
The development of a methodology to measure & verify the impact of a national solar water heating program

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by

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Pred 1:13 “En ek het my hart daarop gerig om met wysheid te ondersoek en na te speur alles wat onder die hemel gebeur. Dit is ‘n moeilike taak wat God aan die mensekinders gegee het om hulle daarmee te kwel.”

Pred 1:17 “Maar toe ek my hart daarop gerig het om wysheid en kennis, onverstandigheid en dwaasheid te leer ken, het ek ingesien dat dit ook ‘n gejaag na wind is.”

Pred 1:13 & 17

DECLARATION

I hereby declare that all the material incorporated in this dissertation is my own original unaided work except where specific reference is made by name or in the form of a numbered reference. The work herein has not been submitted for a degree at another university.

Signed:



René Pierré Coetzee

ABSTRACT

Title: The development of a methodology to measure and verify the impact of a national solar water heating program.

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School: School of Mechanical Engineering, North-West University (Potchefstroom Campus).

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The School for Mechanical Engineering at the North-West University is home to one of South Africa's most established Measurement & Verification (M&V) teams. The team is involved with South Africa's electricity utility, Eskom, and their efforts to reduce the energy demand of the nation through Demand Side Management (DSM). One of the DSM initiatives in the residential energy sector is a National Solar Water Heating Program which encourages homeowners to purchase and install an Eskom accredited solar water heating system by means of a financial incentive. Massive financial investments have been incurred and it is only natural for stakeholders to question their return on investment. The need consequently exists to determine the impact of the National Solar Water Heating Program and establish whether it is being sustained.

Before developing a methodology to measure and verify the impact of a solar water heating program an in-depth study had to be done on M&V as well as the concepts around solar water heating itself. After considering financial, time and accuracy constraints it was decided that an M&V Solar Water Heating Application along with the M&V methodology be developed. The primary aim of the application was to simulate the electrical hot water demand caused by the electrical-backup elements of the solar water heating systems and thereby avoiding the logistically and financially impossible process of measuring the electrical demand.

A high-level simulation application, based on energy balances, was developed with solar water heating system types, geographical locations, weather conditions, hot water demand profiles and installation positions as inputs. The outputs of the application were the uncontrolled, simulated electrical hot water demand and were compared to the actual measured electrical hot water demand of a solar water heating system located in Cape Town.

The outputs from two scenarios were compared to the measured data; one calculated with weather data from the global weather database Meteonorm, and the second calculated with the measured weather parameters acquired during the measurement period. The first scenario indicated relative accuracy with a mean bias error (MBE) and coefficient of variation of the root mean squared errors (CV (RMSE)) of 13.5% and 16.0% respectively. The second scenario revealed improved accuracy with an MBE and CV (RMSE) of -1.1% and 5.5% respectively.

The M&V Solar Water Heating Application and methodology has set the process in motion to measure and verify the impact of the National Solar Water Heating Program and will be refined as more data and information become available.

Keywords: Measurement & Verification, Demand Side Management, methodology, solar water heating, simulation, application.

UITTREKSEL

- Titel: Die ontwikkeling van 'n metodologie om die impak van 'n nasionale son-water-verwarmingsprogram te meet en te verifieer.
- Outeur: René Pierré Coetzee.
- Promotor: Prof. LJ Grobler.
- Skool: Skool van Meganiese Ingenieurswese, Noordwes-Universiteit (Potchefstroom Kampus).
- Graad: Magister Ingenieriae in Meganiese Ingenieurswese

Die Skool vir Meganiese Ingenieurswese by die Noordwes Universiteit huisves tans een van die grootste Meet & Verifieer (M&V) spanne in Suid-Afrika. Die span is betrokke by Suid-Afrika se elektrisiteitsverskaffer, Eskom, en hulle pogings om die energie verbruik van die nasie te verlaag deur Aanvraag-kant-bestuur. Een van die pogings in die residensiële energie sektor is 'n Nasionale Son-Water-Verwarming Program wat huiseienaars aanmoedig om Eskom geakkrediteerde son-water-verwarmers te koop en te installeer deur middel van 'n finansiële aanspoor-skema. Groot finansiële beleggings is gemaak en aandeelhouers sal natuurlik hulle opbrengs op hul belegging wil sien. Die behoefte het dus ontstaan om die impak van die Nasionale Son-Water-Verwarmings Program te bepaal en vas te stel of die impakte volhoubaar is, al dan nie.

Voor die M&V metodologie ontwikkel was, is 'n in-diepte studie gedoen omtrent M&V asook die konsepte rondom son-water-verwarming. Nadat die finansiële, tyd-en-akkuraatheidsbeperkings oorweeg is, is daar besluit om 'n M&V Son-Water-Verwarming rekenaar applikasie en M&V metodologie gesamentlik te ontwikkel. Die primêre doel van die rekenaar applikasie was om die elektriese warm water verbruik, a.g.v. die elektriese ondersteuningselement van die son-water-verwarmer, te simuleer en sodoende die logistieke en finansiële-onmoontlike prosesse om al die verwarmers te meet, te vermy.

'n Hoë vlak rekenaar simulatie pakket, wat gebaseer was op energie balanse, was ontwikkel met die son-water-verwarmer tipes, geografiese ligging, weersomstandighede, warm water aanvraag en installasie posisie as insette. Die uitsette van die simulatie is die onbeheerde elektriese warm water verbruik van die son-water-verwarmer en was vergelyk met werklike data vanaf 'n gemete son-water-verwarmer in Kaapstad.

Die uitsette van twee scenario's is vergelyk met die gemete data; die eerste was waar die berekeninge gedoen was met weerburo data vanaf die Meteoronorm databasis en die tweede waar die berekeninge

gedoen was met werklike, gemete weerdata wat ingesamel is gedurende die meetingsperiod. Die eerste scenario het 'n gemiddelde gemene-fout (GGF) en koëffisiënt van variasie van die gemiddelde vierkantswortel-kwadraat fout (GVKF) van 13.5% en 16.0% onderskeidelik getoon. Die tweede scenario het 'n verbeterde GGF en GVKF van -1.1% en 5.5% onderskeidelik getoon.

Die M&V Son-Water-Verwarming rekenaar applikasie en metodologie het die proses aan die gang gesit om die impakte van die Nasionale Son-Water-Verwarming Program te bepaal. Soos wat meer inligting en data van ander son-water-verwarmers in die hande gekry gaan word sal die rekenaar applikasie en metodologie verfyn word vir meer akkurate resultate.

Sleutelwoorde: Meet en Verifieer, Aanvraag-kant-bestuur, metodologie, son-water-verwarming simulاسie, applikasie.

CONTRIBUTIONS OF THIS STUDY

The M&V Solar Water Heating Application and M&V Methodology will be used in Eskom's, DSM program which aims to reduce the energy demand of the country. The study will therefore contribute indirectly to the efforts made to reduce the nation's energy demand by providing stakeholders with quantifiable impact figures that their investments have realised. The study also improves the sustainability of the savings and provides information and data used to manage the National Solar Water Heating Program.

A presentation of the M&V Methodology as well as the M&V Solar Water Heating Application was made at the Domestic Use of Energy, International Conference held in Cape Town on 15-16 April 2009. The comments and suggestions acquired from industry-experts attending the conference were evaluated and if found to be worthy, were incorporated into the methodology and application.

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LIST OF ABBREVIATIONS

A	Ampere
AMSL	Above Mean Sea Level
BEE	Black Economic Empowerment
BWO	Black women Owned Enterprises
C	Celsius
c	South African Cent
CCI	Clinton Climate Initiative
CEM	Certified Energy Manager
CFL	Compact Fluorescent Light
CMVP	Certified Measurement & Verification Professional
CO ₂	Carbon Dioxide
CV (RMSE)	Coefficient of Variation of the Root Mean Squared Error
DME	Department of Minerals & Energy
DSM	Demand Side Management
Esco	Energy Services Company
FEMP	Federal Energy Management Projects
Geyser	Hot Water Cylinder/Tank/Storage Vessel
HVAC	Heating, Ventilation & Air-Conditioning
ICS	Integral Collector System
IPMVP	International Performance Measurement & Verification Protocol
ISO	International Organisation for Standardisation
K	Kelvin
kPa	Kilopascal
kVA	Kilovolt Ampere
kW	Kilowatt
kWh	Kilowatt Hour
L	Litre
MBE	Mean Bias Error
MW	Megawatt
MWh	Megawatt Hour
NASA	National Aeronautics and Space Administration
NO _x	Nitrous Oxides
NWU	North-West University
PW	Petawatt

R	South African Rand
RLM	Residential Load Management
SABS	South African Bureau of Standards
SANS	South African National Standards
SAWS	South African Weather Service
SMME	Small, Micro and Medium Enterprises
SO _x	Sulphide Oxides
SRCC	Solar Radiation and Certification Corporation
SWH	Solar Water Heating
TJ	Terajoule
TWh	Terawatt Hour
U.S.	United States
Wh	Watt Hour

LIST OF SYMBOLS

C_p	Specific Heat Capacity
C_s	Heat Capacity of Geyser
F_1	Circumsolar Brightness Coefficients
F_{11}	Perez Coefficient for Slope Irradiance
F_{12}	Perez Coefficient for Slope Irradiance
F_{13}	Perez Coefficient for Slope Irradiance
F_2	Horizon Brightness Coefficients
F_{21}	Perez Coefficient for Slope Irradiance
F_{22}	Perez Coefficient for Slope Irradiance
F_{23}	Perez Coefficient for Slope Irradiance
I_D	Diffuse Radiation incident on Horizontal
$I_{D,Tilt}$	Diffuse Radiation Incident on Collector
$I_{E,n}$	Extraterrestrial Radiation Normally Incident
$I_{direct \delta}$	Direct Radiation Incident on Collector
I_{rms}	Current Drawn by Back-up Element
P_0	Standard Atmospheric Pressure
$Q_{electrical}$	Energy Gained from Back-up element
Q_{losses}	Energy Lost through Thermal Losses
$Q_{res \ next}$	Residual Energy from Current Period
$Q_{res \ prev}$	Residual Energy from Previous Period

Q_{solar}	Energy Gained from Solar Radiation
Q_{usage}	Energy Drawn from SWH System through Hot Water
$R_{incentive}$	Incentive from Eskom in Rand
T_a	Average Ambient Air Temperature
T_c	Inlet Water Temperature
T_{cc}	Inlet Temperature of Collector Fluid
T_f	Final Water Temperature of Geyser
T_{geyser}	Average Geyser Temperature
T_i	Initial Water Temperature of Geyser
T_o	Outlet Water Temperature of Geyser
t	Test Period Length
U_s	Heat Loss Coefficient
V_{rms}	Supply Voltage to Back-up Element
a_0	Perez Coefficient
a_1	Perez Coefficient
f_G	Solar Water Heating System Guarantee
f_{LC}	Amount of Local Equipment Content
m'	Air Mass for Different Atmospheric Pressures
m_{hour}	Water Flow Rate
α_1	Alpha1 SABS Coefficient
α_2	Alpha2 SABS Coefficient
α_3	Alpha3 SABS Coefficient
h	Height Above Mean Sea Level
DEC	Solar Declination
Fr	Characterise Parameter for Collector Optical Efficiency
$FrUL$	Characterise Parameter for Collector Thermal Losses
G	Global Radiation
H	Hour Angle
I	Direct Radiation Normal to Rays of Sun
INC	Diffuse Angle of Incidence
LAT	Geographical latitude
P	Actual Atmospheric Pressure
Q	Heat Output
$SOLAZM$	Solar Azimuth
a	Height/Altitude of Sun

m	Air Mass for Standard Atmospheric Pressures
n	Wall-solar Azimuth
z	Zenith Angle
δ	Slope of Collector
η	Collector Efficiency
ρ	Reflective Factor
ϵ	Sky Clearness

1

Chapter

Introduction

Chapter 1 provides introductory information on South Africa's rapidly increasing energy demand and the efforts being made to reduce it. The problem statement of the dissertation is given, followed by the issues to be addressed as well as the need for the standardised methodology. An overview of the dissertation is also provided.

1.1 Background

In 2007, the global energy consumption was 96 348TWh (9.6348×10^{16} Wh) which is equivalent to 346×10^6 TJ per year. Further breakdown indicates that coal, oil, gas and electricity were responsible for more than 80% of the energy consumed globally and is indicated in Figure 1-1. With the world's fossil fuels being depleted at ever increasing rates, combined with the fact that an estimated 400×10^9 TJ of the world's fossil fuels remain, an international endeavour in exploring new horizons for alternative energy resources has been launched [1].

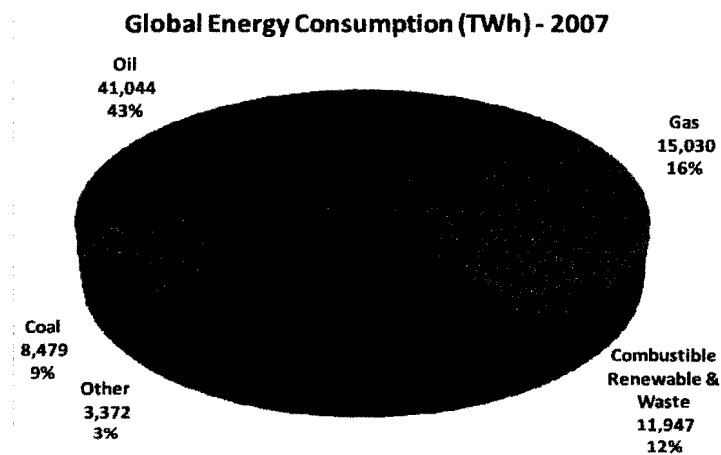


Figure 1-1: Global Energy Consumption breakdown.

As an alternative energy source, renewable energy is becoming more financially viable due to the refinement of the technologies used to harness the available energy from natural phenomena such as

sunlight, wind, oceanic tides and geothermal heat. Wind, solar and tidal-farms are being erected internationally within countries such as Germany and China at the forefront with investments worth \$7 billion (US Dollars) each.

With global warming becoming more of a reality the WWF (World Wide Fund for Nature) organised an Earth Hour event that requests households and business to switch off their non-essential lights and electrical appliances for an hour in order to create awareness towards climate change and ultimately the lurking global energy crisis. But is this sufficient?

1.1.1 South Africa's Current Energy Situation

South Africa's primary electricity utility, Eskom, is one of the top 10 utilities in the world when classified by its generation capacity. The utility generates 95% of the electricity used in South Africa and 45% of the electricity used in Africa. Throughout 2007, Eskom had a total net maximum capacity (including reserves) of 40 413MW and a peak demand (excluding load reductions) of 35 312MW [6]. Furthermore, the total energy demand of South Africa can be divided into the 6 primary sectors, as shown in Figure 1-2. The Department of Minerals & Energy (DME) indicated that the industrial sector accounts for 43% of South Africa's energy demand transport 26%, residential 18% and the commercial sector 7%.

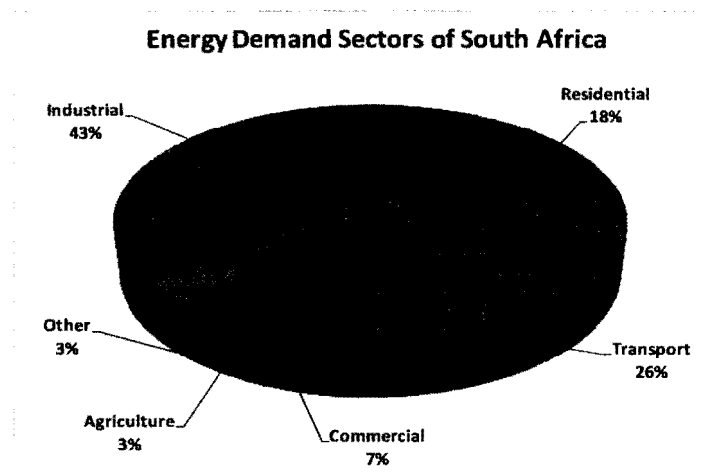


Figure 1-2: South Africa's primary energy demand sectors.

The residential sector can further be divided into sub-sectors where the contribution by hot water is 32%, space heating 27%, lighting 14%, cooking 10%, fridge/freezer 10% and other 8% [28].

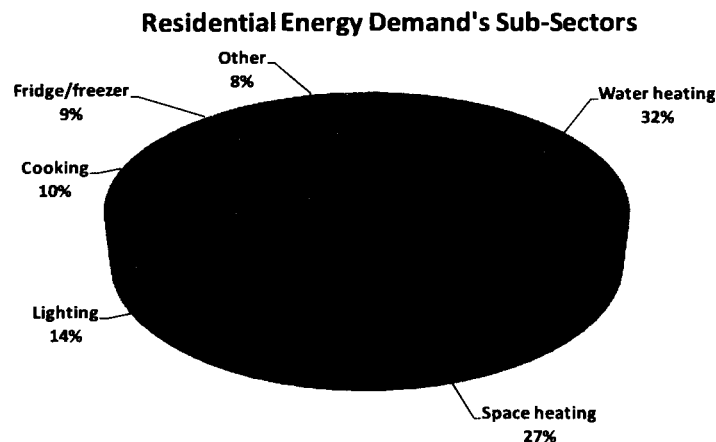


Figure 1-3: Residential sector energy demand contributors.

It is therefore apparent that residential hot water is a substantial contributor to South Africa's energy demand. Although Eskom matched the electricity demand in 2007, the looming electricity crisis finally struck early in 2008 where parts of South Africa were left without electricity for several weeks. Load shedding was imminent to avoid a national black-out.

1.1.2 South Africa's Energy Reduction Efforts

South Africa's existing energy policy is captured in the overarching *White Paper on Energy Policy of the Republic of South Africa* [2]. The White Paper takes a holistic approach on what the Government's intentions are with regards to energy matters in South Africa.

More specific to renewable energy, is the *White Paper on Renewable Energy Policy* which supplements the *White Paper on Energy Policy*. This policy states the Government's long-term goal of establishing a renewable energy industry, uncovering modern energy resources that will offer a sustainable, fully non-subsidised alternative to fossil fuels [20].

Acting towards the long-term goal, the Government has set a medium-term (10-year) target of contributing 10 000GWh's of renewable energy by 2013. This is approximately to 4% (1 667MW) of the projected electricity demand for 2013 (41 539MW) and is equivalent to replacing two of Eskom's 660MW coal fired power stations [20].

One of the renewable energy resources that the DME has been researching in the last couple of years is the harnessing of solar energy. According to macro-economic studies performed by the DME an estimated 23% of the renewable energy target could be contributed by means of solar water heating [7].

1.1.3 Eskom Demand Side Management (DSM)

Demand Side Management (DSM) is the process whereby an electricity supplier influences the way electricity is utilised by the customer or end-user. In broader terms, DSM implies the planning, implementation, and monitoring of activities which are designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand.

The primary objective of DSM is to provide constant, efficient use of electricity thus resulting in lesser amounts of electricity being consumed during Eskom's peak periods, thus managing the demand effectively. The demand targets set by Eskom DSM for the financial year, 1 April 2008 until 31 March 2009, was 1 008MW. Of this total 637MW was planned to be achieved in the residential sector, 429MW in the industrial sector and 22MW in the commercial sector.

DSM has been implemented throughout South Africa during recent years and typical examples of DSM projects are:

- Load shifting on mine pumping activities;
- Load shifting on winder activities;
- Load shifting on compressed air systems;
- Load shifting on residential hot water systems;
- Load shedding on fridge plants;
- Energy Efficiency on lighting; and
- Energy Efficiency on the recent CFL distribution program.

The above-mentioned DSM projects, which are funded by Eskom DSM, are implemented by Esco's (Energy Services Companies). In the case of a load management project, Eskom funds all capital expenditures whereas only 50% of the expenses are funded in the case of energy efficiency projects. A project target is agreed upon between the Esco, Eskom and the client (the entity at which the project will be implemented) and has to be maintained for a contracted period, usually between 5 and 10 years.

In response to the target set by the Government in the *White Paper on Renewable Energy Policy*, Eskom has embarked on a National Solar Water Heating DSM initiative in the commercial and residential sectors to aid in the reduction of the ever-growing National energy demand. The National Solar Water Heating DSM initiative is a new venture for Eskom DSM and four primary reasons exist for the program's existence:

- Water heating in homes account for 30%-50% of the household's electricity consumption;
- South Africa is blessed with a suitable climate that can sufficiently contribute to solar water heating;
- Non-renewable energy resources are being exhausted and renewable energy resources are therefore essential and becomes a viable alternative; and
- The rapid increase in electricity demand needs to be stalled.

In order to ensure the successful completion of this and similar DSM initiatives the impacts need to be quantified to an acceptable degree of accuracy for the various stakeholders involved. Measurement and Verification (M&V) is the process where an independent auditing party, which are contracted by Eskom, determines the impact as a result of all DSM initiatives and give impartial feedback on the findings.

1.1.4 Measurement & Verification (M&V)

In any DSM project a number of stakeholders exists which aid in the implementation of the project and/or ensure that the project targets are reached and sustained. The utility, client, Esko and financier each have their own intentions and objectives for being involved in the DSM project [12]:

- The utility – strives to reduce the energy supply to the client & achieve increased electricity reserve margins.
- The client – strives to lower their energy cost by reducing the energy demand and consumption.
- The Esko – wants to share in the energy cost saving when implementing the project under risk.
- The financier – wants to protect their investments in the project/program (In the case of South Africa the financier is Eskom DSM).

This situation requires that the project impacts be determined to a certain level of accuracy that is acceptable to all stakeholders as the primary questions from each stakeholder will eventually be:

How much have been saved and are the savings being sustained over time?

The process of quantifying and assessing the project impacts must remain impartial and totally transparent. The long-term success of many DSM projects is often hampered by the inability of project stakeholders to agree on the quantity of savings that have been obtained. It is for this reason that an independent party needs to be included in the process of determining and verifying the savings [12].

Measurement & Verification is the fourth, independent party that determines and verifies the impact of DSM projects who reports to all stakeholders on their findings. Figure 1-4 shows the DSM project environment and the interaction between the different stakeholders and the M&V team. Although the

M&V team is set outside the DSM project environment they interact on a continuous basis with all the different stakeholders on an impartial level.

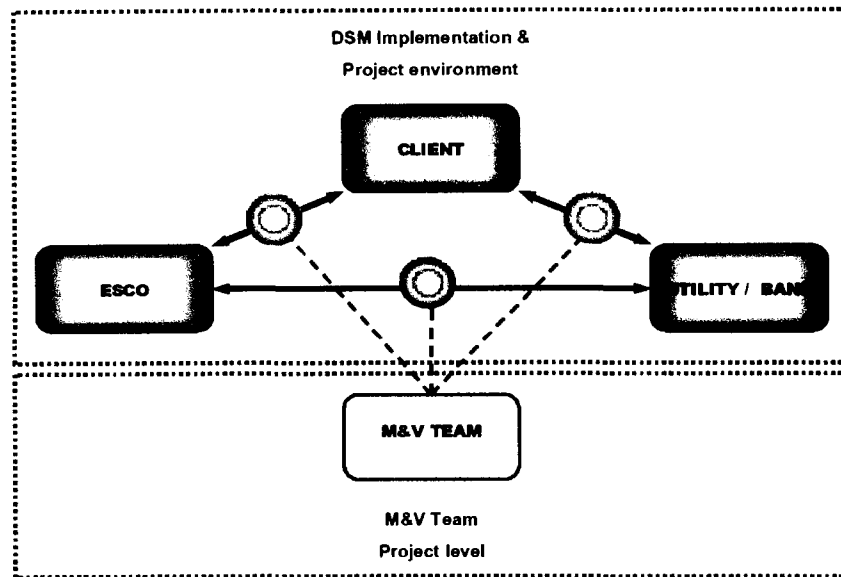


Figure 1-4: The interaction between the DSM stakeholders and the M&V team [12].

Prior to 2000, South Africa has had limited experience in the M&V field. International measurement and verification protocols were researched in order to gain a better perspective of M&V and its requirements. The fundamental principles of M&V were built from the *International Performance Measurement and Verification Protocol (IPMVP)* [4] as well as the U.S. *M&V Guidelines for Federal Energy Management Projects (FEMP)* [21] and were adjusted and expanded to suite the situation and energy market in South Africa. The *South African M&V Guideline* [3] has been developed by South African M&V teams to accurately and cost-effectively determine the impacts of the DSM projects. The foundation on which the impacts of a DSM project are determined is based on the following equation:

$$\text{Energy Savings} = (\text{Baseline energy use}) - (\text{Post-implementation energy use}) \pm \text{Adjustments} \quad (\text{Eq. 1})$$

DSM projects ranging from mine-pumping, fridge plants, compressed air, residential load management and CFL distributions have successfully been Measured & Verified in South Africa since 2001.

Since the 1st of April 2008 until 31 March 2009 the achieved DSM demand reduction was 916MW, of which 660MW was contributed by the residential sector, 240MW by the industrial sector and 15MW by the commercial sector. The residential market consequently makes a substantial contribution and holds great potential for further energy and cost savings. This study consequently forms part of the residential sector and more specifically residential solar water heating.

1.2 Problem statement

Although solar water heating technology is not new, the full potential of it has not been exploited in South Africa. The reputation of previous failed solar water heating rollouts, the very expensive initial capital investment associated with solar water heating, as well as the relatively inexpensive electricity tariffs in South Africa, are reasons why the South African solar water heating market/program never took off earlier.

The attempts to reduce the electricity demand and consumption coupled with the abundant solar energy available in South Africa have driven Eskom DSM to launch a National Solar Water Heating program which will aid in the reduction of the extremely high energy demand and consumption in the country. The program involves an incentive paid to the homeowner when an Eskom accredited solar water heating systems is installed. No fully functioning M&V process or relevant procedures have been available to determine the impact of a National Solar Water Heating program.

A need consequently exist to accurately quantify the impacts of the solar water heating program throughout South Africa. This need is especially evident when considering the various drivers for solar water heating in South Africa, as well as the need to perform M&V on the program.

1.3 Objectives

The objective of this research project is to develop an accurate and cost-effective methodology to measure and verify the electricity demand & consumption impacts of a National Solar Water Heating DSM program. These impacts need to be assessed and verified to determine the cost savings for the client, Esco and Eskom DSM

1.4 Overview of the dissertation

Chapter 2 contains a literature study on solar water heating in general, Eskom's Solar Water Heating DSM program and the related measurement and verification activities of a typical DSM project.

Chapter 3 discusses the proposed M&V methodology and how it is incorporated into the DSM program.

Chapter 4 explains the applications needed to determine the impact of the National Solar Water Heating DSM program. This chapter addresses the M&V Solar Water Heating Application.

Chapter 5 will compare the results generated from the M&V Solar Water Heating Application to actual measured data from a solar water heating system.

Chapter 6 contains the conclusion and recommendations of this study.

Chapter 1 provided background information on the global energy situation as well as the increasing energy demand in South Africa. The possibility of substantial energy and cost savings in the residential sector was explained. The need to accurately and cost effectively determine the impacts as a result of the National Solar Water Heating Program was stated. This was followed by the objectives to be reached and an overview of the chapters of this dissertation.

2

Chapter

Literature Study

This chapter provides an introduction to solar energy and more specifically solar water heating. The different technologies that exist are described. The Solar Water Heating DSM program is also discussed and an overview of the basic M&V procedures used for all other DSM project is given. This chapter also looks into different methodologies to measure and verify solar water heating projects internationally.

2.1 Solar Energy

Solar energy is the energy that is radiated by the sun. Solar energy, along with other weather phenomena result in climate and weather patterns and is vital to sustain life on earth. Planet earth receives 174PW (Petawatt) of incoming solar radiation at any given time of the day. Approximately 85PW of solar energy is either reflected away from the surface of the earth or absorbed by the atmosphere while travelling on its way to the earth as indicated in Figure 2-1 below [9].

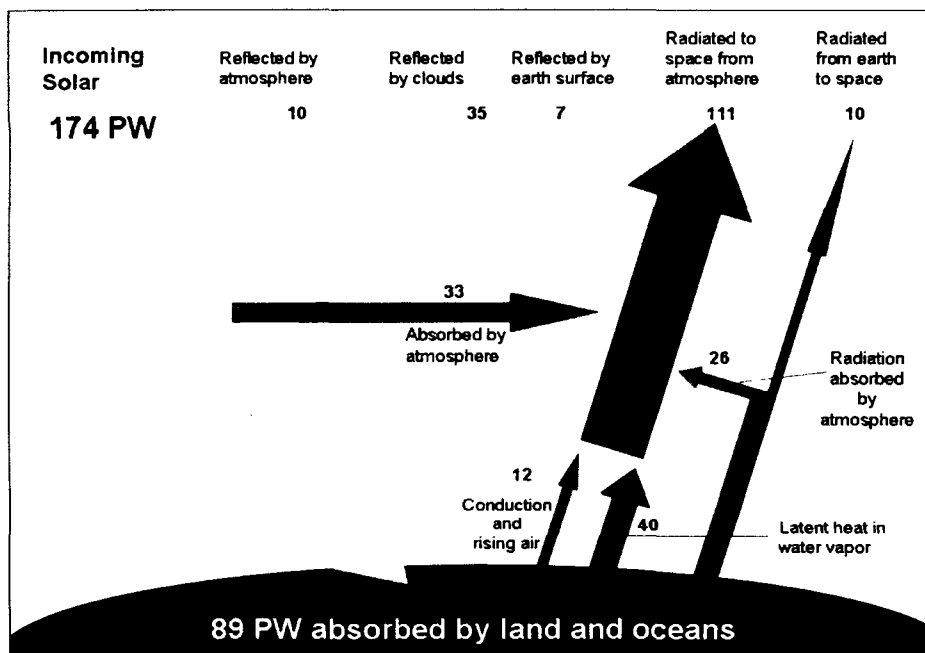


Figure 2-1: Solar Radiation disbursement [10].

The solar radiation that eventually reaches the land and ocean, consist primarily of two components; direct solar radiation, which can be seen as a direct beam of radiation straight from the sun and diffuse solar radiation (also known as scattered radiation), which is a result of atmospheric losses in direct solar radiation. Atmospheric losses in direct solar radiation are caused by four primary phenomena [12]:

- Scattering of direct solar radiation which occurs when the radiation collide with molecules of ideal gases in the atmosphere;
- Scattering of direct solar radiation due to the presence of water vapour molecules;
- Scattering of direct solar radiation due to the presence of dust particles; and
- Selective absorption by ideal gases and by water vapour.

Not all the atmospheric losses from direct solar radiation reach the earth as diffuse solar radiation. Some of the radiation is scattered back to the atmosphere.

South Africa is blessed with an abundance of solar radiation and receives approximately 1 450kWh/m² to 1 950kWh/m² of radiation per annum compared to Europe's 910kWh/m² per annum. Figure 2-2 shows the solar radiation regions in South Africa and the annual solar radiation in MJ/m². It is clear from Figure 2-2 that the northern & north-western part of South Africa is highly suited for solar water heating.

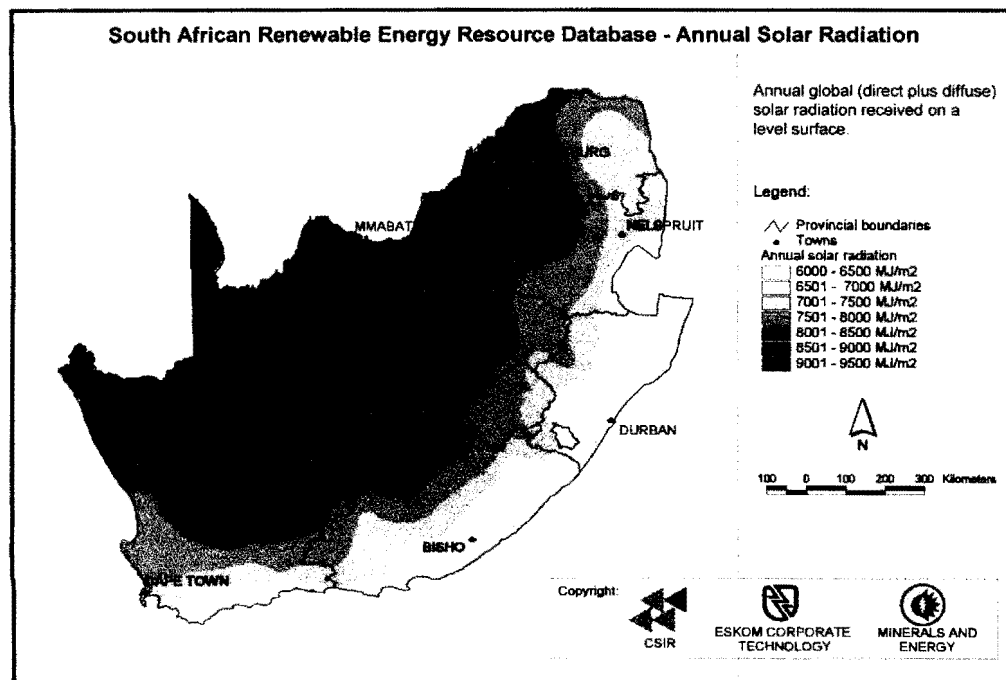


Figure 2-2: Solar Radiation regions in South Africa [11].

The quantity of solar radiation that reaches the earth's surface not only varies through the time of day but also through the seasons. A typical solar radiation profile for a winter and summer-day in the Gauteng Province, South Africa is shown in Figure 2-3. Similar solar radiation trends are seen throughout South Africa [22].

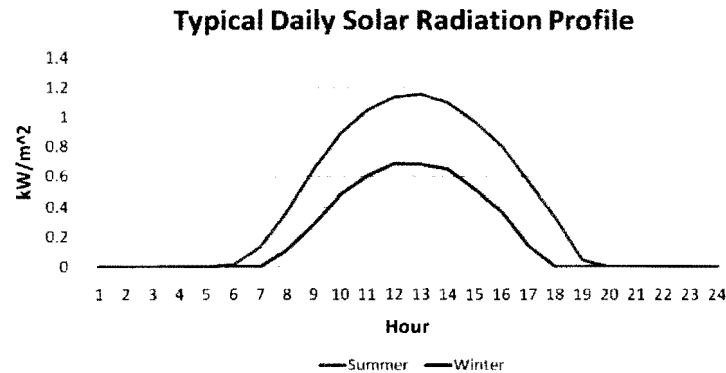


Figure 2-3: A typical daily solar radiation profile on the horizontal plane [22].

The corresponding kWh/m² for the winter and summer day's solar radiation profiles in Figure 2-3 is 4.5kWh/m² and 9.2kWh/m² respectively. This is a 4.7kWh/m² (51%) difference between the winter and summer periods.

The total solar radiation that is incident on a surface is often referred to as global radiation and consists of direct radiation as well as diffuse radiation. Direct radiation is radiation that is incident on a surface directly from the sun whereas diffuse radiation falls onto the surface after being reflected from the surrounding area. Global radiation typically comprises of 78% direct radiation and 22% diffuse radiation however these percentages will vary for different locations [22].

2.2 Solar Water Heating

Solar water heating is a means of capturing the solar energy from the sun to perform a useful function, in this case the heating of water for residential and commercial use. The section that follows provides background on solar water heating and the technologies that are employed today.

2.2.1 Solar Water Heating Fundamentals

The history of solar heating dates back to the mid 1700 when a Swiss naturalist, Horace de Saussure, noted that heat can be trapped inside a small box with a glass lid when exposed to the sun. De Saussure however, was unsure exactly how this occurrence took place but realised that someday the hot box

might have a practical application. Indeed, the hot box has become the prototype for the solar collectors that have provided sun-heated water to millions since 1892 [5].

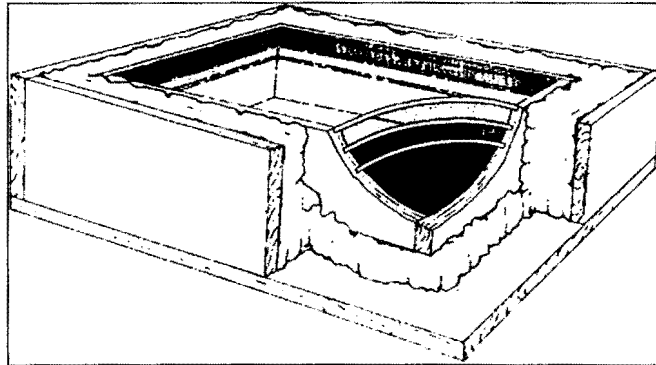


Figure 2-4: An artist's conception of Horace de Saussure's hot box.

The basic theory behind a solar water heating system is based on de Saussure's findings where the heat trapped inside a box is used to heat water. In any solar water heating system the first objective of the system will be to capture the solar energy that is radiated from the sun. Secondly, the energy that has been captured need to heat water so that it can be used for warm water applications. Figure 2-5 shows the basic solar water heating concept.

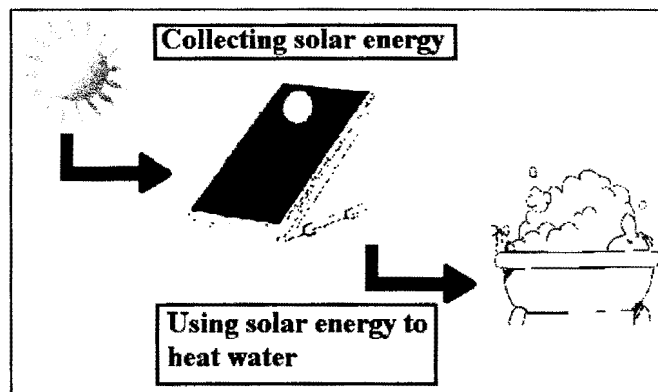


Figure 2-5: Basic solar water heating concept.

To collect the solar energy radiated from the sun, a solar collector is used to absorb the energy from the sun. The solar collector usually consists of a network of tubes running through the collector which contains the heat transfer fluid.

When the heat transfer fluid is heated it flows from the solar collector to the hot water storage vessel (Figure 2-6, no.1) where, in the case of an indirect system, will be used to heat water or in the case of a direct system, will be immediately available to be used in hot water usage applications (Figure 2-6

no.4). At the same time, colder heat transfer fluid enters the solar collector (Figure 2-6, no 3) from the hot water storage vessel (Figure 2-6, no.2) which on its turn will be heated as well. In the case of some solar water heating systems an electrical element might be present to aid in heating the water when insufficient solar energy is available (Figure 2-6, no.5). The different solar water heating technologies will be described in the next section of the dissertation.

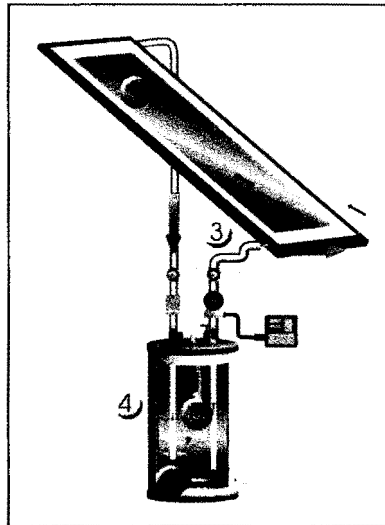


Figure 2-6: Typical solar water heating system diagram [13].

2.2.2 Solar Water Heating Technologies

Since 1892, solar water heating technologies have evolved radically to such an extent that systems can reduce the electricity consumption traditionally used for water heating by 66% [5] and in some cases up to 85% [38]. However, the basic system components of a typical solar water heating system have stayed almost the same over the years and consist of a solar collector, a hot water storage vessel (geyser) and an energy transfer medium. All the solar water heating systems consist of one or more of these three components. Figure 2-7 shows a typical example of a solar collector and a hot water storage vessel. Different types and sizes of solar collectors exist and are preferred in certain areas and applications.

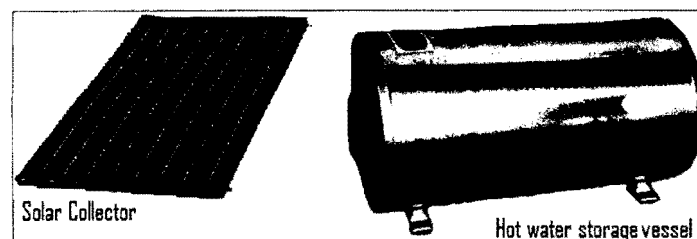


Figure 2-7: An example of a solar collector and a hot water storage vessel.

Two basic solar water heating system types exist, namely active and passive systems. An active solar water heating system uses a pump to circulate the heat transfer-fluid being it, air, glycol, hydrocarbon oils, refrigerants or water through the solar collector. The pump can either be electrically driven or solar powered.

Primarily, two types of active solar water heating systems are found in the world today. An active, direct circulation systems pump domestic water through the collectors and the hot water is then stored in a hot water storage vessel. The water in a direct solar water heating system is exposed to the elements and has the tendency to freeze when exposed to very cold temperatures. Due to the fact that water expands when it is frozen the pipes that the direct system comprises of, might rupture. It is therefore extremely important that direct solar water heating systems, without proper freezing preventions measures, are not used at locations which are exposed to freezing temperatures.

An active, indirect circulation system pumps heat transfer fluid through the collectors which is then used to heat water by means of a heat exchanger. A heat transfer fluid such as glycol acts as an antifreeze solution and circulates through the solar collector without mixing with the household water. In some indirect solar collectors an overheating protection system is installed to ensure that the heat transfer fluid does not become superheated when the hot water demand is low and the intensity of the incoming solar radiation is high.

As a result of the additional heat transfer that is required, the efficiency of an indirect solar water heating system is lower than the direct system. A typical heat exchanger has an efficiency of approximately 60 - 70%. This implies that only 60-70% of the available solar energy will be transferred to the water. Figure 2-8 shows a typical example of an active, indirect solar water heating system.

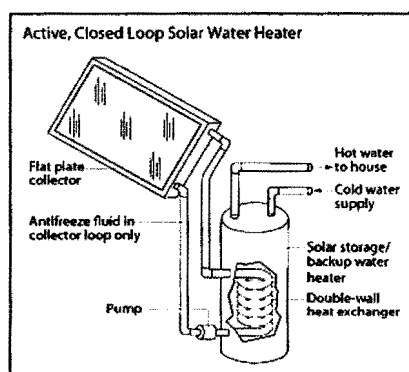


Figure 2-8: An example of an active, indirect (closed loop) solar water heating system [8].

A passive solar water heating system relies on gravity and the tendency of water to naturally circulate as it is heated, also called thermosyphon.

Primarily, two types of passive solar water heating systems are found in the world today. A passive, integral-collector storage system (ICS systems) consists of one or more storage tanks placed in an insulated box with a transparent side facing the sun. ICS systems have the advantage of easy installation and low maintenance and are not as expensive as other systems. Unfortunately a substantial quantity of heat is lost through the transparent cover due to convection and radiation. The time at which the hot water is withdrawn is therefore very important.

An ICS system is installed at application where the hot water is required in the late afternoon or in the early evening. Different methods, such as transparent insulation and sunlight reflectors have been researched to reduce heat loss from the integral-collector storage system [8].

Passive, thermosyphon systems rely on the natural convection of a heated liquid to circulate itself through the collectors. As the liquid is heated up in the collector it becomes lighter and rises naturally while the cooler liquid flows into the bottom of the collector, thus enhancing circulation. Thermosyphon systems have the advantage that no additional circulation equipment is needed but caution has to be taken because reverse convection might occur during the night-time when the collector acts as a radiator and cools the water down. Some thermosyphon technologies have incorporated measures to eliminate reverse circulation.

Figure 2-9 shows a typical example of a passive solar water heating system.

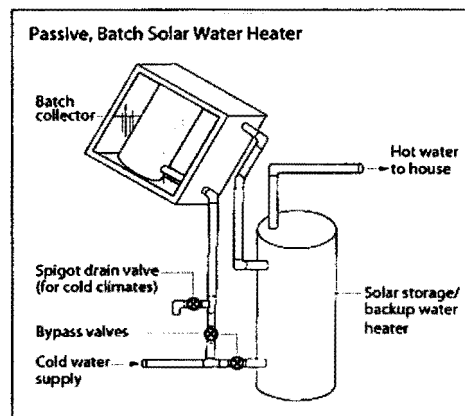


Figure 2-9: An example of a passive solar water heating system [8]

2.3 Solar Water Heating Performance Parameters

The performance of any solar water heating system is dependent upon a vast variety of parameters. Some of these parameters are controllable, while others are entirely dependent upon the forces of nature. It is the function of the solar water heating system designers, suppliers and installers to optimise the controllable parameters to obtain the maximum effect from the uncontrollable parameters. The solar water heating dependant parameters are discussed in the following section.

2.3.1 *Weather Conditions*

Acting as the driving force behind the entire concept of solar water heating, weather conditions is one of the uncontrollable parameters that have to be dealt with in order to eventually determine the amount of solar energy incident on the collector and the performance of the solar water heating system. The weather does not only include wind, precipitation, pressures and temperatures but also include natural phenomenon like the altitude of the sun, solar azimuth angles, direct solar radiation and diffuse solar radiation. In fact, the primary weather phenomena that influence the performance of a solar water heating system are:

- Ambient air temperature ($^{\circ}\text{C}$);
- Direct radiation (W/m^2);
- Diffuse radiation (W/m^2);
- Altitude of the sun ($^{\circ}$); and
- Azimuth of the sun ($^{\circ}$).

Weather forecasts are based upon the interaction of the different weather phenomena and are available from various weather services. The South African Weather Service (SAWS) delivers 7-day weather forecasts and can forecast rainfall up to 10 days ahead. However, some of the primary weather phenomena, that influence the performance of a solar water heating system, are not readily available for different geographic location. Even with the latest technologies the weather can never be 100% accurately predicted and the slightest change in the weather patterns can be caused by the smallest of factors.

A private company Meteotest in Switzerland developed a software application, Meteonorm, which houses a vast range of common and uncommon weather phenomena used for meteorological calculations, calculation procedures for solar applications and system design.

Meteonorm is a global meteorological database which contains historical weather data, gathered over a period of more than 20 years for more than 8 000 weather stations all across the globe.

All the data is available in hourly values and can be exported to Microsoft Excel format for further use in other applications. Figure 2-10 shows a screen capture of the working environment for the Meteonorm global meteorological weather database.

METEONORM Version 5.107

File Import Format Site Basic data Plane Horizon Calculations Language Info

Status

Site: **PRETORIA SF**

Situation: **open**

Horizon: **astronomic**

Format: **Standard**

Type: **Cities**

Plane orient:

Azimuth: **-180** Plane orient

Inclination: **32**

Units:

Radiation (month) [kWh / m2]

Temperature [°C]

Units (User defined)

Basic data:

☒ Mean val. ☐ Extreme val.

☐ Random ☐ Ghmax

Calculations:

Meteo

Hourly values ✓

Save

Preview:

View site View results

Calculation completed

Month	H_Gh	H_Gk
Jan	212	185
Feb	183	173
Mar	181	194
Apr	144	176
May	135	191
Jun	119	181
Jul	133	196
Aug	157	208
Sep	183	211
Oct	199	195
Nov	195	173
Dec	215	182
Year	2057	2264

Progress: 0%

Figure 2-10: Meteonorm global meteorological weather database

2.3.2 Hot Water Demand

The quantity of hot water used and the time at which it is used is another solar water heating performance parameter and can be combined to form a hot water demand profile. A variety of aspects influences the hot water demand profiles and varies with the different households, regions and countries but is mainly influenced by human behaviour. Human behaviour is as unpredictable as the weather but also follows patterns over extended periods of time.

For example, the occupants in a household might not always use 70 litres of hot water at 18:30 when taking a bath on weekdays and might only use 50 litres of hot water at 17:30. However, over an extended period it can be seen that the occupants use an average of 60 litres of hot water at 18:00 to bath during weekdays. The amount of hot water and time it is used will differ for weekends.

Typical weekday and weekend hot water demand profiles are shown in Figure 2-11. These profiles were gathered from a completed DSM project and are representative of a household with an average geyser size of 2.098kW. Figure 2-11 indicates that the household's occupants only start to use hot water at 7:30 during weekends instead of the normal 6:00 during weekdays.

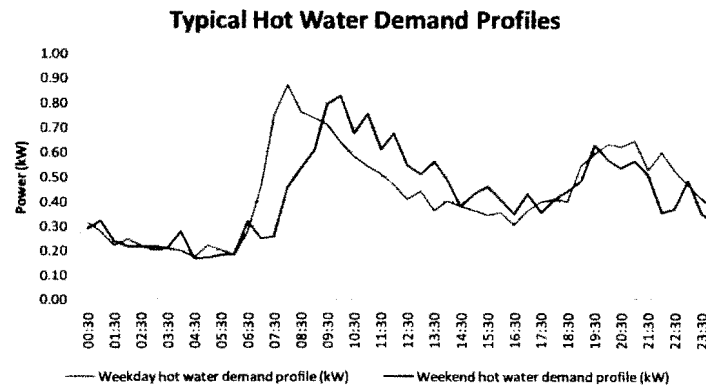


Figure 2-11: Typical weekday and weekend electrical hot water demand profiles [36].

The respective energy consumptions of the weekday and weekend profiles are 10.5kWh and 10.2kWh.

2.3.3 Solar Water Heating System Types

As discussed in section 2.2.2, solar water heating systems consist of various components. The different combinations of components from which the solar water heating system is manufactured will influence the performance of the system. For example, flat-plate solar collector will have a different efficiency than an evacuated tube solar collector of the same size and will therefore perform differently. Some design criteria that influences the performance of a solar water heating system includes the following but are not limited to them:

- Solar collector type (e.g. flat-plate or evacuated tube);
- Solar collector gross area (e.g. 2 m² or 4 m²);
- Solar collector aperture area (e.g. 2 m² or 4 m²);
- Solar collector coating (e.g. glazed or unglazed);
- Direct or Indirect system;
- Heat transfer fluid type (e.g. glycol or water);
- Heat exchanger efficiency in the case of an indirect system;
- Different component materials (e.g. copper or aluminium);
- Insulation (e.g. are the pipes insulated or not and of so with what material);
- Passive or active system;
- Flow rate of heat transfer fluid;
- In-and-outlet positions of heat exchanger fluid on the solar collector;
- Overall Solar collector efficiency (function of the above mentioned parameters);
- Backup heating system (e.g. electrical or gas-backup); and
- Control strategy of the solar water heating system (e.g. on/off of backup heating and pumping system).

By combining several of the above-mentioned design criteria, many different solar water heating system configurations can be designed, each with different performance characteristics that could be suited to its operational conditions & available solar energy.

2.3.4 Installation of Solar Water Heating Systems

As mentioned in section 2.1 the solar radiation that reaches the earth's surface differs for each location. The different solar regions shows that more solar energy is likely to reach the earth's surface inland in South Africa whereas along the coast less solar energy is available for solar energy applications. This represents a direct resemblance between the amount of solar energy and the elevation above sea level of a certain location. Table 2-1 shows the percentage increase in direct solar radiation at varying heights above mean sea level when compared to the altitude of the sun (solar altitude). The term solar altitude will be described in more detail later in this dissertation.

Table 2-1: Percentage increase in direct solar radiation at varying heights above mean sea level [12].

Height above mean sea level	Solar Altitude									
	10°	20°	25°	30°	35°	40°	50°	60°	70°	80°
1000 m	32	22	18	16	14	13	12	11	10	10
1500 m	50	31	26	23	21	18	16	15	14	14
2000 m	65	40	33	29	27	24	21	19	18	18
3000 m	89	52	43	37	34	31	27	24	23	22

Not only the direct solar radiation is influenced by the elevation above mean sea level (AMSL) but the diffuse solar radiation also decreases by approximately 30% at 1000m and by about 60% at 1500m AMSL [12].

The area surrounding the solar water heating system also influences the performance of such a system. Energy reflected from surrounding buildings and surfaces will influence the amount of solar energy incident on the solar collector to some extent. For example, new concrete has a reflectivity factor (ρ) of 0.22 whereas green grass has a reflectivity factor of 0.1. Grass will therefore not reflect the solar radiation as much as concrete, but will rather absorb it.

The position in which the solar collector is installed influences the performance of a solar water heating system immensely. It not only determines the amount of energy output of the solar collector but also the time at which the energy output is available. A solar collector can be installed with two degrees of freedom; the slope and orientation of a solar collector should be adjusted to such an extent that it maximises the energy output while satisfying the needs of the hot water consumer.

The slope of a solar collector is the angle that the collector makes with the horizontal and is primarily determined by the latitude on which the panel is installed. To ensure maximum energy absorption by the solar collector it should be set up in such a way that the incoming solar radiation is normal to the

collector. For example, a solar collector installed on the 25° latitude in the southern hemisphere should have a slope of approximately 25° to have the solar radiation normal on its surface.

The orientation (collector azimuth) of a solar collector is the angle that the collector makes with the true north position. The orientation is usually measured from true north (0°) and increases (+) in the clockwise direction and decreases (-) in the anti-clockwise direction. In other words, a solar collector facing east has an orientation of 90° and a solar collector facing west has an orientation of -90° . The orientation primarily determines the time at which the energy is available to be used.

For example, a solar collector facing east (90°) will have its maximum energy output in the morning while having little or no energy output in the early evening. Figure 2-12 depicts a solar collector with a slope angle of 35° and orientation angle of -180° . A solar water heating system with this collector orientation and slope is a typical installation found in the northern hemisphere at approximately 35° of latitude. The system is expected to provide average performance during the winter and summer months.

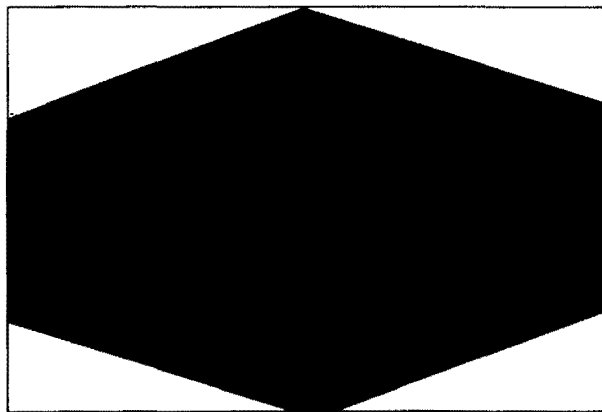


Figure 2-12: Illustration of the slope and orientation angle of a solar collector.

An M&V methodology that determines the impact of all the solar water heating systems by taking into account the weather conditions, hot water demand, solar water heating system types and installation possibilities need to be developed.

2.4 Existing Solar Water Heating Simulation Software

A number of solar water heating simulation software packages has been developed internationally. The primary aim of all the simulation software is to predict the solar energy contribution by the solar water heating system as well as the electrical energy required to fulfil the rest of the hot water needs. The following section discusses the RETScreen[®] software and gives a brief description of the TRNSYS and S*Tol simulation software.

2.4.1 RETScreen® Solar Water Heating Simulation Software

RETScreen® International is a clean energy awareness, decision-support and capacity building centre located in Varennes, Canada [19]. The centre has developed an energy analysis software application that can be used world-wide to evaluate the energy production for various types of energy efficient and renewable energy technologies. The RETScreen® solar water heating software application uses product information, geographical location data, weather database and hot water usage to ultimately determine the impact of a solar water heating system in the form of a monthly amount of renewable energy delivered.

The software application allows the user to select the type of solar water heating system from the product database. Each solar water heating system has its own pre-determined performance coefficients which were calculated from the SRCC 100-2000-002A thermal performance test. The thermal performance tests are done by the Solar Radiation and Certification Corporation (SRCC) which is a non-profit, independent third-party certification organization that administers national certification and rating programs for solar energy equipment [29]. Figure 2-13 shows the system characteristics of the RETScreen® software and describe the performance of the collector with certain inputs.

The performance coefficients are used to calculate the solar collector efficiency through the following equation:

$$\eta = Fr - (FrUL) \times (Ta - Tcc)/G \quad (\text{Eq.2})$$

Where,

- η = the collector efficiency [dimensionless];
- Fr = a parameter used to characterise the collector's optical efficiency [dimensionless];
- $FrUL$ = a parameter used to characterise the collector's thermal losses [(W/m²)/°C];
- Ta = ambient air temperature [°C];
- Tcc = inlet temperature of working fluid entering the collector [°C]; and
- G = the global solar radiation incident on the collector [W/m²].

Additional system characteristics are entered in to the model as shown in Figure 2-13.

System Characteristics		Estimate		Notes/Range
Application type		Service hot water (with storage)		
Base Case Water Heating System				
Heating fuel type	-	Electricity		
Water heating system seasonal efficiency	%	100%		50% to 190%
Solar Collector				
Collector type	-	Glazed		<i>See Technical Note 1</i>
Solar water heating collector manufacturer		Solahart Industries		<i>See Product Database</i>
Solar water heating collector model		Solahart Bt		
Gross area of one collector	m ²	1.98		1.00 to 5.00
Aperture area of one collector	m ²	1.87		1.00 to 5.00
Fr (tau alpha) coefficient	-	0.75		0.50 to 0.90
Fr UL coefficient	(W/m ²)/°C	4.87		1.50 to 8.00
Temperature coefficient for Fr UL	(W/(m ² ·°C))	0.00		0.000 to 0.010
Suggested number of collectors		2		
Number of collectors		2		
Total gross collector area	m ²	4.0		
Storage				
Ratio of storage capacity to coll. area	L/m ²	45.9		37.5 to 100.0
Storage capacity	L	172		
Balance of System				
Heat exchanger/antifreeze protection	yes/no	Yes		
Heat exchanger effectiveness	%	75%		50% to 85%
Suggested pipe diameter	mm	10		8 to 25 or PVC 35 to 50
Pipe diameter	mm	38		8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m ²	0		3 to 22, or 0
Piping and solar tank losses	%	1%		1% to 10%
Losses due to snow and/or dirt	%	3%		2% to 10%
Horz. dist. from mech. room to collector	m	5		5 to 20
# of floors from mech. room to collector	-	2		0 to 20

Figure 2-13: RETScreen® solar water heating system characterisation.

The orientation of the solar collector as well as the location of installation are fed into the software and are shown in Figure 2-14.

Site Latitude and Collector Orientation		Estimate
Nearest location for weather data		Pretoria/Forum
Latitude of project location	N	-25.7
Slope of solar collector	°	25.0
Azimuth of solar collector	°	0.0

Figure 2-14: RETScreen® solar water heating system installation information.

Weather data is generated for each month according to installation information of the solar collector as shown in Figure 2-15. The user may select the fraction of each month to be used in the calculations that follow. The monthly average daily radiation on a horizontal and tilted surface is given in kWh/m²/day. The monthly average temperature, relative humidity and wind speed is also generated from the RETScreen® weather database which is acquired from the National Aeronautics and Space Administration (NASA).

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m ² /d)	Monthly average temperature (°C)	Monthly average relative humidity (%)	Monthly average wind speed (m/s)	Monthly average daily radiation in plane of solar collector (kWh/m ² /d)
January	1.00	6.50	22.6	62.0	1.0	6.32
February	1.00	6.22	22.1	63.0	1.0	5.88
March	1.00	5.62	21.0	63.0	2.0	4.63
April	1.00	4.63	17.9	63.0	2.5	3.30
May	1.00	4.25	14.7	56.0	3.0	2.37
June	1.00	3.94	11.5	54.0	4.0	1.91
July	1.00	4.24	11.9	50.0	4.5	2.14
August	1.00	4.94	14.7	45.0	5.0	3.12
September	1.00	5.67	18.6	44.0	4.0	4.36
October	1.00	6.06	20.1	52.0	3.0	5.38
November	1.00	6.56	21.0	59.0	2.0	6.28
December	1.00	6.81	21.9	61.0	1.0	6.74

Figure 2-15: RETScreen® weather data.

The quantities of hot water used and the frequency of use can be determined by completing the information shown in Figure 2-16. The number of occupants and rate of occupancy is entered after which the hot water used in litres per day is generated.

Water Heating Load Calculation		Estimate
Application type	-	Service hot water
System configuration	-	With storage
Building or load type	-	House
Number of units	Occupant	4
Rate of occupancy	%	100%
Estimated hot water use (at ~60 °C)	L/d	240
Hot water use	L/d	240
Desired water temperature	°C	60
Days per week system is used	d	7

Figure 2-16: RETScreen® hot water usage calculation.

By taking into account all of the above information RETScreen® simulates the performance of a solar water heating system for a certain application and location. The software application only provides an annual figure (which can be worked back into a monthly figure) stating the renewable energy delivered by the solar water heating system (Figure 2-17). RETScreen® therefore does not simulate the solar water heating system in smaller time intervals e.g. hourly.

Annual Energy Production (12.00 months analysed)		Estimate
SWH system capacity	kW _{th}	3
	MW _{th}	0.003
Pumping energy (electricity)	MWh	0.00
Specific yield	kWh/m ²	524
System efficiency	%	33%
Solar fraction	%	49%
Renewable energy delivered	MWh	2.08
	GJ	7.47

Figure 2-17: RETScreen® simulated results.

2.4.2 TRNSYS Energy System Simulation Tool

TRNSYS is a transient energy system simulation software package that simulates the performance of various energy systems over time. The software package has the capability of selecting over 200 system components and simulating the interactive effects along with hourly, generated weather data. Efficiencies and performance characteristics for each of the components in TRNSYS have already been defined and assigned to each however, these can be altered by the user as required. TRNSYS can not only be used to simulate the performance of several types of solar water heating systems but also the performance of HVAC (Heating, Ventilation & Air-Conditioning) Systems in buildings.

The TRNSYS solar water heating model allows the user to vary system parameters such as location, geyser size, element rating, collector area, slope, orientation, efficiencies and the hot water demand profile in order to compare different solar water heating scenarios. The software simulates the

renewable energy delivered as well as the electrical energy required to fulfil the hot water needs in user defined time intervals [25]. Figure 2-18 shows a screen capture of the TRNSYS simulation software package.

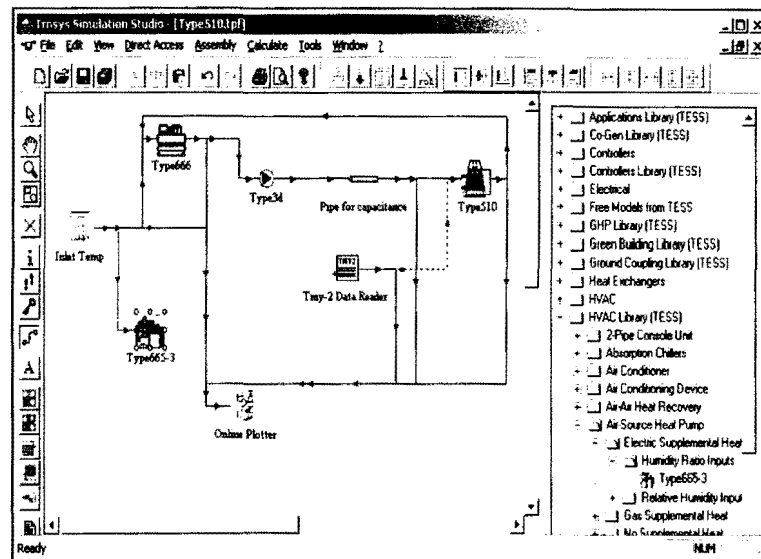


Figure 2-18: TRNSYS Simulation Software [26].

2.4.3 T*SOL[®] Solar Thermal System Simulation Software

T*SOL[®] is a simulation programme for the planning and professional design of solar thermal systems. Like TRNSYS, T*SOL contains a large number of system configurations for domestic hot water demand which can be combined to simulate the performance of different types of solar water heating systems in different scenarios. The user is able to run an automatic parameter variation and, through simulation, observe and determine the influence of the different parameters on target values such as the solar fraction, efficiency and the auxiliary power requirement.

Actual measured data from solar water heating systems can be converted into T*SOL-format and compared with the hourly simulation results. Although T*SOL does not contain any weather data for South Africa in the database, climate data can be imported and used for simulation purposes. Figure 2-19 shows a screen capture of the T*SOL Thermal System Simulation Software.

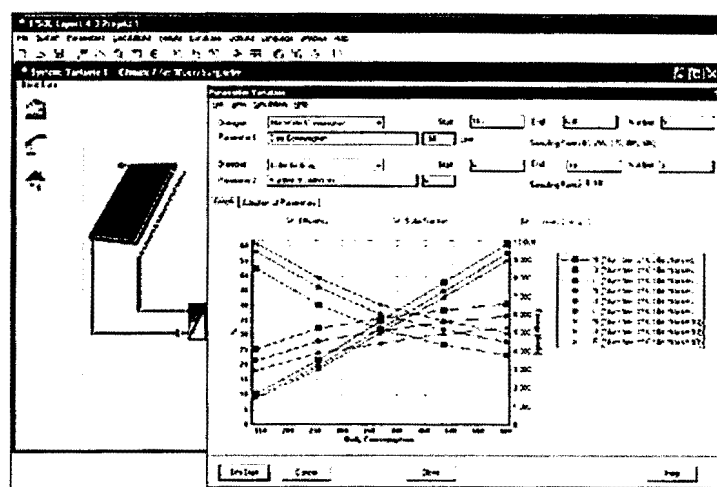


Figure 2-19: T*SOL Simulation Software [27].

2.5 National DSM Solar Water Heating Program

Eskom has embarked on a National Solar Water Heating DSM initiative in the commercial and residential sectors to aid in the reduction of the forever-growing energy demand in the country. The primary aim of the program is to reduce the electricity demand by 578MW over a period of five years starting from 2008. To encourage the public to take part in the initiative Eskom offers subsidies when a solar water heating system is purchased and installed. The following sections describe the DSM Solar Water Heating Program and the guidelines which are to be followed for any suppliers wanting to participate.

2.5.1 Supplier Registration

Any solar water heating system supplier wanting to participate in the solar water heating DSM program must register with the appointed auditing firm, Deloitte & Touche. Supplier registration requires adherence to several criteria which includes the registration of an approved solar water heating system. Solar water heating systems registered by the supplier must comply with the following non-negotiable factors in order to qualify for an incentive [15]:

- The solar water heating system must operate with a high pressure (no less than 100kPa);
- The solar water heating system must have an insulated storage tank;
- The system must either be without an electrical back-up element or with an approved load management device such as a timer or ripple relay;
- If a solar water heating system is installed without electrical back-up it should remain without electrical back-up for the duration of the solar water heating program;

-
- The system must comply with all relevant South African Bureau of Standards (SABS) relating to the solar water heating systems and must have a valid SABS test report or SABS Mark of Approval;
 - The solar water heating system must be offered with a guarantee of a minimum of 5 years and a life expectancy of 10 to 15 years;
 - Suppliers with the SABS Mark of Approval will have to maintain this status according to the SABS requirements;
 - Registered suppliers and systems must comply with the following non-negotiable South African National Standards (SANS) for thermal & mechanical system performance and installation conformance:
 - SANS 1307:2005 (SABS 1307) – Residential solar water heating systems;
 - SANS 6210:1992 (SABS SM 1210) – Residential solar water heating systems-Mechanical qualification test;
 - SANS 6211-1:2003 - Residential solar water heating system Part 1: Thermal performance using an outdoor test method;
 - SANS 6211-2:2003 - Residential solar water heating system Part 2: Thermal performance using an indoor test method;
 - SANS 60335-2:2000 - Household and similar electrical appliances - Safety Part 1: General requirements.

For Measurement & Verification purposes the outcome of the SANS 6211-1:2003 thermal performance test plays a vital role in determining the impact of a solar water heating system and will be discussed in the next section of the dissertation

2.5.2 The SABS Thermal Performance Tests

To relate the design criteria of a single solar water heating system to its performance the SANS, a division of the SABS, has developed test methods to determine the thermal performance of a solar water heating system. The SANS 6211-1:2003 and SANS 6211-2:2003 describes the tests, which were derived from the International Organisation for Standardisation (ISO), and involve the thermal performance evaluation of a solar water heating system under outdoor and indoor conditions respectively. The ISO 9459:1-5 documents were developed to facilitate the international comparison of solar water heating systems [34].

Both SANS tests involve the same testing procedure however the results from the outdoor thermal performance test will be used to finally characterise the performance of the system according to certain variables.

Six independent outdoor tests involve the exposure of a solar water heating system to a solar heating period of no less than 6 hours that is equally spaced around solar noon. During this period the amount of solar radiation that is incident on the solar collector is recorded in W/m^2 .

At the end of each heating period the solar collector is shaded and the accumulated hot water is drawn off at a rate of 600 litres/hour until 3 times the volume of the hot water storage tank has been discharged or when the inlet water temperature (T_c) equals the outlet water temperature. During the draw-off process the inlet, outlet and the ambient temperature (T_a) are recorded.

Six data sets containing different outputs are obtained. The results of three tests are used to draw temperature versus volume-drawn-off graphs and three energy outputs (Q) for the heating periods are calculated [14]. Figure 2-20 shows a typical example of the test results of an outdoor thermal performance test.

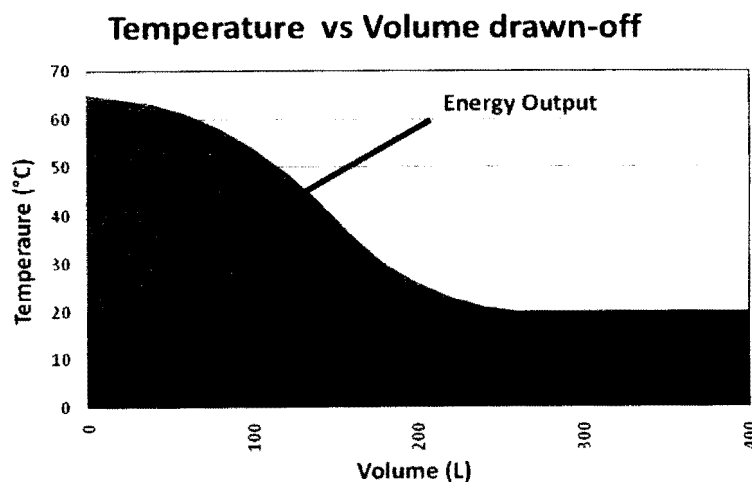


Figure 2-20: Typical example of SANS 6211-1:2003 outdoor thermal performance test.

The area (blue) under the curve and above T_c line is representative of the energy output of the solar water heating system. By using the results from three thermal performances outdoor tests equation 3, which correlates the energy output (Q) of the system, to the solar energy (H) that is incident on the solar collector and the difference between the daily average ambient temperature (T_a) and the incoming cold water temperature (T_c), are developed. The equation is developed through the process of multiple regressions [14].

$$Q = \alpha_1 \times H + \alpha_2 \times (T_a - T_c) + \alpha_3 \quad (\text{eq. 3})$$

Where,

- Q = the heat output, in mega-joules;
- α_1 = the coefficient in the equation for heat output of the system, in square meters;
- H = the radiation received by a surface over a specified time interval, in mega-joules per square meter;
- α_2 = the coefficient in the equation for heat output of the system, in mega-joules per Kelvin;
- T_a = the daily average ambient temperature, in degrees Kelvin;
- T_c = the incoming cold water temperature, in degrees Kelvin; and
- α_3 = the coefficient in the equation for heat output of the system, in mega-joules.

The individual alpha (α) coefficients are unique to a specific solar water heating system and are determined through simultaneous equation solving when the energy obtained from the solar water heating system is compared to the radiation received from the sun. When the alpha (α) values are used in conjunction with the equation mentioned above, the energy performance obtained from a specific solar water heating system can be determined according to varying weather conditions.

A heat loss coefficient of the solar water heating system is also determined through an overnight heat loss test. The test involves the process where the water in the hot water storage tank is heated to a temperature (T_i) greater than 60 °C. The storage tank is left to cool down for a period of 12 hours between sunset and sunrise under the influence of a wind speed of 3 to 4 meters per second to reach the final tank temperature (T_f). The heat loss coefficient is then calculated through equation 4 below.

$$U_s = \frac{C_s}{t} \ln \left[\frac{T_i \times T_a}{T_f \times T_a} \right] \quad (\text{eq. 4})$$

Where,

- U_s = the heat loss coefficient, in watts per Kelvin;
- C_s = the heat capacity of the hot water tank, in joules per Kelvin;
- t = the test period length, in seconds;
- T_i = the initial temperature in the hot water storage tank, in degrees Celsius;
- T_a = the average ambient temperature, in degrees Celsius;
- T_f = the final temperature of in the hot water storage tank, in degrees Celsius.

After the completion of the SANS 6211-1:2003 thermal performance test, a test report containing the results gathered during the test period is developed for each solar water heating system. The result from thermal performance test can be used to predict the performance of a solar water heating system and ultimately the impact thereof in the National Solar Water Heating Program. This report is available for M&V purposes.

A section in the ISO 9459:2 document with regards to the long term performance prediction of solar water heating systems has been omitted from the SANS documents. This section describes the procedure to be followed in order to predict the performance of solar water heating systems on an ongoing daily basis. The procedure takes into account the fact that the water in the geyser after the first day is already at a higher temperature than that of the incoming cold water temperature (T_c). This effect will reduce the amount of heat that is transferred to-and-stored in the geyser [40].

The same performance prediction principle that is described in the ISO 9459:2 might be used for performance prediction in smaller time intervals e.g. hourly.

2.5.3 Retail & Installation of Solar Water Heating Systems

Any Eskom accredited solar water heating system-supplier can retail their solar water heating systems to any home owner wanting to participate in the National Solar Water Heating Program. The home owner will purchase and install the solar water heating system after which a claim form can be submitted to Deloitte & Touche to claim back the incentive. To ensure that home owner's hot water needs are satisfied, guidelines around the size of the solar water heating system is given by Eskom (Table 2-2). Eskom considers an appliance that draws high quantities of hot water as an additional person [18].

Table 2-2: Indication of the optimal solar water heating system size

#	Household size	Solar water heating system size
1	1 Person/no household appliance	100 litre
2	2 Persons/household appliance	200 litre
3	3 Persons/household appliance	200 litre
4	4 Persons/household appliance	200 litre
5	5 or more person/household appliance	300 litre

With the completion of a solar water heating system installation the supplier must complete an installer form which states that the installation was done according to the program requirements. The installer form also contains, but is not limited to, the following information:

- Slope of solar collector (°);
- Direction of solar collector (°, or North, North-East, East etc.);
- Latitude of installation (°, or the City/Town/suburb can also be used but latitude is preferred);
- SABS test results (This is the 3 Alpha values, and heat loss coefficient);
- Geyser set point (°C), size (L) & element size (kW);
- New installation or retrofit;
- Any electrical back-up in hot water supply chain;
- Solar control strategy. (e.g. Timer periods and relays);
- Number of persons/household appliances in household;

- Home owner contact details;
- Supplier/installer contact details; and
- Physical address of installation.

The installer form is made available to M&V. Typical solar water heating system costs range between R12 000 for a 150 litre to as much as R45 000 for a 300 litre system [29].

2.5.4 The Incentive

To ensure the success of the program, four qualifying factors have been put into place which will ultimately determine the provision and the size of the incentive [16]:

- Product range (The selection of an optimal solar water heating system size);
- Energy output (As determined by the SABS);
- Guarantees offered (At least a five year guarantee is required); and
- Local content (Which takes into account Black Economic Empowerment (BEE), Black women Owned Enterprises (BWO) and Small, Micro and Medium Enterprises (SMME).

The incentive ($R_{\text{incentive}}$) will be determined by the following formula which relates the energy output (Q) of the solar water heating system, as determined by the SABS test results, the amount of local content (f_{LC}) in the system and the guarantee (f_G) [15].

$$R_{\text{incentive}} = R500 \times Q \times f_{LC} \times f_G \quad (\text{eq. 5})$$

The local content factor also takes into account BEE, BWO and SMME which can increase or reduce the incentive amount by up to 5%. The guarantee factor can increase or reduce the incentive amount by up to 20%. Typical incentives range around R3 000 although in some cases the incentive can be as great as R4 925 [29]. The incentive claim process is entirely the responsibility of the home owner however adequate assistance is supplied by the solar water heating installer to the home owner to complete the claim form.

2.6 Typical M&V activities of a DSM Project

When firms like Eskom, invest large amounts of capital in energy efficiency they would naturally want to know how much energy is being saved and are these savings being sustained. Many different energy efficiency projects, ranging from energy efficient lighting to energy efficient pumping systems are evident at this day and age.

To aid in the determination of energy savings of the different projects a replicable methodology, known as the IMPVP has been developed [4]. The South African M&V process & methodologies are based upon the IPMVP and provides guidance on how the savings can be determined for different types of project scenarios within the South African context. The South African M&V methodology is captured in the M&V Guideline for Demand Side Management Projects [3]. The guideline offers four M&V options to choose from (depending on the type of project) and will be discussed in the following section. The project stages involved and the deliverables accompanying each stage of the M&V process will also be discussed.

2.6.1 DSM and M&V Project Stages

M&V activities are conducted in conjunction to the DSM project and occurs in different stages while the projects progress. The completion of each project stage is marked by the issuing, and in some cases the agreement, of deliverables. M&V project deliverables play such a vital role in the success of the DSM project that the DSM project is halted until the deliverable and its findings are agreed upon by all the stakeholders involved.

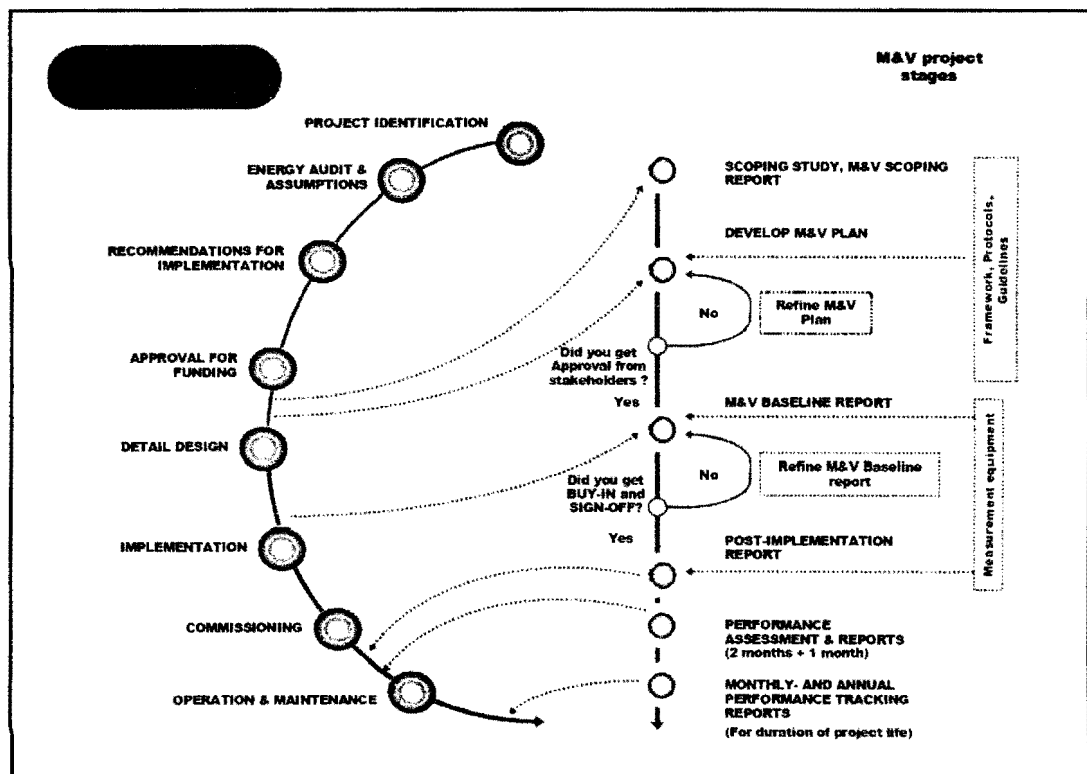


Figure 2-21: DSM and M&V project stages [3].

Figure 2-21 shows the interaction between the DSM and M&V project stages each with their corresponding deliverable.

After the DSM project has been identified an M&V Scoping study is done. The purpose of the M&V scoping study is to determine the M&V scope of work for the project and to estimate the feasibility of the proposed project activities. This is done by assessing and verifying the proposed energy management measures and its potential impact on electricity demand and energy consumption. The M&V Scoping report also provides the conclusions and comments of the M&V team with regards to the proposed DSM project.

Following the M&V Scoping study is the M&V Plan. The purpose of the M&V Plan is to provide an overview of the project specific M&V activities that will be performed and the planned conceptual processes these activities will follow. These activities are then scheduled within the DSM project's schedule. Buy-in on the M&V Plan must be obtained by all stakeholders before the M&V project can continue. Information that is typically included in the M&V Plan is the following:

- M&V project classification according to the South African M&V Guideline thereby determining the M&V methodology (Option A, B, C or D will be discussed in the next section); and
- The specification and installation procedures for the project-specific metering to collect the necessary data to develop, characterise and verify the baseline. The activities necessary to obtain the required M&V data after project implementation;

After acquiring the necessary DSM project data, the baseline model can be developed. The baseline represents what the electricity use would have been if the project was not implemented but under post-implementation conditions. The M&V Baseline report might contain additional information regarding service level adjustments which is used the scale the baseline to represent the electricity usage as it would have been prior to project implementation. Buy-in on the M&V Baseline report must be obtained by all stakeholders before the M&V project can continue.

After the project has been implemented an M&V Post-Implementation Assessment report is issued to all stakeholders. The purpose of the M&V Post Implementation Assessment report is to determine whether the DSM project has been implemented as intended. The M&V team will note the proposed DSM project intentions and compare them to the actual findings.

The project will now enter the performance assessment phase wherein the project will be evaluated against the energy consumption and power demand target. The evaluation period lasts for a period of three months which allows the Esco to alter the DSM measure to ensure that the intended electricity targets are reached if it has not done so. M&V Performance Assessment reports for each month are developed clearly stating the performance of the DSM intervention with regards to the intended electricity targets.

Accompanying the third M&V Performance Assessment report is the M&V-Performance Certificate and M&V Wrap-up report. These reports summarises the performance of the project up-to-date and certifies the achieved impacts.

The project will now enter the performance tracking phase wherein a monthly M&V Performance Tracking report is developed stating the performance of the project for that specific month as well the accumulated impacts, achieved after the project has been implemented. The tracking of DSM projects usually last for approximately 5 years depending on the performance contract between the stakeholders.

2.6.2 M&V Project Options

Each DSM project has its own constraints with regards to time, accuracy level, finances and has its own level of complexity. To accommodate the each constraint to a certain extent the South African M&V Guideline offers four different M&V Options which provide guidance in the determination of the impact of the project. These options are:

M&V Option A involves the isolation of the energy use of the affected equipment from the energy use of the rest of the facility. To isolate the relevant equipments' energy use, measurement equipment is used during the pre-implementation and post-implementation phase of the project. Option A only involves the measurement of some parameters and the stipulation of the remaining parameters. When stipulating parameters one has to show that the combined impact of the most likely errors from all such stipulations will not radically affect the reported impact. Option A is also called the Partially Measured Retrofit Isolation Option and is most commonly used in lighting retrofit projects. An example of M&V Option A is where the operating capacity of the lighting system is measured while the operating hours are stipulated [3].

M&V Option B also involves the isolation of the energy use of the affected equipment from the energy use of the rest of the facility. However, Option B demands that all parameters must be measured and no stipulation is allowed. The measurement period of Option B can be shorter than that of Option A but keeping in mind that continuous metering provides greater certainty of the impact calculation in some projects. Option B is also called the Retrofit Isolation Option and is most commonly used in water pumping projects. An example of M&V option B is where the operating capacities of the pumps are measured during both the pre-and post-implementation phase of the project [3].

M&V Option C involves the use of utility meters or sub-meters measuring the whole building to assess the energy performance of the entire building. Option C can be used to determine the impact of any type of project in a certain area/building/facility. If the specific area/building/facility has more than one energy savings project implemented the combined impact of all the projects are reported on. Option C is also called the Whole Facility Option and may be used in cases where there is a high degree of interaction between implemented energy saving activities or between the energy saving activities and the rest of the building. This option can also be used to determine the impact of an individual project when it is too difficult or costly to isolate the activity from the rest of the area/building/facility [3].

M&V Option D involves the use of computer simulation model to predict the impact of the project. Such a simulation model must be calibrated so that it predicts the energy-and-demand patterns to match the actual energy-and-demand patterns of either the pre-implementation or a post-implementation year to a certain extent. Option D is also called the Calibrated Simulation Option and is most commonly used in the residential/industrial load management projects. An example of M&V Option D is where the impact of switching off hot water cylinders or calorifiers during peak periods is simulated by a computer simulation model [3].

2.6.3 Existing M&V Methodologies

A vast range of M&V methodologies, based upon the different M&V Options in section 2.6.2, have been developed. M&V Pumping Project Guidelines, M&V Thermal Storage Guidelines and M&V CFL Project Guidelines are all project specific, directive documents that assist the M&V team in the M&V process. The following section will give a brief discussion of the National CFL Rollout, DSM RLM Projects as well as an M&V methodology used for solar water heating in the U.S.

National M&V CFL Rollout Methodology

The National CFL rollout methodology was developed in 2006 and is currently being used for Eskom's multi-million rand National CFL rollout.

The CFL rollout is very similar to the solar water heating program in the sense that in both cases an energy efficient product is installed in the residential sector to achieve demand and energy consumption impacts. Once the energy efficient product is installed it becomes the property of the home owner and is extremely difficult to track and determine the impact of each and every product without invading the privacy of the homeowners.

Due to the nature and the size of the CFL rollout it was decided that M&V Option A be used to determine the impact. Option A involved a software package in the form of an M&V CFL Application which uses pre-metered lighting profiles along with stipulated lamp counts to predict the operation of lighting system of a residential home before and after the installation/distribution of the CFLs. The difference between the pre-implementation (Baseline) and post-implementation conditions yield the impact of the project.

It was decided to classify the residential homes in three categories. Low (Classification 1), medium (Classification 2) and high (Classification 3) income households were fitted with profile metering and typical normalised operating profiles for each were developed (Figure 2-22). These profiles would serve as the basis of the baseline development.

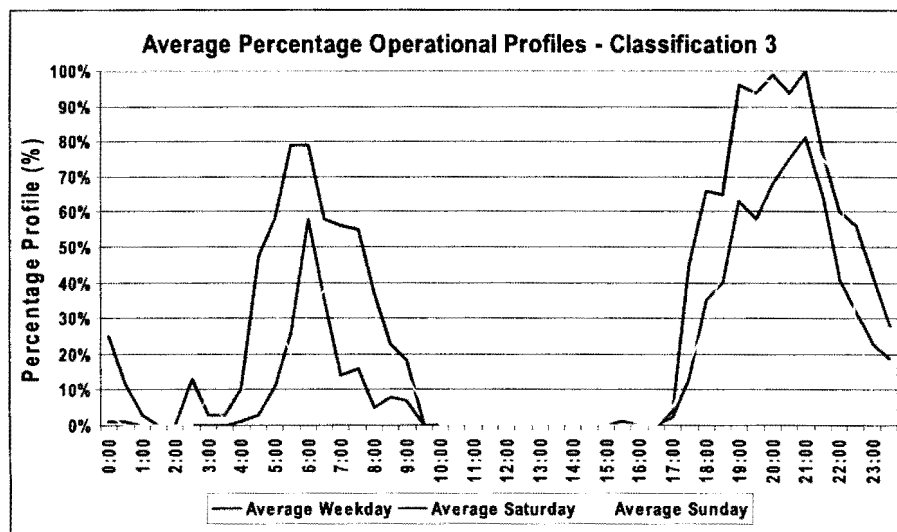


Figure 2-22: Normalised lighting profiles for a typical high income household [17].

The M&V process involved the gathering of information in order to develop and submit a combined Scoping & Baseline Report. The typical household income classification of the houses was noted and corresponding, normalised lighting profiles (Weekday, Saturday & Sunday profiles) were selected accordingly. The normalised profiles were adjusted with the number and size of the typical lights present in the homes to acquire baseline demand lighting profiles. Figure 2-23 shows an example of the baseline demand lighting profiles for an entire city with 18 000 high income households.

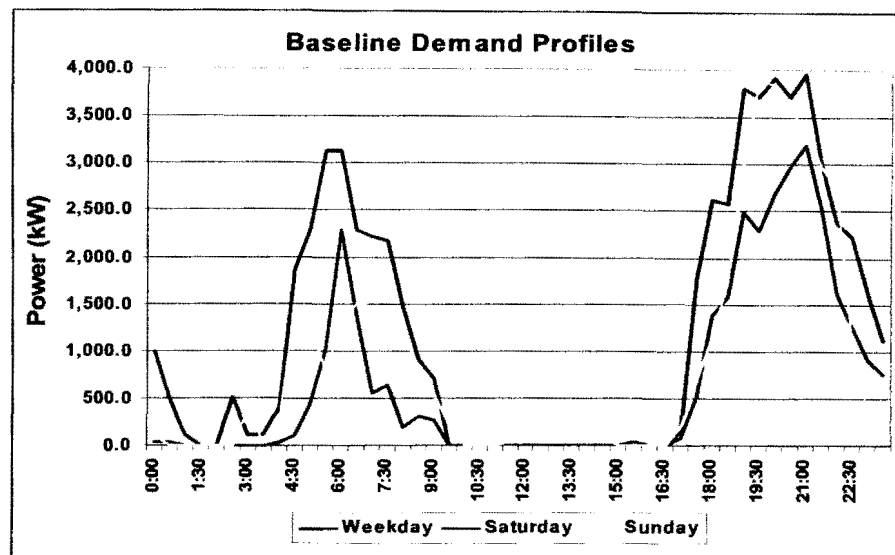


Figure 2-23: Baseline demand profiles for a city with a typical high income household [17].

The baseline demand profiles are developed in the M&V CFL Application and a screen capture of the application is given in Figure 2-24 showing the developed baseline profiles in blue.

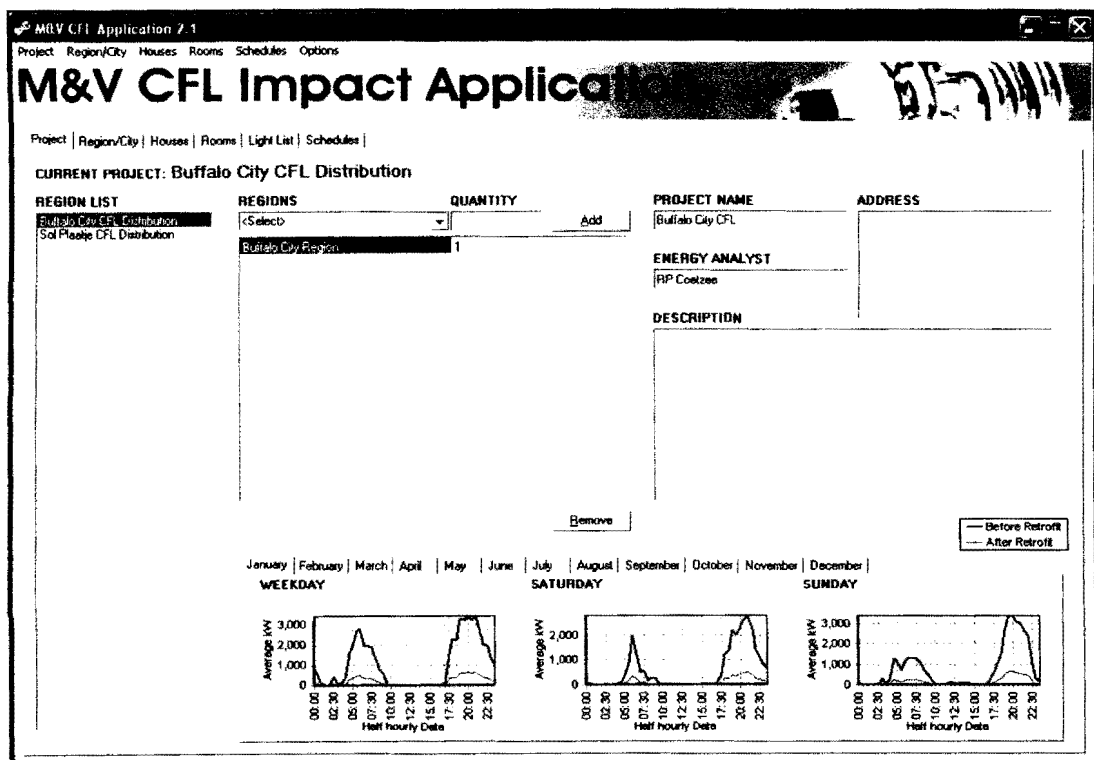


Figure 2-24: M&V CFL Application [17].

The baseline demand profiles along with the project information, project objectives as well as the proposed impact calculations are stipulated in the Combined Scoping & Baseline report. The Combined Scoping & baseline report is submitted to the stakeholders for approval and sign-off.

Upon completion of the project the M&V team conducts a post-implementation site visit. The site visit involves spot checks of the installations or distributions in the region and all findings and discrepancies are noted. With the help of the M&V CFL Application the post-implementation lighting operating profiles (Figure 2-24, red profiles) are determined and the impact of the project is determined. A Combined Post-Implementation and Performance Assessment report, stating the post-implementation findings and the performance of the project, is developed and submitted.

The project now enters the performance tracking phase where the impact of the project is determined by the M&V CFL Application on a six and twelve month basis. Sustainability assessments are also done on a six and twelve month basis in order to determine the sustainability of the project. This is done either telephonically or by means of a site visit to the households where after all the findings are reported on in the M&V Sustainability Assessment report.

Since the program began in 2004, Eskom has distributed more than 18 million CFLs to more than 315 000 residential houses. In the Western Cape region alone, 5.3 million CFLs were distributed which yielded a massive 229MW of measured and verified saving [28].

Residential Load Management M&V Methodology

The DSM, RLM project involves the installation of ripple control technology which prevents geysers from switching on during Eskom's peak demand periods. What distinguishes the RLM projects from the other DSM projects is the fact that developing the Baseline before implementation is virtually impossible as it is not possible to isolate the hot water demand profile of the geyser from the rest of the sub-station loads. The sub-station load hides the effect of the ripple technology and therefore makes it extremely difficult to determine the impact of the technology. Installing metering equipment on all the geysers (typically 15 000) is also not feasible from a cost and time perspective.

An M&V methodology has been developed to work around these problems which stipulates the impact of the RLM projects to an extremely high degree of accuracy. The methodology involves the conducting of notch tests which are done after the project is implemented. The notch tests are used to simulate what the electricity use of the geysers would have been prior to project installation but under post-implementation conditions.

The notch test determines the electrical hot water demand profile of all the geysers affected by the ripple control technology. All geysers receive an off-signal and after 5 minutes the on-signal is given again.

This process is repeated every 30 minutes and a notch profile is generated as shown in Figure 2-25 and Figure 2-26, below.

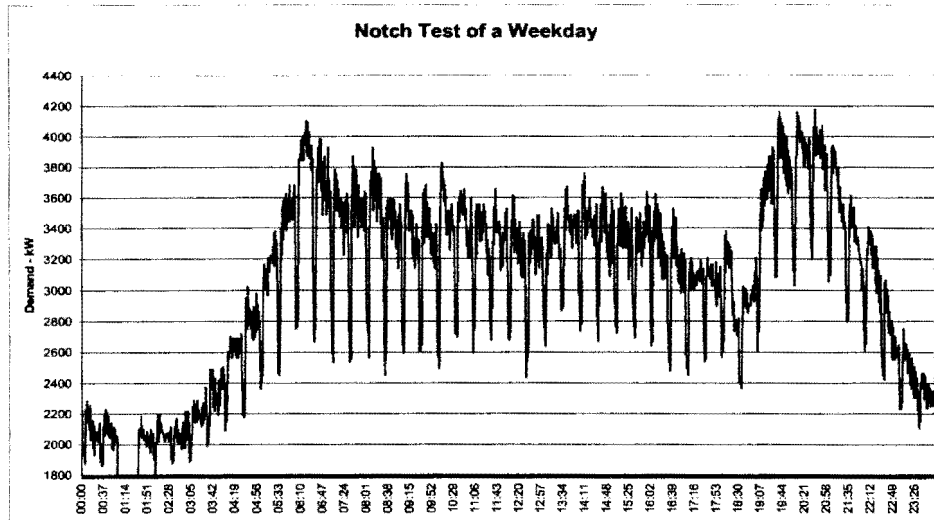


Figure 2-25: Example of notch test results at substation level for approximately 500 geysers [30].

The notch tests are done when no load control is done during the peak period in order to obtain the electrical hot water demand profile.

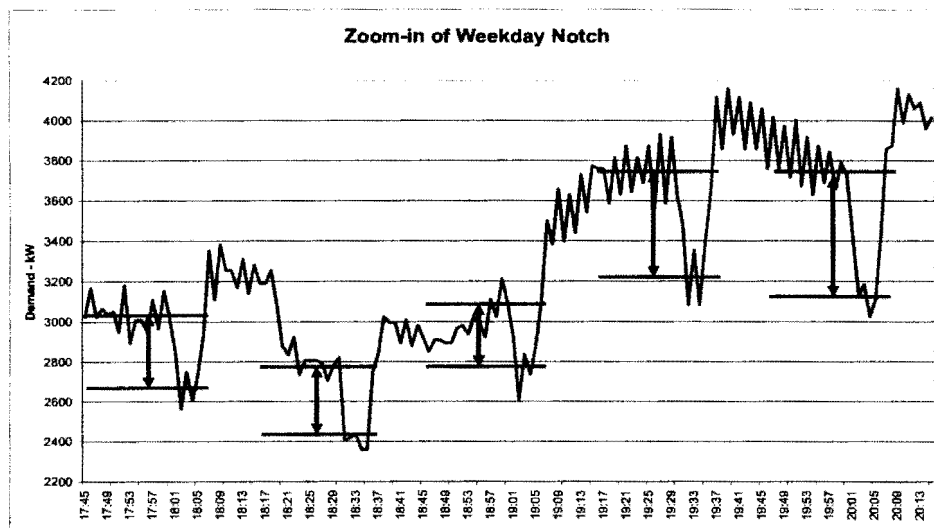


Figure 2-26: Zoomed-in of notch test results [30].

The extraction of this notch profile provides the electrical hot water demand profile of the affected geysers prior to the project implementation. The notch profile is imported into an RLM Simulation Application which firstly simulates it in terms of the usage events (%) and the amount of hot water used per event (litres) and secondly simulates the effect that the load shifting period has on the geysers.

Due to the load shifting activities in the peak demand periods it is expected that the geyser will lose thermal energy through standing losses as well as hot water usage and would therefore cause an electrical comeback load at the point where the geysers are switched back on. The RLM Simulation Application simulates this comeback load of the geysers with engineering equations and thermal energy balances.

Figure 2-27 shows a screen capture from the RLM Simulation Application where the comeback load of the geysers can be seen in the red profile. The blue profile indicates the electrical hot water demand profile prior to project implementation. The average storage capacity, inlet water temperature and set point of the geysers which is used as inputs along with the notch profile can also be seen.

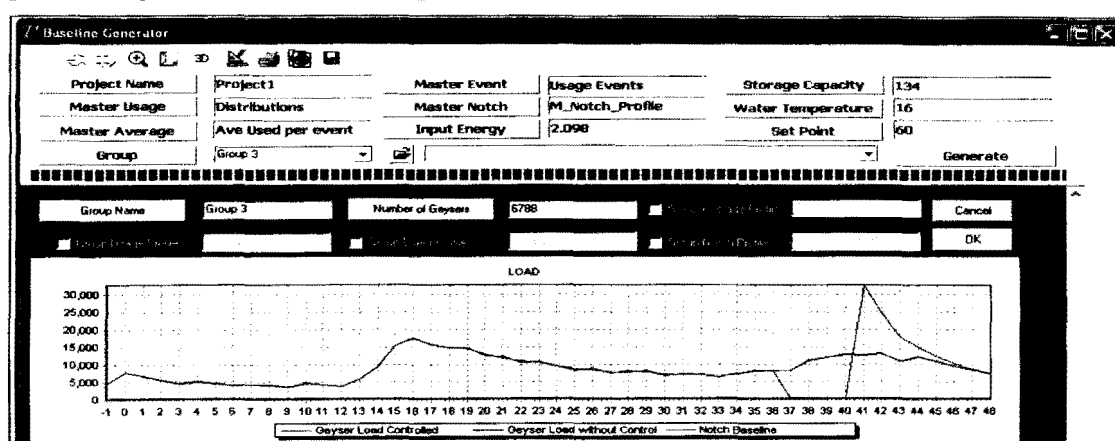


Figure 2-27: RLM Simulation Application.

The usual M&V deliverables like Scoping, M&V Plan, Baseline, Performance Assessment and Performance Tracking reports accompany the RLM project.

International M&V Solar Water Heating Methodology

More specific to solar water heating, an M&V methodology has been developed internationally. The United States' FEMP has published an M&V guideline for renewable energy project which include solar water heating. The guideline does not specifically state the M&V procedure but rather provides examples of solar water heating projects and which M&V Option was used to determine the savings.

According to the FEMP a project containing small systems, such as residential solar water heating systems, where the cost of M&V instrumentation may exceed the cost of the energy system, M&V Option A is suggested. The energy and cost savings of the solar water heating systems are stipulated based on engineering calculations in computer models and/or ratings provided by the SRCC. It is also suggested that periodic physical and operational inspections be done on some systems in order verify the sustained performance.

The FEMP suggests M&V Option B be used where the systems are located in close proximity of each other and the cost of the M&V instrumentation does not exceed the cost of the energy system. The full spectrum of metering equipment is installed ranging from thermal energy metering to electrical metering. The impact calculations can be done in the following ways:

- Control Group - Compare the metered results with similar loads that do not have renewable energy systems installed;
- Before and After - Allow for pre-installation metering period and compare with the post-implementation data;
- On and Off - Turn the renewable energy system off by bypassing it and compare the metered results with that of the renewable energy system switched on; or
- Calculated Reference - Determine the baseline by engineering calculations and compare with the metered results.

According to the FEMP, M&V Option C should be used where renewable energy systems form part of a larger suite of energy efficiency activities in a facility. The facilities metering or utility bills can be used to calculate the impact by subtracting the energy data from the baseline. The baseline can either be determined by one of the four methods mentioned above.

The “Calculated Reference” baseline in this case involves the identification of independent key performance indicators and relating them to the entire facilities energy-use through the form of a model. The baseline can therefore be adjusted as the service level changes. The FEMP experience showed that an accuracy of no better than $\pm 20\%$ is achieved with this option and therefore recommends that it be used for application where the renewable energy contribute a large part of the facilities load.

M&V Option D in the FEMP involves a calibrated simulation model which is developed from a short-term test. The model correlates the measured independent variable and the measures system performance through coefficients which can be adjusted to provide the most accurate simulated results. The disadvantage of this option is the fact that tests for all different types of solar water heating systems need to be done in order to simulate each to an acceptable degree of accuracy. However, running the simulation model with varying annual weather conditions and hot water demand profiles provide good estimates of the annual performance.

Although M&V methodologies have been developed for other Eskom DSM project no M&V solar water heating methodology has been developed to date. The internationally developed solar water heating methodologies act as good guidelines, however they have to be adapted to suite the South African solar water heating environment in order to ultimately determine the impact of Eskom's National Solar Water Heating Program. The need therefore exist to develop a methodology to measure and verify the impact of the National Solar Water Heating Program.

The knowledge areas applicable to this study were discussed in this chapter. The basic concepts around solar energy were discussed and a detailed look was taken at solar water heating and the existing simulation software. The National Solar Water Heating Program and its function in the DSM environment was explained. An overview of the existing M&V methodologies was presented and the need for an M&V methodology for the National Solar Water Heating Program explained.

3

Chapter

Proposed M&V Solar Water Heating Methodology

This chapter describes the proposed M&V Solar Water Heating Methodology. The methodology is discussed in the form of an M&V Guideline which will be used for the National Solar Water Heating Program.

3.1 Introduction

Due to the fact that the solar water heating program has a similar procedure to that of the CFL rollout, the methodologies are similar in some aspects. However, the solar water heating technology is much more complicated with a vast range of external influential factors and therefore has to be considered in more detail. A solar water heating system will also provide varying amounts of solar energy depending on all the parameters discussed in section 2.3.

The requirements from Eskom DSM, the solar water heating suppliers, financial-and-time constraints as well as the different solar water heating performance parameters were taken into account when the M&V methodology was developed. The following section describes the proposed methodology to M&V the impact of Eskom's National Solar Water Heating Program.

3.2 Proposed M&V Methodology

The M&V solar water heating methodology was designed to provide an impartial quantification and assessment of the program impacts that result from the DSM activities. A number of standardised deliverables have been developed to achieve the objectives of this type of M&V program. An M&V Plan is not omitted, since the prescribed M&V Solar Water Heating Guideline acts as the plan.

Formal instruction to start with the M&V of a certain number of pre-installed solar water heating systems (from here on called batch 1), are sent to the M&V team in the form of an Eskom request. The request will contain the following information with regards to each installation:

- Request date;
- M&V team's contact details;
- Eskom's contact details;
- Project number (Batch number);
- Project description;
- DSM sector (e.g. Residential);
- Project type (e.g. Energy Efficiency);
- Home owner name;
- Home owner address;
- Home owner contact number;
- Supplier name;
- Type of solar water heating system installed;
- Installation date;
- Installation number (bar code for that specific installation); and
- Batch MW target.

The M&V process start by visiting a sample of the solar water heating systems in order to verify the above information and to take photos of the installations. The following sections describe the M&V methodology, deliverables and the applications used to determine the impact of the National Solar Water Heating Program.

3.2.1 Pre-determined Baseline Profiles

Typical electrical hot water demand profiles (baseline profiles) for residential homes were acquired from other DSM projects due to the fact that no pre-installation metering period (Baseline metering period) is possible as any home owner can purchase and install any solar water heating system, anywhere in South Africa, at any given time. Hence, by the time M&V is notified the system is already installed.

Therefore, pre-determined baseline profiles were acquired and categorised. The baseline profiles are categorised by their location and the amount of people living in the home. The profiles are listed in the M&V Solar Water Heating Guideline for the use in the solar water heating methodology. The reason for this categorisation is because Eskom's guideline to install the optimal solar water heating system size is already categorised as discussed in section 2.5.3.

Not all categories have been assigned with baseline profiles at the time of this study due to a lack of data. However, if any further projects produce the electrical hot water demand profiles of the vacant categories these can be added. New baseline profiles can be added to the M&V solar water heating

methodology by sending the profile as well as its description to the North-West University (NWU) M&V team to incorporate them into the M&V Solar Water Heating Guideline. If no baseline profile is assigned to a category the average baseline profile for that location can be used. An example of some average weekday baseline profiles for different locations is shown in Figure 3-1.

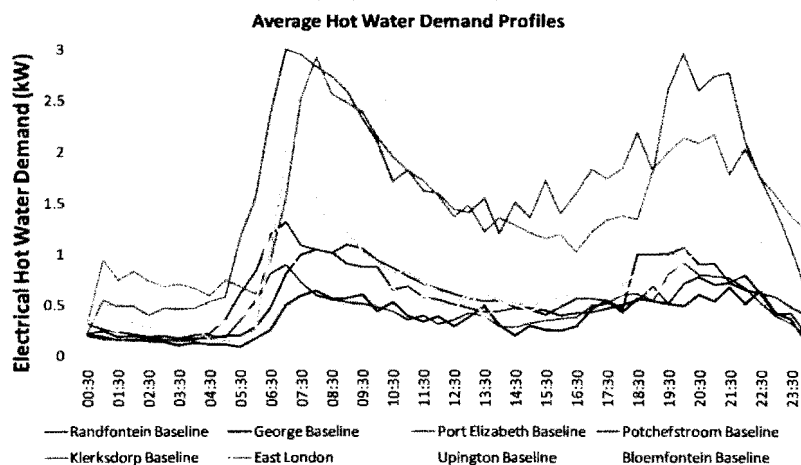


Figure 3-1: Average weekday baseline profiles [37].

3.2.2 Combined Scoping, Baseline & Performance Assessment Report

It was decided to submit a combined Scoping, Baseline and Performance Assessment report. The reason for this decision is due to the fact that the Eskom request is received after the solar water heating systems are installed and their impact can therefore be determined immediately. The purpose of the combined Scoping, Baseline and Performance Assessment report is to enable the M&V team to gather all relevant and available information, develop the baseline and determine the impact of the batch of solar water heating systems.

Scoping Section

The information that should be acquired and stated in the scoping part of the report is the following:

- M&V team's contact details;
- Eskom's contact details;
- Project Number (Batch number);
- DSM sector (e.g. Residential);
- Project type (e.g. Energy Efficiency);
- Home owner name;
- Home owner address;
- Home owner contact number;
- Supplier name;

- Type of solar water heating system installed;
- Installation date;
- Installation number (bar code for that specific installation); and
- Batch MW target.

A more detailed description of the proposed DSM activity can be included in the report, as well as the photos taken on the initial sample site visits.

An M&V Solar Water Heating Application (refer to Chapter 4) has been developed to assist in developing the baseline and simulating the post-implementation energy use of the solar water heating systems. The application is Microsoft Excel based in which the user supplies/selects the solar water heating performance parameters (section 2.3) as inputs and simulates the performance of a solar water heating system. A detailed description of the M&V Solar Water Heating Application is given in section 4.

Baseline Section

In order to develop the baseline for the batch of solar water heating systems, the M&V Solar Water Heating Application requires only the location of installation and the number of people living in the home for each installation. The baseline for each solar water heating system is calculated by selected in an electrical hot water demand profile from the drop-down menu in the application as shown in Figure 3-2 and applying a simulation adjustment factor. The simulation adjustment factor, as approved by the IPMVP, was incorporated in the application in order to take into effect simulation as well as metering errors incurred during the development stage but as more data become available the aim will be to refine the application so that the simulation adjustment factor is not needed.

Select Baseline (Hot Water Demand) Profile	Port Elizabeth Profile 4 Baseline
Baseline (Hot Water Demand) Profile	Port Elizabeth Profile 4 Baseline
01:00	Port Elizabeth Profile 5 Baseline
02:00	Potchefstroom Ave Baseline
03:00	Potchefstroom Profile 1 Baseline
04:00	Potchefstroom Profile 2 Baseline
05:00	Potchefstroom Profile 3 Baseline
06:00	Potchefstroom Profile 4 Baseline
07:00	Potchefstroom Profile 5 Baseline
08:00	1.05
09:00	0.34
10:00	0.83
11:00	2.00
12:00	1.33
13:00	0.34
14:00	0.28
15:00	0.08
16:00	0.18
17:00	0.11
18:00	0.40
19:00	0.53
20:00	2.44
21:00	1.96
22:00	1.43
23:00	0.26
00:00	0.10
	0.64
	0.12

Figure 3-2: Selecting the baseline profile.

The selectable baseline profiles in the drop-down menu represent the following scenarios:

- Average Baseline – Representative of an average size home in that town/city/area;
- Profile 1 – Representative of a home with person/household appliance in that town/city/area;
- Profile 2 – Representative of a home with 2 persons/household appliances in that town/city/area;
- Profile 3 – Representative of a home with 3 persons/household appliances in that town/city/area;
- Profile 4 – Representative of a home with 4 persons/household appliances in that town/city/area; and
- Profile 5 – Representative of a home with 5 or more persons/household appliances in that town/city/area.

Although only the above-mentioned profiles are incorporated in the M&V methodology at this point in time, M&V teams with more relevant baseline profiles can send their profiles to the NWU M&V team to incorporate in the M&V Solar Water heating Application. Again it should be noted that Eskom considers an appliance that draws high quantities of hot water as an additional person.

The baseline for the batch of solar water heating systems is automatically calculated in the application by summing the different baseline profiles for each solar water heating system. The information that should be included in the baseline section of the report is:

- Each baseline profile that was used to develop the batch baseline profile in half-hourly intervals;
- The number of each baseline profile;
- The batch baseline profile in hourly intervals;

Performance Assessment Section

The M&V Solar Water Heating Application will be used to simulate the performance of each solar water heating system without any load management control (no ripple relay technology and/or timer switches effects) taken into account. The following inputs to the model are needed to simulate the performance solar water heating system:

- Geographical Location (for weather condition purposes);
- Slope of the solar collector (°);
- Orientation of the solar collector (°);
- Alpha 1 Performance coefficient of the solar water heating system (m^2);
- Alpha 2 Performance coefficient of the solar water heating system (MJ/K);
- Alpha 3 Performance coefficient of the solar water heating system (MJ);
- Heat loss coefficient of the solar water heating system (W/K);
- Average inlet water temperature (°C);
- Geyser set point (°C);

- Baseline (Hot water demand) profile (kW); and
- Electrical backup-installed or not.

The simulated results for each of the solar water heating system are summated to form the post-implementation, simulated electrical profile for the batch of systems.

To take the effect that load management activities have on the solar water heating systems the post-implementation, simulated electrical profile for the batch of systems should be inserted into the M&V RLM Application and simulated according to the normal RLM project procedure which is given in M&V RLM Guideline [31]. The only difference between the RLM project simulations and the solar water heating program simulation is the fact the post-implementation, simulated electrical profile is used as the notch profile and not the baseline profile.

Figure 3-3 shows an example of the expected come-back load (red profile) of a batch of solar water heating systems caused by load management activities between 18:00 and 20:00. Note that this is not an actual simulation and is for illustration purposes only.

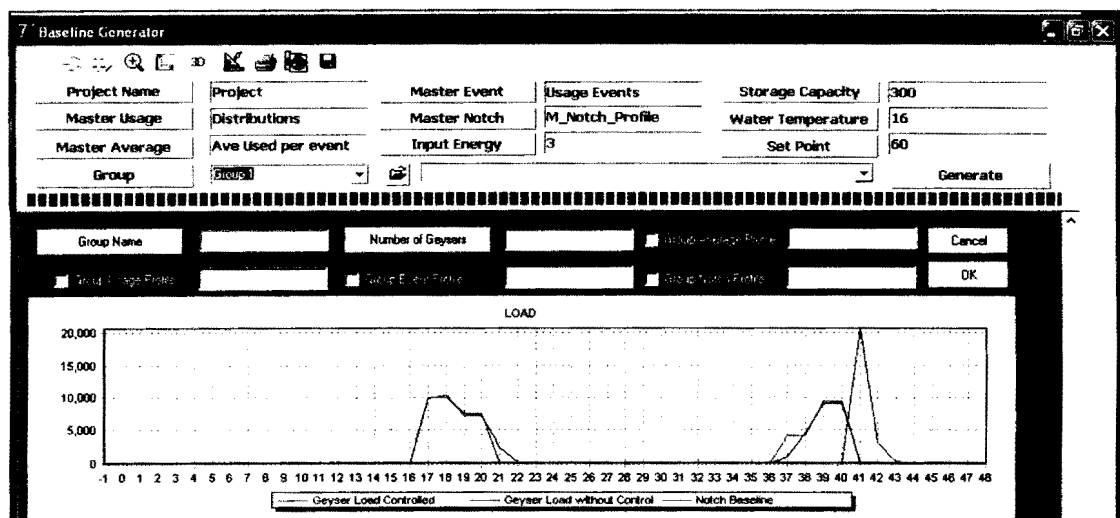


Figure 3-3: Simulating the comeback-load caused by load management activates.

The post-implementation electrical demand profile, with load management activities taken into account, can now be subtracted from the baseline profile to determine the impact of the batch of solar water heating systems. The information required to determine the energy, demand and cost savings of the National Solar Water Heating Program are:

- Baseline (Hot water demand) profile for the batch of solar water heating systems (kW);
- Post-implementation electrical demand profile, with load management activities taken into account (kW);
- Energy tariff structure by which the households are billed (R/kVA and R/kWh); and
- Conversion factors to determine emissions impacts (kg/MWh).

The achieved impacts of the batch of solar water heating systems for the month should be reported in the performance assessment part of the report in the form as indicated in Figure 3-4 below:

Actual vs. Intended Weekday Impact: (Reporting period e.g. 1 - 31 January 2009)							
	Weekday (MW)						
	Morning Off-peak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Evening Off-peak
Baseline Demand							
Actual Demand							
Actual Impact							
Intended Impact							
Over / Underperformance	%	%	%	%	%	%	%

Actual vs. Intended Weekend Impact: (Reporting Period e.g. 1 - 31 January 2009)						
	Saturday (MW)				Sunday (MW)	
	Morning Off-peak	Morning Standard	Midday Off-peak	Evening Standard	Evening Off-peak	Sunday Off-peak
Baseline Demand						
Actual Demand						
Actual Impact						
Intended Impact						
Over / Underperformance	%	%	%	%	%	%

Total Electricity Consumption (MWh): (Reporting period e.g. 1 - 31 January 2009)				
	Weekday	Saturdays	Sundays	Total
Baseline				
Actual				
Impact				

Financial Impacts: (Reporting period e.g. 1 - 31 January 2009)							
	Weekdays (Rand)		Saturdays (Rand)		Sundays (Rand)		Total
	Energy Consumed	Maximum Demand	Energy Consumed	Maximum Demand	Energy Consumed	Maximum Demand	Rand
Baseline							
Actual							
Impact							

Total Emissions Impacts: (Reporting period e.g. 1 - 31 January 2009)					
	Emissions				
	CO ₂ (kg)	NO _x (kg)	SO _x (kg)	Particles	Water (kl)
Baseline					
Actual					
Impact					

Figure 3-4: Impact reporting template of the solar water heating program.

The Combined Scoping, Baseline and Performance Assessment report will be sent to Eskom and not to the home owners or solar water heating suppliers. If any feedback with regards to achieved impacts is

required by the home owners or suppliers, Eskom can be contacted directly. Table 3-1 shows the installation possibilities that will be encountered in the solar water heating program:

Table 3-1: Installation possibilities for solar water heating systems.

	Prior to SWH System Installation	After SWH System Installation
Possibility 1	New Installation: Household has no geyser installed (In other words, no electrical element is present)	Household is supplied with a SWH System with no electrical backup (In other words, no electrical element is present any where in the hot water supply chain)
Possibility 2	New Installation: Household has no geyser installed (In other words, no electrical element is present)	Household is supplied with a SWH System with electrical backup (In other words, an electrical element is present any where in the hot water supply chain)
Possibility 3	Retrofit: Household has a geyser installed (In other words, an electrical element is present)	Household is supplied with a SWH System with no electrical backup (In other words, no electrical element is present any where in the hot water supply chain)
Possibility 4	Retrofit: Household has a geyser installed (In other words, an electrical element is present)	Household is supplied with a SWH System with electrical backup (In other words, an electrical element is present any where in the hot water supply chain)

For the purpose of the solar water heating program it is assumed that in the case of new installations (Possibility 1 & 2), a normal geyser would have been installed in any case and a baseline profile (not zero) will therefore be assigned to the installation. In the instance where no electrical backup element is installed (Possibility 1 & 3) the post-implementation electrical demand profile will be zero. However, all of last mentioned assumptions are taken into account automatically in the M&V Solar Water Heating Application.

3.2.3 Performance Certificate

One month after the Combined Scoping, Baseline and Performance Assessment report has been submitted to and acceptance by Eskom, the Performance Certificate will be issued. The Performance Certificate certifies that the M&V performance assessment period for the batch of solar water heating systems has been completed and that the performance is as stipulated in this report. This report is no different than the previously submitted Performance Certificates of the other M&V projects and the same format can therefore be used.

3.2.4 Performance Tracking

Both the Combined Scoping, Baseline & Performance Assessment report and the Performance Certificate is developed and submitted for a batch of solar water heating systems on which M&V is requested on in the Eskom request. Thus, when a new request is received for the next batch of solar water heating systems both the last mentioned deliverables have to be developed for the specific batch.

However, continuous tracking of the solar water heating systems is required and a Performance Tracking report consequently has to be submitted every March and September. A Collaborated Performance Tracking report is done where the data for all the batches are combined and the impact of all the installed solar water heating systems are determined. The Collaborated Performance Tracking reports will therefore provide a holistic overview of the performance of all the solar water heating systems and thus, the program.

The Combined Performance Tracking report has the same basic structure and sections as indicated in Figure 3-4 above. In addition to the report is the reporting of the savings for the accumulated period (since the installation of the solar water heating systems) and the reporting on the savings for the period since the start of the financial year end.

Prior to developing the Combined Performance Tracking report the M&V team should perform spot-checks on a 5% sample (as a minimum) in each batch in order to determine whether the solar water heating systems are still functioning and that the reported savings are actually being sustained. An M&V fieldworker form (Figure 3-5) should accompany the M&V team during the spot-checking and should be filled out in order to determine if the solar water heating system is still operating as intended.

The Combined Performance Tracking reports therefore will act as sustainability assessments to ensure that the M&V team reports on the actual achieved savings.

M&V Fieldworker's form		
A Fieldworker Information		
Name and Surname		
Tel number of Fieldworker		
Signature of Fieldworker		
B House Information		
Date Visited (yyyy/mm/dd)		
Name and Surname of home owner		
Tel number of home owner		
Street Address		
City		
GPS Coordinates (DD.mm'.ss")		
Home Information (✓ in applicable block) :		
1 Person / no household appliances that draws high quantities of water?		
2 Persons / household appliances that draws high quantities of water?		
3 Persons / household appliances that draws high quantities of water?		
4 to 5 Persons / household appliances that draws high quantities of water?		
5 or more Persons / household appliances that draws high quantities of water?		
PS: Every appliance counts as one additional person		
Answer Yes/No:		
Timer or ripple relay still active?		
Picture/Photo of the House:		
A digital photo with referenced photo number can be used in this space		
C Technical Information		
Solar Water Heating System		
Solar Water Heating System Name		
Solar Water Heating System Size (Litres, collector)		
Slope of collector (°)		
Orientation of collector face (°)		
Electrical Back-up installed?		
Geyser Set point (°C)		

Figure 3-5: M&V fieldworker form.

Chapter 3 discussed the proposed M&V Solar Water Heating Methodology and the M&V deliverables that accompany it. The M&V Solar Water Heating Application was introduced and the detailed description of the calculations done in the application will be given in chapter 4.

4

Chapter

M&V Solar Water Heating Application

A detailed description of the M&V Solar Water Heating Application is given in this chapter. The equations used to calculate weather parameters, baseline profiles and post-implementation electrical hot water demand profiles are also presented.

4.1 Introduction

The M&V Solar Water Heating Application has been developed to assist in determining the baseline and simulating the post-implementation electrical hot water demand profile of the solar water heating systems. The application is Microsoft Excel based in which the user supplies/selects the solar water heating performance parameters described in section 2.3 as inputs and simulates the performance of a solar water heating system without the effect of load management activates taken into consideration. The outputs of the application are the baseline profile and simulated electrical hot water demand of a batch of solar water heating systems in half-hourly intervals. Figure 4-1 illustrates an overview of the application and sections it consist of.

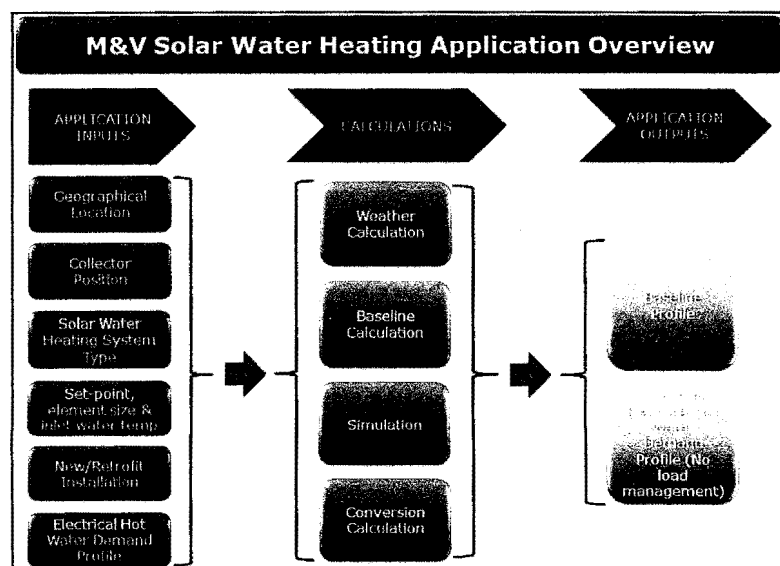


Figure 4-1: M&V Solar Water Heating Application Overview.

The M&V RLM Application, on its turn uses the electrical hot water demand profile to simulate the load management activates implemented on the solar water heating systems. A detailed description of the M&V Solar Water Heating Application is given in section 4.

4.2 Application Inputs

Primarily the application has six inputs for each solar water heating system. All cells marked in blue are editable and reserved for the user inputs while the cells in orange are either not editable or are selected automatically.

4.2.1 Geographical Location

The geographical location of each solar water heating system can be selected from a drop-down menu currently hosting 33 locations across South Africa. Weather data from the Meteonorm weather database for only these 33 locations are currently available however, as more data becomes available the locations list will be updated. Figure 4-2 shows the drop-down menu and some of the geographical locations available.

Solar Water Heating Model Inputs	System 1
Select Geographical Location:	Sasolburg ▾
Enter Collector Slope (°):	Sasolburg ▲
Enter Collector Orientation (°):	Soweto
Select Solar Water Heating System Type:	Springs
Alpha 1 value (m ²):	Tembisa
Alpha 2 value (MJ/K):	Umlazi
Alpha 3 value (MJ):	Upington
	Vereeniging
	West Rand

Figure 4-2: Selecting geographical location.

The hourly weather parameters available for each location for a period of a year are:

- Global solar radiation (diffuse radiation and direct radiation) on the horizontal plane (W/m²);
- Diffuse solar radiation on the horizontal plane (W/m²);
- Extraterrestrial radiation on the horizontal plane (W/m²);
- Solar azimuth (°);
- Height/altitude of the sun (°); and
- Ambient air temperature (°C).

The above mentioned weather parameters are used along with the collector position information to calculate the available solar radiation on the plane of the solar collector in hourly intervals and will be described in section 4.3.1.

4.2.2 Collector Position

The solar collector's slope and orientation are entered in the model in degrees (°). The slope of the collector is measured from the horizontal and range between 0° (horizontal) and 90° (vertical). The orientation of the collector is measured from South (0° in the case of the M&V Solar Water Heating Application) to North (180° in the case of the M&V Solar Water Heating Application). A collector facing West will therefore have an orientation of 90° and -90° when facing East.

E.g. A collector located in Sasolburg that is tilted 35° with respect to the horizon and facing North-West will have collector position inputs as indicated in Figure 4-3.

Solar Water Heating Model Inputs	System 1
Select Geographical Location:	Sasolburg
Enter Collector Slope (°):	35
Enter Collector Orientation (°):	135

Figure 4-3: Entering the collector position.

4.2.3 Solar Water Heating System Type

The M&V Solar Water Heating Application contains a database of all of the Eskom accredited solar water heating system types as well as their individual alpha coefficients, heat loss coefficients and geyser sizes. The user selects the solar water heating system type from a drop-down menu, as indicated in Figure 4-4, where after the relating alpha coefficients, heat loss coefficients and geyser sizes are automatically selected in the rows below the system type.

Solar Water Heating Model Inputs	System 1	System 2
Select Geographical Location:	Sasolburg	East London
Enter Collector Slope (°):	35	10
Enter Collector Orientation (°):	135	150
Select Solar Water Heating System Type:	Solahart 300L Direct	Atlantic 150L Direct
Alpha 1 value (m ²):	Solahart 300L Direct	0.75
Alpha 2 value (MJ/K):	Solahart 180L Direct	0.32
Alpha 3 value (MJ):	Solardome 200L Direct	0.61
Heat Loss Coefficient (W/K):	Solardome 300L Direct	4.14
Enter Geyser size (L):	Solardome 300L Indirect	150
Enter electrical back-up element size? (0 if no back-up):	Atlantic 150L Direct	2.00

Figure 4-4: Selecting the solar water heating system type.

At the time of the completion of this dissertation a total of 71 solar water heating system types were available in the application's database.

4.2.4 Geyser Set-point, Element Size and Average Inlet Water Temperature

The estimated geyser set-point in degrees Celsius (°C), geyser element size (kW) and the average inlet water temperature to the geyser are entered in to the model. Typical geyser set-points range from 55°C-65°C but can differ for the individual installations. The user has a choice when entering the average inlet water temperature. Although the inlet water temperature of the geyser varies according to weather

conditions at the time an average value of 16°C has been used in the RLM Application when determining the impact of the RLM, DSM projects. Until September 2009 the impact of more than 15 RLM, DSM projects have been reported on by using a 16° average inlet water temperature and have proven to be acceptable.

If the user chose to either have a varying average inlet water temperature, the word "CALC" can be entered in the corresponding cell which will allow the M&V Solar Water Heating Application to calculate the inlet water temperature with regards to the hourly-varying ambient air temperature. The following equation was derived from a year's measured half-hourly ambient air and inlet water temperature data and calculates the average hourly inlet water temperature:

$$T_i = 0.7846 \times T_a + 1.6357 \quad (\text{eq. 6})$$

Figure 4-5 shows the relation that was derived from the data and shows that the derived equation has an accuracy of 88.65%.

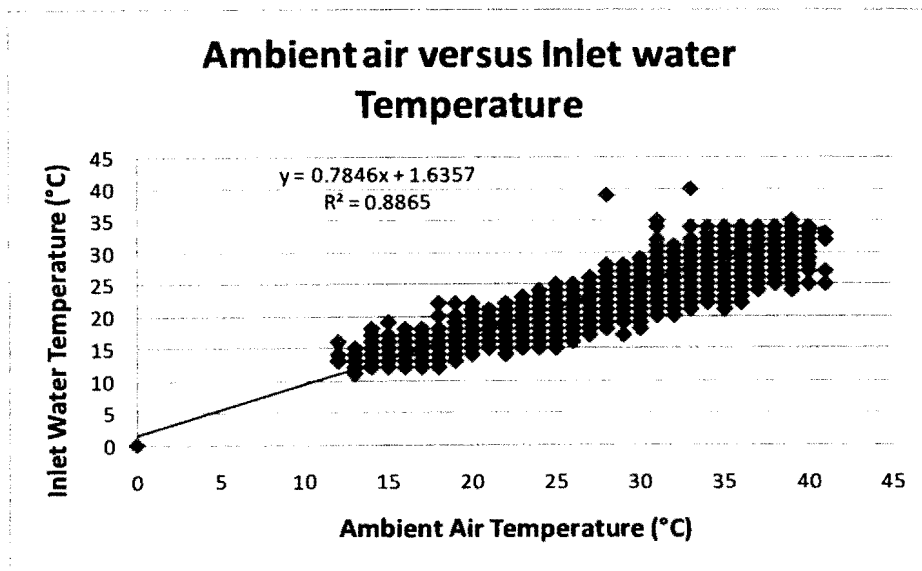


Figure 4-5: Ambient air versus inlet water temperature.

4.2.5 New or Retrofit Installation

The user enters the installation type for each of the solar water heating systems. By distinguishing between a new and retrofit installation in combination with whether the installation is fitted with electrical back-up the installation possibility as indicated in Table 3-1 can be identified. The calculation of the Baseline and post-implementation simulated electrical hot water demand profile can then be determined as explained in Table 4-1.

Table 4-1: Baseline and post-implementation simulated electrical hot water demand calculation.

	Prior to System Installation	After System Installation	Baseline Profile	Post-Implementation Electrical Demand Profile
Possibility 1	New installation: Household has no geyser installed (In other words, no electrical element is present)	Household is supplied with a solar water heating system with no electrical backup (In other words, no electrical element is present any where in the hot water supply chain)	As selected in M&V Solar Water Heating Application	Profile = 0
Possibility 2	New installation: Household has no geyser installed (In other words, no electrical element is present)	Household is supplied with a solar water heating system with electrical backup (In other words, an electrical element is present any where in the hot water supply chain)	As selected in M&V Solar Water Heating Application	Profile is simulated in M&V Solar Water Heating Application
Possibility 3	Retrofit: Household has a geyser installed (In other words, an electrical element is present)	Household is supplied with a solar water heating system with no electrical backup (In other words, no electrical element is present any where in the hot water supply chain)	As selected in M&V Solar Water Heating Application	Profile = 0
Possibility 4	Retrofit: Household has a geyser installed (In other words, an electrical element is present)	Household is supplied with a solar water heating system with electrical backup (In other words, an electrical element is present any where in the hot water supply chain)	As selected in M&V Solar Water Heating Application	Profile is simulated in M&V Solar Water Heating Application

4.2.6 Electrical Hot Water Demand Profile

The M&V Solar Water Heating Application contains a database of all available electrical hot water demand profiles which have been characterised as baselines according to the procedure in section 2.5.3. Not all the electrical hot water demand profiles were available and characterised at the start of the solar water heating program and therefore an additional category was added which is to be used in such cases where the required profile is not available. An additional average electrical hot water demand profile was created and represents a combination of category 1 to 5.

The user selects the most appropriate electrical hot water demand profile for that specific installation from a drop-down menu where the corresponding hourly profile will be shown in kW-values in the cells below (Figure 4-6). The referenced daily electrical energy consumption is also given at the bottom in kWh.

Select Hot Water Demand Profile	Stilfontein Ave Baseline
Hot Water Demand Profile	Stilfontein Ave Baseline
01:00	Stilfontein Profile 1 Baseline
02:00	Stilfontein Profile 2 Baseline
03:00	Stilfontein Profile 3 Baseline
04:00	Stilfontein Profile 4 Baseline
05:00	Stilfontein Profile 5 Baseline
06:00	Upington Ave Baseline
07:00	Upington Profile 1 Baseline
08:00	0.14
09:00	0.61
10:00	1.65
11:00	0.25
12:00	0.71
13:00	1.79
14:00	0.71
15:00	0.55
16:00	0.28
17:00	0.20
18:00	0.09
19:00	0.13
20:00	0.23
21:00	0.69
22:00	1.76
23:00	1.85
00:00	0.31
	0.58
	0.53
	0.46
kWh	14.26

Figure 4-6: Selecting the electrical hot water demand profile.

At the time of this dissertation 60 electrical hot water demand profile categories have been included in the database.

4.3 Application Calculations

The M&V Solar Water Heating Application consists of four calculation buttons which calculates four sections to ultimately provide the Baseline and simulated electrical hot water demand profiles. The four buttons shown in Figure 4-7 and the calculations that they address will be discussed in the next section of this dissertation.

Weather Calculation
Baseline Selection
Simulate
Hourly to Half Hourly

Figure 4-7: Calculation buttons.

4.3.1 Weather Parameter Calculation

By pressing the “Weather Calculation” button the total radiation incident on the plane of the user-defined collector is calculated. The total radiation consists of two mainly components. The direct solar radiation and the diffuse solar radiation are calculated by making use equations from Jones’s [39] and Perez et al.’s [32]. Jones calculates the direct radiation incident on a solar collector as follows:

$$I_{direct\delta} = I \times \sin a \times \sin \delta \pm I \times \cos a \times \cos n \times \sin \delta \quad (\text{eq. 7})$$

Where,

- $I_{direct\delta}$ = direct radiation incident on the collector, in watts per m²;
- I = direct radiation normal to the rays of the sun, in watts per m²;
- a = height/altitude of the sun, in degrees;
- δ = slope of the solar collector, in degrees; and
- n = wall-solar azimuth in degrees.

Perez et al. calculates the diffuse radiation incident on a solar collector as follows:

$$I_{D,Tilt} = I_D \times \left[(1 - F_1) \times \cos^2 \left(\frac{\delta}{2} \right) + F_1 \times \left(\frac{a_0}{a_1} \right) + F_2 \times \sin(\delta) \right] \quad (\text{eq. 8})$$

Where,

- $I_{D,Tilt}$ = diffuse radiation incident on the collector, in watts per m²;
- I_D = diffuse radiation incident on the horizontal plane, in watts per m²;
- F_1 = circumsolar brightness coefficients, which is dimensionless;
- F_2 = horizon brightness coefficients, which is dimensionless;
- $a_0 = \max[0, \cos(\text{INC})]$;
- $a_1 = \max[\cos(85^\circ), \cos(z)]$; and
- z = zenith angle, in degrees.

Perez et al. calculates the zenith angle as follows:

$$z = \cos^{-1}[\sin(LAT) \times \sin(DEC) + \cos(LAT) \times \cos(DEC) \times \cos(H)] \quad (\text{eq. 9})$$

Where,

- LAT = geographical latitude at which the collector is located, in degrees;
- DEC = solar declination for the southern hemisphere, in degrees; and
- H = hour angle/angle of radiation due to time delay, in degrees ($15^\circ \times (\text{Time} - 12)$).

Perez et al. calculates the angle of incidence that the sun's beam strikes a tilted collector as follows:

$$INC = \cos^{-1}[\cos(a) \times \cos(SOLAZM - n) \times \sin(\delta) + \cos(\delta) \times \sin(a)] \quad (\text{eq. 10})$$

Where,

- INC = diffuse angle of incidence, in degrees; and
- $SOLAZM$ = solar azimuth, in degrees.

The brightness coefficients F_1 and F_2 are functions of the zenith angle (z), sky clearness (ε) and the sky brightness (Δ). Sky clearness (ε) and sky brightness is calculated as follows:

$$\varepsilon = \left\{ \frac{I_D + I}{I_D} + 5.535 \times 10^{-6} \times z^3 \right\} / \{1 + 5.535 \times 10^{-6} \times z^3\} \quad (\text{eq. 11})$$

$$\Delta = m' \times I_D / I_{E,n} \quad (\text{eq. 12})$$

Where,

- m' = air mass for different atmospheric pressures; and
- $I_{E,n}$ = extraterrestrial radiation normal incident on the collector.

The air mass m' is calculated by the following three equations:

$$m' = m \times \left(\frac{P}{1013.25} \right) \quad (\text{eq. 13})$$

$$m = [\sin(a) + 0.50572 \times (a + 6.07995)^{-1.6364}]^{-1} \quad (\text{eq. 14})$$

$$\frac{P}{P_0} = \exp(-0.0001184 \times h) \quad (\text{eq. 15})$$

Where,

- m = air mass for standard pressure (1013.25 mbar);
- P = actual atmospheric pressure around the collector, in mbar;
- P_0 = standard atmospheric pressure, in mbar; and
- h = height above mean sea level, in meters.

The brightness coefficients F_1 and F_2 are then calculated as follow:

$$F_1 = \max[0, \{F_{11} + F_{12} \times \Delta + (\pi/180) \times z \times F_{13}\}] \quad (\text{eq. 16})$$

$$F_2 = F_{21} + F_{22} \times \Delta + (\pi/180) \times z \times F_{23} \quad (\text{eq. 17})$$

Where $F_{11}, F_{12}, F_{13}, F_{21}, F_{22}$, and F_{23} , are obtained from Table 4-2 by using the sky clearness (ϵ).

Table 4-2: Perez et al. slope irradiance coefficients [32]

Perez et al. Coefficients								
Eta(ϵ)	1	2	3	4	5	6	7	8
Lower bound.	1.000	1.065	1.230	1.500	1.950	2.800	4.500	6.200
Upper bound.	1.065	1.230	1.500	1.950	2.800	4.500	6.200	-
Irradiance								
F11	-0.0083	0.1299	0.3297	0.5682	0.8730	1.1326	1.0602	0.6777
F12	0.5877	0.6826	0.4869	0.1875	-0.3920	-1.2367	-1.5999	-0.3273
F13	-0.0621	-0.1514	-0.2211	-0.2951	-0.3616	-0.4118	-0.3589	-0.2504
F21	-0.0596	-0.0189	0.0554	0.1089	0.2256	0.2878	0.2642	0.1561
F22	0.0721	0.0660	-0.0640	-0.1519	-0.4620	-0.8230	-1.1272	-1.3765
F23	-0.0220	-0.0289	-0.0261	-0.0140	0.0012	0.0559	0.1311	0.2506

Finally equation 6 and 7 are solved to calculate the direct and diffuse radiation incident on the tilted solar collector.

4.3.1 Baseline Calculation

By pressing the “Baseline Selection” button the application applies the selected electrical hot water demand profiles to each day of the year, applies the simulation adjustment factor and summates it into a yearly Baseline profile. Figure 4-8 shows an extract of the summated Baseline profile in hourly intervals.

Timestamp	Time	Q_Baseline [kW]
2009/01/01	00:00	0.421
2009/01/01	01:00	0.114
2009/01/01	02:00	0.115
2009/01/01	03:00	0.117
2009/01/01	04:00	0.138
2009/01/01	05:00	0.611
2009/01/01	06:00	1.649
2009/01/01	07:00	0.247
2009/01/01	08:00	0.715
2009/01/01	09:00	1.791
2009/01/01	10:00	0.708
2009/01/01	11:00	0.546
2009/01/01	12:00	0.283
2009/01/01	13:00	0.197
2009/01/01	14:00	0.088
2009/01/01	15:00	0.130
2009/01/01	16:00	0.225

Figure 4-8: Extract of summated Baseline profile.

4.3.2 Simulation Calculation

By pressing the “Simulate” button the application simulates the post-implementation electrical hot water demand profile for systems with electrical back-up installed. The theory on which the application simulates what the electricity use of the solar water heating systems is based on the high-level, hourly energy balance of a solar water heating system and is given in the following equation:

$$Q_{usage} + Q_{losses} + Q_{res\ next} = Q_{solar} + Q_{electrical} + Q_{res\ prev} \quad (eq. 18)$$

Where,

- Q_{usage} = energy drawn from the solar water heating system in the form of hot water, in kWh;
- Q_{losses} = energy lost from the solar water heating system in the form of thermal losses, in kWh;
- Q_{solar} = solar energy gained from the solar radiation as calculated by the SABS equation (eq.3), in kWh;
- $Q_{electrical}$ = electrical energy inserted into the solar water heating system by the back-up element, in kWh;
- $Q_{res\ prev}$ = residual energy that was not used from the previous period and is carried over to the current period, in kWh; and
- $Q_{res\ next}$ = residual energy that was not used from the current period which is carried over to the next period, in kWh.

Included in Q_{usage} is a simulation adjustment factor that was derived from a comparison between actual measured data and simulation data and was found to be in the order of 0.46kWh/hour on average. The simulation adjustment factor compensated for simulation errors caused by metering errors that might have been present in the development stages of the application. However, as more data become available the aim will be to refine the application so that the simulation adjustment factor is required.

Due to the fact that the selected electrical hot water demand profile already contain standing losses for a normal geyser, only the standing losses due to the solar water heating system is incorporated in the energy balance. With favourable weather conditions a solar water heating system is capable of heating the water above the set-point temperature of the geyser and would therefore cause additional standing losses to those that have already been included in the selected electrical hot water demand profile.

I.e. The standing losses for the temperatures ranging between the inlet water temperature up to the geyser set-point temperature was already incorporated into the electrical hot water demand profile and only the standing losses caused by the temperatures above the geyser set-point temperature needs to be incorporated. The standing losses for the solar water heating system are calculated as:

$$Q_{losses} = C_s \times (T_a - T_{geyser}) \quad (eq.19)$$

Where,

- C_s = heat loss coefficient of the solar water heating system as calculated by the SABS in W/Kelvin;
- T_a = average ambient air temperature, in Kelvin; and
- T_{geyser} = average geyser temperature, in Kelvin.

It should be noted that equation 19 is only valid when T_{geyser} is greater than the geyser set-point. For geyser temperatures lower than the geyser set-point the solar water heating system's losses have already been included in the electrical hot water demand profile.

When Q_{solar} is calculated for the first hour it is calculated as indicated in section 2.5.2. For the following periods the inlet cold water temperature (T_c) is replaced with the geyser temperature (T_{geyser}). The geyser is therefore simulated from the time it is filled with cold water and heated by the solar energy. For the purpose of the M&V Solar Water heating Application it was assumed that the solar water heating system was already at operating temperature and therefore the temperature of the geyser (T_{geyser}) was assumed to be the geyser set-point temperature at the first hour of simulation.

The post-implementation electrical hot water energy ($Q_{\text{electrical}}$) required to deliver the remaining energy is calculated as follow:

$$Q_{\text{electrical}} = Q_{\text{usage}} + Q_{\text{losses}} - Q_{\text{solar}} - Q_{\text{res previous}} \quad (\text{eq.20})$$

The electrical energy $Q_{\text{electrical}}$ is limited to only supply the maximum energy for the calculation period. E.g. If the required electrical energy is calculated to be 2.2kWh and the electrical element can only deliver 2.0kWh, $Q_{\text{electrical}}$ for that period is calculated to be 2.0kWh and the remaining 0.2kWh is caught up in the next period.

4.3.3 Conversion Calculation

By pressing the "Hourly to Half Hourly" calculation button the hourly, backward-filling Baseline and post-implementation electrical hot water demand data for the year is converted to half-hourly, forward-filling data. The simulation calculations was done with hourly, backward-filling data due to the fact that the measured data that was gathered from the solar water heating metering equipment was in this format. Eskom however, requires M&V to report on project impacts in half-hourly forward-filling data.

4.4 Application Outputs

The outputs of the M&V Solar Water Heating Application are currently hourly and half-hourly, forward-filling Baseline and post-implementation electrical hot water demand data for a solar water heating system. Figure 4-9 illustrates a screen capture from the "Output" tab of the M&V Solar Water Heating Application.

HOURLY				HALF-HOURLY			
		With Electrical Backup				With Electrical Backup	
Timestamp	Time	Q_Baseline [kW]	Q_Electrical [kW]	Timestamp	Time	Q_Baseline [kW]	Q_Electrical [kW]
2009/01/01	00:00	0.839	0.839	2009/01/01	00:00	0.838643398	0.838643398
2009/01/01	01:00	0.801	0.801	2009/01/01	00:30	0.838643398	0.838643398
2009/01/01	02:00	0.776	0.776	2009/01/01	01:00	0.801320207	0.801320207
2009/01/01	03:00	0.743	0.743	2009/01/01	01:30	0.801320207	0.801320207
2009/01/01	04:00	1.024	1.024	2009/01/01	02:00	0.776340595	0.776340595
2009/01/01	05:00	1.071	1.071	2009/01/01	02:30	0.776340595	0.776340595
2009/01/01	06:00	3.196	3.196	2009/01/01	03:00	0.742662725	0.742662725
2009/01/01	07:00	2.042	2.032	2009/01/01	03:30	0.742662725	0.742662725
2009/01/01	08:00	2.239	2.178	2009/01/01	04:00	1.023594546	1.023594546
2009/01/01	09:00	2.690	2.542	2009/01/01	04:30	1.023594546	1.023594546
2009/01/01	10:00	1.362	1.055	2009/01/01	05:00	1.070776981	1.070776981
2009/01/01	11:00	1.986	1.558	2009/01/01	05:30	1.070776981	1.070776981
2009/01/01	12:00	1.264	0.736	2009/01/01	06:00	3.195784448	3.195784448
2009/01/01	13:00	1.259	0.675	2009/01/01	06:30	3.195784448	3.195784448
2009/01/01	14:00	1.549	0.957	2009/01/01	07:00	2.041851784	2.031799674
2009/01/01	15:00	1.248	0.693	2009/01/01	07:30	2.041851784	2.031799674
2009/01/01	16:00	1.749	1.260	2009/01/01	08:00	2.239147522	2.177935804

Figure 4-9: Screen capture of “Output” tab.

The electrical profile in the “Output” tab is the post-implementation electrical hot water demand of the uncontrolled solar water heating system. To simulate controlled solar water heating systems (I.e. a solar water heating system with a load management device) the electrical data can be averaged into an average Weekday and Weekend profile which acts as input (notch profile) to the RLM Application. The normal RLM procedure should be applied by means of the RLM Application Guideline to assist in simulating load management activities of the solar water heating systems [31].

The purpose of the RLM Application is to simulate the electrical hot water demand profile of the solar water heating system by taking into account the effect of load management technologies like timers and ripple control. By simulating the controlled electrical hot water demand profile in the RLM Application, energy is shifted from one period (typically 7:00-10:00 and/or 18:00-20:00) to the next and is therefore considered to be energy neutral on a daily basis. The effect of the load management technologies are thereof visible in the hourly or half-hourly electrical hot water demand profile and not in the daily energy, hence energy neutral.

For the purpose of this study the accuracy of the simulated electrical hot water demand of the solar water heating system was determined on a daily basis hence, the utilisation of the RLM Application was not necessary as it would have no effect on the daily energy consumption. The following section of the dissertation involves the applied M&V Solar Water Heating Application and the determination of the accuracy of the results.

In this chapter the M&V Solar Water Heating Application was discussed. The application's user-interface was described and the equations used to calculate weather parameters, baseline profiles and post-implementation electrical hot water demand profiles were also presented.

5

Chapter

Applied M&V Solar Water Heating Application

The specific solar water heating system as well as the solar water heating metering system that was used to gather data from is discussed in this chapter. This chapter also constitutes the utilisation of the M&V Solar Water Heating Application and the comparison between the measured results and simulated results from the M&V Solar Water Heating Application.

5.1 Solar Water Heating System

In order to determine the accuracy of the M&V Solar Water Heating Application measured data from a solar water heating system had to be obtained. The Eskom accredited solar water heating system in Figure 5-1, the name of which is confidential, was identified for data acquisition purposes. The system had undergone the SANS 6211-I:2003 thermal performance test and the following performance coefficients were awarded to the system [33]:

- $\alpha_1 = 0.62 \text{ MJ/m}^2$;
- $\alpha_2 = 0.09 \text{ MJ/K}$;
- $\alpha_3 = -0.75 \text{ MJ}$; and
- $C_s = -4.044 \text{ W/K}$.

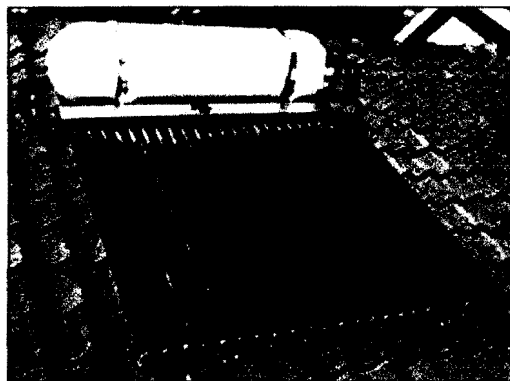


Figure 5-1: Example of the solar water heating system used for data acquisition purposes.

The system was located in Cape Town and was installed at a home with 4 residents. The direct, 200 litre, evacuated tube solar water heating system with a 1.8kW electrical back-up element. The system was installed on a single story, tile roof house and was orientated to face north-west and had a slope of 35°.

A solar water heating metering system had to be developed or sourced in order to measure different solar water heating dependant parameters and to ultimately compare the actual measured data to the simulated results from the M&V Solar Water Heating Application. In order to compare the results from the actual measured system and the M&V Solar Water Heating Application the measured data had to be analysed /processed. The following section explains the functions of the metering system, as well as the calculations used to process the measured data.

5.1.1 Metering system

A solar water heating metering system, specifically designed for solar water heating applications, was sourced and was used to measure a variety of parameters. The following parameters were measured at the locations as indicated in Figure 5-2:

- Cold water inlet temperature (°C) (point 1);
- Hot water supply temperature (°C) (point 2);
- Ambient air temperature (°C) (point 5);
- Water flow rate (l/s) (measured at point 1);
- Electrical energy consumed (kWh)(measured at point 3); and
- Radiation from the sun incident on a surface (kWh/m²) (measured at point 4).

Not only did the solar water heating metering system had to measure the above-mentioned parameters accurately but had to be able to read and store all the measured parameters in minutely intervals in order to be remotely downloadable. Unfortunately the sourced metering system was unable to accommodate logging intervals of less than 30 minutes due to a combination of appalling communication networks and memory storage. With the time and equipment constraints at hand, it was therefore decided that half-hourly data would have to be used for the time being.

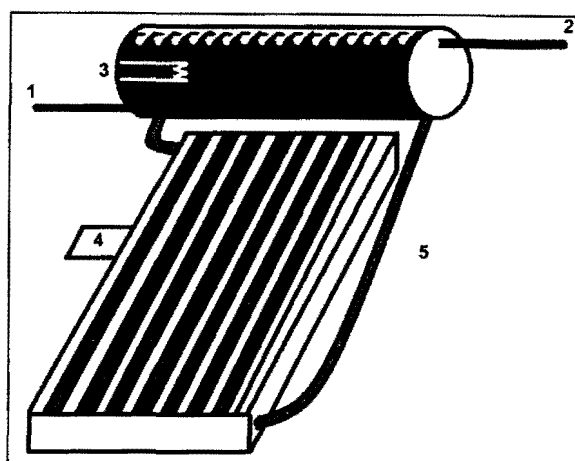


Figure 5-2: Typical solar water heating system with possible metering points indicated.

Water temperature measurements were done through non-intrusive PT-100 temperature probes which were strapped to copper pipes at the in-and-outlet of the geyser. The cold water inlet temperature probe was located as far as possible from the geyser in order to avoid the hot water temperature creep from the geyser. For a similar reason, the hot water outlet temperature probe was located as close as possible to the outlet of the geyser to avoid the temperature creep caused by the ambient air on the hot water outlet. The ambient air temperature was also measured through a PT-100 temperature probe located in close proximity of the solar water heating system. Figure 5-3 shows an example of the installation of the PT-100 temperature probes prior to being insulated.



Figure 5-3: Example of PT-100 temperature probe installation.

The electrical energy consumed by the electrical back-up element was not measured directly but rather through an on/off signal pickup that only determines when the element is on/off. Electrical energy consumption was therefore automatically calculated by the metering system through the following equation:

$$Q_{\text{electrical}} = (V_{\text{rms}} \times I_{\text{rms}}) \times \text{Element time} \quad (\text{Eq. 21})$$

Where,

- $Q_{\text{electrical}}$ = electrical energy consumed by the back-up element, in kWh;
- V_{rms} = Supply voltage (fixed voltage of 220V were selected);
- I_{rms} = Current drawn by a 1.8kW element (fixed amperage of 8.18A were selected); and
- Element time = determined from on/off signal pickup of metering system.

An intrusive flow meter was installed on the cold water inlet side of the geyser. The flow meter provided electrical pulses as output at 0.5 litres per pulse. The metering system automatically calculated the flow rate in half-hourly intervals. Figure 5-4 shows a typical example of the location of the flow meter.

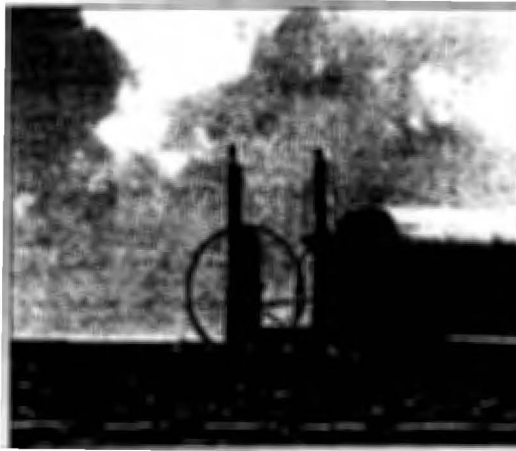


Figure 5-4: Example of flow meter installation on cold water inlet.

A silicon pyranometer was used to measure the radiation incident on the plane of the collector. The pyranometer was installed at the same slope as the solar collector as shown in Figure 5-5.



Figure 5-5: Example of pyranometer installation on same slope as solar collector.

The solar water heating metering system was installed on 22 June 2009 where it captured half-hourly data from the solar water heating system. After 44 days the measured data was acquired from the metering system and analysed/processed in order to be used to evaluate the accuracy of the M&V Solar Water Heating Application.

The reason why the metering system was setup for half-hourly intervals was due to a combination of an extremely poor remote-communications network, the small data storage capacity of the metering system and various time constraints. Knowing that data accuracy will decrease as logging intervals are increased, it was decided that half-hourly data would be used to evaluate the M&V Solar Water Heating Application for the time being.

5.1.1 Data Gathering, Analysis and Processing

Half-hourly data for 44 days were gathered through the metering system and converted into hourly values in order for it to be processed and used as inputs in the M&V Solar Water Heating Application. The hourly water flow, inlet and outlet water temperature were used to calculate the amount of energy drawn off in the form of hot water and was calculated by the following equation:

$$Q_{\text{usage}} = m_{\text{hour}} \times C_p \times (T_o - T_i) \quad (\text{eq. 22})$$

Where,

- Q_{usage} = energy drawn off in the form of hot water, in kWh;
- m_{hour} = the water flow rate, in litres;
- C_p = specific heat capacity of water, assumed to be fixed at 4.18 KJ/kg-K for simplicity reasons;
- T_o = outlet temperature of the water drawn off, in K; and
- T_i = inlet temperature of the water, in K.

As suspected the temperature readings of the hot water outlet were affected by the half-hourly logging intervals. What would happen was that hot water would be drawn for 2 minutes which would register a high (above geyser set-point) temperature reading however, for the remaining 28 minutes no hot water would be drawn off and temperature creep caused by the exposure of the pipe to the ambient air, would cause the temperature of the water to decrease. A half-hourly, average temperature lower than that of the geyser set-point temperature was logged by the metering system.

It was therefore decided to use the geyser set-point of 65°C (338.15K) rather than the measured outlet water temperatures in the calculation of Q_{usage} . This assumption was justified by the fact the electrical back-up element would ensure that the temperature of the hot water inside the geyser would not drop below the set-point as the measured data showed and was therefore considered to reflect more accurate representation of the hot water temperature.

The inlet water temperature readings were not affected as bad as the hot water outlet temperature for exactly the opposite reasons as mentioned above, and was therefore used as is. It was noted that large than usual quantities of hot water was drawn off by the household residents. Over the 44 day period an average of 439 litres per day of hot water was drawn off and was confirmed by the high electrical energy consumed by the electrical back-up element. An average household similar to this one would expect an average of 220 litres per day.

The standing losses of the solar water heating system and the hourly electrical energy consumed by the back-up element was calculated as indicated in equations 19 and 21 respectively. The total radiation incident on the plane of the solar collector as measured by the silicon pyranometer as well as the average inlet water temperature during draw offs and the average ambient temperature was also converted to hourly intervals.

For the purpose of avoiding large amounts of data and easy reading of the dissertation, the hourly data was converted in to daily values and are shown in Table 5-1 below. Figure 5-6 also shows the daily energy consumption data as depicted in Table 5-1.

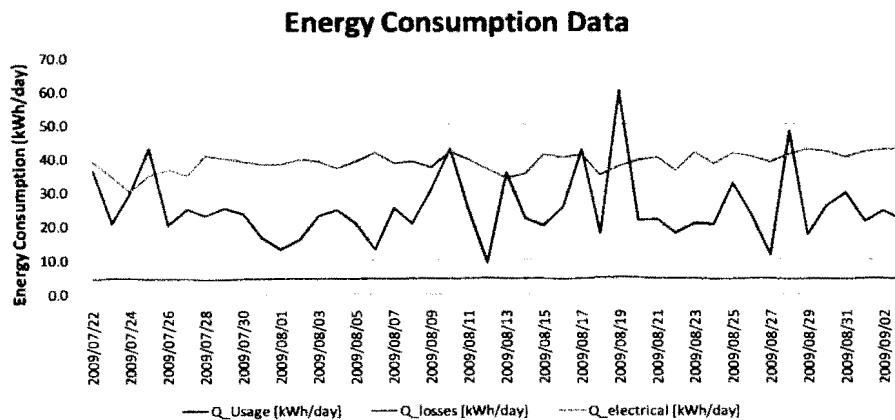


Figure 5-6: Graphical representation of daily measured energy consumption data.

As was previously mentioned, the M&V Solar Water Heating Application will be evaluated against the daily measured values inspection 5.2 of the dissertation.

Table 5-1: Daily measured and processed data.

Date	Average Cold Water Inlet Temp [°C]	Ambient Air Temp [°C]	Water Flow [l/day]	Q_Usage [kWh/day]	Q_losses [kWh/day]	Q_electrical [kWh/day]	Sun Energy [MJ/m ² /day]
2009/07/22	15.5	17.8	633.0	36.4	4.6	39.2	4.0
2009/07/23	11.7	14.7	341.0	21.1	4.9	34.8	4.2
2009/07/24	13.5	15.4	501.0	30.0	4.8	30.2	6.5
2009/07/25	14.4	16.8	732.0	43.0	4.7	35.1	6.5
2009/07/26	16.2	17.7	362.0	20.5	4.6	36.9	6.8
2009/07/27	18.9	19.0	467.0	25.0	4.5	35.0	6.6
2009/07/28	20.2	22.2	445.0	23.1	4.2	41.0	5.2
2009/07/29	15.2	20.6	440.0	25.5	4.3	40.0	4.2
2009/07/30	15.2	18.5	407.0	23.5	4.5	39.1	5.7
2009/07/31	14.8	17.4	289.0	16.8	4.6	38.3	4.7
2009/08/01	16.2	17.2	235.0	13.3	4.6	38.4	7.7
2009/08/02	16.7	18.1	289.0	16.2	4.6	39.6	7.1
2009/08/03	14.2	18.8	391.0	23.0	4.5	39.2	7.9
2009/08/04	14.1	16.6	418.0	24.7	4.7	37.2	2.3
2009/08/05	14.5	17.8	352.0	20.7	4.6	39.3	4.5
2009/08/06	16.1	18.5	236.0	13.4	4.5	41.8	6.2
2009/08/07	14.3	18.9	428.0	25.2	4.5	38.7	16.4
2009/08/08	15.6	19.5	360.0	20.6	4.4	39.1	8.2
2009/08/09	16.3	18.4	544.0	30.8	4.5	37.6	8.1
2009/08/10	17.2	19.5	771.0	42.8	4.4	42.0	7.1
2009/08/11	15.0	18.8	431.0	25.0	4.5	39.7	8.5
2009/08/12	9.7	14.7	144.0	9.3	4.9	36.9	5.3
2009/08/13	14.9	16.4	615.0	35.8	4.7	34.4	7.7
2009/08/14	17.9	19.5	403.0	22.0	4.4	35.6	33.2
2009/08/15	15.8	19.4	354.0	20.2	4.4	41.2	5.3
2009/08/16	19.2	20.6	479.0	25.5	4.3	40.3	9.0
2009/08/17	16.0	18.7	748.0	42.5	4.5	41.1	8.7
2009/08/18	11.1	14.1	286.0	17.9	4.9	35.1	2.5
2009/08/19	12.6	16.1	987.0	60.0	4.7	37.8	31.0
2009/08/20	13.8	16.1	361.0	21.5	4.7	39.6	18.5
2009/08/21	12.9	16.5	363.0	22.0	4.7	40.4	2.6
2009/08/22	14.4	16.7	304.0	17.9	4.7	36.3	10.9
2009/08/23	13.8	19.6	350.0	20.8	4.4	41.8	9.8
2009/08/24	16.2	21.1	361.0	20.5	4.3	38.4	10.0
2009/08/25	19.4	21.4	615.0	32.6	4.2	41.6	8.8
2009/08/26	15.7	18.5	409.0	23.4	4.5	40.7	6.8
2009/08/27	13.9	19.0	195.0	11.6	4.5	39.0	10.1
2009/08/28	14.3	21.7	817.0	48.1	4.2	41.1	8.3
2009/08/29	17.4	22.0	314.0	17.4	4.2	42.7	9.4
2009/08/30	15.8	21.6	452.0	25.8	4.2	42.1	11.9
2009/08/31	15.9	21.9	520.0	29.6	4.2	40.3	9.5
2009/09/01	16.0	19.0	376.0	21.4	4.5	42.0	7.5
2009/09/02	14.4	19.8	418.0	24.6	4.4	42.6	7.1
2009/09/03	15.6	20.3	374.0	21.5	4.3	42.6	7.5
Average	15.3	18.6	439.0	25.3	4.5	39.0	8.6

The daily average over the 44 days for the measured and processed data are also provided in Table 5-1 and indicates the average amount of energy drawn from the solar water heating system in the form of hot water is 25.3kWh/day. The average amount of standing losses and the average electrical energy consumed by the back-up element are 4.5kWh/day and 39.0kWh/day respectively. Due to the slope and orientation of the solar collectors only 8.6MJ/m²/day are incident on the plane of the collector.

It should be noted that the standing losses were calculated by using the set-point temperature of the geyser and therefore only includes the losses up to this temperature. The losses due to higher geyser temperatures were not calculated above however, the M&V Application does in fact do so.

5.2 Applied Application & Data Comparison

The daily electrical hot water demands of two scenarios were evaluated against the actual measured electrical hot water demand. One scenario involved the simulation of the electrical hot water demand by using the historical weather data from the Meteonorm global meteorological weather database whereas the second scenario used the actual measured data gathered from the metering system. In both cases the measured daily average energy required by the home was 29.8kWh/day (25.3kWh/day plus 4.5kWh/day).

Except for the weather data, which was altered for the two scenarios, the inputs to the M&V Solar Water Heating Application was preset, as seen in Figure 5-7 below.

Solar Water Heating Model Inputs		System 1
Select Geographical Location:		Cape Town
Enter Collector Slope (°):		35
Enter Collector Orientation (°):		135
Select Solar Water Heating System Type:		E3 200L Direct
Alpha 1 value (m ²):		0.62
Alpha 2 value (MJ/K):		0.09
Alpha 3 value (MJ):		-0.75
Heat Loss Coefficient (W/K):		4.04
Enter Geyser size (L):		200
Enter electrical back-up element size? (0 if no back-up):		1.80
Enter Geyser set point (°C):		65
Enter Average Inlet water Temp or type "Calc" to be calculated (°C):		Calc
New Installation or Retrofit?		Retrofit
Select Hot Water Demand Profile		Cape Town Ave Baseline
Hot Water Demand Profile		
01:00		0.25
02:00		0.24
03:00		0.24
04:00		0.24
05:00		0.54
06:00		0.82
07:00		2.87
08:00		1.47
09:00		1.59
10:00		1.96
11:00		0.55
12:00		1.09
13:00		0.31
14:00		0.25
15:00		0.51
16:00		0.20
17:00		0.72
18:00		1.64
19:00		4.09
20:00		2.95
21:00		2.04
22:00		2.81
23:00		2.54
00:00		0.28
kWh		29.79

Figure 5-7: Screen capture of "Input" tab for simulated solar water heating system in Cape Town.

The following section discusses the results acquired and the indices used to quantify the accuracy of the data.

5.2.1 Statistical Comparison Indices

The M&V Solar Water Heating Application simulates the electrical hot water demand profile of a solar water heating system in hourly intervals. However, due to the various restrictions of the high-level simulation some adjustments still need to be made to the application in order to be more accurate in

hourly intervals. Therefore, the results from the M&V Solar Water Heating Application were compared to actual measured data on a daily basis and not on an hourly basis. The accuracy of the application was evaluated by means of two statistical indices as prescribed by the IPMVP. These two indices are the following:

- Mean bias error; and
- Coefficient of variation of the root mean squared error.

The MBE is calculated by subtracting the simulated values from the measured values for all the data points over the measured period. The differences are summed and then divided by the sum of the measured values over the same period.

The MBE is expressed as:

$$MBE_{period} (\%) = \frac{\sum_{Period} (M-S)_{day}}{\sum_{Period} (M)_{day}} \times 100 \quad (\text{Eq. 23})$$

Where,

- M indicates the actual measured values; and
- S indicates the simulated values.

The CV (RMSE) is obtained by squaring the difference between paired daily data points, summing the squared differences over the period and then dividing it by the number of points which yields the mean squared error. The square root of that number yields the root mean squared error (RMSE). The CV (RMSE) is obtained by dividing the RMSE by the mean of the measured data for the measured period.

The root mean square is calculated by:

$$RMSE_{period} = \sqrt{\frac{\sum_{Period} (M-S)^2_{day}}{N_{day}}} \quad (\text{Eq. 24})$$

Where,

- N_{day} is the number of days in the measured period.

The mean of the measured period is calculated as:

$$A_{period} = \frac{\sum_{Period} (M)_{day}}{N_{day}} \quad (\text{Eq. 25})$$

The CV (RMSE) is then calculated by:

$$CV (RMSE)_{period} = \frac{RMSE_{period}}{A_{period}} \times 100 \quad (\text{Eq. 26})$$

The acceptable tolerances for MBE and CV (RMSE) according to the IPMVP [4] are:

- $MBE_{period} = \pm 7\%$
- $CV (RMSE)_{period} = \pm 15\%$

These indices have been used in more than 15 M&V RLM project simulations and have proven to produce credible results. The last-mentioned indices and their respective tolerance bands were used as statistical accuracy indicators on the results produced by the M&V Solar Water Heating Application.

5.2.2 Simulation of Radiation

The accuracy of simulating the global radiation (direct and diffuse), incident on a solar collector, for different locations and solar collector positions (slope and orientation) had to be determined. An hourly comparison between the simulated radiation, produced by the M&V Solar Water Heating Application, and the radiation from the Meteonorm weather database was done for a period of 1 year. Seven locations in South Africa were chosen for the comparison and the results are listed in Table 5-2 below. Note, that the collector orientation is as described in section 4.2.2 where North is equal to 180° or -180° .

Table 5-2: Radiation comparison result for seven locations.

	Bloemfontein	Cape Town	East London	Port Elizabeth	Pretoria	Sasolburg	Uptington
Collector Slope (°)	30	15	60	45	20	5	28
Collector Orientation (°)	-90	160	90	180	-135	135	-180
MBE (%)	0%	2%	0%	1%	1%	1%	2%
CV (RMSE) (%)	4%	9%	15%	7%	3%	5%	7%
MBE Tolerance (%)	$\pm 7\%$	$\pm 7\%$	$\pm 7\%$	$\pm 7\%$	$\pm 7\%$	$\pm 7\%$	$\pm 7\%$
CV (RMSE) Tolerance (%)	$\pm 15\%$	$\pm 15\%$	$\pm 15\%$	$\pm 15\%$	$\pm 15\%$	$\pm 15\%$	$\pm 15\%$

From Table 5-2 the maximum MBE and CV (RMSE) is 2% and 15% which is within the allowable tolerance band as depicted in the IPMVP. An extract of the data comparison of Uptington is provided in Appendix B of the dissertation.

5.2.3 Scenario 1: Simulation with Meteonorm Weather Data

The accuracy of the application's simulated electrical hot water demand had to be determined. Scenario 1 involved the simulation of the electrical hot water demand where the weather conditions from the Meteonorm global meteorological weather database were used. This entailed that averaged, historical weather data, gathered over a period of more than 20 years be used in the simulation. Table 5-3 shows the Meteonorm weather data along with the measured and simulated electrical energy.

Table 5-3: Simulation data by using Meteonorm data.

Date	Meteonorm Ambient Air Temp [°C]	Meteonorm Sun Energy [MJ/m ² /day]	Q_electrical (measured) [kWh/day]	Q_electrical (simulated) [kWh/day]
2009/07/22	17.2	19.6	39.2	37.1
2009/07/23	15.6	8.3	34.8	37.3
2009/07/24	14.9	19.5	30.2	34.2
2009/07/25	13.7	6.0	35.1	36.1
2009/07/26	11.8	19.4	36.9	31.2
2009/07/27	14.0	18.9	35.0	32.8
2009/07/28	14.4	19.6	41.0	33.5
2009/07/29	15.9	19.6	40.0	34.8
2009/07/30	13.9	21.5	39.1	33.5
2009/07/31	15.1	12.6	38.3	35.3
2009/08/01	12.8	18.6	38.4	32.9
2009/08/02	12.2	5.6	39.6	34.0
2009/08/03	11.2	5.5	39.2	33.1
2009/08/04	10.1	6.9	37.2	31.5
2009/08/05	11.9	20.1	39.3	30.3
2009/08/06	11.7	21.1	41.8	30.8
2009/08/07	10.7	20.8	38.7	29.6
2009/08/08	12.1	19.6	39.1	31.0
2009/08/09	11.4	11.6	37.6	32.3
2009/08/10	12.5	6.7	42.0	33.6
2009/08/11	13.1	10.6	39.7	33.6
2009/08/12	13.6	13.4	36.9	33.8
2009/08/13	12.9	12.1	34.4	33.6
2009/08/14	13.7	19.5	35.6	32.6
2009/08/15	13.2	8.4	41.2	34.8
2009/08/16	13.4	17.8	40.3	32.5
2009/08/17	14.9	13.3	41.1	34.7
2009/08/18	16.8	7.5	35.1	37.8
2009/08/19	17.8	23.0	37.8	36.5
2009/08/20	15.3	17.2	39.6	35.7
2009/08/21	13.9	11.7	40.4	35.1
2009/08/22	12.4	17.2	36.3	32.3
2009/08/23	12.6	20.9	41.8	31.3
2009/08/24	14.0	23.4	38.4	32.3
2009/08/25	15.0	18.7	41.6	34.4
2009/08/26	14.2	19.0	40.7	33.7
2009/08/27	15.5	22.2	39.0	34.0
2009/08/28	14.7	23.7	41.1	33.6
2009/08/29	14.4	13.8	42.7	35.0
2009/08/30	14.5	23.6	42.1	32.8
2009/08/31	15.8	22.8	40.3	34.1
2009/09/01	15.8	18.4	42.0	35.7
2009/09/02	16.2	24.1	42.6	34.5
2009/09/03	16.6	22.7	42.6	35.1
Average	13.9	16.5	39.0	33.7

During the 44 day evaluation period the average daily ambient temperature, according to the Meteonorm weather database, was 13.9°C with a daily average radiation of 16.5MJ/m². The simulated electrical hot water demand of the solar water heating system according to the M&V Solar Water Heating Application was 33.7kWh/day on average. When compared to the measured electrical hot water demand of 39.0kWh/day a difference of 5.3kWh/day on average was noted.

Figure 5-8 shows the measured, daily electrical energy of the solar water heating system when compared to the simulated, daily electrical energy. The reason why the simulated electrical energy is lower than the measured electrical energy is primarily because of the higher radiation level (higher than what was actually measured as indicated in Table 5-4), predicted by the Meteonorm weather data.

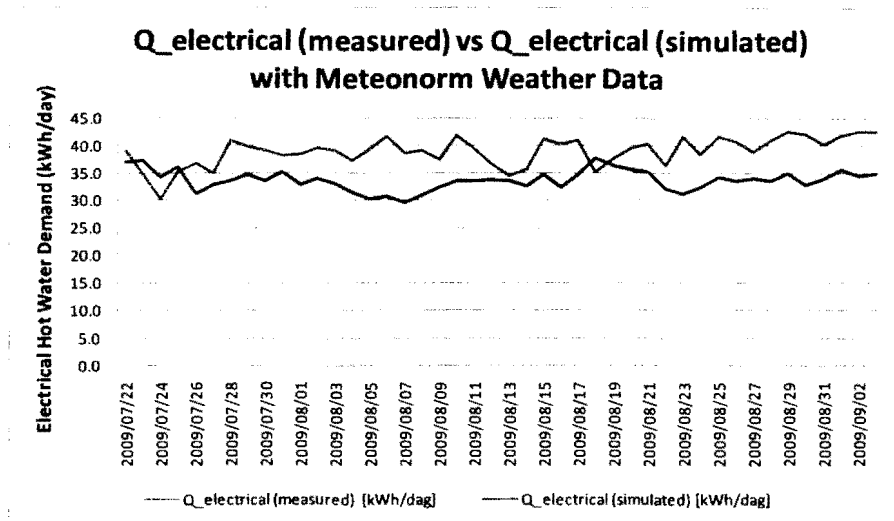


Figure 5-8: Electrical hot water demand comparison when using Meteonorm weather data.

The MBE and CV (RMSE) of the simulation using Meteonorm weather data are calculated to be 13.5% and 16.0%. These results indicate a reasonably sense of accuracy considering the fact that historical weather data was used in the calculation which will always differ from constantly changing actual weather patterns and would therefore influence the outcome of the simulation. These figures exceed the tolerance bands of the MBE and CV (RMSE) by 6.5% and 1.0% respectively however it is expected that they will improve if more data is available to be used for comparison.

5.2.4 Scenario 2: Simulation with Actual Measured Weather Data

Scenario 2 involved the simulation of the electrical hot water demand where the weather conditions from the actual measurements were used. Table 5-4 shows the actual weather data along with the measured and simulated electrical energy.

Table 5-4: Simulation data by using actual measured data.

Date	Measured Ambient Air Temp [°C]	Measured Sun Energy [MJ/m ² /day]	Q_electrical (measured) [kWh/day]	Q_electrical (simulated) [kWh/day]
2009/07/22	17.8	4.0	39.2	41.0
2009/07/23	14.7	4.2	34.8	37.3
2009/07/24	15.4	6.5	30.2	36.4
2009/07/25	16.8	6.5	35.1	38.1
2009/07/26	17.7	6.8	36.9	39.3
2009/07/27	19.0	6.6	35.0	39.4
2009/07/28	22.2	5.2	41.0	42.5
2009/07/29	20.6	4.2	40.0	43.2
2009/07/30	18.5	5.7	39.1	41.4
2009/07/31	17.4	4.7	38.3	39.1
2009/08/01	17.2	7.7	38.4	38.6
2009/08/02	18.1	7.1	39.6	39.5
2009/08/03	18.8	7.9	39.2	39.6
2009/08/04	16.6	2.3	37.2	39.5
2009/08/05	17.8	4.5	39.3	39.2
2009/08/06	18.5	6.2	41.8	40.1
2009/08/07	18.9	16.4	38.7	38.5
2009/08/08	19.5	8.2	39.1	41.2
2009/08/09	18.4	8.1	37.6	39.2
2009/08/10	19.5	7.1	42.0	40.9
2009/08/11	18.8	8.5	39.7	40.8
2009/08/12	14.7	5.3	36.9	37.1
2009/08/13	16.4	7.7	34.4	37.5
2009/08/14	19.5	33.2	35.6	34.4
2009/08/15	19.4	5.3	41.2	42.8
2009/08/16	20.6	9.0	40.3	40.9
2009/08/17	18.7	8.7	41.1	40.2
2009/08/18	14.1	2.5	35.1	37.5
2009/08/19	16.1	31.0	37.8	33.4
2009/08/20	16.1	18.5	39.6	34.7
2009/08/21	16.5	2.6	40.4	39.1
2009/08/22	16.7	10.9	36.3	37.1
2009/08/23	19.6	9.8	41.8	40.3
2009/08/24	21.1	10.0	38.4	41.7
2009/08/25	21.4	8.8	41.6	41.7
2009/08/26	18.5	6.8	40.7	41.8
2009/08/27	19.0	10.1	39.0	39.5
2009/08/28	21.7	8.3	41.1	41.6
2009/08/29	22.0	9.4	42.7	43.2
2009/08/30	21.6	11.9	42.1	43.2
2009/08/31	21.9	9.5	40.3	42.7
2009/09/01	19.0	7.5	42.0	41.2
2009/09/02	19.8	7.1	42.6	41.0
2009/09/03	20.3	7.5	42.6	41.5
Average	18.6	8.6	39.0	39.8

During the 44 day evaluation period the measured average daily ambient temperature, was 18.6°C with a daily average radiation of 8.6 MJ/m². The simulated electrical hot water demand of the solar water heating system according to the M&V Solar Water Heating Application was 39.8kWh/day on average. When compared to the measured electrical hot water demand of 39.0kWh/day a 0.8kWh/day difference on average was noted. Figure 5-9 shows a graph of the measured electrical energy of the solar water heating system when compared to the simulated electrical energy.

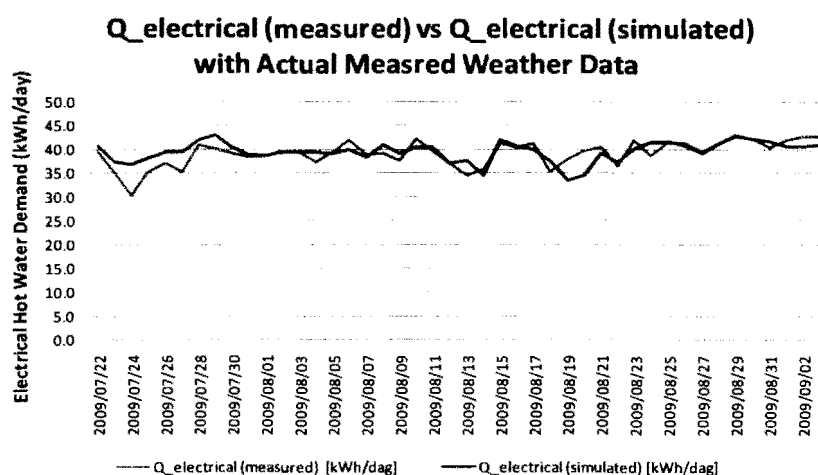


Figure 5-9: Electrical hot water demand comparison when using actual measured data.

The MBE and CV (RMSE) of the simulation acquired by using actual measured weather data are calculated to be -1.0% and 5.5% respectively. These results are well within the tolerance bands while an obvious trend between the two profiles is visible.

Table 5-5 shows the impacts achieved over the 44 day measurement period. A reduction of 49.3kWh was achieved which is only 3% of the electricity use. By looking at the amount of hot water demand for the residents and the size of the solar water heating system it is clear that the system is undersized. Contributing to the lower-than-expected impact is the collector position which does not face north to ensure maximum exposure to the radiation.

The solar water heating system can thus not keep up with the high hot water demand and therefore causes the electrical back-up element to be on for most of the time. Instead of sourcing its energy from the sun when it is available, the energy is inserted into the water through the solar water heating system's electrical back-up element.

Table 5-5: Impact achieved with actual measured data as inputs.

	Weekday	Saturdays	Sundays	Total
Baseline	1,292.65	243.13	247.92	1,783.71
Actual	1,256.40	237.21	240.83	1,734.44
Impact	36.26	5.92	7.09	49.27

The emission impacts achieved by the solar water heating system during the 44 days are shown in Table 5-6 below. The following emission factors, acquired from the Eskom Annual Report [35], were used to determine the emission impacts:

- CO₂: 1000kg/MWh;
- NO_x: 4.39 kg/MWh;
- SO_x: 8.69 kg/MWh;
- Particles: 0.23 kg/MWh; and
- Water: 1.44 kg/MWh.

Table 5-6: Emission impacts achieved with actual measured data as inputs.

	<i>CO₂ (kg)</i>	<i>NO_x (kg)</i>	<i>SO_x (kg)</i>	<i>Particles</i>	<i>Water (kl)</i>
Baseline	1,783.71	7.83	15.50	0.41	2.57
Actual	1,734.44	7.61	15.07	0.40	2.50
Impact	49.27	0.22	0.43	0.01	0.07

Chapter 5 presented the solar water heating system and the metering system used to gather data from. This chapter also explained the indices that were used to determine the accuracy of the M&V Solar Water Heating Application. The results from two simulation scenarios were compared and their accuracies were stated. The impacts achieved by the measured solar water heating system were also provided.

6

Chapter

Conclusions and Recommendations

Chapter 6 contains conclusions and recommendations both in terms of the M&V Solar Water Heating Application and Methodology. The dissertation is then concluded with some final remarks.

6.1 Conclusions

The objective of this study was to develop an M&V methodology to measure and verify the impact of a National Solar Water Heating Program. A research study had to be conducted to determine whether existing methodologies and technologies are able to produce the required results with regards to M&V. The research lead to the conclusion that an M&V methodology and application had to be developed in order to determine the impact of the National Solar Water Heating Program.

By taking into account the requirements and information available from a South African based solar water heating program in the Eskom, DSM environment along with financial, time and logistic constraints it was decided that an Option D approach be used to conduct the M&V. An Option D approach involved the development of a calibrated software computer simulation application which simulates the performance of a solar water heating system and therefore providing the solution to the variables in equation 1 of the dissertation.

Prior to developing the M&V Solar Water Heating Application, in-depth research on the fundamentals and more complex aspects of solar water heating had to be completed. Weather conditions, hot water demand, solar water heating system types and installation orientation were considered to be the most influential solar water heating system performance parameters.

The M&V Solar Water Heating Application enables the M&V teams to determine the impact of solar water heating systems without installing any expensive metering equipment. The application simulates the performance of a solar water heating system by providing inputs like geographical location, collector position, solar water heating system type, geyser set-point, element size and electrical hot water demand profile. The application calculated the solar contribution from the solar water heating system by means of

the SABS equation provided in section 2.5.2. It was assumed that with the prescribed ISO adaption the equation could be used for performance prediction on hourly intervals. The outputs of the application are half-hourly Baseline and Post-implementation electrical demand profiles which are used in equation 1. From the results in section 5.2 it is shown that the M&V Solar Water Heating Application is capable of providing accurate results that can be used to determine the impact of a solar water heating system.

Along with the application, an M&V Solar Water Heating Methodology had to be developed. Prior to developing the methodology, in-depth research on the fundamentals and more complex aspects around M&V had to be completed and fully understood. In order to obtain a better understanding of M&V in the energy management field the international accredited CMVP (Certified Measurement & Verification Professional) and CEM (Certified Energy Manager) training courses were attended and the author was awarded with the qualifications. Also, the author completed more than 20 M&V projects while the solar water heating methodology was developed in order to obtain knowledge in other M&V fields that might be useful in the solar water heating environment.

With the program procedure, time constraints, financial constraints and stakeholder's requirements in mind a proposed M&V methodology was developed to assist M&V teams in:

- Obtaining the information required by the M&V Solar Water Heating Application;
- Applying the M&V Solar Water Heating Application; and
- Reporting on the achieved impacts of the National Solar Water Heating Program to all the stakeholders involved.

The methodology not only involved the determination of the immediate impact of the solar water heating systems, but also the recurring sustainability assessments which determines whether the impacts are sustained over time.

6.2 Recommendations

The following recommendations are made to ensure continuous improvement of the M&V Solar Water Heating Methodology and the Application.

6.2.1 M&V Solar Water Heating Methodology

The M&V Solar Water Heating Methodology should be tailored to overcome any logistical inconveniences experienced when gaining access to the solar water heating systems. Through this improvement M&V teams should be able to acquire relevant data more easily and would therefore substantially shorten the time that is spent on site.

6.2.2 M&V Solar Water Heating Application

The current M&V Solar Water Heating Application hosts only 10 of the categorised 60 electrical hot water demand profiles which acts as baseline profiles. As time progresses and more electrical hot water demand profiles become available the application should be updated. More electrical hot water demand profiles will increase the versatility of the application as well as its credibility.

The application hosts only 33 locations and their weather parameters. Although difficult to find, location with their relating weather parameters should be sourced in order to cover more areas in South Africa.

The application currently caters for only one solar water heating system to be simulated at a time. In order to accommodate the thousands of solar water heating systems installed under the jurisdiction of the Eskom, DSM Solar Water Heating Program the application has to be expanded to simulate at least 1000 systems or more. By expanding the application to accommodate more systems time, money and resources will be saved in the long term.

The application was only verified by using data from one solar water heating system. It is advised that more metering systems be installed on solar water heating systems in order to obtain more data so that the application can be calibrated even further. A better calibrated application will result in more accurate impact predication which will provide stakeholders with an enhanced representation of their investment's performance.

6.3 Closure

Although the M&V Solar Water Heating Application and the proposed M&V Methodology has not been implemented prior to the completion of the dissertation they have set the process in motion to perform M&V on solar water heating systems installed across South Africa. Since July 2009, 1800 Eskom accredited solar water heating systems have been installed and the request to perform M&V on those systems was received in October 2009. Eskom is also in the process of supplying M&V teams with more solar water heating metering systems to ultimately obtain more data which will assist in tailoring the methodology and application.

Minister of Minerals & Energy, Ms Dipuo Peters said in her budget speech in June 2009 that the Department will install 1 million solar water heating systems within the next 5 years in order to reach their 10 000GWh target as set in the *White Paper on Energy Policy*. Also, the South African Government

along with the Clinton Climate Initiative (CCI) have signed a Memorandum of Understanding to develop a plan to establish a solar park in the Northern Cape before the end of 2009.

That being said, the future of solar energy in South Africa appears to be promising and while huge financial investments are being made, the need for M&V in the solar energy industry subsequently increases.

APPENDIX

Appendix A: Data CD

- 1. Dissertation in PDF format**
- 2. Microsoft Excel version of the M&V Solar Water Heating Application**

Note: Copyright of the M&V Solar Water Heating Application is reserved. No publication or dissemination of its contents is allowed without the author's written permission.

Appendix B: Extract from Radiation Data Comparison (Uppington)

		M&V SWH Application Global Rad (W/m ²)	Meteonorm Global Rad (W/m ²)			M&V SWH Application Global Rad (W/m ²)	Meteonorm Global Rad (W/m ²)			M&V SWH Application Global Rad (W/m ²)	Meteonorm Global Rad (W/m ²)			M&V SWH Application Global Rad (W/m ²)	Meteonorm Global Rad (W/m ²)
2009/01/01	01:00	0	0	2009/01/03	01:00	0	0	2009/01/05	01:00	0	0	2009/01/07	01:00	0	0
2009/01/01	02:00	0	0	2009/01/03	02:00	0	0	2009/01/05	02:00	0	0	2009/01/07	02:00	0	0
2009/01/01	03:00	0	0	2009/01/03	03:00	0	0	2009/01/05	03:00	0	0	2009/01/07	03:00	0	0
2009/01/01	04:00	0	0	2009/01/03	04:00	0	0	2009/01/05	04:00	0	0	2009/01/07	04:00	0	0
2009/01/01	05:00	0	0	2009/01/03	05:00	0	0	2009/01/05	05:00	0	0	2009/01/07	05:00	0	0
2009/01/01	06:00	0	0	2009/01/03	06:00	0	0	2009/01/05	06:00	0	0	2009/01/07	06:00	0	0
2009/01/01	07:00	47	48	2009/01/03	07:00	23	36	2009/01/05	07:00	23	35	2009/01/07	07:00	23	35
2009/01/01	08:00	188	193	2009/01/03	08:00	178	190	2009/01/05	08:00	182	187	2009/01/07	08:00	183	188
2009/01/01	09:00	374	407	2009/01/03	09:00	389	398	2009/01/05	09:00	349	368	2009/01/07	09:00	408	443
2009/01/01	10:00	612	643	2009/01/03	10:00	510	531	2009/01/05	10:00	628	660	2009/01/07	10:00	632	659
2009/01/01	11:00	831	850	2009/01/03	11:00	628	646	2009/01/05	11:00	787	809	2009/01/07	11:00	826	846
2009/01/01	12:00	953	962	2009/01/03	12:00	616	622	2009/01/05	12:00	904	905	2009/01/07	12:00	965	975
2009/01/01	13:00	1018	1004	2009/01/03	13:00	741	733	2009/01/05	13:00	931	916	2009/01/07	13:00	1052	1049
2009/01/01	14:00	1007	980	2009/01/03	14:00	788	769	2009/01/05	14:00	946	914	2009/01/07	14:00	1037	1015
2009/01/01	15:00	914	881	2009/01/03	15:00	644	631	2009/01/05	15:00	867	816	2009/01/07	15:00	949	929
2009/01/01	16:00	752	716	2009/01/03	16:00	527	518	2009/01/05	16:00	733	680	2009/01/07	16:00	777	751
2009/01/01	17:00	546	521	2009/01/03	17:00	630	577	2009/01/05	17:00	531	470	2009/01/07	17:00	561	534
2009/01/01	18:00	311	275	2009/01/03	18:00	342	284	2009/01/05	18:00	294	270	2009/01/07	18:00	360	313
2009/01/01	19:00	66	62	2009/01/03	19:00	81	66	2009/01/05	19:00	84	76	2009/01/07	19:00	94	84
2009/01/01	20:00	0	0	2009/01/03	20:00	0	0	2009/01/05	20:00	0	0	2009/01/07	20:00	0	0
2009/01/01	21:00	0	0	2009/01/03	21:00	0	0	2009/01/05	21:00	0	0	2009/01/07	21:00	0	0
2009/01/01	22:00	0	0	2009/01/03	22:00	0	0	2009/01/05	22:00	0	0	2009/01/07	22:00	0	0
2009/01/01	23:00	0	0	2009/01/03	23:00	0	0	2009/01/05	23:00	0	0	2009/01/07	23:00	0	0
2009/01/01	00:00	0	0	2009/01/03	00:00	0	0	2009/01/05	00:00	0	0	2009/01/07	00:00	0	0
2009/01/02	01:00	0	0	2009/01/04	01:00	0	0	2009/01/06	01:00	0	0	2009/01/08	01:00	0	0
2009/01/02	02:00	0	0	2009/01/04	02:00	0	0	2009/01/06	02:00	0	0	2009/01/08	02:00	0	0
2009/01/02	03:00	0	0	2009/01/04	03:00	0	0	2009/01/06	03:00	0	0	2009/01/08	03:00	0	0
2009/01/02	04:00	0	0	2009/01/04	04:00	0	0	2009/01/06	04:00	0	0	2009/01/08	04:00	0	0
2009/01/02	05:00	0	0	2009/01/04	05:00	0	0	2009/01/06	05:00	0	0	2009/01/08	05:00	0	0
2009/01/02	06:00	0	0	2009/01/04	06:00	0	0	2009/01/06	06:00	0	0	2009/01/08	06:00	0	0
2009/01/02	07:00	51	54	2009/01/04	07:00	24	37	2009/01/06	07:00	42	46	2009/01/08	07:00	23	33
2009/01/02	08:00	186	191	2009/01/04	08:00	209	219	2009/01/06	08:00	175	204	2009/01/08	08:00	198	205
2009/01/02	09:00	388	422	2009/01/04	09:00	457	472	2009/01/06	09:00	428	453	2009/01/08	09:00	418	445
2009/01/02	10:00	638	667	2009/01/04	10:00	692	709	2009/01/06	10:00	662	680	2009/01/08	10:00	581	613
2009/01/02	11:00	843	864	2009/01/04	11:00	875	892	2009/01/06	11:00	871	887	2009/01/08	11:00	803	826
2009/01/02	12:00	980	989	2009/01/04	12:00	977	988	2009/01/06	12:00	973	983	2009/01/08	12:00	949	958
2009/01/02	13:00	1051	1048	2009/01/04	13:00	1042	1035	2009/01/06	13:00	1041	1033	2009/01/08	13:00	1029	1018
2009/01/02	14:00	1035	1027	2009/01/04	14:00	1032	1017	2009/01/06	14:00	1028	1009	2009/01/08	14:00	1023	995
2009/01/02	15:00	949	926	2009/01/04	15:00	940	919	2009/01/06	15:00	933	906	2009/01/08	15:00	905	858
2009/01/02	16:00	762	722	2009/01/04	16:00	784	747	2009/01/06	16:00	781	735	2009/01/08	16:00	761	718
2009/01/02	17:00	549	518	2009/01/04	17:00	543	498	2009/01/06	17:00	536	493	2009/01/08	17:00	581	534
2009/01/02	18:00	346	303	2009/01/04	18:00	323	273	2009/01/06	18:00	327	280	2009/01/08	18:00	262	251
2009/01/02	19:00	89	80	2009/01/04	19:00	85	75	2009/01/06	19:00	85	69	2009/01/08	19:00	98	88
2009/01/02	20:00	0	0	2009/01/04	20:00	0	0	2009/01/06	20:00	0	0	2009/01/08	20:00	0	0
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2009/01/02	22:00	0	0	2009/01/04	22:00	0	0	2009/01/06	22:00	0	0	2009/01/08	22:00	0	0
2009/01/02	23:00	0	0	2009/01/04	23:00	0	0	2009/01/06	23:00	0	0	2009/01/08	23:00	0	0
2009/01/02	00:00	0	0	2009/01/04	00:00	0	0	2009/01/06	00:00	0	0	2009/01/08	00:00	0	0

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