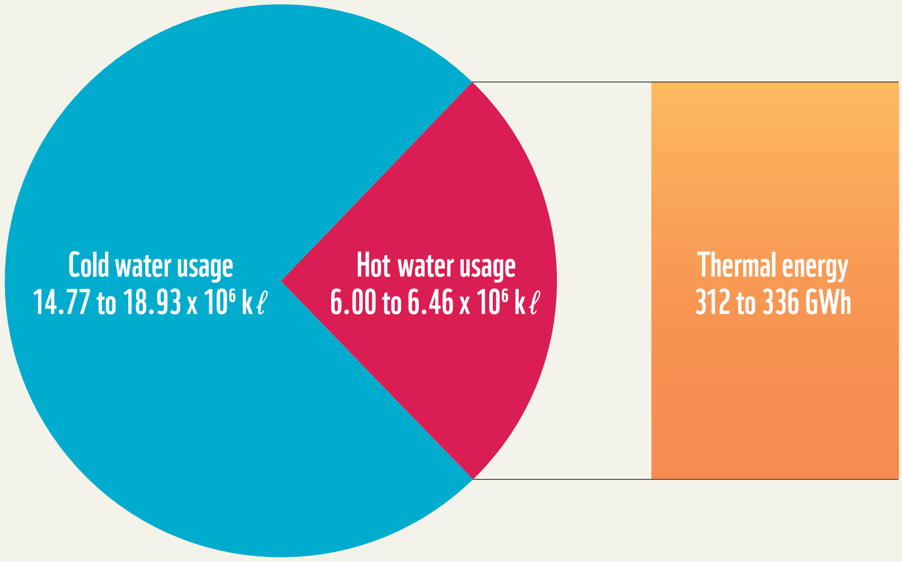
Table 3: Daily hot water consumption and thermal energy requirement of hospitals in South Africa, the USA and Europe

Country	Hot water consumption	Thermal energy range requirement
South Africa	130–140 ℓ/bed/day	6.77–7.29 kWh/bed/day
USA	100–150 ℓ/bed/day	5.28–7.78 kWh/bed/day
European countries	80–130 ℓ/bed/day	4.17–6.94 kWh/bed/day

SOURCE: BUJAK, 2010

To get an overview of the expected annual thermal energy demand of all 696 hospitals identified in South Africa based on daily hot water usage per bed as set out in SANS 10252-1, an extrapolation was done using the total number of beds accounted for in the database. The results are shown in Figure 16. It should be noted that this estimation assumes that all 696 hospitals consume hot water within the range that is set out in SANS 10252-1 for general hospitals, and does not compensate for the variation in hot water usage based on different functions of hospitals as seen in Table 2.

Figure 16: Annual water usage and thermal energy demand of all hospitals in South Africa

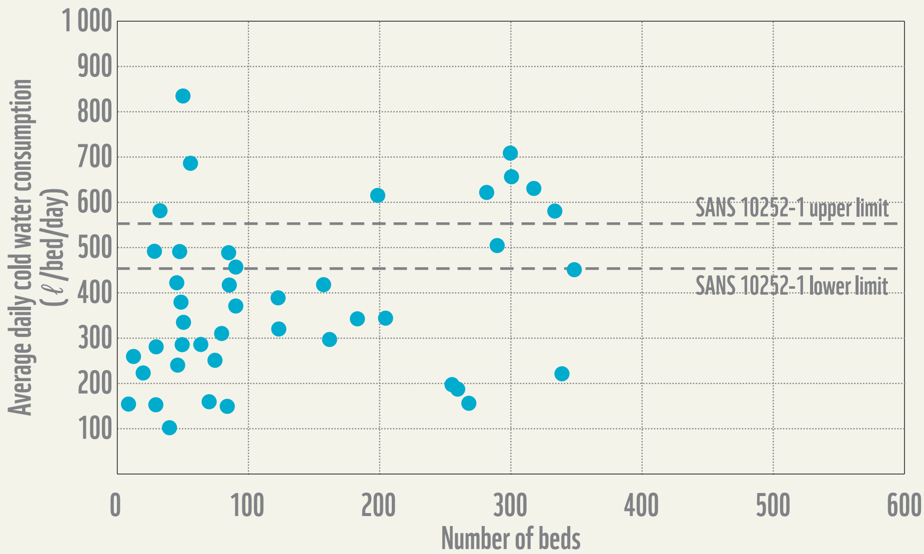


It is approximated that all 696 hospitals in South Africa have a combined thermal energy requirement range of 312 to 336 GWh/year to heat the total hot water demand to 60 °C for domestic purposes. This excludes heat requirements attributed to steam to operate autoclaves for sterilisation and humidification, and heating. It is expected that many hospitals in the database will consume hot water well above or below the range set out for general hospitals in SANS 10252-1, based on the type and size of the hospital. This could have a significant impact on the approximation made for the combined annual heat demand of hospitals in South Africa.

A database that identifies all hospitals under ownership of the Western Cape Government was made available by the Western Cape Department of Health. The database identifies key information, such as the average daily water and electricity usage per bed, the number of beds and current heating technologies installed at each hospital. The database identifies a total of 52 hospitals managed by the Western Cape Department of Health, including small and large hospitals.

This data was used to show the discrepancy in water usage of hospitals when compared to the guidelines provided in SANS 10252-1. Based on SANS 10252-1, it is expected that hospitals consume between 450 and 550 ℓ/bed/day. Figure 17 shows the average daily cold water consumption per bed for a number of hospitals managed by the Western Cape Department of Health. It is expected that a similar discrepancy can be found for the hot water consumption data.

Figure 17: Average daily cold water consumption per bed for hospitals managed by the Western Cape Department of Health



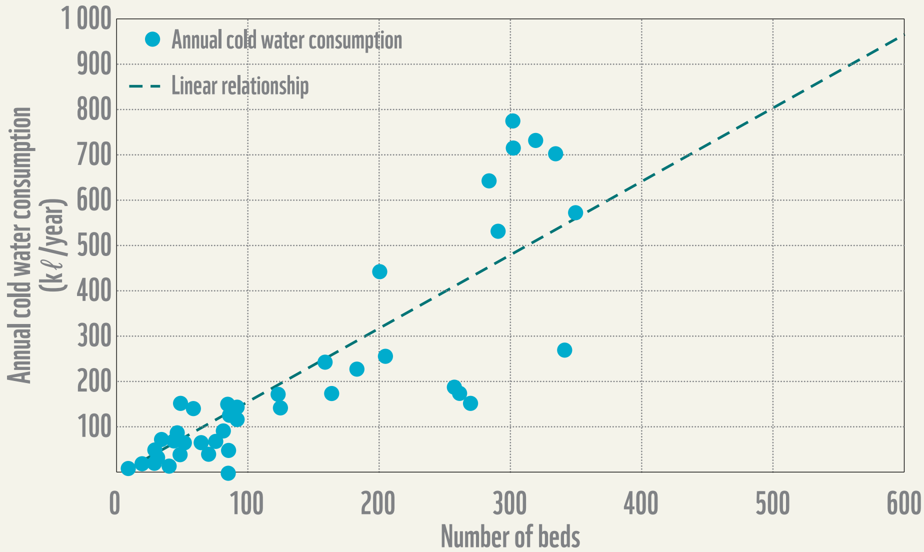
It can be seen from Figure 17 that most hospitals fall well below the lower limit specified in SANS 10252-1 (450ℓ/bed/day). However, there are a number of hospitals that consume more than the 550 ℓ/bed/day.

This variation in cold water usage could be related to the variation in services offered by each hospital on a day-to-day basis, patient capacity, age of the infrastructure, geographical location, and whether it is situated in a rural or urban area. The cold water usage is the overall water usage of the hospital, a portion of which is used for hot water. Hot water usage will be impacted by the same variables. This makes estimating the cold and hot water demand difficult, as shown in Figure 17: the demand will vary significantly for each hospital. Unfortunately, very few hospitals measure their water consumption on a frequent basis and most hospitals do not record their hot water consumption at all.

The lack of generic information and data makes it very difficult to determine the potential of solar thermal solutions for hospitals in South Africa. This finding highlights the importance of hospitals measuring not only their cold water but also their hot water consumption. They must also determine the energy required to produce hot water so that the best solution can be found to reduce their dependence on conventional fuels and thermal technologies.

To get a more realistic estimation of the annual hot water demand and total thermal energy requirements of hospitals in South Africa, the hot water demand is derived from the annual cold water consumption using the data of the Western Cape Department of Health, based on the number of beds. The annual cold water consumption of these hospitals and the linear relationship with the number of beds is shown in Figure 18.

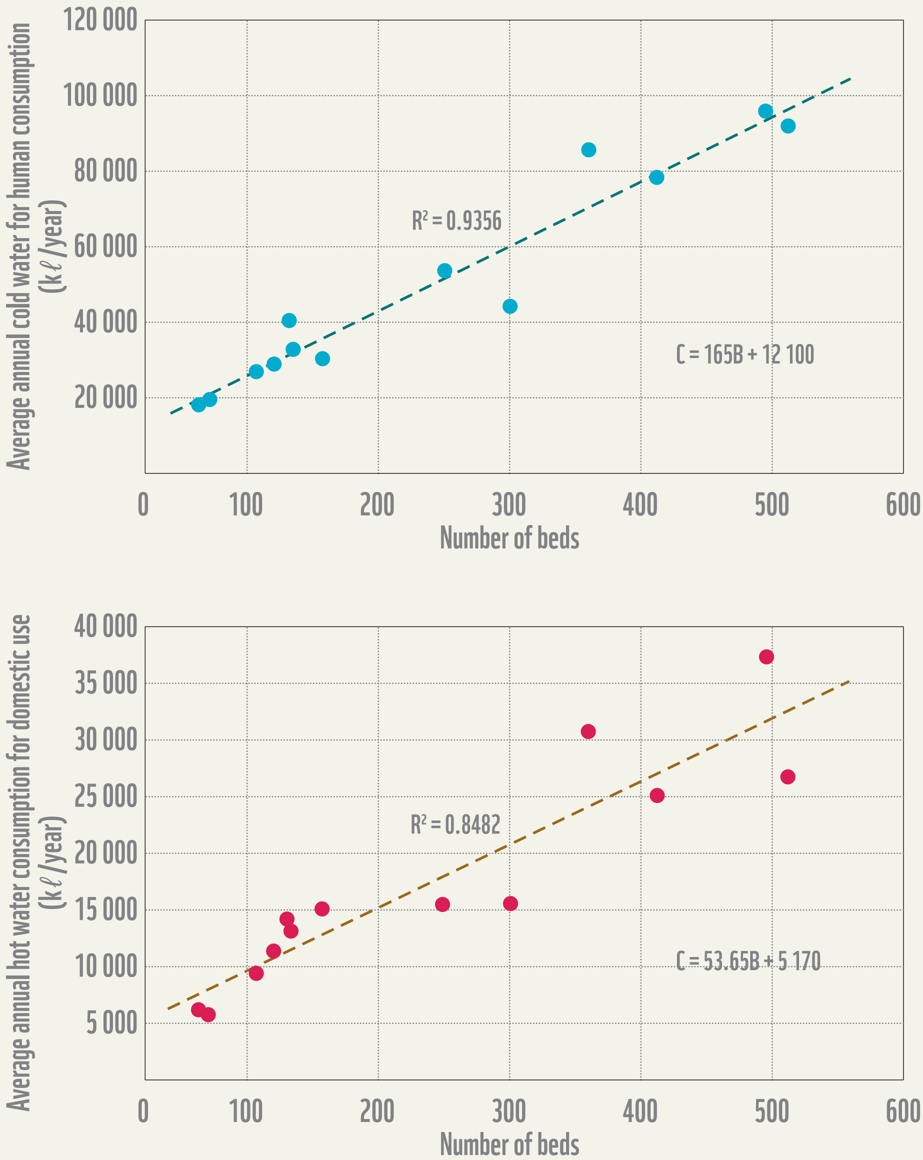
Figure 18: Annual cold water consumption of Western Cape Department of Health hospitals and linear relationship with the number of beds



The linear relationship displayed in Figure 18 will be used to more accurately estimate the annual cold water consumption of the 696 hospitals identified in this study. This is done to more accurately estimate the annual hot water consumption of these hospitals, based on actual measurements.

A study done by Garcia-Sanz-Calcedo et al (2017) proves the quantifying of the cold and hot water consumption for human consumption and domestic use in hospitals, based on the number of beds and built surface area of hospitals as opposed to using a fixed ratio. The study makes use of the measured cold and hot water consumption of 13 public hospitals in Spain. The relationship identified by Garcia-Sanz-Calcedo et al (2017) for the average annual cold and hot water consumption for domestic use in hospitals based on the number of beds is shown in Figure 19.

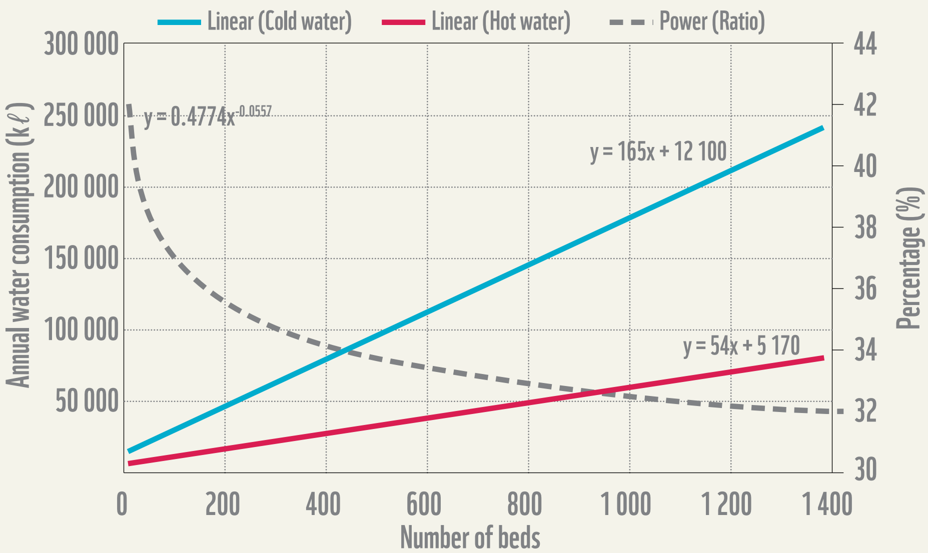
Figure 19: Relationship between the average annual cold water for human consumption (top) and average annual hot water consumption for domestic use (bottom) based on the number of beds in a hospital



SOURCE: GARCIA-SANZ-CALCEDO ET AL, 2017

The linear relationship for the annual cold and hot water consumption and the number of beds as presented in Figure 19 was used to establish a varying ratio relationship between the hot water and cold water consumption with the change in the number of beds (Garcia-Sanz-Calcedo et al, 2017). In Figure 20 this ratio is graphically presented on a percentage basis alongside the linear relationship for annual cold and hot water consumption that was given in Figure 19.

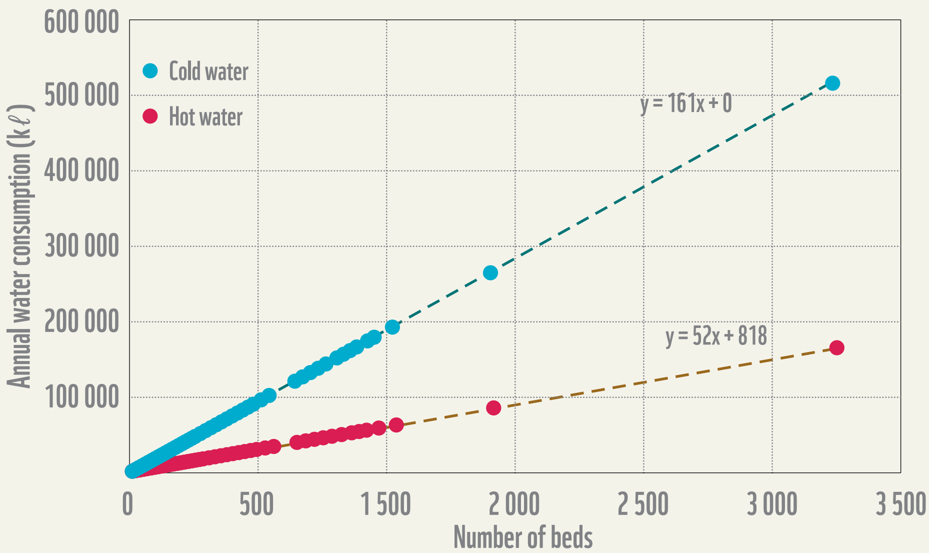
Figure 20: Relationship between the annual cold and hot water consumption in hospitals based on the number of beds



SOURCE: GARCIA-SANZ-CALCEDO ET AL, 2017

The linear relationship developed for the annual cold water consumption of hospitals in South Africa, shown in Figure 18, and the relationship developed between the cold and hot water consumption of hospitals based on the study by Garcia-Sanz-Calcedo et al (2017), shown in Figure 20, was used by CRSES to more accurately estimate the annual cold and hot water consumption of the 696 hospitals identified in South Africa. This is shown in Figure 21.

Figure 21: Annual cold and hot water consumption of the 696 hospitals identified in South Africa



By making allowance for the change in ratio between the cold and hot water consumption in hospitals with the variation in bed numbers, fixed values of the total cold and hot water consumption for all 696 hospitals could be established, as well as the thermal energy requirements for heating the total hot water volume to 60 °C. These values, along with other key figures, are given in Table 4.

Table 4: Results of cold and hot water consumption and thermal energy requirements for the 696 hospitals in South Africa

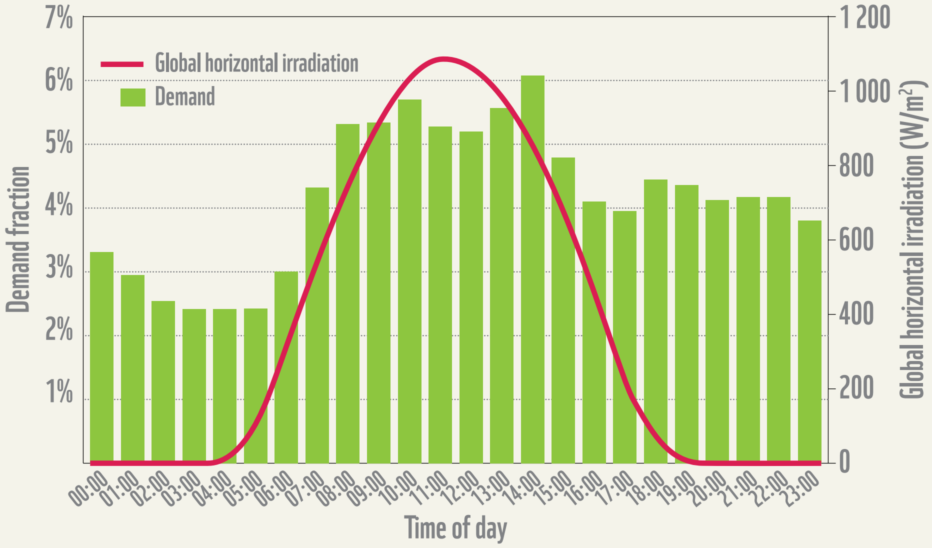
Cold water	Annual consumption	20 394 109 kℓ
	Average daily cold water consumption per bed	442 ℓ/bed/day
Hot water	Annual consumption	7 099 964 kℓ
	Average daily hot water consumption per bed	154 ℓ/bed/day
Thermal energy	Annual thermal energy demand	370 GWh

The results in Table 4 show that, based on a more realistic approximation, the average annual cold water consumption and average daily cold water usage per bed falls just below the range of 450 to 550 ℓ/bed/day stated in SANS 10252-1. However, the approximation of the annual hot water consumption and average daily hot water usage per bed given in Table 4 is well above the building guideline range of 130 to 140 ℓ/bed/day stated in SANS 10252-1. Thus, based on a detailed assessment of existing cold water consumption and literature, the earlier estimation of the annual thermal energy demand for all hospitals in South Africa, which was 312 to 336 GWh (see Figure 16), was recalculated as 370 GWh. This represents a more accurate and realistic approach for determining the total thermal energy needs of hospitals and will be used in this study to investigate the potential for the large-scale application of solar thermal technologies at hospitals in South Africa.

Hospital demand profile

The hot water demand profile of a hospital is an indication of its heat demand, which can be used to determine whether solar thermal technologies can reduce dependence on conventional fuels and thermal technologies. To illustrate the impact of a hospital's daily heat demand for producing hot water, an average daily heat demand profile was adopted from the study done by Bujak (2010), where the hourly heat demand of a 690-bed provincial hospital in Poland was measured over a four-year period. For the CRSES study, this demand profile was reconfigured to represent the hourly heat demand on a percentage basis over a single day and is plotted alongside the typical hourly GHI (W/m^2) over a single sunny day in Cape Town shown in Figure 22. This demand profile should serve as the case for most large hospitals in South Africa, with minor variations in certain cases.

Figure 22: Daily demand profile of a provincial hospital (Bujak, 2010) and the hourly GHI in Cape Town



As most hospitals serve a common purpose, it is expected that most large hospitals that operate on a 24-hour basis throughout the year will exhibit daily heat demand profiles very similar to those depicted in Figure 22. Smaller hospitals that operate for fixed hours throughout the day are expected to have a different demand profile, with little to no heat demand overnight.

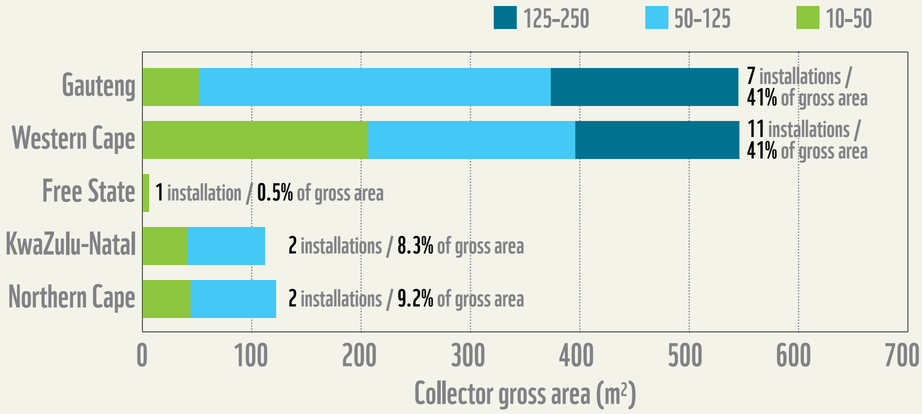
A factor that favours the implementation of solar thermal solutions at hospitals is the increase in the diurnal heat demand, during periods when the solar thermal technologies operate most efficiently. With the correct sizing of collector areas and thermal storage capacity, solar water-heating systems can also supply the heat demand of hospitals during overnight periods when needed. This allows these technologies to effectively contribute to the hot water demand of hospitals and achieve high solar fractions and financial savings in applications where they are used to offset the use of electric boilers, which are commonly used in South African hospitals.

Solar thermal installations at hospitals in South Africa

The database created by CRSES was redefined to present all large-scale solar thermal installations at hospitals in South Africa. It should be noted that this database was created through extensive market research and online information and its inclusion is subject to information being available to researchers.

Based on the information gathered in the database, there are 23 large-scale solar thermal systems installed at hospitals in South Africa, equating to a total solar thermal collector area of 1 333 m². Figure 23 displays the total collector area and number of systems per province, based on the specific collector area range of each system. These systems range in a gross collector area from 10 m² to 250 m².

Figure 23: Large-scale solar thermal system installed at hospitals in South Africa, per province



From Figure 23 it can be seen that most of the solar thermal systems installed at hospitals in South Africa are in the Western Cape, with 11 of the 23 recorded systems. These Western Cape systems account for 547 m^2, or 41%, of the total collector area installed at South African hospitals. Gauteng has a total of seven recorded systems, amounting to a total installed collector area of 546 m^2. Other provinces, including the Free State, KwaZulu-Natal and the Northern Cape, have five recorded systems with a total collector area of 240 m^2, amounting to 18% of the total collector area. Furthermore, it is noticeable that most of these systems have a total gross collector area ranging from 50 m^2 to 125 m^2. It should be noted that most of these installations were done at privately owned hospitals.

The database was used to identify the most commonly installed solar thermal collector type for hospital applications in South Africa. The results are shown in Figure 24, displaying the total of each collector type on a percentage basis and total gross area.

Figure 24: Solar collector type used for installing solar thermal systems in South Africa

Figure 24 shows that evacuated tube collectors are the most commonly installed solar technology to supply the 60 °C hot water temperature requirement of hospitals, accounting for 910 m² (68%) of the 1 333 m² of total collector area installed at hospitals in the country.

However, based on the information presented under 'Solar thermal technologies for hospital applications' on page 16, and the geographical location of the provinces where most of these systems have been installed, one would expected that flat-plate collectors would be the ideal technology for meeting the hot water temperature requirements of hospitals. As mentioned, the choice of evacuated tube collectors could be driven by installers' expertise and recommendations.

A flat-plate collector system is the ideal technology for meeting the hot water requirements of hospitals in South Africa.

POTENTIAL FOR SOLAR THERMAL TECHNOLOGIES FOR HOSPITALS IN SOUTH AFRICA

Current applications of heating technologies in hospitals

The database of hospitals managed by the Western Cape Department of Health was used to get an overview of current thermal technologies used by hospitals in South Africa. As mentioned, the database identifies key information, including the current heating technologies installed at each of the 52 hospitals.

Figure 25 shows the type of heating technologies employed by the Department of Health hospitals in the Western Cape, based on fuel source. All these hospitals make use of either coal-fired or electric boilers and heat pumps or, in smaller hospitals, electric geysers.

Figure 25: Thermal technologies used by hospitals managed by the Western Cape Department of Health, based on the number of beds and overall bed-count in each category

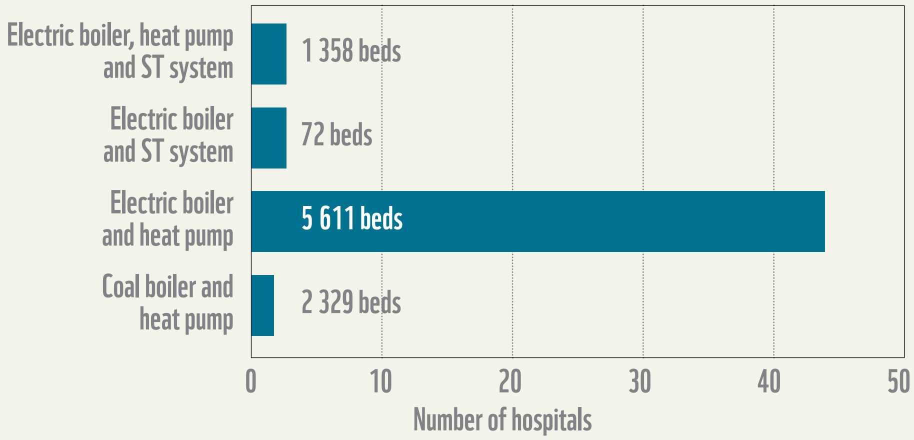


Figure 25 shows that only two of the hospitals managed by the Western Cape Department of Health make use of coal boilers, although these do house the most beds per hospital, accounting for 2 329 beds (25%) of the total 9 370 beds managed by the department. Both of these hospitals also have heat pumps installed.

Fifty of the hospitals make use of electric boilers. Of these, 44 also have heat pumps installed, three have a solar water-heating system installed, and three also have combined solar water-heating and heat pump systems installed.

Figure 25 shows that 49 of the hospitals managed by the Western Cape Department of Health have heat pumps installed. At least 10 of these hospitals recorded in the database have newly installed heat pumps. Individual solar water-heating systems were rolled out at three of the smaller hospitals, with 72 beds in total.

Figure 26: Paarl Provincial Hospital heat pump system (left) and electric boiler (right)

The large number of heat pumps in provincial hospitals makes the installation of solar thermal technologies at these hospitals very challenging. Heat pumps provide significant electricity savings and are generally reliable and affordable. It would also be challenging to prove the financial feasibility of solar thermal technologies for the larger hospitals that make use of coal to meet their heat demand, since coal is a low-cost fuel source in South Africa, significantly cheaper than solar thermal solutions when compared to the levelised cost of heat (LCOH) for each thermal energy source.

If this is the case for most provincial hospitals, which account for 52% of hospitals in South Africa, it will be difficult to prove the feasibility of solar thermal systems for provincial hospitals. In cases where large heat pumps have been installed, much smaller solar thermal systems would be the most sensible solution, although this option still carries the risk of presenting longer payback periods compared to hospitals that solely depend on conventional electric and coal boiler technologies.

On the other hand, privately owned hospitals have undertaken the installation of renewable energy technologies, including solar thermal and solar PV solutions. In many cases, these hospitals have installed combined solar and heat-pump systems, where in some cases electrical resistive heating is used as a back-up heat source. These systems demonstrate how the different technologies can effectively work together to supply in the hot water needs of hospitals.

If integrated correctly, solar thermal systems have the potential to effectively operate in conjunction with heat-pump systems to produce low-temperature hot water at 60 °C in hospitals. These systems will also improve the efficiency at which the heat pumps operate and present an attractive financial investment, as illustrated in the case study of Paarl Provincial Hospital below.

Case study: Paarl Provincial Hospital

CRSES conducted a solar thermal feasibility study on Paarl Provincial Hospital as a case study for the project. Paarl Provincial Hospital is located on the corner of Hospital Street and Bergrivier Boulevard in Paarl, Western Cape, and consists of 301 beds. The hospital primarily uses hot water for staff ablutions and the domestic needs of patients.

Figure 27: Paarl Provincial Hospital

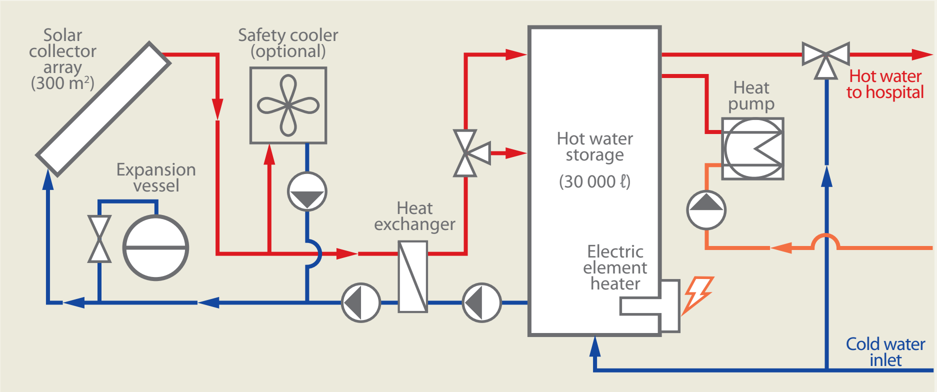
SOURCE: GOOGLE STREET VIEW

The hot water temperature requirement of the hospital is 60 ˚C. Paarl Provincial Hospital currently makes use of three heat-pump systems and two electric boilers for heating water to 60 °C. The two electric boilers are used to heat water in two individual 5 000 ℓ tanks. The hot water system of the hospital consists of another four 5 000 ℓ insulated, hot water storage tanks, connected in parallel to one another.

Based on the monthly hot water usage profile developed, the hospital uses a total of 13 397 kℓ of hot water at 60 °C each year. The monthly heat energy demand profile is shown on a percentage basis of the total annual heat energy demand of 666 852 kWh.

A hydraulic diagram for a solar thermal system for Paarl Provincial Hospital is shown in Figure 28. The system consists of a 300 m² collector array that absorbs solar irradiance and transfers the heat through heat exchangers to the existing 30 000 ℓ hot water storage tanks. The designed solar water heater system and its integration with the existing heating system, as modelled, are shown in Figure 28.

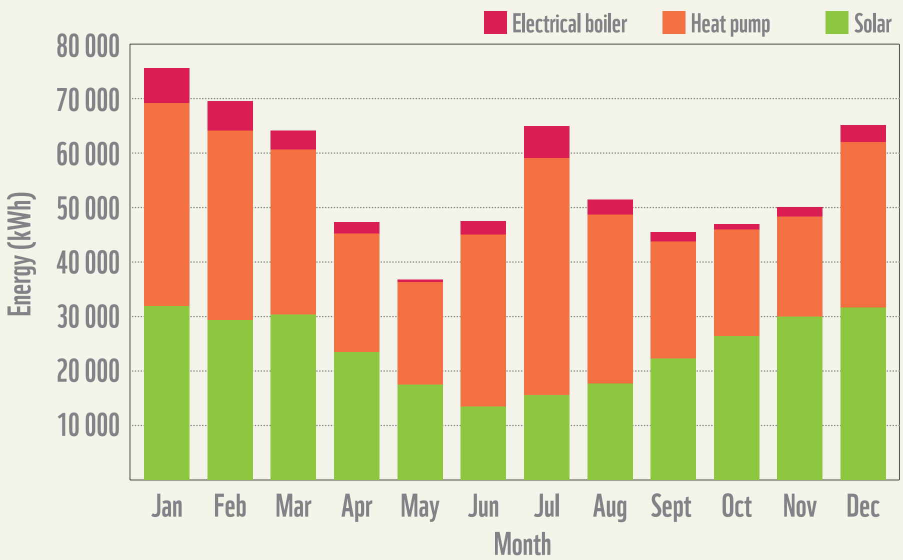
Figure 28: Layout diagram of simulated thermal system for Paarl Provincial Hospital



Both solar fraction (SF) and specific gains (SG) values should be maximised, but they form a trade-off. In this case, the recommended solar thermal solution is to have a 300 m² collector array, which would give a SF = 44% and a SG = 968,4 kWh/m²/year. The SF means that 44% of the heat energy requirements to heat the annual hot water requirement of 13 397 kℓ to 60 °C will be provided by the proposed solar water heater system. In these framework conditions, the 30 000 ℓ existing storage, which can be heated up to 90 °C, can effectively buffer solar heat and provide 60 °C hot water to the hospital during the night.

Based on the simulation results of the system, shown in Figure 29, the 300 m² solar water heater system provides a total of 291 772 kWh of heat energy for meeting the hospital's annual heat energy demand of 666 852 kWh. The heat pumps and electric boilers provide 338 774 kWh and 36 306 kWh of heat energy per year, respectively.

Figure 29: Simulation results of monthly thermal energy contribution of heating technologies at Paarl Provincial Hospital



The study shows that the hospital currently consumes a total of 233 525 kWh of electricity each year to produce hot water at 60 °C. Paarl Provincial Hospital currently pays R0,34/kWh for thermal energy and the existing system will generate hot water at a levelised cost of heat (LCOH) of R0,88/kWh at an assumed discount rate of 6% over the next 20 years. Electricity usage will be less than the heat demand, owing to the high coefficient of performance of the heat pumps. After the installation of the 300 m^2 solar water heater system, the heat pumps and electric boilers will consume a total of 122 756 kWh of electricity each year to meet the annual heat energy demand of the hospital. This is a saving of 110 769 kWh and a 47% reduction in electricity usage.

The cost of the solar water heater system is estimated to be R1 893 495. A conservative financial performance assessment shows that with 30% equity, a 10% annual electricity price increase, and without subsidies, the internal rate of return (IRR) would be 10% and the simple payback period 12,3 years. The solar thermal system would generate heat at an LCOH of R0,62/kWh and generate a total saving of R5 616 648 over the 20-year project lifespan. The solar water heater project was found to be a moderately attractive financial investment for the hospital as it is primarily competing against an energy-efficient technology such as heat pumps. Over its service life of 20 years, the system will reduce the financial risk of dependency on increasingly costly electricity.

Future projections of solar thermal technologies in hospitals

The study showed that hospitals in South Africa have a total heat demand of approximately 331 GWh/year and a gross collector area of 1 333 m^2 installed throughout hospitals in South Africa. This means that currently solar thermal systems provide less than 0,5% of the annual hot water demand of hospitals in the country. It is understood that heat-pump technologies contribute a noticeable portion of this annual heat demand.

A number of factors have led to the low uptake of solar thermal technologies in the industry (discussed under 'Challenges and difficulties for the uptake of solar thermal technologies in hospitals' on page 45). The most common reason is the large-scale implementation of heat-pump technologies in public and privately owned hospitals. It is expected that this factor will slow down the process of implementing solar thermal technologies in the industry. Some hospitals will seek potential in other renewable energy technology such as PV to further improve the efficiency of their processes.

The biggest potential for solar thermal technologies exists within public and private hospitals that still solely make use of conventional electric boilers to produce hot water. This potential will increase with increasing electricity prices.

Large hospitals that still rely on coal boilers for water-heating purposes may be incentivised to invest in solar thermal projects in order to reduce carbon emissions and improve air quality. Implementing solar thermal projects in this case will lead to extended payback periods and low internal rate of return (IRR), but this may prove to be a sensible solution when replacing outdated coal boiler systems.

Figure 30: Newly installed solar thermal system at Melomed Private Hospital, Gatesville, Western Cape

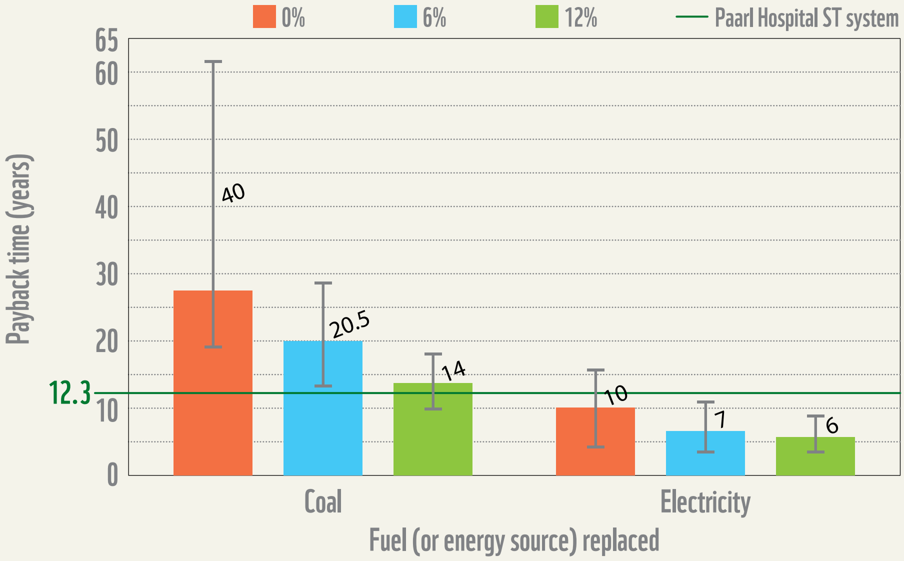
A positive factor that was identified in the case study was that many hospitals already possess the existing infrastructure, specifically thermal storage, which would significantly reduce the capital costs of investing in solar thermal systems. This improves the financial attractiveness of solar thermal projects in the industry.

Financial feasibility of large-scale solar thermal solutions for hospitals

When considering the findings of this study and the large uptake of heat-pump systems in most of the provincial hospitals in the Western Cape, as well as the Paarl Provincial Hospital case study, solar thermal projects may present extended amortisation times compared to those presented in the study by Joubert et al (2016).

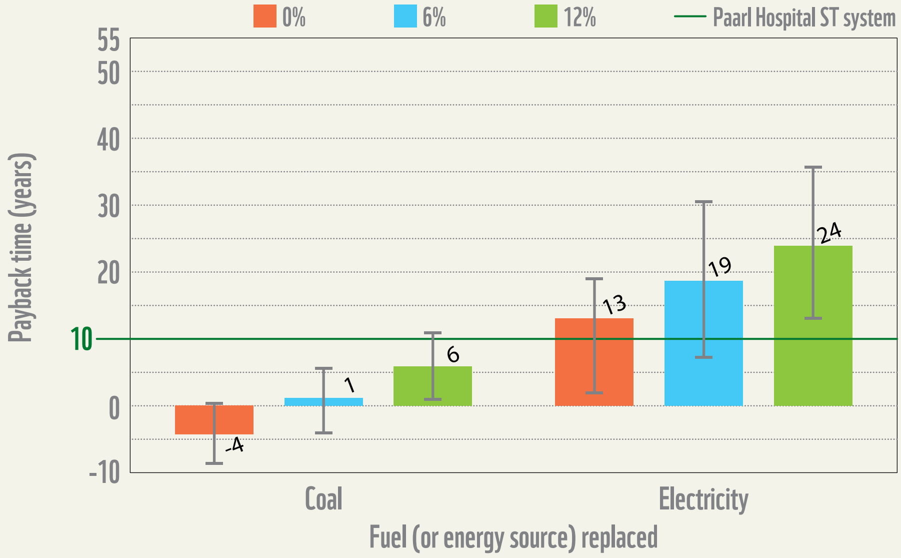
The study done by Joubert et al (2016) identified the amortisation times and IRR of large-scale solar thermal systems in South Africa for a system cost of €603/m² and at an exchange rate of R15.30/€, shown in Figure 31 and Figure 32, respectively. The study shows the payback period for solar thermal that can be expected when replacing conventional energy sources, based on different annual increases of 0 to 12% on the cost of these energy sources, which are commonly coal and electricity in South African hospitals. The results of the Paarl Provincial Hospital case study are illustrated in both Figure 31 and Figure 32 in reference to the financial outcomes that can be expected for hospitals that make use of heat pumps.

Figure 31: Amortisation times of a current large-scale ST system when substituting coal and electricity (system costs €603/m², installed in the Western Cape)



SOURCE: JOUBERT ET AL, 2016

Figure 32: Internal rate of return (IRR) for a current large-scale ST system with a service life of 20 years replacing coal and electricity



SOURCE: JOUBERT ET AL, 2016

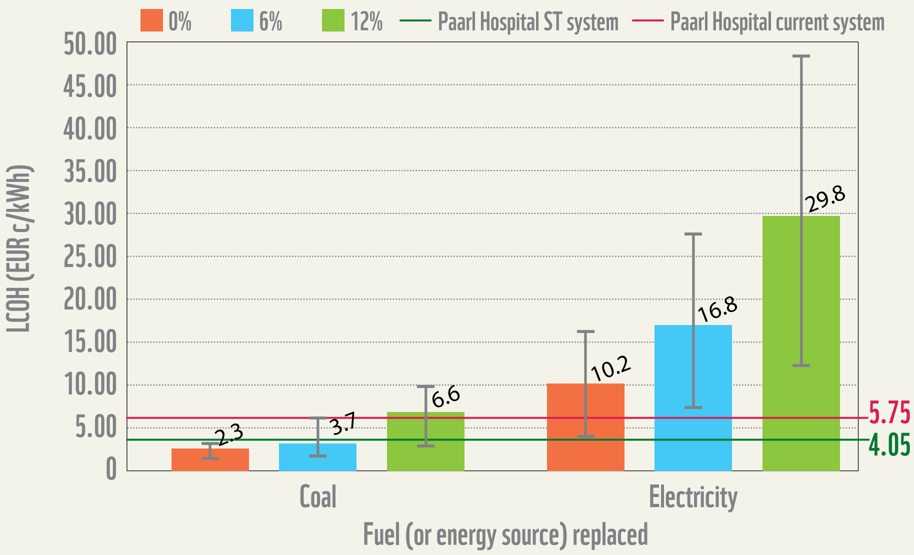
Based on the findings of the study, it can be assumed that most hospitals rely on electric boilers for generating hot water in cases where heat pumps are not installed. In these cases, hospitals can be expected to invest in solar thermal projects presenting simple payback periods ranging from 6 to 10 years and an IRR ranging between 13 and 24%. In the case of older, larger hospitals that still rely on coal for heating, projects with a simple payback period of 14 to 40 years can be expected, making the investment unfeasible.

From Figure 31 and Figure 32 it can be seen that Paarl Provincial Hospital presented a payback period of just over 12 years and a project IRR of 10%, respectively, on account of the hospital primarily depending on energy-efficient heat pumps for hot water and the proposed 300 m² solar thermal system offsetting their usage to a certain extent. The financial outcomes for the Paarl Provincial Hospital case study would, in all likelihood, represent many hospitals in the country that primarily make use of heat pumps and back-up electric boiler systems and where investment in solar thermal systems of this scale is considered.

Currently, companies in South Africa regard an IRR of 10% or greater as a good investment (Joubert et al, 2016). The Paarl Provincial Hospital case study has shown that a project IRR of 10% is achievable at hospitals where heat pumps have been installed. This shows that solar thermal installations have the potential to provide hospitals that currently make use of heat pumps and conventional boiler technologies with a good investment, when sized and implemented correctly.

The study done by Joubert et al (2016) identifies the LCOH of various conventional fuel sources in South Africa used for heating in industrial processes. The LCOH of coal and electricity is based on a constant exchange rate of R15,30/€ and a discount rate of 6% over a 20-year period (Joubert et al, 2016). These results are presented in Figure 33 alongside the LCOH values identified in the Paarl Provincial Hospital case study for the proposed 300 m² system and the existing heat pump and electric boiler system.

Figure 33: LCOH over 20 years for coal and electricity based on the assumption that energy prices from September 2015 onwards increased by 0%, 6% or 12% annually



SOURCE: JOUBERT ET AL, 2016

Figure 33 shows that the LCOH of coal and electricity is 2,3 to 6,6 EUROc/kWh and 10,2 to 29,8 EUROc/kWh, respectively, based on an annual fuel increase of 0 to 12% and a discount rate of 6% over 20 years (Joubert et al, 2016). The results of the Paarl Provincial Hospital case study show that, based on the exchange rate of R15,30/€, an LCOH of 4,05 EUROc/kWh (R0,62/kWh) is achievable for the proposed 300 m² solar thermal system. This is lower than the LCOH of 5,75 EUROc/kWh (R0,88/kWh) that Paarl Provincial Hospital is expected to pay over the next 20 years for using the existing heat pump and electric boiler systems to generate hot water.

This case study serves as a good representation of the expected LCOH for hospitals using heat pumps and back-up electric boilers for generating hot water, which is expected for most hospitals in the country, based on the findings of this study and how it compares to the LCOH of solar thermal solutions of this scale.

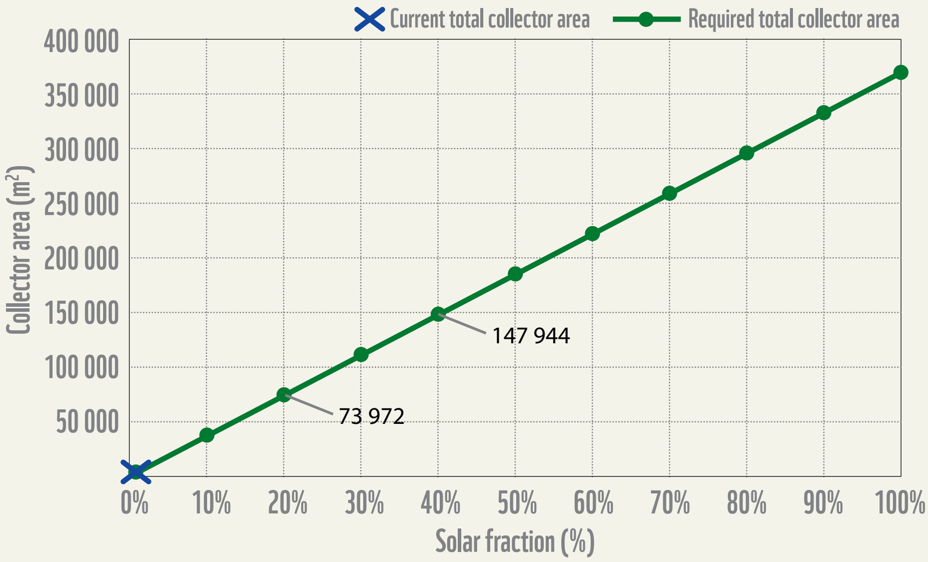
Potential of large-scale uptake of solar thermal solution by hospitals

The roll-out of heat pump technology can be seen in the private and public sectors. Assuming the continuation of this trend, the scale at which solar thermal technologies could be implemented to offset the thermal energy needs of hospitals in South Africa would be limited to a point where its application would prove financially unfeasible. This point would likely occur when the application of solar thermal technologies starts to largely replace heat-pump technologies, instead of reducing the hospitals' dependence on coal or electricity as the main sources of heat.

Figure 23 shows that the size of most thermal systems installed at hospitals in South Africa is below 125 m². Based on the size of the specific hospitals where these solar thermal systems have been successfully installed, it is assumed that, in most cases, these systems provide a solar fraction of 20 to 40% towards the thermal energy needs of these hospitals and operate in conjunction with heat pumps and electric boiler back-up systems. The contribution of heat pumps to the thermal energy needs for generating domestic hot water is undefined, making the approximation of the scale to which solar thermal technologies could be feasibly implemented very challenging. However, if it is assumed that the data presented in Figure 25 is a representation of all hospitals in the country, it can be extrapolated that the maximum limit to which solar thermal technologies can be feasibly implemented at hospitals will likely result in a contribution (solar fraction) of 20 to 40% of the total 370 GWh of thermal energy needed each year to produce domestic hot water in hospitals. This statement is primarily based on the assumption that the majority of hospitals in South Africa have heat pumps installed.

Figure 34 depicts the scale and size to which solar thermal technologies would have to be implemented at hospitals in South Africa to achieve a different solar fraction of the total annual thermal energy demand of 370 GWh, as well as the current total collector area installed at hospitals in the country. Figure 34 was generated assuming an average specific gain of 1 000 kWh/m²/year throughout the country where hospitals are located.

Figure 34: Relationship of total collector area and solar fraction of the total thermal energy needs of hospitals in South Africa



Currently, South African hospitals have a total installed collector area of 1 333 m², as indicated in Figure 34. This collector area only accounts for approximately 0,4% of the total annual thermal energy needs for producing domestic hot water in all hospitals the country, estimated at 370 GWh.

It can be realistically assumed that hospitals can increase their overall solar thermal capacities to compensate for 20 to 40% of their combined annual thermal energy needs by enhancing the performance of installed heat-pump systems and also by reducing the industry's dependence on boilers and conventional fuel sources. This would require the installation of approximately 73 972 m² to 147 944 m² of collector area throughout the 696 hospitals identified in South Africa.

Challenges and difficulties for the uptake of solar thermal technologies in hospitals

A number of issues and challenges that will have a negative impact on the uptake of solar thermal technologies in hospitals in South Africa were identified while conducting site visits for this study and the Paarl Provincial Hospital case study.

- **A lack of data and information on hot water demand for South African hospitals**

  Most hospitals in South Africa are not equipped with measuring instruments to record the daily or hourly hot water consumption. This information is essential to characterise the hot water demand of hospitals as it may vary for each type of hospital depending on the number of beds, ownership, geographical location, facilities and specific services provided by the hospital. Without this information it is not possible to accurately determine whether solar thermal technologies will reduce a hospital's dependence on conventional heating technologies such as electric or coal boilers, or whether solar thermal technologies can be effectively integrated with heat-pump systems.

PV installation as opted solution

Investigation into the current thermal technologies used by hospitals in South Africa has shown that a number of hospitals have installed PV systems. This allows hospitals to reduce their annual electricity consumption from the grid, thereby reducing their electricity bills and carbon footprint. It also allows hospitals to reduce their dependence on conventional fuel sources for thermal energy requirements where electric boilers and heat pumps are used. Owners of hospitals currently making use of PV systems may have a lack of interest or funding to invest further in other renewable energy technologies, even if solar thermal technologies offer a further reduction in the electricity consumption from the grid.

Existing problems in hot and cold water supply systems

Problems identified with current hot and cold water systems during the selection process of hospitals in the Western Cape include the following:

- corrosion of pipes and ineffective maintenance of leaks in hot and cold water pipes in larger hospitals (these problems could be common to all larger hospitals in the country)
- outdated, less efficient heating technologies such as electric and coal boilers in older hospitals
- non-existent or poor insulation in piping and storage tanks, leading to preventable heat losses in hot water systems.

These issues would have to be resolved before or during the installation of a solar thermal system to ensure the efficient operation of all systems. However, resolving these problems may be very costly, which could delay the uptake of solar thermal solutions by older and larger hospitals affected by these problems.

Space to install storage tanks

Some large and smaller hospitals may not have enough space to install the large storage tanks that are required for solar thermal systems. In some large hospitals, many large storage tanks and boilers are located on the top floors of the building, making the removal and addition of these tanks very costly and labour intensive. This may have a negative impact on the financial viability of installing solar thermal projects in some hospitals.

Asbestos roofs

Large and older hospital buildings have been constructed with asbestos roofs. Installers may be reluctant to mount solar collectors on asbestos roof areas owing to asbestos legislation and the serious health risks associated with asbestos work. In most cases these roofs will need to be replaced first. Work on an asbestos roof has to be done by a registered asbestos contractor and could lead to additional costs for solar thermal projects, which could negatively affect the financial feasibility of these projects. Alternatively, the installation of solar collectors would have to be done on roof areas of the hospital that are not constructed from asbestos, where possible.

- **Limited roof space**

Roof areas may prove to be the optimal installation area for collectors owing to available area, height above obstructions, slope and orientation. However, roof space for optimally mounting solar collectors at large hospitals may be limited. Larger hospitals, especially in urban areas, are designed to increase floor areas vertically to accommodate a large number of beds, resulting in a small area of usable roof space. Also, in many instances where there is an existing PV installation, solar thermal systems have to compete for the available space.

- **Reluctance to share information and data**

Gathering data on the cold and hot water demand of hospitals and information on current technologies used for water heating is a valuable part of investigating the potential of solar thermal technologies for hospitals in South Africa. Hot water demand will vary for each hospital depending on the type of hospital, geographical location and services offered, and cannot always be characterised by the number of beds in the hospital or building guidelines presented in SANS 10252-1, as seen in this study. Some private hospitals were reluctant to share this information and some government hospitals had no interest in sharing or did not have information to share.

- **Large uptake of heat-pump technology in hospitals**

Based on the information gathered throughout this study, many public and private hospitals in the country have installed heat-pump systems in conjunction with conventional boiler technologies to reduce dependence on boilers and become more energy efficient. Newly built hospitals are also equipped with heat pumps as part of the new SANS building regulations (energy efficiency) in South Africa. Heat pumps provide heat energy for generating hot water at a low cost, in a way that is competitive to what can be achieved with solar thermal technologies. Hospitals that currently operate heat pumps and decide to invest in solar thermal technologies may have extended payback periods owing to the low cost and high electrical efficiency of heat pumps. Furthermore, the use of solar thermal technologies may be unfeasible in certain cases if these technologies are not designed and sized correctly to allow for the optimal functioning of existing and new thermal technologies. If implemented correctly and with the necessary control measures to ensure optimal performance of each technology, solar thermal solutions can still present a highly attractive investment for large and small public and privately owned hospitals currently using heat pumps, but this will depend on the location and the electricity tariff.

An industrial-scale solar thermal system used for supplying hot hater.

CONCLUSION

This study shows that most of the 696 hospitals in South Africa are located in Gauteng (22%), the Western Cape (17%) and KwaZulu-Natal (17%). Data on the cold water consumption was limited and no actual measurements of the hot water consumption of hospitals were available at the time of the study. The total thermal energy requirements for producing domestic hot water was estimated within the range of 312 to 336 GWh/year using the building guidelines set out in SANS 10252-1.

The study showed that, realistically, the variation in the cold and hot water consumption of hospitals from the estimations presented in SANS 10252-1 can be significant, based on the type of hospital, size, geographical location and specific services offered. This variation was accounted for using actual cold water measurements and available literature. The study showed that the total thermal demand of all 696 hospitals in South Africa could be approximated at 370 GWh.

Solar thermal technologies have great potential for supplying the thermal energy requirements of hospitals to produce low-temperature hot water at 60 °C. The study investigated the current status of the application of solar thermal technologies at hospitals in South Africa and identified the conventional technologies and fuel sources used in the industry sector. A total of 23 solar thermal systems were identified at hospitals in South Africa, accounting for a total installed collector area of 1 333 m^2. This accounts for approximately 0,4% of the total annual thermal energy needs to produce domestic hot water in all hospitals in the country, estimated at 370 GWh, as mentioned above. The study also showed that evacuated tube technologies are most commonly installed for hospital application (rather than flat-plate collectors), accounting for 68% of the total collectors installed in the industry sector.

Investigation into the current thermal technologies used by hospitals showed that heat pumps and electric boilers are the most common systems used in new and old hospitals, with a small number of larger and older public hospitals using coal boilers. The implementation of heat pumps is being driven by new building regulations in South Africa. Based on the data gathered throughout this study, it can be presumed that most private and public hospitals make use of heat pumps and electric boilers, or will do so in the future. The implementation of solar thermal technologies is still low and mostly seen in specific privately owned hospitals.

A clear trend was identified based on the type of renewable energy technology and private ownership: certain hospitals were fitted with solar PV systems as a renewable energy alternative to offset the hospital's energy dependence on electric and coal boilers.

The Paarl Provincial Hospital case study showed that solar thermal system investments may exhibit a project internal rate of return (IRR) of 10% and a payback period of 12,3 years. Based on the exchange rate of R15,30/€, a levelised cost of heat (LCOH) of 4,05 EUROc/kWh (R0,62/kWh) is achievable with solar thermal systems installed at hospitals where heat pumps and electric-boiler technologies are used. This was proved to be lower than the LCOH of 5,75 EUROc/kWh (R0,88/kWh) that Paarl Provincial Hospital is expected to pay over the next 20 years for using the existing heat pump and electric boiler systems to generate hot water.

Based on the findings of this study, it can be realistically assumed that hospitals can feasibly increase their overall solar thermal capacities to compensate for 20 to 40% of their combined annual thermal energy needs by enhancing the performance of installed heat-pump systems and by reducing the industry's dependence on boilers and conventional fuel sources. This would require the installation of approximately 73 972 m^2 to 147 944 m^2 of collector area throughout the 696 hospitals identified in South Africa.

Problems and challenges that could hamper the uptake of solar thermal technologies at public and private hospitals in South Africa were identified. These include a lack of data and information on the hot water demand; using PV systems instead of solar thermal technologies as the preferred renewable-energy option; existing problems with cold and hot water systems; reluctance to share information on current thermal systems and hot water consumption; insufficient and asbestos roof spaces; limited space for installing storage tanks; and the large uptake of heat-pump technologies at old and new hospitals in South Africa. These challenges will continue to be barriers to the large-scale implementation of solar water heaters in South Africa.

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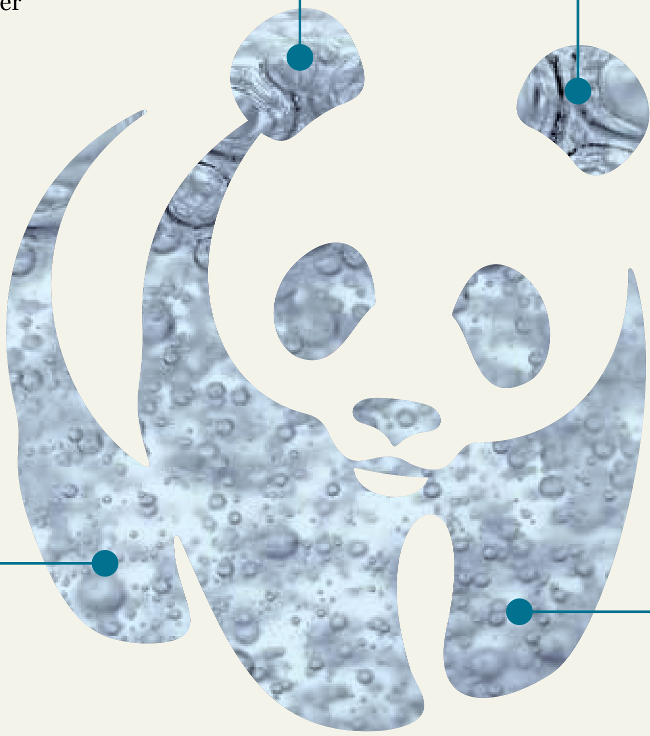
12,3 YEARS

The average payback period for investments in solar thermal systems.

>130 LITRES OF HOT WATER/BED/DAY

The average amount of hot water consumed per bed per day.



R0,62 / kWh

The achievable levelised cost of heat (LCOH) with solar thermal systems.

10%

The possible internal rate of return from solar thermal investments.

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