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Design of the Zimbabwe National Sports Stadium Solar District Water Heating System

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Abstract

The Zimbabwe National Sports Stadium is a venue for the country's major national and sporting events. It comprises of 34 stadium bays, which were constructed to accommodate 60 000 people. The facility also houses several corporates at its administrative complex and residents who maintain the ground. The stadium has recently experienced deterioration due to lack of maintenance and meaningful corporate investments in the sporting arena. One of the major sticky issues is the deplorable state of ablution facilities such as toilets and showers. The patriotic fever has led the Zimbabwean government, the citizens and other stakeholders to come up with plans to completely renovate the stadium. It has come to the attention of the engineering fraternity to contribute through designing a solar district water heating system and its incorporation into the comprehensive stadium overhaul programme to address the problem of ablution facilities. A thorough energy audit was carried out to assist in the design of the district hot water system for the facility. Through making use of the energy audit results, an appropriate solar district water heating system was designed for the Zimbabwe National Sports Stadium. A recommendation was made for the authorities to consider implementation of the design.

Keywords
Solar, district, water, heating, design

1. Introduction
Modern sporting facilities are equipped with proper amenities including toilets and bathrooms. Khalil, Y. (2023) explains that located in the heart of Harare, the magnificent Zimbabwe National Sports Stadium serves as a thriving

hub for football enthusiasts from all walks of life. The stadium's central location ensures easy accessibility, allowing avid fans to come together and revel in the electric atmosphere created by the united support for their beloved teams. The stadium holds a unique significance in the local community, transcending mere sporting excellence. It encapsulates the unifying power of sports, bringing people together regardless of their background, to celebrate the shared passion and the spirit of competition without boundaries. The national importance of the Zimbabwe National Sports Stadium necessitated the research aimed at raising the international profile of the facility through use of solar district heated water.

1.1 Objectives

The research's main aim is to complement government and corporates renovation efforts on the Zimbabwe National Sports Stadium through introducing a solar thermal water heating system. The objectives are to

1. Carry out an energy audit to establish the Zimbabwe National Sports Stadium's hot water requirements.
2. Design a solar water heating system to supply the stadium hot water requirements.
3. Recommend to the Zimbabwean Government the project implementation.

2. Literature Review

The Zimbabwe National Sports Stadium in Harare, Zimbabwe, Africa, is a world-class venue that boasts impressive capacity and top-notch facilities for sports enthusiasts. Figure 1 shows the aerial view of the elliptical facility and labelled bays forming part of the total number of thirty-four.

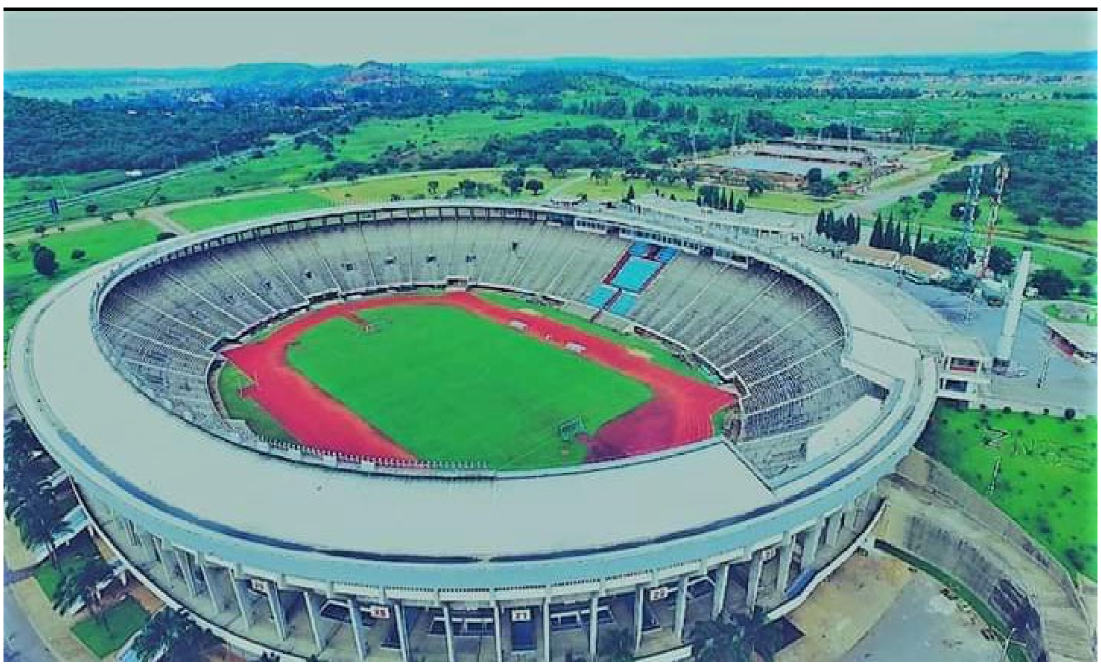

Figure 1. Aerial view of the Zimbabwe National Sports Stadium

Khalil, Y. (2023) cites that the Zimbabwe National Sports Stadium is one of Africa's largest sports arenas. This vast seating arrangement provides ample room for fans to cheer on their favorite teams and experience the thrilling atmosphere of live events. The stadium is committed to inclusivity by providing accessibility features for differently abled spectators. Wheelchair ramps, designated seating areas with optimal visibility, and accessible restrooms are amenities available to ensure equal enjoyment for all. That stadium in Harare truly sets the stage for unforgettable sporting experiences with its impressive capacity, diverse seating options, exceptional facilities, and inclusive accessibility features. It is renowned for hosting a wide range of significant sports events, concerts, and other memorable occasions. This iconic stadium has witnessed record-breaking moments and unforgettable performances that have left a lasting impact on both the local and international audience. The facility has served numerous sporting spectacles, attracting athletes from across the globe. From thrilling football matches to captivating rugby clashes, the stadium has witnessed some remarkable moments in the sporting world. It has hosted international football tournaments such as the African Cup of Nations and World Cup qualifiers for Zimbabwe's national football team. The stadium has also hosted cricket games and athletics competitions, creating an exhilarating atmosphere for fans and participants alike. Apart from and church conventions, the Zimbabwe National Sports Stadium hosts a multitude of concerts and live performances. Renowned national and international musical artists have graced its stage, captivating audiences with their mesmerizing talent. From unforgettable solo performances to energetic music festivals, the stadium has been a hub of entertainment, showcasing the rich musical culture of Zimbabwe and Africa as a whole (Khalil, 2023). Recently, numerous Christian denominations that include The Methodist Church in Zimbabwe, The United Methodist Church, Jehovah's Witness, The Salvation Army and several Pentecost churches have held conventions, memorials and other events at the gigantic stadium. The Zimbabwe National Sports Stadium is made up of 34 spectator holding bays, which every two bays share adjacent public toilets, one for males and the other for females. It is also made up of corporate offices and residents who also demand hot water in order to avoid hot water generation redundancy. The current design accommodates a boarding facility in the event that a conference venue is constructed. Figure 2 shows that the main complex is oval in shape.

Figure 2. Zimbabwe National Sports Stadium's interior oval shape

2.1 District Water Heating System Design

The district water heating system distribution for the main complex would follow the existing oval network from bay to bay. The hot water supply to each of the 17 pairs of bay toilets and bathrooms is through thermally insulated piping. Hot water is stored in a 50 litre insulated tank per bay toilet pair. The adjacent corporate offices tap their requirements from the stadium network. Additional piping is carried out supply residents whose dwellings are located at 100 meters away. The worldwide trend is to transform into renewable energy use in heat and hot water supply for residential, industrial and commercial buildings in both public and private sectors. Figure 3 shows an event venue in Austria to which solar hot water collectors are mounted. It is very important to consider such systems for recreation centers such as the Zimbabwe National Sports Stadium.

Figure 3 Solar collector arrays on top of Hallwang Event Center, Salzburg (Weiss and Spork-Dur, 2022)

2.2 Solar thermal energy

The renewable energy system selected for the Zimbabwe National Sports Stadium is solar thermal. The term solar thermal energy refers to a suite of technologies that include flat panel collectors, evacuated tube collectors, air collectors, and mirror devices, all of which capture energy from the sun for direct heating or cooling applications, industrial process heat, or conversion to electricity through mechanical means (Reed et al, 2015). There are various types of solar thermal systems in use. Flat plate collector produces heat to temperatures of around 90^{o}C and the parabolic trough collector temperature ranges from 50^{o}C to 400^{o}C (Kalogirou, 2014). However, the current research selects the flat plate collector. This is because of the terrain at the stadium which is clear from vegetation and therefore allows for mounting of solar collector racks. Also, flat plate collector temperature range is low to medium, thus, meeting hot water demand thermal energy. Industrial solar thermal technologies such as air collectors, water systems and concentrators collect solar energy for drying, process and space heating and cooling (International Energy Agency-Energy Technology Systems Analysis Programme and International Renewable Energy Agency, IEA-ETSAP and IRENA, 2015).

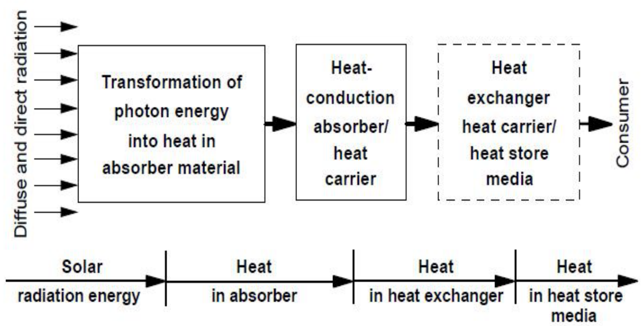

Figure 4. Energy conversion chain from solar into usable thermal energy (Syafaruddin & Hiyama, 2020)

Figure 4 shows electromagnetic conversion of solar energy to heat. Thermal conversion is an engineering method that applies the scientific phenomenon where a dark surface placed in sunshine, it absorbs solar energy and heats up (Goswami, 2015). Thermal collectors working on this principle face the sun and transfer part of the absorbed energy to a fluid medium (Goswami, 2015). A heat exchanger is a device or system which transfers heat from one fluid to another (Kreith, et al, 2011). Solar energy collectors are special heat exchangers transforming solar radiation to internal energy of a transport medium (Kalogirou, 2014). A major solar systems component, a collector absorbs incoming solar radiation which it converts into heat which is transferred into air, water, or oil. The carrier moves the heat to water, space conditioning equipment or thermal energy storage tank for drawing on demand (Kalogirou, 2014). The magnitude of hot water supply by a solar district water heating system is similar to an industrial set up. Figure 5 shows arrays of solar thermal collectors supplying hat water to an adjacent industrial plant in the USA.

Figure 5 Arrays of solar flat plate collectors at an industrial plant in USA (Taylor, 2006)

2.3 Solar flat plate collector

The basic solar thermal technology is the flat plate collector (FPC) made up of steel, galvanised iron, aluminium or thermoplastics (Saini et al, 2018). All FPCs have an absorber, a transparent cover, a heat transport fluid and insulation (Mohseni-Languri et al, 2009). Flat plate collector supporting devices comprise of can be a heat storage medium with none, one or several heat exchangers, pumps with a drive to maintain the heat carrier cycle, sensors and solar loop control instruments (Syafaruddin et al, 2020). Figure 6 shows an active basic solar flat plate collector circuit.

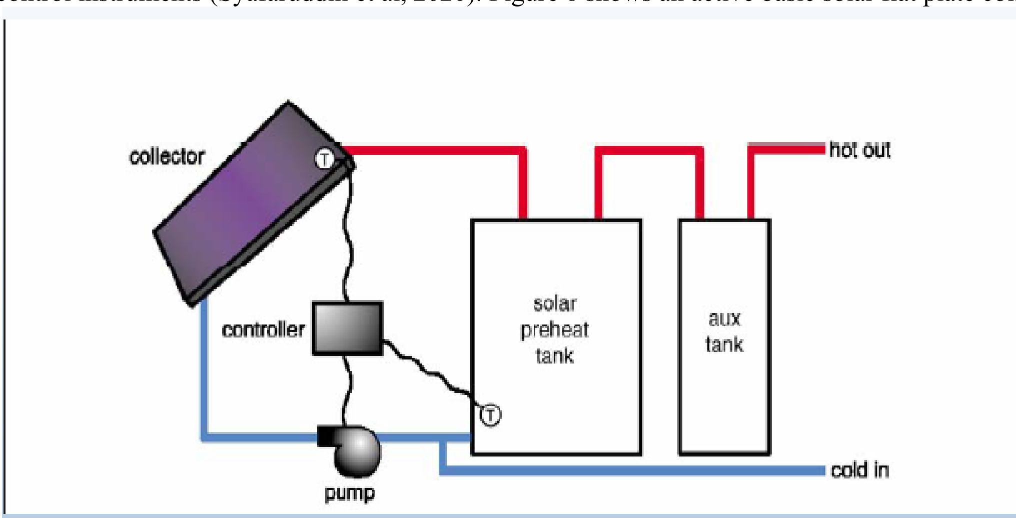

Figure 6. an active open loop pumped direct system (Taylor, 2006)

3. Methods

The methods are to conduct an energy audit requirement for the hot water requirement of the facility and then followed collector sizing using the energy and power relationships. Project cost estimates are also carried out.

4. Data Collection

The data collection was carried out through conducting a thorough energy audit. The sizing of a solar array and heat exchangers were calculated using the total daily hot water demand at the Zimbabwe National Sports Stadium facility. An extrapolation using existing large projects worldwide was carried out to derive the boiler capacity.

4.1 Energy audit and hot water demand calculations

An energy audit is conducted for the Zimbabwe National Sports Stadium hot water requirements. The major assumptions for the energy audit are hereby developed. The hot water will be supplied to the entire stadium facility, including the 34 bays' toilets, 8 corporate toilets and bathrooms, 40 toilets and bathrooms for residents. There are 40 family units in the complex, with five people per household. For design purposes, there will be no birth, death or migration in and out of the residential complex. There will be 100 corporate employees who work during normal hours from 7a.m.to 6.p.m. Provision is made for future boarders once a conference facility is put in place. Occasional events attendees are put at 40 000. This will be in line with the envisaged bucketing system capacity to be in place in the near future. Table 1 shows the hot water demand energy audit form designed for the Zimbabwe National Sports Stadium based on above assumptions.

Table 1 The Energy Audit for Zimbabwe National Sports Stadium hot water demand

Time of Day	4-7a.m.	7-12p.m.	12-3p.m.	3-6p.m.	6-8p.m.	8-4a.m.	Total
Residents 200 at 20 liters per person per day	200 × 7L **= 1 400L**	200 ×1.0L **= 200L**	200 × 5L **= 1 000L**	200 ×1.0L **= 200L**	200 × 5L **= 1 000L**	200 × 1.0L **= 200L**	**4 000L**
100 corporates employees	100 × 0L **= 0L**	100 × 1L **= 100L**	100 × 5L **= 500L**	100 × 1L **= 100L**	100 × 0L **= 0L**	100 × 0L **= 0L**	**700L**
Boarders	50 × 7L **= 350L**	50 × 1L **= 50L**	50 × 5L **=250L**	50 × 1L **= 50L**	50 × 5L **= 250L**	50 × 1L **=50L**	**1 000L**
Sub-total @ no events	**1 750L**	**350L**	**1 750L**	**350L**	**1 250L**	**250L**	**5 700L**
40 000 Events attendees	40 000 × 0.3L **=12 000L**	40 000 × 0.3L **=12 000L**	40 000 × 0.3L **=12 000L**	40 000 × 0.3L **=12 000L**	40 000 × 0.3L **=12 000L**	40 000 × 0L **0L**	**60 000L**
Total Hot Water Demand on events	**13 750L**	**12 350L**	**13 750L**	**12 350L**	**12 350L**	**250L**	**64 800L**
Energy required to heat the water from 20ºC to 90ºC: **(Δθ = 90ºC - 20ºC)** **E = (m × c × 70ºC)**	13 750 × 4.2kJ × 70 = **4 042.5 MJ**	12 350 × 4.2kJ × 70 **= 3 630.9MJ**	13 750 × 4.2kJ × 70 = **4 042.5 MJ**	12 350 × 4.2kJ × 70 **= 3 630.9MJ**	12 350 × 4.2kJ × 70 **= 3 630.9MJ**	250 × 4.2kJ × 70 **= 73.5MJ**	**64800× 4.2kJ × 70 = 19051.2MJ**

Table 1 shows that the daily hot water requirement for the Zimbabwe National Sports Stadium facility is calculated as:

13 750 × 2 + 12 350 × 2 + 250 litres = 64 800 litres.

The specific heat capacity of water, c, used in Table 1 calculations = 4 200 J/(Kg × ºC). Therefore, the total daily energy requirement for Zimbabwe National Sports Stadium hot water at a temperature difference of 70ºC is calculated as: $E = m \times c \times 70^{o}C \times \Delta\theta$ where ($\Delta\theta = 90^{o}C - 20^{o}C$).

This yields: $E = (m \times c \times 70^{o}C)$ = 64 800 kg × 4.2kJ/kg × 70ºC = 19 051 200kJ = **19051.2MJ.**

(The calculations assume that 1 litre of water is equal to 1kg at standard temperature and pressure).

4.2 Sizing of the solar collector requirement:

Daily energy requirement = 19 051.2MJ = 19 051 200 000J

Assuming the solar availability from 9a.m. to 4p.m. = 7 hours of sunshine, and an energy intensity of 750W/m^2 which translates to 750J/(s×m^2) (Figure 7);

And also, solar energy availability of 60 percent due to transience and cloudiness, Flat plate collector area required, A is given by: 750J/(s×m^2) × 7 hours × 60 minutes/hour × 60 seconds/minute × A × 0.6 = 19 051 200 000J. Therefore, the total solar collector area, A = 19 051 200 000 ÷ (750 × 7 × 60 × 60 × 0.6) = **1 680m^2**. If the solar system is to be mounted in a square form, it would require a square area of 40.5m × 40.5m. Figure 7 shows a roof mounted 3500m^2 in Graz, Austria, which is exactly twice the size as the array system calculated for the Zimbabwe National Sports Stadium heat requirements.

Figure 7. Roof mounted 3 500m² of flat plate solar collectors supply heat to drive a 660 kW absorption chiller at the company AVL in Graz, Austria (Weiss and Spork-Dur, 2022)

Therefore, a 42m × 42m square thermal collector array system would be mounted on racks at the southern end of the Zimbabwe National Sports Stadium inclined at 20º to the horizontal and facing North. This will provide 1.25 Megawatt thermal (MW_{th}) for hot water demand per day (Weiss and Spork-Dur, 2022). At a cost estimate of US$300/$m^2$, the total installation cost will be US$300 × 1 764$m^2$ = US$ 529 200. With other installation fixtures, the cost reach US$600 000. This amount will be amortized in a straight-line depreciation at US$30 000 per annum for the next 20 years which is the economic lifetime of the project.

Table 2. Twenty largest district heating systems (Weiss and Spork-Dur, 2022)

Installation	SDH Project	Country	Installed Collector Area m^2	Installed Capacity MW_{th}
2016	Silkeborg	Denmark	156,694	110
2016	Inner Mongolia	China	93,000	65
2015	Vojens stage 2	Denmark	52,492	37
2014	Dronninglund	Denmark	37,573	26
2011	Rhiad	Saudi Arabia	36,305	25
2015	Gram stage 2	Denmark	34,851	24
2019	Zhongba, Tibet	China	34,650	24
2019	Ringe	Denmark	31,224	22
2016	Brønderslev	Denmark	26,929	19
2018	Aabybro	Denmark	26,195	18
2019	Sæby, stage 2	Denmark	25,313	18
2019	Hadsten	Denmark	24,517	17
2016	Aalestrup	Denmark	24,129	17
2018	Langkasi, Tibet	China	22,275	16
2019	Salaspils	Latvia	21,672	15
2015	Hjallerup	Denmark	21,546	15
2014	Vildbjerg	Denmark	21,244	15
2019	Grenaa, stage 2	Denmark	20,673	14
2015	Hadsund	Denmark	20,513	14
2019	Høng	Denmark	20,160	14

The energy audit conducted deduced a daily energy requirement of 19 051 200 000J to deliver hot water. Based on those energy calculations, the collector requirement was dimensioned to be 1 764m^2. Table 2 shows relationship of collector area to rated power output on pro rate. Using the Silkeborg, Denmark figures of 156 694m^2 collector area and rated thermal power output of 110MW_{th} to calculate the Zimbabwe National Sports Stadium hot water daily power requirements on a pro-rate basis yields:

(1 764 ÷ 156 694) × 110MW_{th} = 1.238 MW_{th}. For design purposes, this is put at a standard rating of **1.25 MW_{th}**.

5. Results and Discussion

Figure 8 shows the network of the solar district water heating system generation and distribution at the Zimbabwe National Sports Stadium. The proposed solar array layout position in relation to the whole facility is also indicated. Main heat distribution pipes as well as local distribution pipes are also shown on the schematic. Because the renewable energy system selected is solar thermal energy, the solar flat plate collectors will be put to use. The southern rooftop of the stadium can be used to mount the collector system. These will be mounted facing north and inclined at 20^o as the approximate latitude of Harare. If there is space inadequacy at the rooftops, the solar collectors can be mounted on racks. In any of the two mounting options, the dimensions of the solar thermal array system will accommodate a total solar collector absorption surface area of 42m × 42m = 1 764m^2.

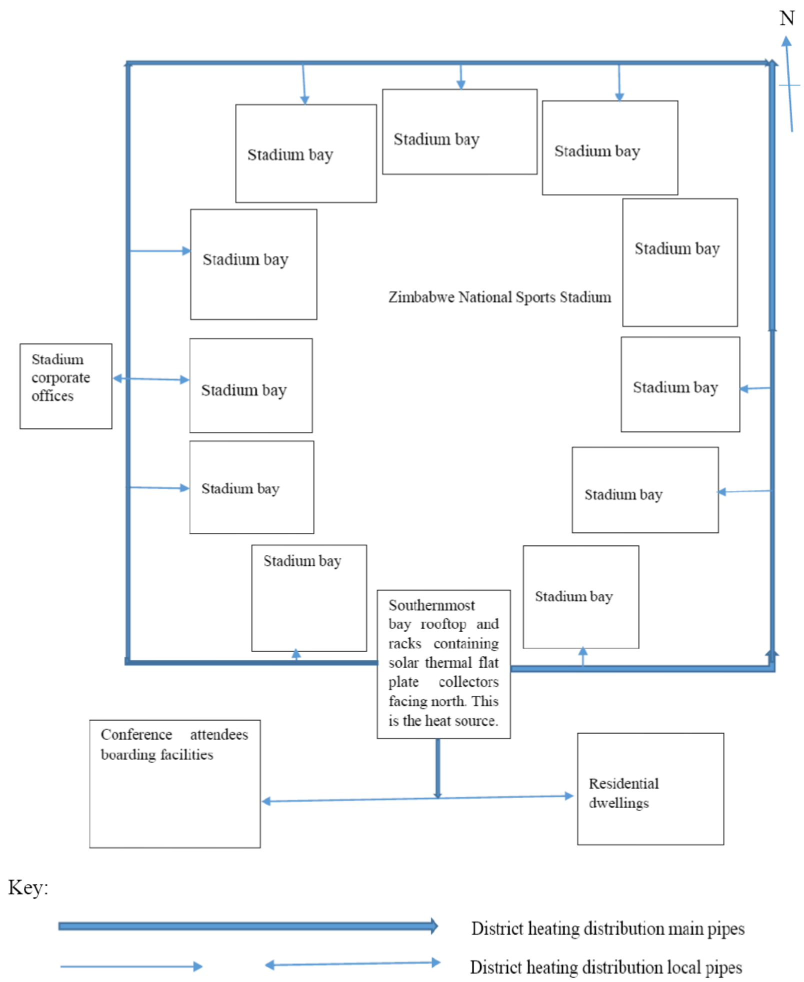

Figure 8. A schematic of the Zimbabwe National Sports Stadium district water heating network

5.1 Numerical Results

The daily hot water demand for the Zimbabwe National Sports Stadium was calculated through an energy audit and found to be 64 800 liters. The energy required to raise the temperature from 20 to 90^{o}C of usable hot water was worked out to be 19 051 200 000J. This value of energy was used to size the collector array at a solar intensity of 750W/m^2 daily insolation, on the assumption that there are 7 hours of useful sunshine hours from 900hours to 1600hours. The solar array area requires was found out to be this 1680m^2. For a proper square array, a 42m × 42m giving total solar absorption collector area of 1 764m^2 was adopted for Zimbabwe National Sports Stadium hot water demand solar collector installations. Using data from top twenty international solar array projects, the power rating of the heat exchangers and boilers was extrapolated through data prorating as 1.25MW$_{th}$. Each of the 17 pairs of toilets would have a 50 litre hot water storage tank installed. Similarly, a 50 litre hot water storage tank would each be installed at corporate offices, residential complex and boarding facility. This brings to 20 the number of storage tanks at the places of use. Therefore, a 10 000 litre storage tank would be the main storage tank at the solar system. Since the piping system is in place, only major connections from the solar system to existing networks would be installed. This connection measures 20 meters from the intended solar site of it is rooftop or 50 meters where racks are mounted outside the stadium.

5.2 Proposed Improvements

The solar system would be sufficient because of its thermal energy storage system water tanks. However, as in any renewable energy system, disadvantages of energy unavailability as a result of transience, cloudiness and nighttime might necessitate an auxiliary biomass energy system installation to work in hybrid with the solar. This is a full proof or contingency measure to ensure uninterrupted energy availability.

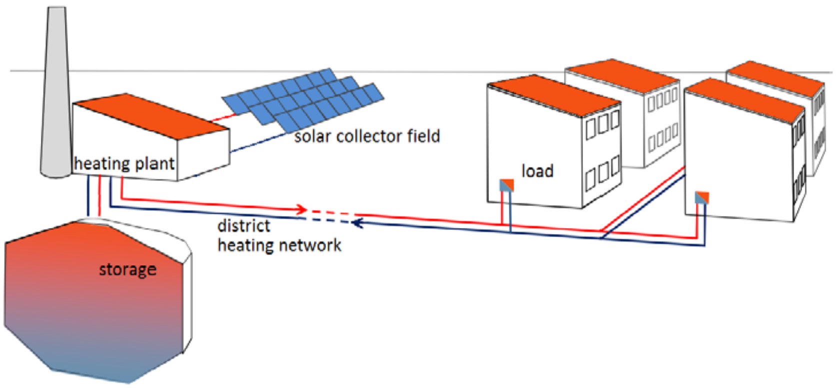

Figure 9 A scheme of a solar heating network at a district heating plant (Miedaner et al, 2012)

Figure 9 shows a typical solar hybrid district water heating system circuit. When the solar energy is unavailable or inadequate, the biomass auxiliary heating system can be used either to supply the whole load or to top up the energy to reach the required temperature.

6. Conclusion

Figure 10 shows a similar installation at a hospital in neighboring Namibia as a source of motivation. Zimbabwe National Sports stadium is undergoing renovations to conform with Confederation of African Football international standards. Improvement of bathrooms, toilets and other amenities are part of that compliance measures. Part of the improvement is the provision of hot water at least cost.

Figure 10 Partial view of the solar installation on Lady Pohamba Hospital rooftop in Windhoek, Namibia (Weiss and Spork-Dur, 2022)

University of Zimbabwe engineers carried out research to propose an installation of a solar thermal energy system at the giant Zimbabwe National Sports Stadium for provision of hot water to users at an almost free energy resource of solar thermal. It is a project with long term benefits to the country. The main aim to design a solar thermal energy flat plate collector array for the Zimbabwe National Sports Stadium was carried out. A 42m x 42m = 1764m^2 solar flat plate collector array was proposed. Through a pro-rate of existing major solar thermal systems, the boiler was sized a 1.25Megawatt thermal. The total cost of project was estimated at US$600 000, which would be amortized in a straight line method at US$30 000 per annum for 20 years. This long term beneficial renewable energy project is recommended to the Government of Zimbabwe and partners.

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Biographies

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