SOLAR ENERGY FOR DOMESTIC USE

by

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A dissertation submitted in fulfillment of the Masters
Degree in Technology (Chemical Engineering)

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Cape Technikon

December 2000

DECLARATION

I hereby certify that this thesis is my own original work, except for the acknowledgements in the text

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October 2000

ABSTRACT

The demand for pool heating has increased dramatically over the last few years. This is ascribed to the idea that a swimming pool is expensive and can only be used for four months of the year. Therefore, a need for a relatively inexpensive solar heating system, capable of heating pool water to comfortable temperatures for an extended period, does exist.

The least expensive solar heating system for swimming pool heating on the market in South Africa is in the order of R 11000. This is a fixed system, usually mounted on the roof of a house. In order to ensure the safety of minors, a safety net or sail must be installed. This is an additional cost, which approximates R1500, yielding a total cost for safety and heating in the order of R 12500. Copper pipes packed in black material are utilised in these conventional heating systems, and it is the cost of this good heat conductor that makes these units expensive.

In this study an alternative pool heating system constructed of PVC was investigated. The system is designed to be flexible, mobile, act as a safety mechanism and absorbs the maximum amount of solar energy available. Dark blue material as opposed to black PVC was selected for aesthetic reasons at the expense of maximum efficiency.

The material strength was tested as well as the strength of adhesion. The influence of factors such as exposure to the sun and the effect of water containing chlorine and acid on the material were evaluated. Also, various means of channelling the water through the system for increased efficiency was investigated.

A pilot model was constructed and its performance evaluated. It has been concluded that the alternative approach provides effective heating at a lower cost

than current systems. Also, the durability of the design was found to be acceptable.

ACKNOWLEDGEMENTS

I wish to thank the following people/institutions for their contribution in the completion of this work.

- The Department of Chemical Engineering at the Cape Technikon for the use of the instrumentation and other laboratory facilities.
- Mr. Willie Coetzee, my supervisor, for his guidance and support.
- The company Plastamid for the use of their equipment in obtaining some experimental results.
- Dr. Fourie and Mr. Vlok for their help.
- My family for their support and encouragement.

CONTENTS

Page

CHAPTER 1

INTRODUCTION

For years, solar process heat systems have been contributing to hundreds of industrial, government, and commercial facilities in the U.S.A and all over the world, contributing significantly to their thermal energy loads. It is said that currently solar thermal systems exist on over 1 million buildings throughout the U.S.A and in aggregate constitute an equivalent thermal capacity of over one nuclear power plant.

In South Africa, solar energy is mostly used in heating pool water and in a lesser extent for heating domestic water, or preheating. Solar energy is currently utilised on a very small scale in South Africa, but is an energy force that must be considered.

Although pool heating by means of solar power does exist in this country it is currently very expensive and could not be afforded by most. A solar system for a medium sized pool costs between R8000 – R15000. In this study a reliable and less expensive solar heater is investigated.

1.1 Solar Process heat systems

Solar process heat systems exploit a readily available, free and constant source of energy, the sun. Depending on the application, there are several potential system designs and technology types that may be utilised.

Table 1.1 below is designed to illustrate the many market sectors, facility types, and applications where solar process heating systems can be found today all over the world [1].

Table 1.1

Market Sectors	**Facility Types**	**Applications**
Industry	Large Manufacturing Facilities	Air Preheating & Ventilation
Government	Hotels & Restaurants	Process Hot Air
Commerce	Multifamily Housing	Process Water Heating
	Hospitals	Water Heating
	Schools	Process Steam
	Prisons	Cooling & Refrigeration

For many of these market/application pairs (e.g. water heating systems for prisons), solar thermal energy systems represent a cost-effective and environmentally friendly alternative to traditional fossil fuel technologies.

In this study the heating of swimming pools and possibly the preheating of water for household use, at an affordable cost, was investigated. However, the use of solar energy should be used far more than that. It is currently an untapped, under utilised energy source in South Africa.

1.2 Pool heating

A pool is bought for enjoyment, entertaining and possibly for health reasons. It is found that on many days when an individual would like to use his/her pool, it is just too cold for comfort. Whether for recreation or relaxation, a comfortable pool is a great gathering place for family and friends.

Not only will the right solar heater make a pool warmer and more comfortable, it will add months to a swimming season. More relaxation, more exercise and more fun! As a bonus, greater values from the investment in buying a swimming pool!

1.3 Solar heating

Millions world wide have been enjoying solar heated swimming pools for over two decades. Heating swimming pools is today the largest use of solar energy in the world and there are good reasons for this.

For users in the industry, commerce and government, solar process heat offers several attractive advantages:

- It is a long lasting, reliable source of clean thermal energy that can replace 20-80 percent of thermal energy requirements provided by fossil fuels (e.g. fuel oil, natural gas, and electricity) [1].
- Solar systems are often more cost-effective on a life-cycle basis than alternative process heat systems. Since solar systems are designed to last 20-30 years, and pay for themselves in 3-10 years, they provide owners with as many as 20 years of practically free energy, saving a facility thousands of rands. greater capital layout but No (or minimal?) running/maintenance costs. Erase!
- Reliability and safety: Solar heating systems have no heat exchangers that fail from corrosion, no fan motors or compressors to break down. No other heating system offers that protection. Solar systems have no flames or fans, they just keep heating a pool quietly, safely and reliably, year after year.
- Protect the environment: You can enjoy the comfort of your solar heated pool, knowing that you are using an environmentally friendly energy source, while you conserve natural resources.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR RADIATION

To understand the practical aspects of solar energy, the basic resource, solar radiation, has to be understood [2].

Solar energy will be explained using the following:

- Waves. Solar radiation is an example of a general phenomenon called wave motion.
- Important properties of light.
- Black body radiation.

2.1.1 Wave motion

Two common types of waves are transverse and longitudinal waves.

Transverse waves are probably best explained by example. Take a pebble and drop it into a pond. A circular wave pattern spreads out from the point of impact. To illustrate the fact that the water does not move forward along the direction of the wave motion, a piece of wood is floated on the water. The wood only moves up and down and not in the direction of the wave. Therefore, it is called a transverse wave. This is because the medium through which the wave passes vibrates in a direction perpendicular (transverse) to the direction of the wave. This is further illustrated in Figure 2.1.

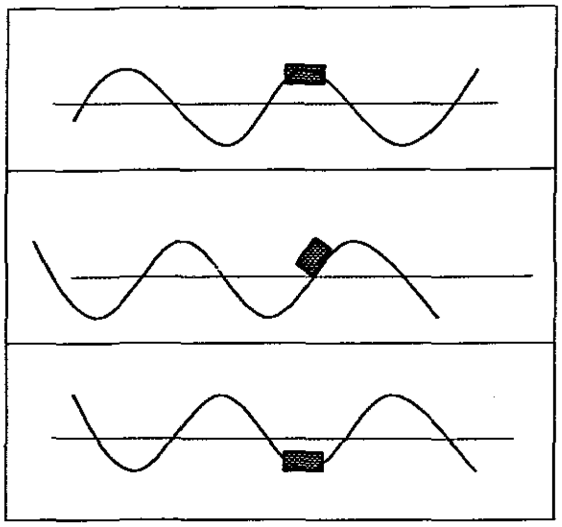


FIGURE 2.1 An illustration of a transverse wave.

To explain longitudinal wave motion, sound is taken as an example. When a loudspeaker vibrates it produce a wave disturbance that travels outward. As this wave motion moves outward the air molecules move in a localised region, back and forth along the direction of the wave. Therefore, it is called a longitudinal wave. Figure 2.2 is an illustration of such a case.

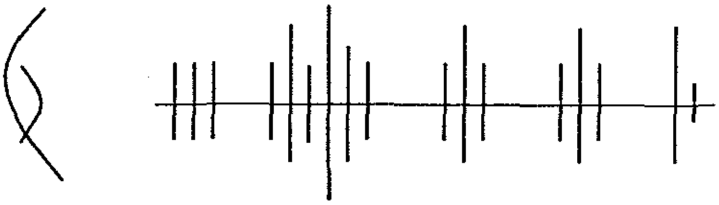


Figure2.2 An illustration of a longitudinal wave.

The similarity of these two wave types is that in each case a disturbance travels through some kind of medium, it can be air, water or something else.

When light is considered it is found that it has a unique feature, no material medium is necessary for the propagation of light. However, light is a transverse wave just like the water wave described in Figure 2.1.

2.1.2 Light

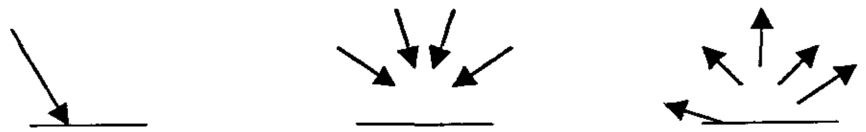
The sun, stars and lamps produce light. This type of wave motion is of great importance. Objects such as a desktop, carpet or paper does not produce light, and therefore it is said that whether an object emits light or not depends on its condition. This important condition is its temperature [2]. ↳ The Sun McDaniels

Light also does not need any physical medium to propagate, while other forms of wave motion does. Light is one form of a general type of wave motion called electromagnetic waves. Here the electric and magnetic fields vibrate and in a vacuum all such waves have the same velocity, irrespective of their frequency or wavelength [2].

Electromagnetic waves are named according to their different frequencies or wavelengths and their origin. If the sun is considered, the radiation coming from it can be divided into three wavelength regions:

1. Ultraviolet radiation (UV)
2. Visible spectrum
3. Infrared radiation (IR)

1. Ultraviolet radiation is a short wavelength radiation and is not visible to the human eye. Furthermore, solar, or short - wave radiation originates from the sun, in the wavelength range of 0.3 to 3.0 µm [3]. Solar radiation includes both beam and diffuse components unless otherwise specified. In Figure 2.3 short wave radiation is illustrated.



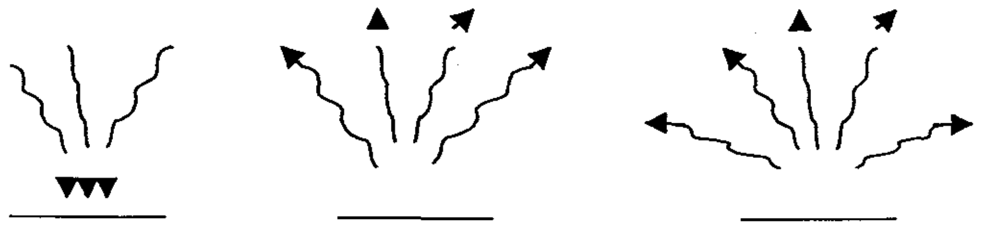
Beam solar radiation Diffuse solar radiation Reflected solar radiation

Figure 2.3 An illustration of short wave radiation

These rays are primarily responsible for suntan [2]. As UV radiation enters the solar atmosphere most of it is absorbed and does not reach the earth's surface. Due to damage to the ozone layer by certain chemicals, more UV radiation enters our solar atmosphere and hence the overall temperatures rise and the probability for skin cancer increases.

2. The visible spectrum is the middle wavelengths and can be seen by the human eye. When this white light is passed through a prism it brakes up into colours varying from violet to red. This occurs as a result of the varying speeds at which these wavelengths travel. In comparison to Ultraviolet and Infrared radiation, the visible spectrum is an extremely narrow band.

3. Infrared radiation (IR) is of long wavelength. Long wave radiation originates from sources at temperatures near ordinary ambient temperature [3]. All objects, the atmosphere, a collector, even ice or any other body, at ordinary temperatures emits long wave radiation. In Figure 2.4 long wavelength radiation is illustrated.



Long wave radiation from sky Reflected long wave sky radiation Long wave surface radiation

Figure 2.4 An illustration of long wave radiation.

The amount of energy radiated depends strongly on the temperature of the object [2]. Radiation emitted from surface temperatures below 426.67°C is very different in quality to the radiation of the sun since they only emit in the infrared and not in the visible or ultraviolet regions.

Solar collectors absorb energy of all three-wavelength regions although certain losses do occur. For example, glass covers normally used in solar collectors do not transmit (convey) very long wavelengths. All bodies reflect some of the light that falls on them.

2.1.3 Blackbody radiation

Warm materials emit radiation. At first it cannot be seen and as the temperature rises, visible radiation, that can be detected with the human eye, is emitted. The object will go from red hot to white hot as the temperature increases. The energy radiated by hot objects is distributed continuously over a wide range of wavelengths. More energy is associated with each wavelength, especially the shorter ones as the temperature increases. Later it was also found that at any specified wavelength, there was a maximum amount of radiation to be emitted. Therefore, when an object emits as efficiently as possible (an ideal emitter), it is referred to as a blackbody emitter [2].

To explain why it is called a blackbody emitter the following must be noted. Kirchoff showed that at any given temperature the emitting power of a surface is directly proportional to its absorbing power [2]. Therefore, a surface that absorbs all radiation of all wavelengths would also be the best possible emitter at all wavelengths. The total radiation from it depends solely on its temperature.

Kirchoffs law: EMISSIVITY = ABSORBTIVITY

$$\varepsilon = \propto$$

Thus, a black object that totally absorbs all radiation incident on it ($\propto = 1$) can also be defined as an object that emits radiation at the maximum rate possible ($\varepsilon = 1$). When this occurs it is called a blackbody emitter.

Most hot objects are not perfect emitters. The total radiation emitted by a real object is reduced by the factor ε, which is always smaller than 1.
Thus, total radiation by a real object:

$$E = \varepsilon\sigma T^4$$

where E = Radiation emitted (W/cm^2)
T = Temperature (Kelvin)

In order to utilise the radiant energy coming from the sun the precise nature of the rules that govern solar radiation are investigated. Three relations are considered:

- Planck's distribution function
- The Stephan-Boltzman radiation law
- Wien's displacement law

The first relation is the Planck distribution function. Instead of looking at the complicated mathematical form, the curves in figure 2.5, which precisely fit the blackbody theory of Planck, is considered. Each curve represents a blackbody emitter of a different temperature. The sun curve, which corresponds to 5800 K, is not shown, as it would be far off the top of the page. From the curves it is noticeable that any hot emitter emits radiation with a broad range of wavelengths. It is also important to note that the higher the temperature of the blackbody emitter, the more its radiation is concentrated at the shorter wavelengths and the larger the total amount of radiation that is emitted.

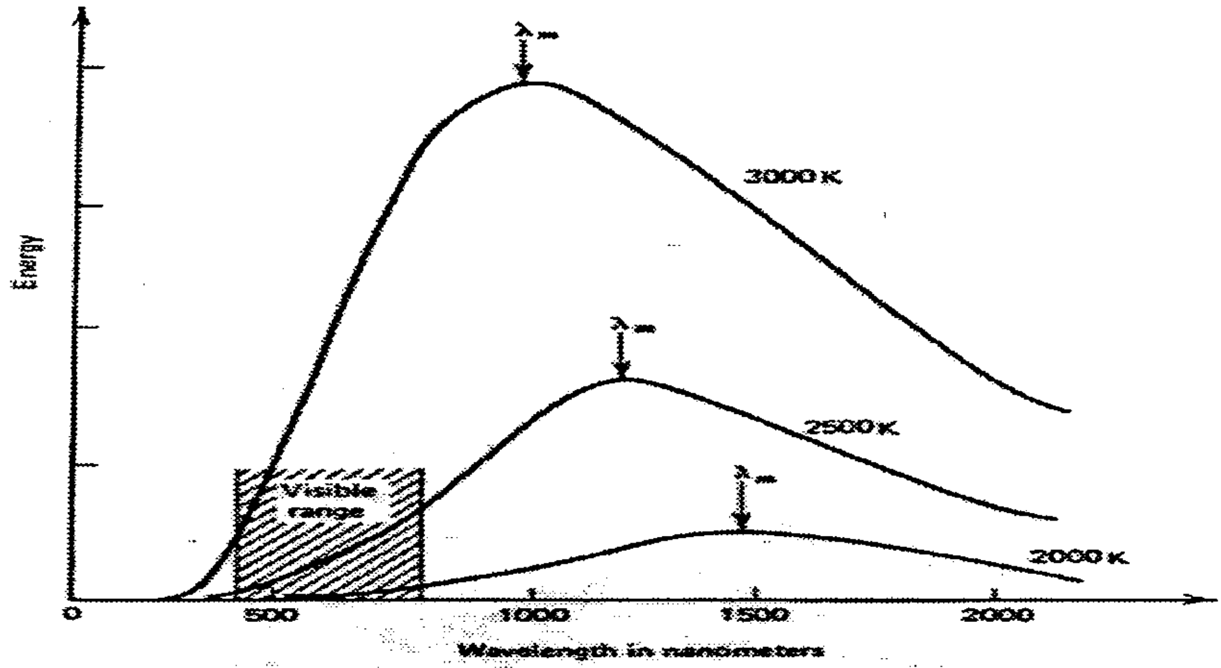


FIGURE 2.5 Distribution of energy emitted as a function of wavelength from a hot object. The solid lines show plots of the blackbody radiation curves for temperatures of 2000 K, 2500 K, and 3000 K. The wavelength at which the maximum amount of energy (per unit wavelength interval) is radiated is indicated by an arrow.

Figure 2.5 shows that the amount of energy radiated depends strongly on temperature. Boltzman showed that the energy radiated away from a surface was proportional to T^4 where T is the absolute temperature in degrees Kelvin. Boltzman derived this same relation theoretically by using general thermodynamic reasoning.

The Stefan-Boltzman radiation law, which expresses the relation between emitted radiative energy and temperature was then formulated.

$$E = \sigma T^4$$

$\sigma = 5.67 \times 10^{-12}$ W/ cm^2 K^4 and E is the total power emitted at all wavelengths.

Wien's displacement law shows another very important relation for solar energy collection and is concerned with the position of the maximum wavelength (λ_m) on the curves. As temperature increases the corresponding wavelength decreases.

This law is of fundamental importance in describing the trapping of solar energy by the greenhouse effect.

Wien's displacement law:

$$\lambda_m = \frac{\text{constant}}{T} \qquad \text{OR}$$

$$\lambda_{5800} T_{5800} = \text{CONSTANT} = \lambda i T i$$

$\lambda i T i$ is the wavelength and temperature of another body e.g. an absorber plate.

Most solar collectors are covered with a glass or plastic cover. These covers are normally transparent to most of the light from the sun. A small portion of long wavelengths is lost due to re-radiation of the surface. This phenomenon is known as the greenhouse effect.

Total radiation intensity on a surface can be reflected, transmitted or absorbed. Let r = fraction reflected, α = fraction absorbed and τ = fraction transmitted, then:

$$r + \alpha + \tau = 1$$

Assume total radiation intensity is I. Then:

$$rI + \alpha I + \tau I = I$$

For a white surface r = 1 and α = 0, while a black surface have an r = 0 and α = 1. Thus, a black body absorbs the entire radiation incident on it and a white surface reflects all radiation incident on it. Real surfaces are never perfectly white or perfectly black. It is normally a combination of the two. Absorptivity (α) normally varies as the wavelength changes. With the aid of Kirchoff's law ($\varepsilon = \propto$), it is then possible to show why an ideal emitter is called a blackbody emitter.

I

2.2 SOLAR RADIATION MEASUREMENT

Solar instruments measure energy associated with radiation incident on a plane of given orientation [2]. These instruments convert the solar radiation incident into another form of energy that can be measured more conveniently.

In order to measure solar radiation instruments of two basic types are used:

2.2.1 Pyrheliometer

A pyrheliometer is also called an actinometer. It is an instrument for measuring solar radiation. It measures radiation from the sun and from a small portion of the sky around the sun (beam radiation), at normal incidence.

A pyrheliometer is represented schematically in Figure 2.6

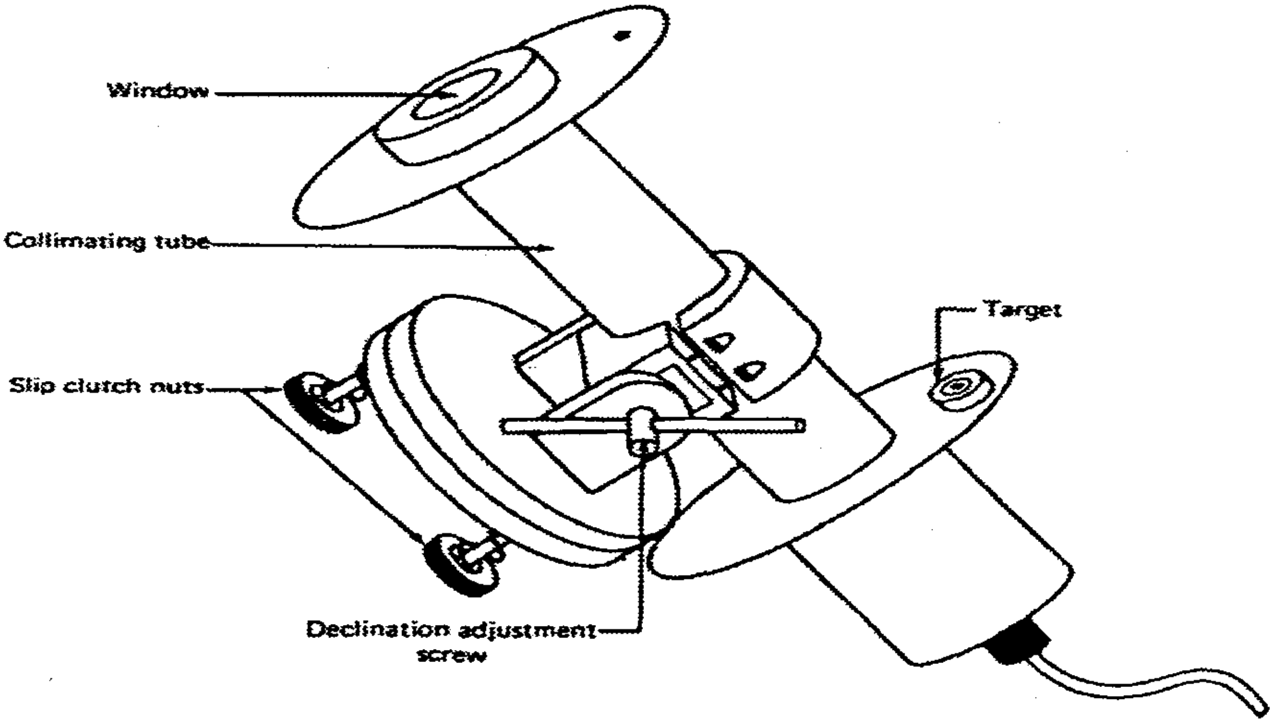


FIGURE 2.6 Illustration of the geometry used for a pyrheliometer. This instrument accepts radiation in a cone making a full angle of 6°. The sensing element at the bottom can be similar to that used in a pyranometer. The walls of the collimating tube are painted black to eliminate scattered light.

The receiving element is similar to that used in a Pyranometer. Directional sensitivity is achieved through the use of a long collimator as seen in Figure 2.6. Pyrheliometers are constructed to include a part of the radiation from the sky immediately around the sun to reduce errors of imperfect alignment with the sun. The Pyrheliometer is mounted on a polar tracking mechanism similar to those used in astronomical telescopes. It rotates 360 ° every 24 hours.

2.2.2 Pyranometer

A Pyranometer is also called a solarimeter. It is an instrument for measuring total hemispherical solar radiation (beam + diffuse), usually on a horizontal surface. It measures the direct solar radiation and that scattered by particles and molecules in the atmosphere. If shaded from the beam radiation by a shade ring or disc, a pyranometer measures diffuse radiation.

A Pyranometer is schematically illustrated in Figure 2.7.

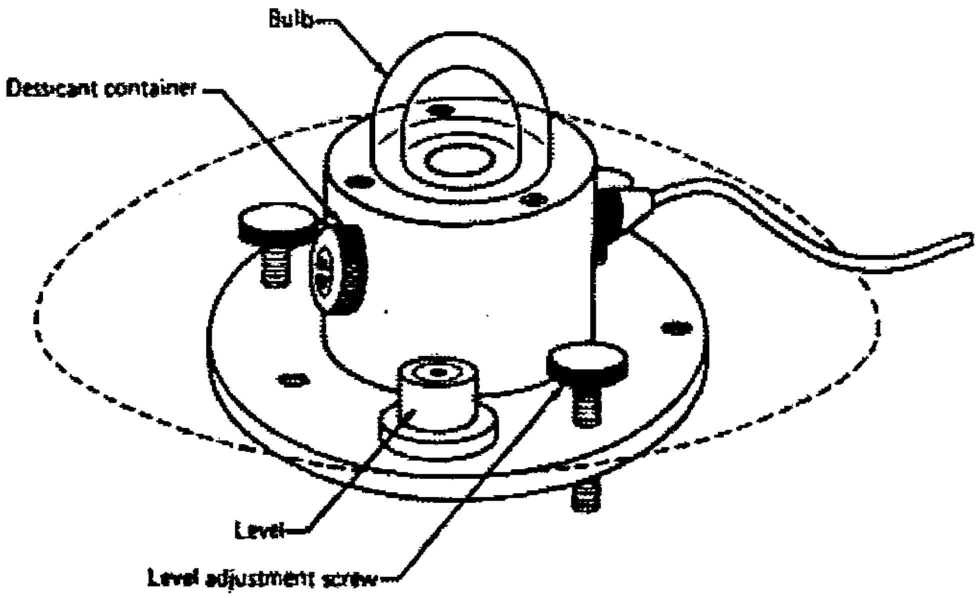


FIGURE 2.7 Pictorial representation of a pyranometer. The light absorbed by the black absorber develops a temperature difference between it and the surrounding world. This temperature difference is proportional to the energy absorbed.

The receiver consists of two concentric rings, the outer white ring and an inner black ring. The rings are often silver foil rings with magnesium oxide and Parson's black coatings. A thermal insulator is then inserted between the rings. A temperature difference is the generated between the absorbing black ring and the reflecting white ring. This temperature difference is then measured with a number of thermocouples.

2.3 WATER HEATER SYSTEMS

A new solar heater had to be designed in this study and therefore previous models had to be investigated. The most common types of systems are discussed below.

2.3.1 Natural circulation systems

A natural circulation system is a passive water heater. The tank is located above the collector, and water circulates by natural convection. Solar energy in the collector adds energy to the water in the collector leg and so establishes a density difference. Auxiliary energy is added into the tank near the top to maintain a supply of hot water.

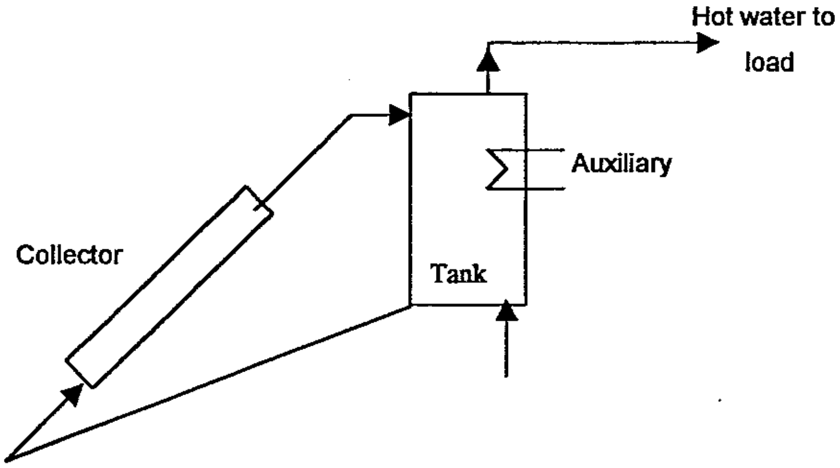


Figure 2.8 Natural circulation system

2.3.2 One tank forced circulation systems

For a forced circulation system a pump is required, which is usually controlled by a differential thermostat. The thermostat turns on the pump when the temperature at the top header is higher than the temperature of the water in the bottom of the tank by a sufficient margin, to insure control stability. A check valve is needed to prevent reverse circulation. Auxiliary energy is shown added to the water in the pipe leaving the tank to the load by a heater having no storage capacity.

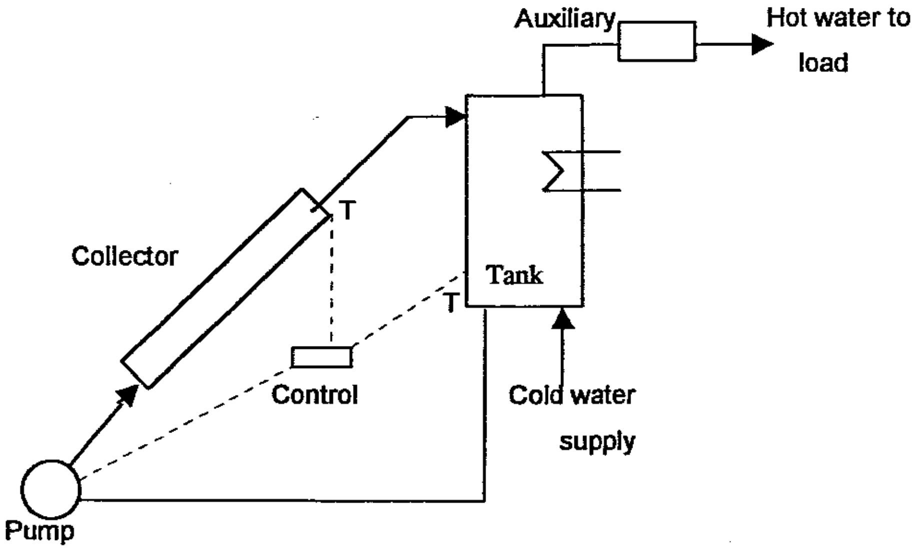


Figure 2.9 A forced circulation system.

In climates where freezing occurs, these designs are modified. Nonfreezing fluids are used in the collector. The collector heat exchanger can be either internal or external to the tank. In figure 2.10 auxiliary energy is shown added to the water in the storage tank by a heat exchanger in the tank. Auxiliary energy can also be provided by a standard electric, oil, or gas water heater with storage capacity of its own as in figure 2.11, the two tank system. Equipment not shown can include surge tanks, pressure relief valves and tempering valves that mix cold supply water with heated water to put an upper limit on the temperature of the hot water going to the distribution system.

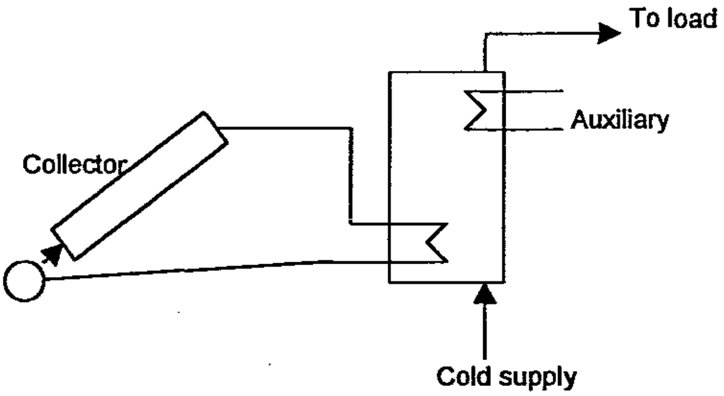


Figure 2.10 A forced circulation system with added auxiliary energy

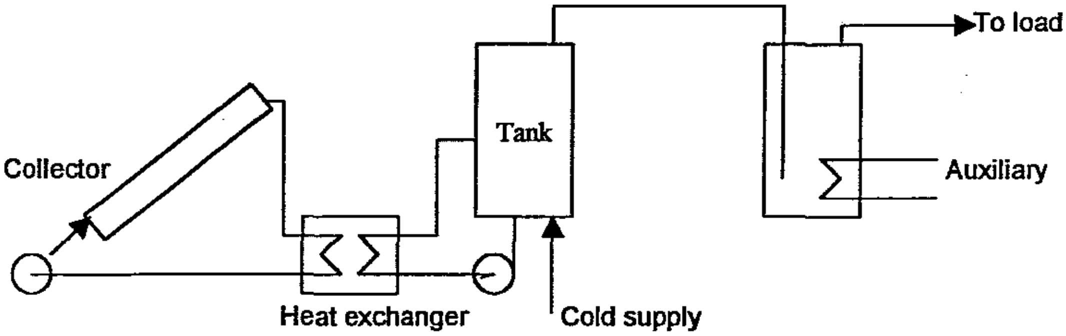


Figure 2.11 A two tank system

2.4 Solar water heaters in general

Collectors used in most water heating systems are similar to that shown in the figure 2.12 [2].

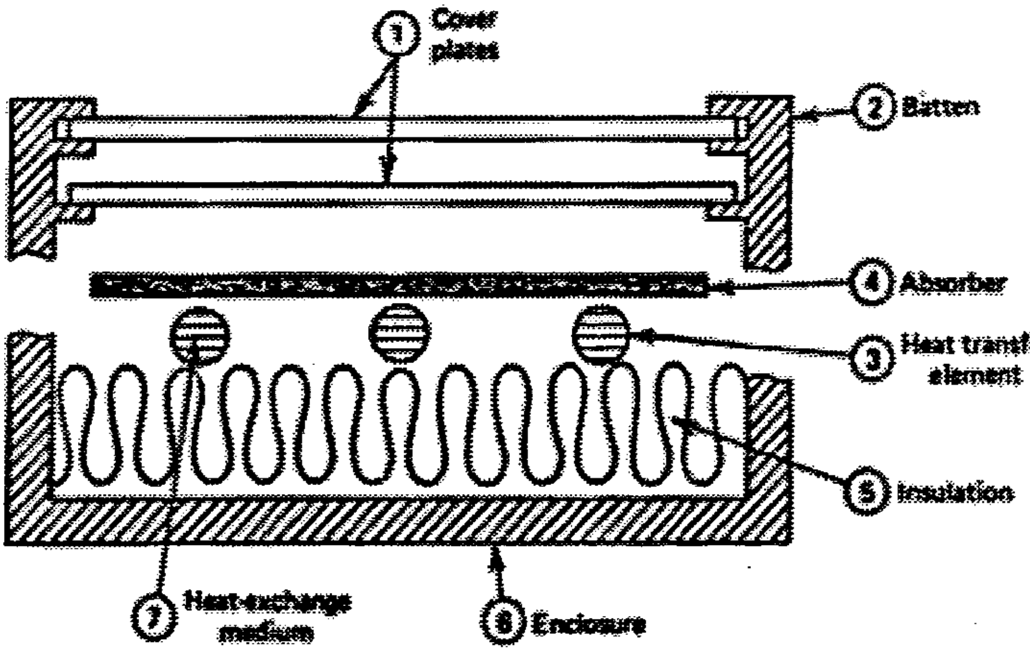


FIGURE 2.12 Exploded view of a flat-plate solar collector that utilizes tubes to transport the heat-exchange medium.

Some plate designs consist of two spot-welded, seam-welded, or roll-bonded plates of stainless or ordinary steel, copper or aluminum. Aluminum has a higher specific heat but a serious difficulty with aluminum is that pure water cannot be used as the heat exchange medium, due to corrosion problems. In this case fluid containing corrosion-inhibiting agents must be used. Plate materials are therefore mainly copper. Fluid passages between the plates are formed by hydraulic expansion after welding. The absorber plates are mounted in a metal box, with 50 to 100 mm of insulation behind the plate and one or two glass covers over the plates. Some styles of flat plate collectors are shown in Figure 2.13

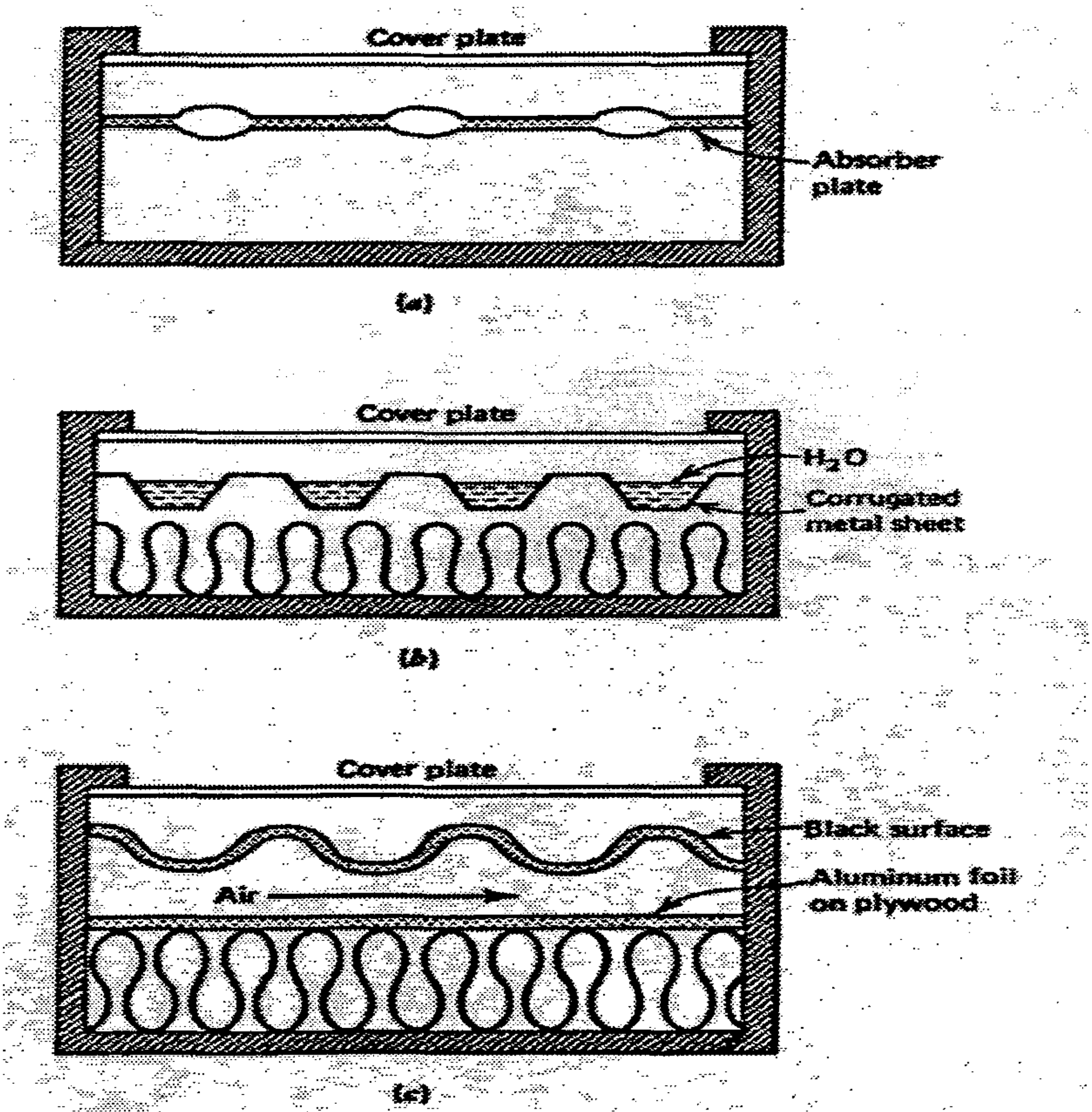


FIGURE 2.13 Examples of several styles of flat-plate solar collectors. *(a)* Tube-in-Sheet. *(b)* Thomason "trickle" collector. (c) Air collector.

The collector plate dimensions differ according to place of production. The most common is 0.9 x 2.1m, 0.6 x 1.2m or 1.2 x 1.2m. The collector area and tank size needed is determined according to the volumes of water used and at which time of day the most water is used. This, together with the amount of radiation and seasonal changes is used to design a solar heating system for a specific use. It is important to remember that solar energy is very much dependant on the amount of radiation and the weather, therefore, backup systems like auxiliary heating is required when hot water is required on a permanent basis.

Freezing and boiling

Solar water heaters should be designed to avoid damage from freezing or boiling. Temperatures may go as low as 0 °C and during days with high radiation and low pump circulation the temperatures in the collector may rise above 100 °C.

Five approaches have been developed to protect collectors against damage by freezing.

1. Antifreeze solutions can be used in the collector loop with a heat exchanger between the collector and the storage tank as in figure 2.2 and 2.3. Common antifreeze liquids are ethylene glycol-water and propylene glycol-water solutions. Ethylene glycol is toxic and therefore at least two metal interfaces between the toxic fluid and the potable water supply is needed. This is accomplished by two heat exchangers in series or by a double walled heat exchanger [2].

2. Air can be used as the heat transfer fluid in the collector-heat exchanger loop of figure 2.3. Air heating collectors are less effective than liquid heating collectors, but no toxic fluids are involved, no second heat exchanger interface is needed, leakage is not critical and boiling does not occur.

3. Another way of freeze protection is to circulate warm water from the tank through the collector to keep it from freezing. Thermal losses from the system are then significantly increased and an additional control mode must be

provided. This method is normally only provided in climates where freezing is infrequent [2].

4. The fourth method of freeze protection is based on draining water from the collectors when they are not operating. Draining systems must be arranged so that collectors and piping exposed to freezing temperatures are completely emptied, and the collectors must be vented.

5. Some collector plates and piping is designed to withstand occasional freezing. Designs have been proposed using butyl rubber risers and headers that can expand if water freezes internally.

If boiling is likely to occur, for example in summer, when occupants of a residence are away from home, radiation is high and there is no fluid circulation, some precocious factors have to be build in. The following factors may mitigate this problem:

- Antifreeze solutions used in collector loops have elevated boiling points.
- Operate the system at higher pressures, which will raise the boiling points even further.
- As temperatures rise the collector loss coefficients also rise.
- Include pressure relief valves in the system.

2.5 The Measurement of colour

The colour of the PVC in this study is very important for maximum heat absorption and for a professional look on a swimming pool. Therefore, a study of colour measurement had to be included, since a dark coloured PVC is used to construct the solar heater, which will be exposed to sunlight, chlorine and acid. These elements fade colour and therefore have an influence on its performance. The tempo at which the colour fades had to be measured to determine whether the material is suitable.

2.5.1 Colorimetry

Colorimetry [5], or colour measurement is the means whereby the colour of an object may be stated in terms of numerical values.

A numerical value for colour is needed, since a human eye absorbing the same wavelengths, may interpret colours differently. This is ascribed to differing personalities, certain biases and the difficulty in describing of for example: How red is red?

2.5.2 Describing colour

Some specific characteristics enable us to accurately describe colour. Take as example two red balls. Firstly the colour itself, a red ball says something. By closer examination the one ball may appear brighter or may have a more vivid colour. To accurately express colour the term's **value (lightness)**, **hue** and **chroma** are used [6].

Hue: The colour of the ball is its hue, e.g. red apples and a yellow banana.
Value: Value or lightness is a scale of light to dark.
Chroma: Chroma is independent of hue and lightness, and is described as saturation or vividness of the colour. Comparing the yellow of a banana to that of a pear. The banana is more vivid yellow or more saturated in yellow. It has a higher chroma.

2.5.3 Colour measurement

Instruments for measuring colour have improved in recent decades with the demand for more accurate and precise measurements. The spectrophotometer is able to measure far beyond the capabilities of the human eye [6]. However, it must be kept in mind that colour measurement must be according to how the human eye perceives it. Therefore, it has to restrict itself to the wavelengths associated with human colour perception.

By adding various amounts of the three primary colours, red, green and blue most colours can be matched. This finding led to the CIE (Commission Internationale de l'Eclairage) 1931 X,Y,Z colour description system. A set of imaginary primaries from which all colours can be matched according to a standard observer is chosen. The X and Y coordinates are chromaticity coordinates on a plane and the Z value is lightness.

There were numerous systems devised and suggested in the measuring of colour, especially in the food industry, but the primary colour measurement tools depends upon the following colour representations:

1) CIE Tristimulas X,Y,Z scale.
2) Hunter L, a, b colour scale
3) CIE 1976 L*a*b* colour scale

Transformations between these various scales are accomplished by simple algebraic manipulation of the values.

2.5.3.1 CIE Tristimulas X,Y,Z Scale

As mentioned above, the CIE Tristimulas X,Y,Z scale, consist of three coordinates x,y,z. A sample can be plotted in the tristimulas CIE colour space using spectrophotometers, but it requires one of two possible equipment configurations [6]. The first is the measuring of the light reflected off the test sample from the light source at an angle of 45 ° (diffuse reflection). Secondly, it requires the use of an integrating hollow sphere painted white inside. For both these spectrophotometer configurations, readings are obtained over the visible spectrum and a response curve is generated.

The Munsell Color Space, a system for describing surface colours, typifies three dimensional colour space. The Munsell system is documented by a series of colour charts, each representing a different hue. The colour chart – based on Munsell notation specifies the elements of perceived colour as follows:

- Value or lightness from black to white on a scale of 0 to 10.
- Chroma, degree of departure from gray towards pure chromatic colour
- Hue (red, green, yellow, etc.)

Tristimulas colorimeters use filters that simulate the X,Y,Z primary colours and is more commonly used in measuring food colours. These colorimeters illuminate the object of interest and measures the reflected colour by monitoring light transmission through filters designed to simulate observation of primary colours by a standard observer.

2.5.3.2 Hunter L, a, b colour scale

A common tristimulas colour scale developed in 1942 is utilized on some instruments, notably the Hunter L,a,b calorimeter. The Hunter L,a,b colour scale presents results in terms of:

L : lightness
+a : redness , -a : greenness
+b : yellowness , -b : blueness

Figure 2.14 is an illustration of the Hunter L,a,b colour scale.

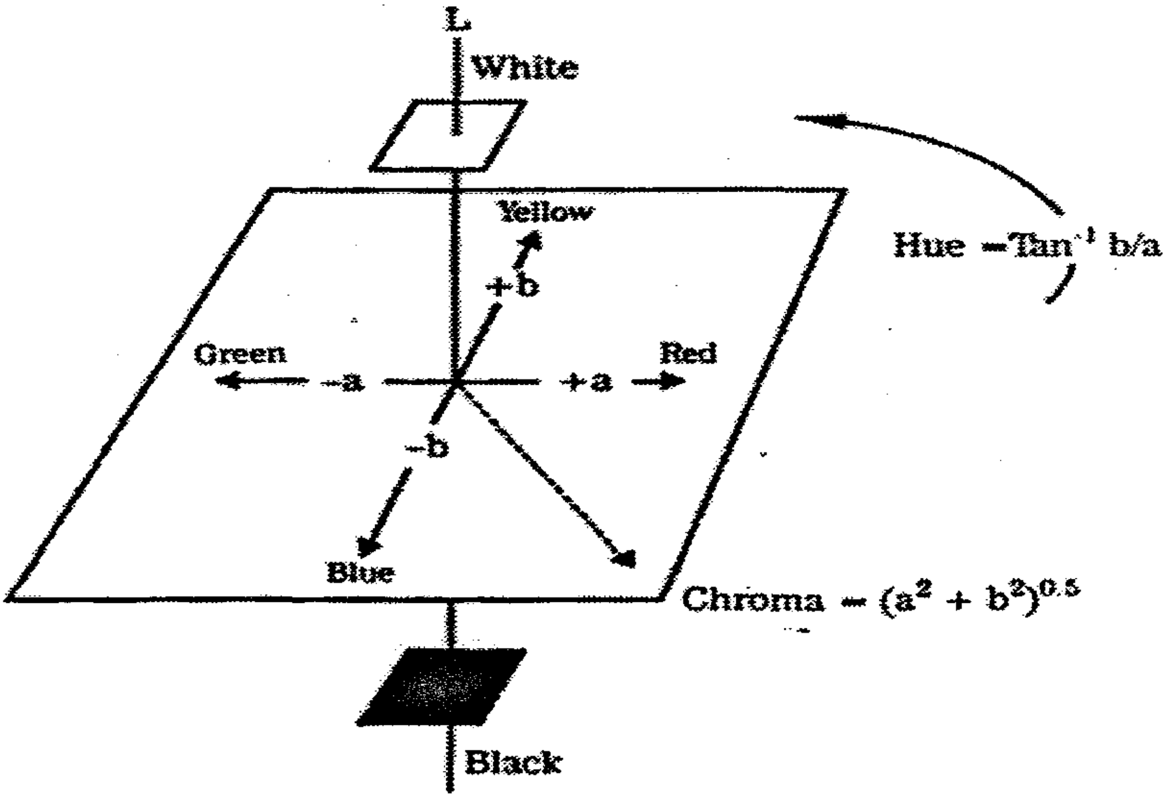


FIGURE 2.14 Graphic configuration of the Hunter, L, a, b color solid.

2.5.3.3 CIE 1976 L*a*b* colour scale

This method, also abbreviated as CIELAB involves a lightness coefficient, L* which ranges from black = 0 to white = 100 and is roughly analogous to the Munsell value scale times 10. The coordinates a* and b* locate the colour on a rectangular- coordinate grid perpendicular to the L* axis. The colour at the grid origin, a* = 0 and b* = 0, is achromatic (gray).

On the horizontal axis the values indicate the following:

+a : red-purple , -a : bluish-green
+b : *yellowness* , -b : *blueness*

It is important to remember that these variables are not independent variables.

The Cartesian co-ordinates can be converted into the cylindrical co-ordinates L*, C* and h with the equations:

$$C^* = [(a^*)^2 + (b^*)^2]^{0.5}$$
$$H = \arctan b^*/a^*$$

This then quantifies the variables of the best-known visual colour space, that of Munsell.

L* = Munsell value on a 0-100 scale and is termed psychometric lightness,
C* = Munsell Chroma and is termed psychometric chroma
h = Munsell Hue and is termed hue- angle. Measured from a* +axis.

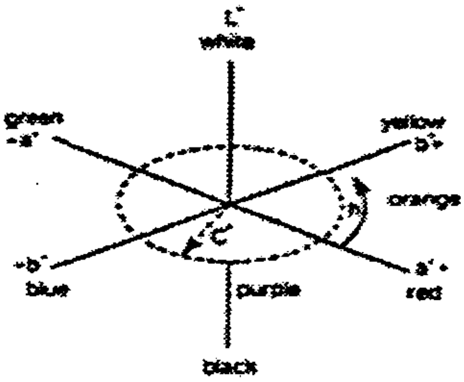


FIG2.15 The configuration of CIELAB space showing the relationships between the three variables of perceived colours.

2.5.4 Quantification of colour

Many studies were undertaken and equations derived to obtain the perfect colour difference equation. Most relationships failed because when studies were carried out to determine how well any equation correlated with the visual judgements of professional shade passers in industry, it performed worse than several widely used equations [7].

These extensive studies resulted in a new colour difference equation, CIELAB, replacing the 1964 recommendation. This equation is based on the CIELAB uniform colour space already described.

$$\Delta E_{(CIELAB)} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$$

Advantages of this relationship over others are as follows:

- No other equation consistently gives a higher correlation coefficient against visual data.
- Any colour difference is split into three components
  1. A lightness difference

     $$\Delta L^* = L^*_{sample} - L^*_{standard}$$

  2. A chroma difference,

     $$\Delta C^* = C^*_{sample} - C^*_{standard}$$

  3. A hue difference,

     $$\Delta H^* = [(\Delta E)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{0.5}$$

- Calculating ΔE from XYZ values of sample and standard is much simpler than for any other equation.

CHAPTER 3

POOL HEATING THEORY

In this chapter the different losses concerning pool heating together with the absorber efficiency are considered. Also theoretical temperature gains in pool water at certain conditions are calculated.

The following equation is normally used to calculate the useful energy absorbed, by solar heaters [8]:

Useful energy: q_u = Energy absorbed - Energy lost

$$= G_T \, . \, \tau_{su} \, . \, \alpha_{su} \, . \, A_c \; - \; U_L \, . \, A_c \, . \, (T_p - T_a)$$

G_T = Insolation on collector (W/m^2)

τ_{su} = Transmissivity of cover. Fraction that reaches absorber.

α_{su} = Absorbtivity of absorber

A_c = Collector area (m^2)

U_L = Overall heat transfer coefficient between absorber and surroundings ($W/m^2 \; {}^\circ C$)

T_p = Absorber plate temperature (° C).

T_a = Ambient temperature of atmosphere (° C).

Most of these values can be measured or has been calculated through different experiments.

When pool heaters are considered, the formula changes drastically. Firstly, there are normally no covers over the collector. This discards the transmissivity losses. The absorber plate temperature and the atmosphere temperature is very close to each other, because there are pool water running through the system continuously. There will be minimal losses to the atmosphere, because the heat absorbed is immediately taken away by the water running through the system. This will make the overall heat transfer coefficient between absorber and surroundings very small. In the end the heat absorbed by the pool and pool heater can be calculated with the following equations [8].

Energy absorbed by collector

Useful energy: q_{coll} = Energy absorbed

$$= \eta \,.\, G_T \,.\, A_c \,.\, T$$

or

$$q_{coll} = \eta \,.\, G_T \,.\, S.\ T$$

η = Collector efficiency

G_T = Mean irradiation for horizontal surfaces during time that pump is running (kWh/m^2 per day).

A_c = Collector area (m^2)

T = Fraction of the day that the pump is running. Say the pump runs 6hr a day at maximum radiation times then $T = 6/24 = 0.25$

S = Fraction of pool area needed for a solar system to heat pool to desired temperature. Explained better in the end at overall pool balance.

For uncovered collectors the efficiency is a strong function of wind speed [8]. For sheltered collectors a value of 0.75 can be assumed and for collectors that are exposed to high winds the value can drop to as low as 0.5.

Direct radiation absorbed by pool

An uncovered pool absorbs a large amount of direct radiation energy. The absorption coefficients vary between 0.8 and 0.95 depending on different factors. Assuming a value of 0.8.

Energy absorbed by pool (q_{Dir}):

$$q_{Dir} = 0.8 \, . \, G \, . \, k' \, . \, k \qquad \text{kWh / m}^2 \quad \text{per day}$$

G : Mean daily irradiation for horizontal surface (kWh / m^2 per day).

k' : Proportion of the day that the pool is not artificially shaded by trees or buildings. Assume pool is not shaded during main radiation times, that is between ten and five o' clock, then k' will be 1.

k : Proportion of the day that the pool is not covered with the new pool heating system.

Convection loss

The convection losses from the swimming pool to the atmosphere is calculated with the following two equations.

Convective heat transfer coefficient (h):

$$h = 0.136 + 0.091 \, v \qquad \text{kWh / m}^2 \, {}^\circ\text{C} \quad \text{per day}$$

Convection loss (q_c):

$$q_c = h \, (T_w - T_a) \qquad \text{kWh / m}^2 \quad \text{per day}$$

v = 0.5 m/s : Average wind speed at surface of a relatively sheltered pool. In places where there is normally high wind speeds or pool surroundings are quite open, the wind speed can be measured and implemented into the equation.

T_w = 24.5 °C : Desired water temperature throughout the year.

Ta : Average air temperature in °C.

Evaporation loss

Evaporation loss occurs when the pressure of the water vapour in the air is lower than the vapour pressure of the pool water.

Evaporation loss depends highly on the time that the pool will not be covered with the pool cover. When the pool cover is on the evaporation loss will be close to zero.

Evaporation loss (q_E):

$$q_E = 1.85 \,.\, h \,.\, (p_w - p_a) \,.\, k \qquad \text{kWh / m}^2 \quad \text{per day}$$

h : Convective heat transfer coefficient. Formula given under convection losses.

p_w : Saturated vapour pressure of air at pool surface at water temperature.

p_a : Average vapour pressure.

k : *The proportion of time that the pool is not covered. When there is no* pool cover, k = 1. When pool is covered 50% of times, k = 0.5

Radiation loss

Radiation losses to the surroundings occur when the water temperature is higher than that of the surroundings. The following two equations are used to calculate radiation loss (q_R):

$$e_a = 0.8 + 0.0038\, T_d$$

$$q_r = 1.1 * 10^{-9} \, [\, T_w^4 - e_a \, T_a^4 \,] \qquad \text{kWh / m}^2 \quad \text{per day}$$

e_a : The apparent emissivity of the surroundings which is a function of the dew point temperature T_d.

Tw : Water temperature in °K.

Ta : Average air temperature in °K.

Overall heat balance

It can now be calculated whether the absorbing area of the heat model will be sufficiently large to heat a pool to desired temperatures. Most of the losses were incorporated, but there are other losses not mentioned. Some would be the heat loss or gained to atmosphere through the pump and piping system. The heat loss through the make up water and the loss of heat through the pool walls to the ground. The over-designing of the system will incorporate these losses, considered to be small.

The following equations are used to calculate which fraction of pool area is needed for a solar heater to heat a pool to desired temperatures

Pool heat balance over 24hr day:

$$q_{coll} + q_{Dir} = q_R + q_C + q_E$$

$$S = \text{Fraction}$$

The fraction (S) of pool area needed for a solar heater is calculated through this energy balance. This gives an idea whether the absorbing area is sufficiently large to heat the pool to desired temperatures. If the pool area is known, the pool temperature can more of less be calculated for each month of the year.

When all these calculations are performed it is noticeable that the main heat loss from a pool is a result of evaporation. Therefore, if the pool is covered with the heating system when not in use the losses can be reduced drastically. From literature it is seen that normally an area of approximately 65% of pool area is needed for a solar panel to heat a pool in normal conditions [8].

Swimming pool calculations

The average swimming pool has the following approximate dimensions:

LENGTH = 6m

WIDTH = 3.5m

DEPTH = 1.3m (average)

This gives a volume of :

VOLUME = LENGTH * WIDTH * DEPTH

= $(6 * 3.5 * 1.3)\text{m}^3$

= $27.3\ \text{m}^3$

= 27300 liters of water

or roughly 30000 liters of water

Cross-sectional area of pool:

AREA = LENGTH * WIDTH

= 6m * 3.5m

= $21\ \text{m}^2$

Mass of the pool water:

MASS = VOLUME * DENSITY

= 30000L * 1 kg/l

= 30000 kg

Determining the heat needed to raise swimming pool temperature by 1°C with no heat loss to wind or evaporation:

HEAT = MASS * Cp * TEMPERATURE RAISE

$Q = M * Cp * (T_o - T_i)$

= 30000 kg * 4.184 kJ/kg-°C * 1 °C

= 125520 kJ

= 125.5 2 MJ

The sun supplies an enormous amount of energy, which can be used to supply heat energy to water in aid to raise its temperature. From Table 3.1 it is clear that sufficient energy is available per square meter to heat the water.

Energy available per swimming pool cross-sectional area:

Heat available = Total radiation/day * Area

The following averages were calculated from data received of the weather bureau in Johannesburg, measured at Cape Town International airport by the methods explained in section 2.2. The units are in MJ/m^2.

MONTH	Average radiation/hr over 6 max hours of Radiation (MJ/hr)	Total radiation during 6 max radiation hours (MJ/6hr)	Total day radiation (MJ/day)	Heat available per day per pool area MJ/day-Area	Heat available per 6max hour radiation per pool area. MJ/6max-Area	Total pool temperature raise per max 6 hours (°C)
January	3.1	18.6	27.6	579.65	390.85	3.42
February	3.04	18.24	25.79	541.67	382.81	3.35
March	2.33	13.98	18.67	392.14	293.46	2.56
April	1.9	11.4	14.34	301.18	239.42	2.09
May	1.26	7.56	9.15	192.22	158.84	1.39
June	1.19	7.14	8.35	175.29	149.42	1.30
July	1.26	7.56	9.08	190.76	158.62	1.38
August	1.76	10.56	13.19	276.98	222.16	1.94
September	2.16	12.96	17.18	360.87	272.06	1.38
October	2.53	15.18	21.06	442.28	318.94	2.79
November	2.82	16.92	24.87	522.27	355.75	3.11
December	2.94	17.64	26.45	555.38	369.93	3.24

Table 3.1

From the table it is apparent that the pool contents can be raised by at least 3°C per day for nearly 7 months of the year. Remembering that a pool will be covered at the cooler time of the day, such as nighttime, the losses in temperature will be less. It can therefore be assumed that the raise in water temperature will be cumulative to a certain maximum. In winter the same would apply. If there are a few hot days the water temperature would rise enough for swimming. This will not be possible without an absorbing unit that absorbs the heat and releases it to the contents of the pool.

CHAPTER 4

EXPERIMENTAL

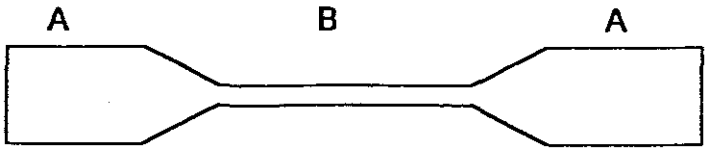
This chapter describes the experimental procedures conducted in this study.

4.1 MATERIAL STRENGTH TESTS

The melting point of the material was evaluated to ensure that the PVC material could withstand heat to a sufficient degree. The data received were then plotted on a graph to determine how and at what speed the material melts. The PVC sail also consists of two different materials and therefore each individual melting point had to be evaluated.

The materials' physical strength was tested with a tensile tester. Several samples were stretched until broken. This data gave an idea of what force is required to tear the material.

In order to conduct these tests, several test samples of exactly the same size had to be cut. The samples had to have the same thickness, width and length, since the force, per unit area, to break the samples had to be calculated and compared. A pounce was used to attain this:



The reasons for the selected shape are as follows:

- The wider part A is for the machine clutches to get a firm grip onto the material.
- The narrow part B is to ensure that the samples break in this region and not where the clutches grip.

4.2 STRENGTH OF ADHESION

In order to make the heater system the sail has to be glued together. The strength of this joining procedure was evaluated by a similar method as described in 4.1.

The ultimate aim of these tests was to determine whether the joining point is weaker than the material itself. There are two methods of adhesion and stretching the material and both ways were evaluated.

Firstly, the narrow parts of two samples were joined. They were then stretched in the following two ways:

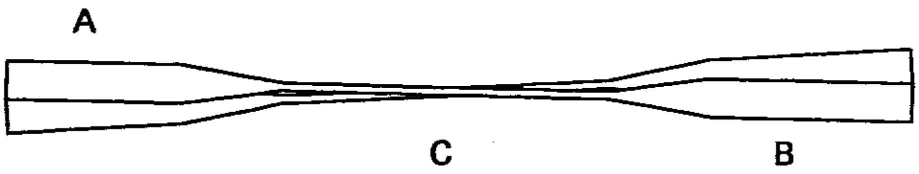


Figure 4.1

In figure 4.1 (C) are the narrow parts of the two samples, which is joined together. The wide part of the one sample (A) is inserted into the one clutch and the wide part at the opposite side of the other sample (B) is inserted into the other clutch. It is then stretched to determine when and how it breaks.

The second way of stretching is as follows:

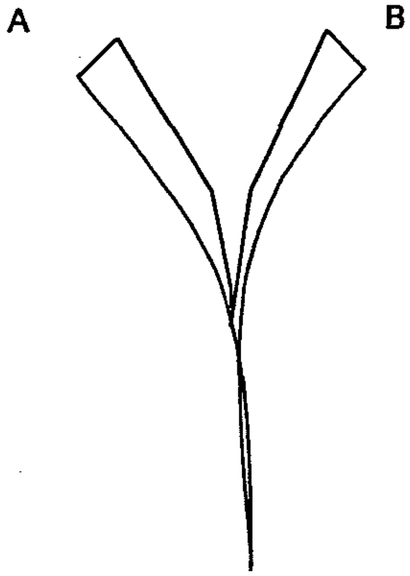


Figure 4.2

Here the two samples are stretched away from each other in opposite directions. Again only the narrow parts were joined.

4.3 BEST JOINING PROCEDURE

The aim of this experiment was to determine which manner of joining the material is best in practice. In order to achieve this, two similar 'bags' were made, joined in different ways.

The one bag consisted of two square pieces of material and a valve, but it was joined so that the edges were rounded. This is illustrated below in Figure 4.3.

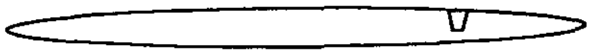


Figure 4.3

The other bag consisted of a valve and two square pieces of material, joined in a flat position at the edges. This is illustrated in Figure 4.4.

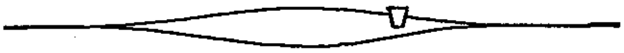


Figure 4.4

Both bags were pressurised to test strength of joining.

4.4 DETERMINING THE BEST WAY OF CHANNELING THE WATER THROUGH THE MODEL

In this experiment the best way of channeling the water in the pilot model were tested. This was done to ensure maximum absorbency of solar energy and minimum risk of damage to either the pump or the material.

The first is illustrated in Figure 4.5. It resembles a big 'bag' with an inlet and an outlet. This model was never made and tested for reasons that will be discussed later in the results and discussion.

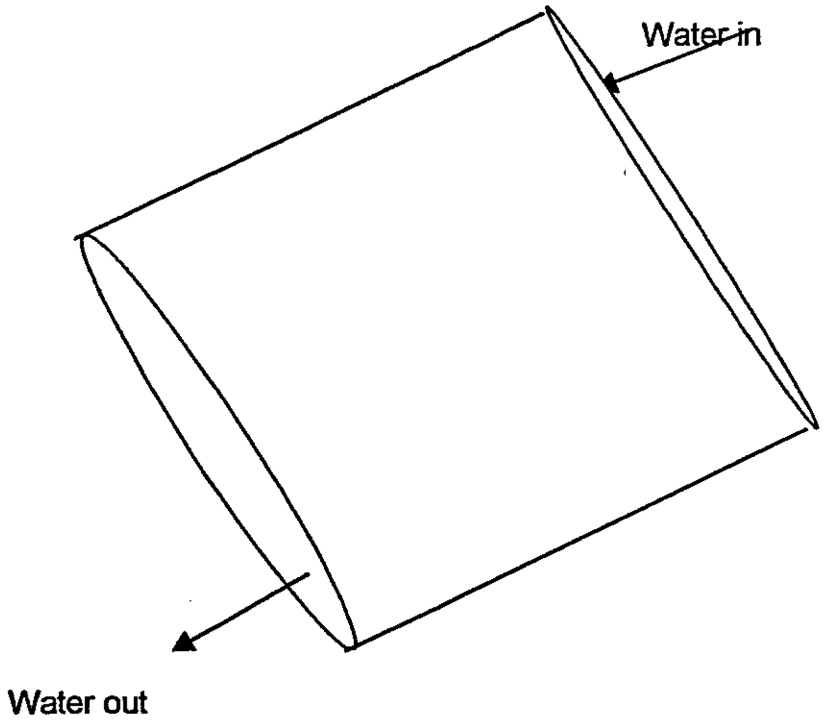
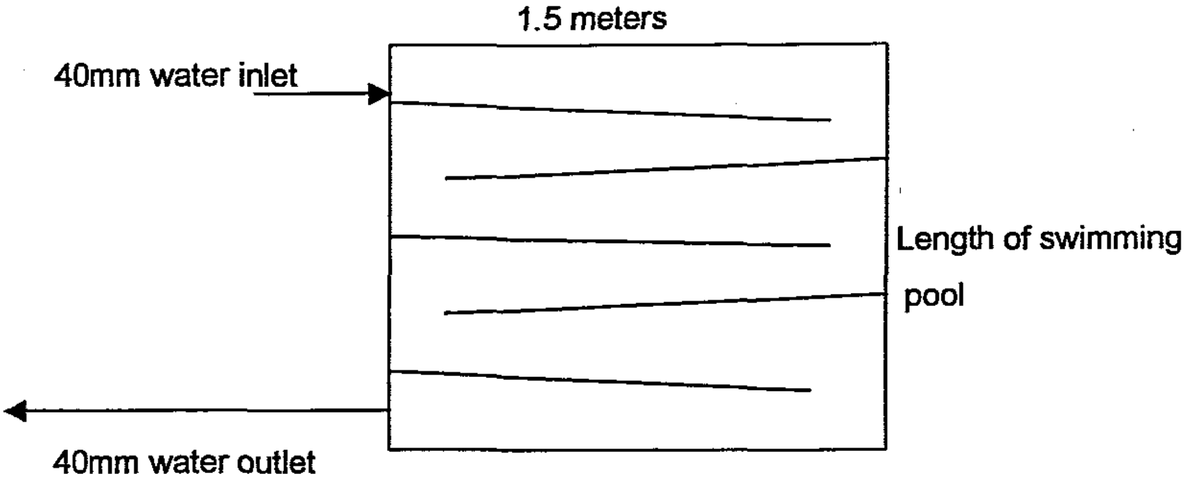


Figure 4.5

The next model that was considered also resembles a big bag one meter by 1,5 meters, but incorporated channels.

Each bag had one continuous channel that flowed from one end of the bag to the other. The channels, when full, had a diameter of more or less nine centimeters at the one end and eight centimeters at the other end. This is to ensure that when the sail is rolled up all the water could be compressed towards the exit. If the channels were only pasted horizontally the water could be compressed into a corner which could damage the sail when rolled up.

The intention was not for the sail to fill totally with water, only to be half full during operation. This model was built. A top view is illustrated below:



Channel width when full: 8 – 9 centimeters

Figure 4.6

The third model that was considered and tested had dimensions 1meter by 1.5meters, with channels vertically down and evenly spaced. The channels were small individual units and not continuous as in the previous model.

The channel width when full would be 1.3 cm in diameter. To make the channel, a long strip had to be joined between channels. This adhesion area where made 2 cm wide and nearly the length of the model. At the input side flexible hose with small holes were used to feed each of the channels. The fixed and rigid black pipe coming from the pump was fitted to this hose. At the exit side the water was collected also in a flexible hose which was then joined with the pool feed line. A top view is illustrated in figure 4.7:

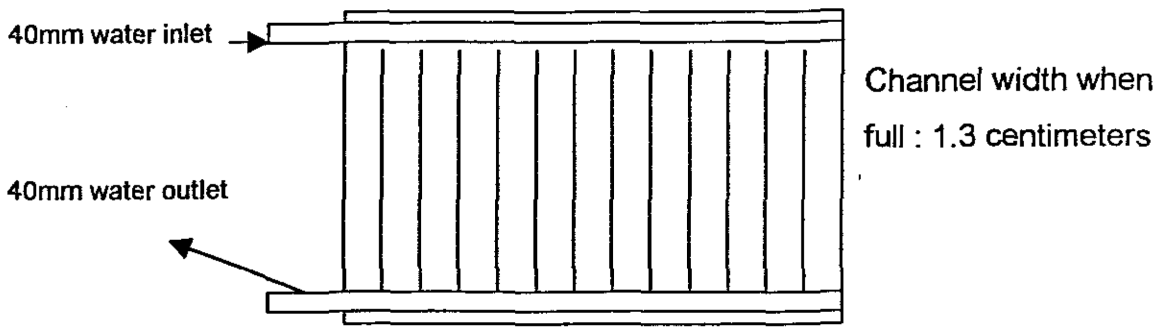


Figure 4.7

4.5 AVAILABILITY OF SOLAR ENERGY IN CAPE TOWN

In this experiment the aim was to determine the availability of solar energy in the Cape Town region over a one-year period. This will give an idea whether a solar heater will work effectively. Also, the influence of temperature on solar radiation is evaluated.

All this data was measured at the Cape Town airport for the weather bureau. With this data made available by the Weather Bureau processing and charting of the data was done to see and understand the trends of the temperature and radiation available over a period of time.

To measure all the available solar energy a pyranometer is used which is explained in section 2.2.
The temperature is measured with an electronic measuring device.

4.6 TESTING THE PERFORMANCE OF A PILOT MODEL

In this experiment a complete pilot model was tested to evaluate performance.

The following were needed for the experiment:

- Two thousand-liter containers lowered into the ground.
- *40 mm black piping to connect the water with the solar heater.*
- A swimming pool pump that is normally used to circulate the water through the filters.
- A solar heater model with dimensions 2m by 1.5m
- A solar heater model with dimensions 1m by 1.5m.
- Thermometer

The complete set-up is illustrated in Figure 4.8.

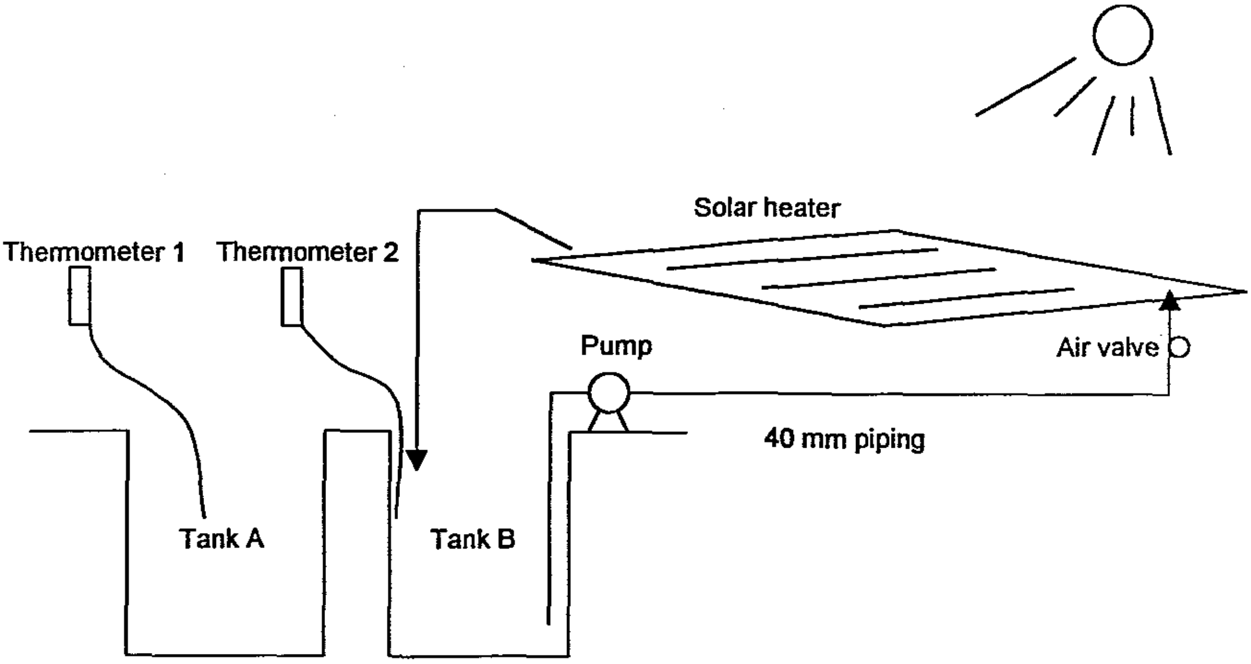


Figure 4.8 Set-up of a pilot model.

Two tanks had to be used to compare the temperatures of a tank without a solar heater and one with a solar heater. A one-meter length solar heater was used to absorb solar radiation. Calculations on how much energy is absorbed per meter length of heater material were made from this. Temperature changes over time were also taken. Two different solar heaters were tested. The one with the one continuous channel and the one with the evenly spread parallel channels. Both models gave positive data but for reasons explained in experiment 4.4 the model with the evenly spread parallel channels was selected.

4.7 THE INFLUENCE OF THE SUN ON BOTH MATERIAL AND ADHESION AREAS

In solar energy absorption the colour of the absorbent material is very important. The darker the material the better. The sun does fade most materials and often weaken the structure.

In this experiment the influence of the sun on the strength and the fading of colour of the material was tested. The influence of the sun on the strength of the adhesion areas over a period of time also needed to be evaluated.

In order to achieve this, samples were exposed to the sun over a few months. Normal and glued samples, not exposed to the sun, were tested first. Tests on colour and strength depreciation were tested. Three samples per month, over a period of time were tested in each of these experiments. At least three samples per experiment needed to be tested to ensure reproducibility. From this monthly data the reaction of the material and glued material to the sun over a long period of time could be estimated.

The following were needed for the experiment:

- A tensile testing machine to test material strength by stretching it.
- A colour measuring apparatus to measure the colour depreciation if any over a period in time.
- Twelve samples, three each for months May to August.
- Twelve glued samples to be stretched as explained in figure 1 of experiment two. Again three for each month.
- Twelve adhesion samples to be stretched as explained in figure 2 of experiment two. Also three for each month.
- To ensure that only the one side of the samples was exploited to the sun over the experiment period, as would be the case in practice, the samples were pinned to a piece of wood to ensure that they could not turn over.

4.8 THE INFLUENCE OF ACIDIC WATER ON BOTH MATERIAL AND ADHESION AREAS

The aim of this experiment was to test the influence of strong acidic water on the strength and colour of the material. In order to test this samples had to be submerged into strong acidic water over a long period of time.

An important test is the strength depreciation test to evaluate what would happen if pool water were overdosed. The colour test is also important but because the water is inside the model and only in contact with the bottom part of the heater material it will not influence the absorbency quality of the top part of the heater material.

Normal pool acid (Hydrochloric Acid) is used to adjust swimming pool pH. The recommended pH for pool water is between 7 and 7.6 for best results and smallest chance of damage to the pool and the pump. However, overdosing results in lower pH levels in many cases in practice.

The following were needed for the experiment:

- The tensile testing machine to test its strength by stretching it.
- A colour measuring apparatus to measure the colour depreciation, if any, over a period of time.
- Twelve samples, three each for months May to August.
- Twelve glued samples to be stretched as explained in figure 1 of experiment two. Again three for each month.
- Twelve glued samples to be stretched as explained in figure 2 of experiment two. Also three for each month.
- Acidic water in a jug at a pH of less than 6.8

4.9 THE INFLUENCE OF CHLORINE SOLUTION ON BOTH MATERIAL AND ADHESION AREAS

The influence of strong chlorine water on the strength and colour of the material were tested in this experiment. In order to test for these properties the samples were submerged into strong chlorine solutions over an extended period of time.

Again an important test is the strength depreciation test to see what would happen if the pool water were overdosed with chlorine. Chlorine is a bleaching product, hence fading of the material can be expected. The question that needed to be answered was the magnitude and rate of colour change. Again this is not of crucial importance since the area for radiation absorption will not be exposed to pool water.

Pool HTH (dry granular chlorine) was used to chlorinate the water. The recommended free chlorine for pool water is between 1 and 2 ppm for best results and smallest chance of fading the pool. Higher free chlorine levels (more than 2) will cause damage but nevertheless were tested since overdosing does occur in practice

A similar experimental procedure was followed as described in 4.7 and 4.8.

4.10 THE INFLUENCE OF IDEAL SWIMMING POOL WATER ON BOTH MATERIAL AND ADHESION AREAS

In this experiment the influence of normal pool water on the strength and colour of the material had to be tested. In order to test this the samples had to be submerged into pool water with a pH of between 7and 7.6 and a free chlorine contents between 1 and 2 ppm over an extended period of time.

The experimental procedure is similar to the procedures used in experiment 4.7 and experiment 4.8.

CHAPTER 5

Results and Discussion

5.1 MATERIAL STRENGTH TEST

In the first experiment the melting point of the PVC material was tested. Graph 5.1 was plotted from data obtained.

The following is observed:

- The heat flow (in MW) increases slowly and steadily between room temperature and approximately 220 °C.
- The PVC melts at 239.7 °C.
- The material contains Polyester strands for additional strength, which melted at 254.6 °C.

This data indicates that the material can withstand the necessary heat since, during operation the temperature will never rise above 50 °C. Therefore, the probability of the model to perish rapidly due to heat, is eliminated.

Stretching it until it breaks tested the material's strength. This gave some indication of what type of force is needed to let the model burst and whether it is strong enough to carry a human's mass when covering the pool. This is one of the important safety features of the model.

From the breakpoint determined the following can be concluded:

- It is a very strong material and can withstand relatively large forces acting upon it.

- For a material width of 7.6 mm breaking occurred at 180 N. This means it can carry about 2.4 kg for each millimeter in width of material or 24kg/cm. This is sufficient to carry a person of mass 120kg without the possibility of breaking.
- *The probability of tearing due to pressure inside the model is remote.*
- The material can however be cut or torn with sharp objects.

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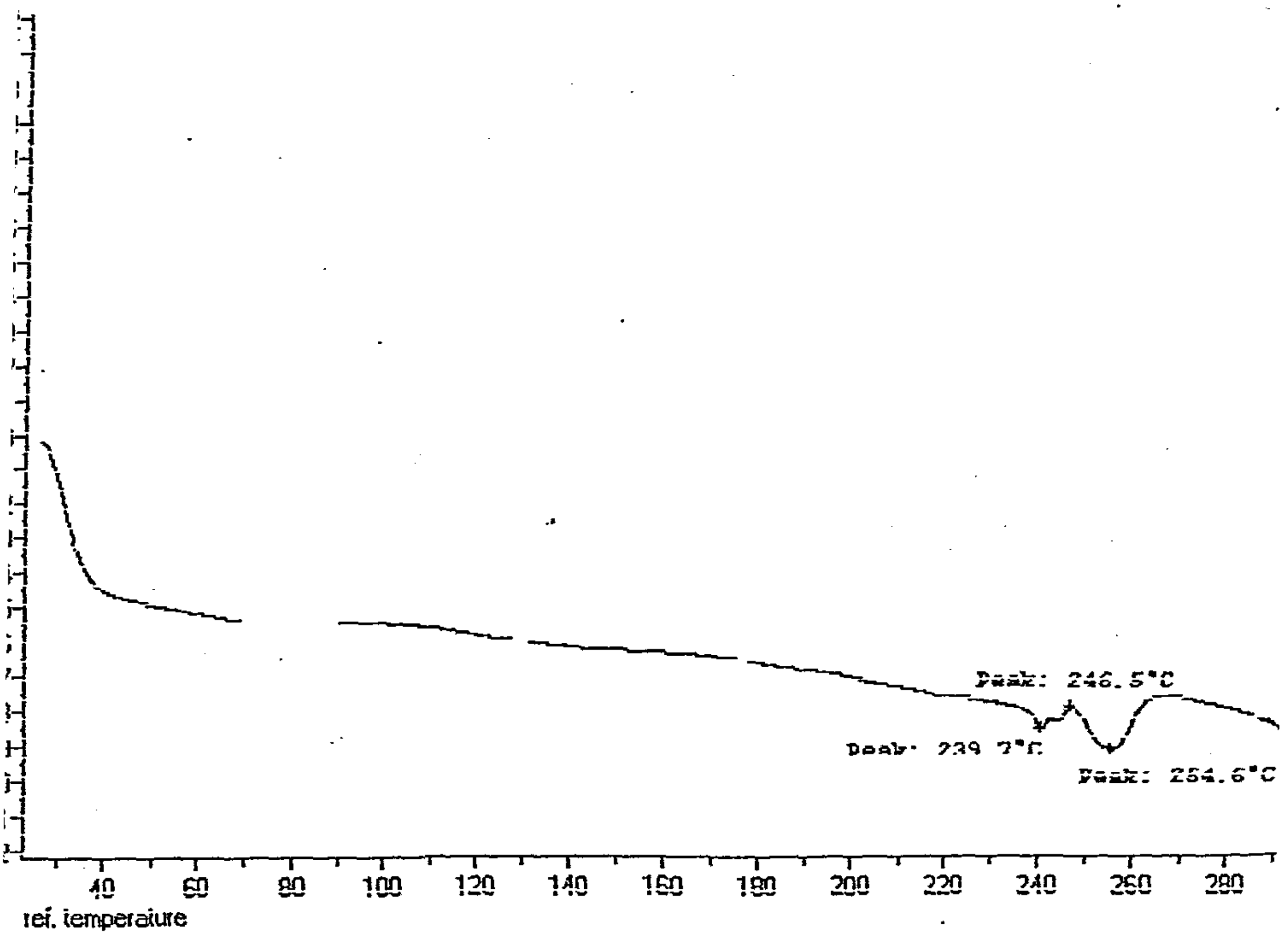
Thermal Analysis DSC 6



Graph 5.1 Melting points of the PVC material

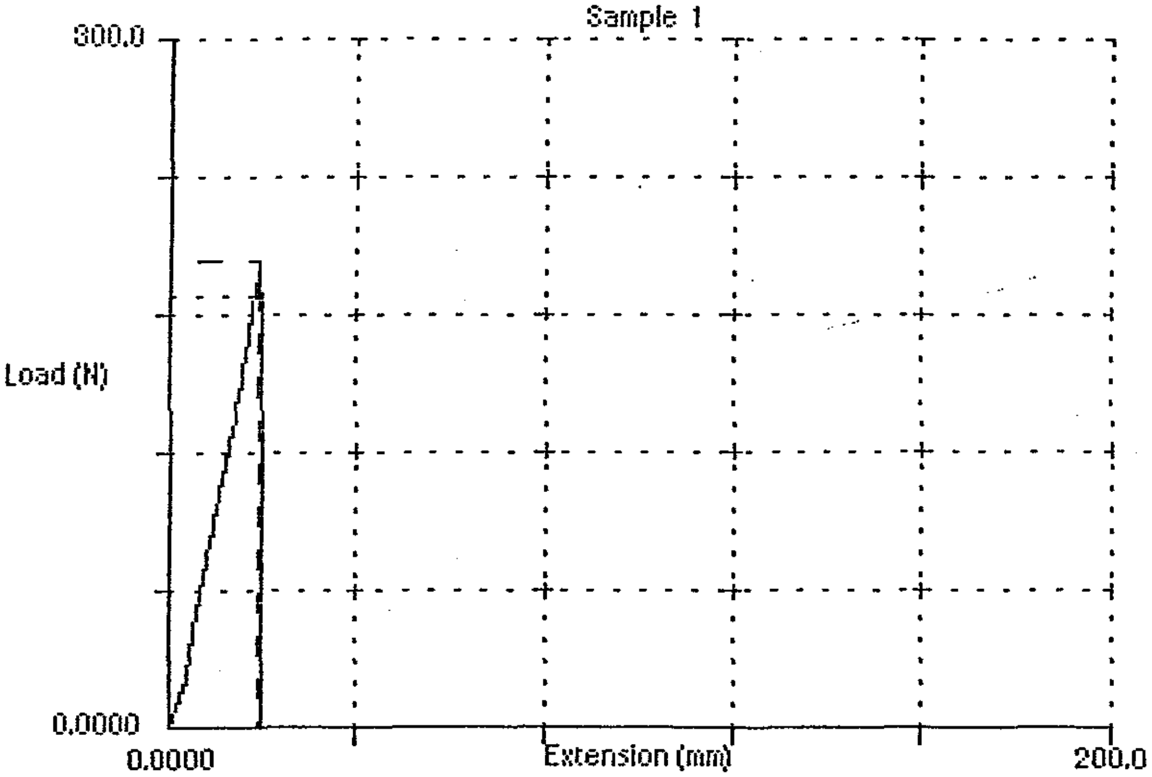
5.2 STRENGTH OF ADHESION

Graph 5.2 illustrates the strength of the glued material with the first type of stretching (as explained in the experimental methods: "Strength of adhesion"). The adhesion area material breaks at approximately 203 N, per 7.6mm of glued material.

With the second type of stretching, where the samples are stretched in opposite directions, the glued material breaks in the region of between 32.81N and 36.62 N per 7.6 mm of glued material as shown on Graphs 5.3 and 5.4. It is a adhesive method and therefore it does not tear at exactly the same point, but it does tear more or less in the same region.

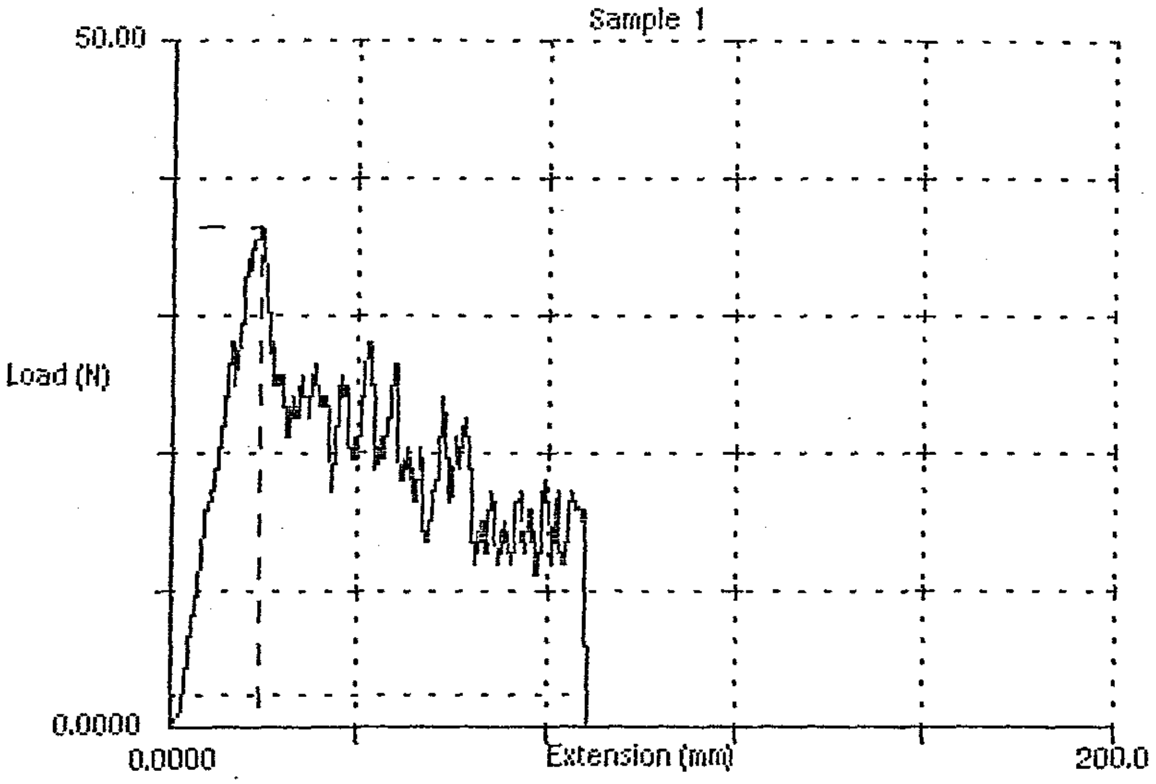
From these two graphs and from the visual examination of the samples the following can be concluded:

- The first method of joining, as explained in the experimental chapter under "Strength of adhesion ", is much stronger than the second method.
- In both cases the PVC material at one side of the polyester tears.
- Tearing occurs next to the adhesion area, indicating that the material at this point is weaker than the joined area itself.



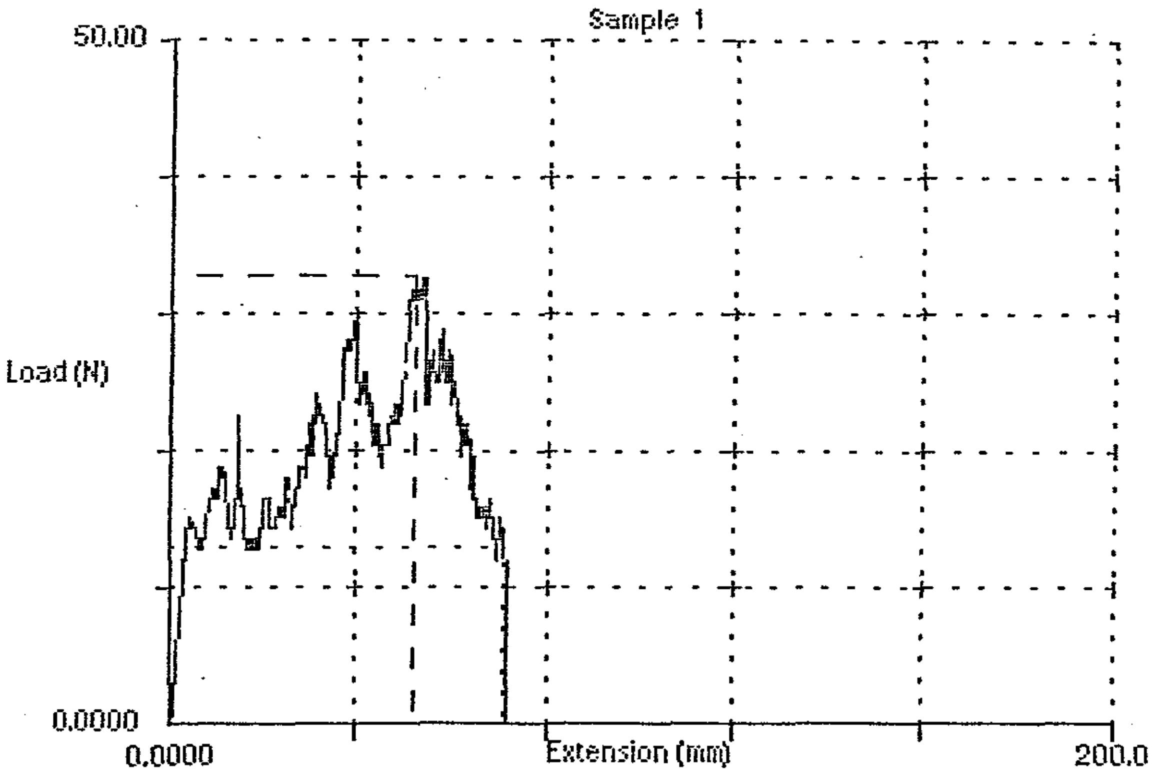
```
Maximum    Ext @    Load @    Ext @
 Load    Max Load   Break     Break
  (N)      (mm)      (N)      (mm)
  203.7    18.92     189.2     19.38
```

Graph 5.2 Tensile strength test for glued material (Pulled away from each other as described in figure 4.1)



```
Maximum    Ext @     Load @     Ext @
 Load    Max Load    Break     Break
  (N)      (mm)       (N)      (mm)
  36.62    18.46     2.289     88.35
```

Graph 5.3 Tensile strength test for glued material (Pulled away from each other as described in figure 4.2)



```
Maximum    Ext @    Load @     Ext @
 Load   Max Load    Break     Break
  (N)      (mm)      (N)      (mm)
  32.81    52.03    12.97     71.11
```

Graph 5.4 Tensile strength test for glued material (Pulled away from each other as described in figure 4.2)

5.3 PRACTICAL TESTING FOR ADHESION METHOD

In this experiment the gluing methods were tested practically. The first bag (Figure 4.3 in experimental methods) was at least five times stronger than the bag in Figure 4.4.

In the experiment with the second bag it was again obvious that because the two materials are stretched away from each other the PVC on the outside tears first and then the materials strength is very weak. It is actually the polyester layer between the PVC layers that produces the strength of the material.

When the materials are joined as in the first model, (Figure 4.3), the pressure applied is distributed over a larger joined area and is therefore found to be the strongest.

Therefore, whenever the second way of joining is used the pressure in that part of the model has to be minimized, to ensure that it does not tear. It can withstand a large pressure but caution should be taken.

5.4 WATER CHANNELING

In this experiment the best way of channeling the water through the model was tested. Three different models were tested and the results are as follows:

The first model as shown in Figure 4.5 was not tested. It was decided that this method would be impractical due to the uneven distribution of water in the system and also the quantity of water that will be contained in the system during operation.

The model as described in Figure 4.6 was constructed and tested. In this system only one channel is utilised and apart from minor design problems, yielded positive results. The positive and negative aspects are listed below:

Positive features

- The temperature difference between the incoming water to the 2 by 1.5m model and that leaving was 0.3 °C. This was observed during a day in winter with a temperature of 22 °C. This rate of energy absorbency is exceptionally good.

Negative features

- The water had to turn through 180° for each new channel. This led to an enormous pressure drop through the system.
- The idea of tapering each channel so that the water is forced outwards and so-doing not damage the sail when compressed in a corner worked well. However, this will increase the difficulty of manufacture.
- System pressure can be reduced by increased channel width. However, this will result in an increase in water inside the system.
- This specific model had no air release valve. The air in the system accumulated at the highest point. When the temperature rose the air expanded and this was one of the factors that contributed to tearing.

The final model that was tested had individual one-pass channels. The following positive and negative aspects were found.

Positive features:

- Much less water is in the heater at one point in time. This made the heater much lighter and more maneuverable when in operation.
- The channels are all parallel straight downwards. This ensured less elbows and a lower system pressure. The size of the channels where also

decreased substantially which lowered the pressure on the channel sides. These facts then ensured that no tearing of channels occurred.

- This method of channeling also made it easier to get the water out of the system when full. With a simple roll up station the water can be forced out of the system.
- A much bigger area of water is exposed to solar radiation. This is due to the smaller channels.
- If a channel should become blocked, the water can still flow through the others. In the one channel model this was not possible.

Negative features:

- To produce a system with so many channels is labour intensive. However, easier ways of joining the material is possible on a commercial basis.

5.5 AVAILABILITY OF SOLAR ENERGY IN CAPE TOWN

After processing the data received from the Weather Bureau, Graphs 5.5 – Graphs 5.10 were generated. The main aim was to determine whether there is sufficient solar heat to heat pool water and for what period can swimming time be extended.

Graph 5.7 gives the average day radiation. When this system is in operation the pool pump would be set to operate during maximum periods of solar radiation. Therefore, only the six-hour maximum radiation curve is considered.

From this graphs the following observations can be made:

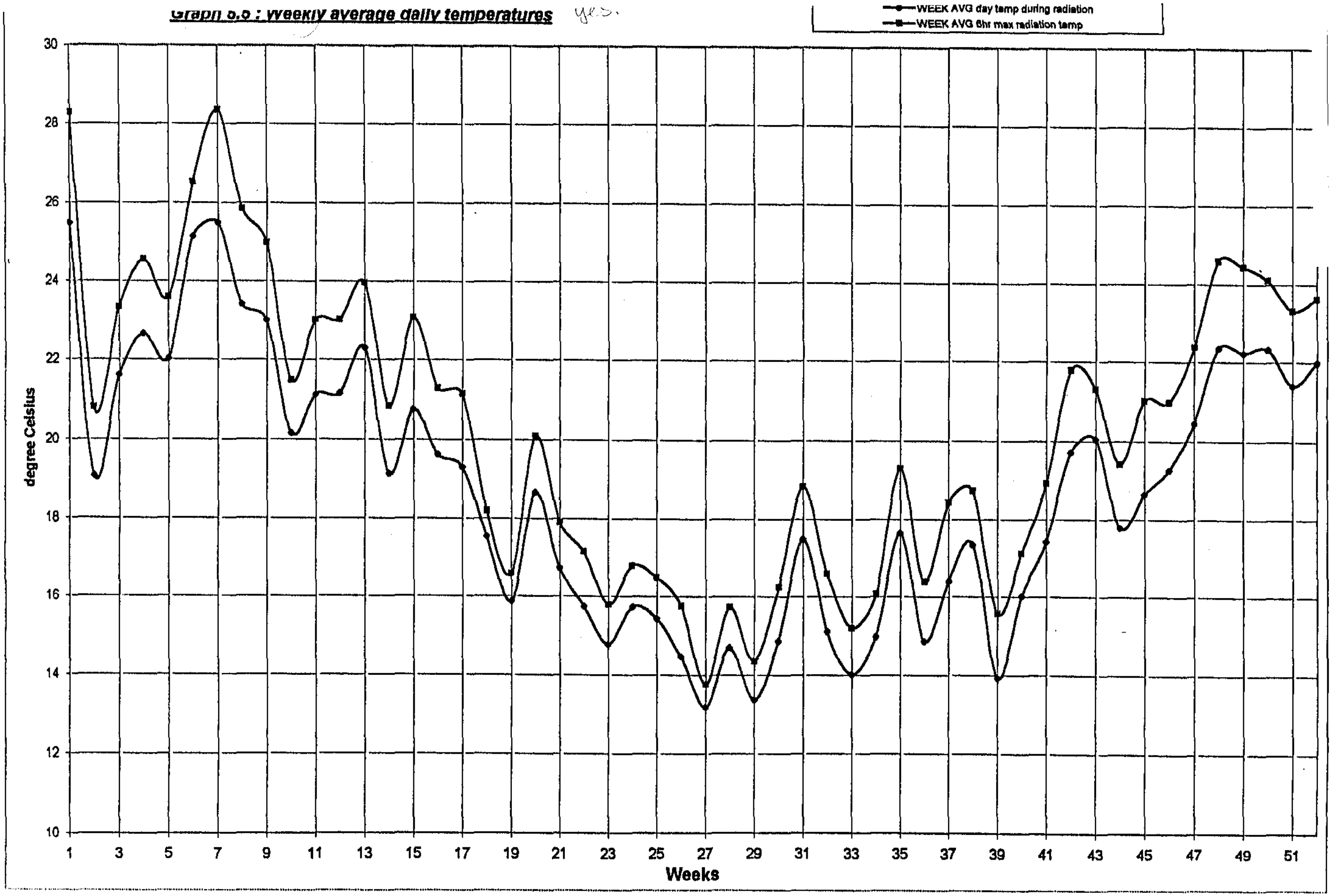
- Only between week 16 and week 34 does the average daytime radiation drop below 2MJ per hour. This indicates that only between May and

August will difficulty be experienced in raising the pool contents sufficiently. This is also shown in Graphs 5.9 and Graph 5.10.

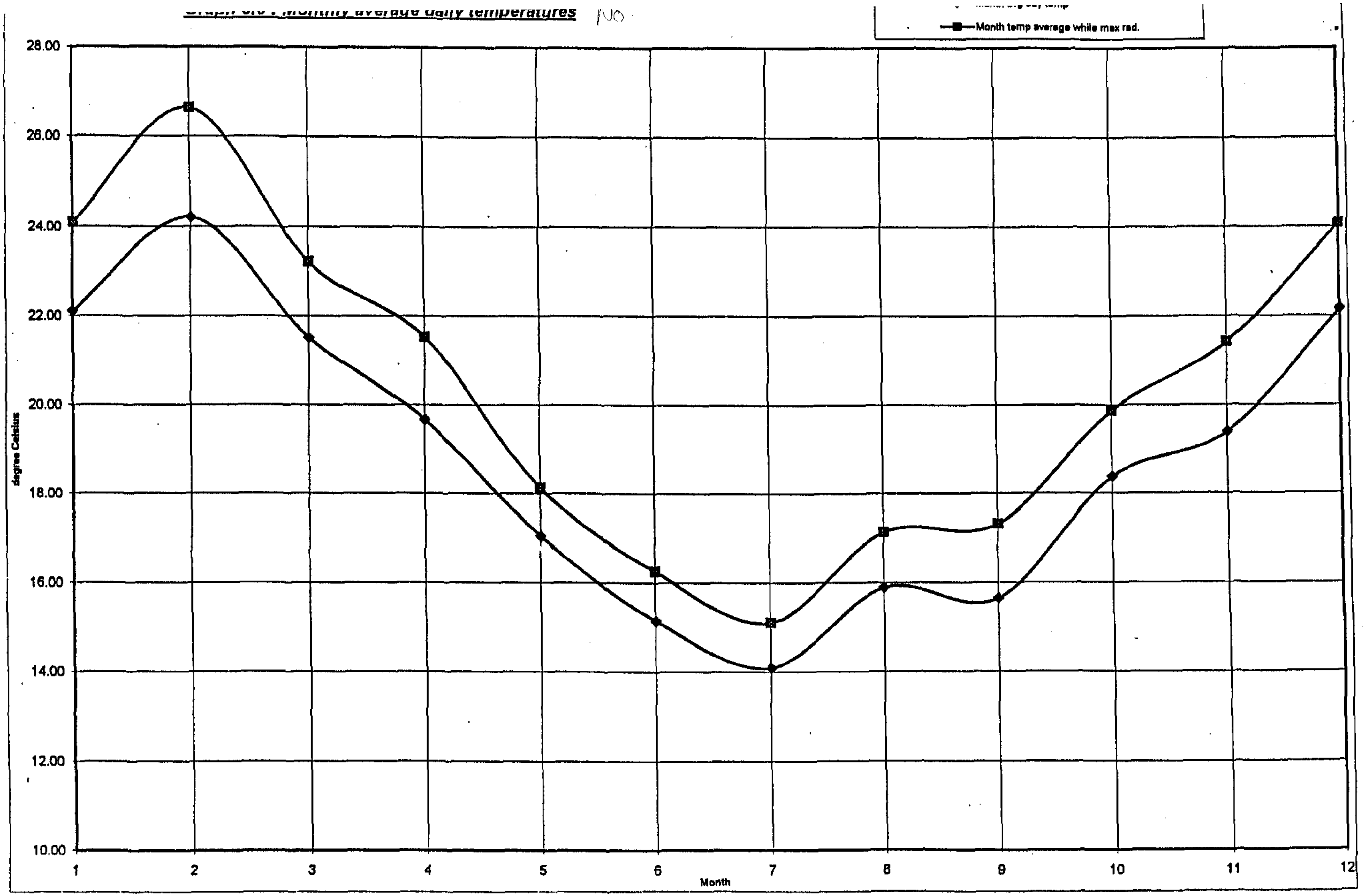
- During certain warm weeks in colder months it will be possible to raise pool temperatures sufficiently for swimming.
- During the rest of the year there are more than sufficient solar radiation to heat swimming pool contents.

On Graphs 5.5 and Graph 5.6 the average day temperatures over this period of time is plotted. The following observations are made:

- Extremely high temperatures are not always needed for adequate radiation. During the months September to November the temperatures is still below 20 °C but the radiation has already increased to acceptable levels. Therefore, temperatures are important, but low temperatures does not necessarily imply low radiation levels.

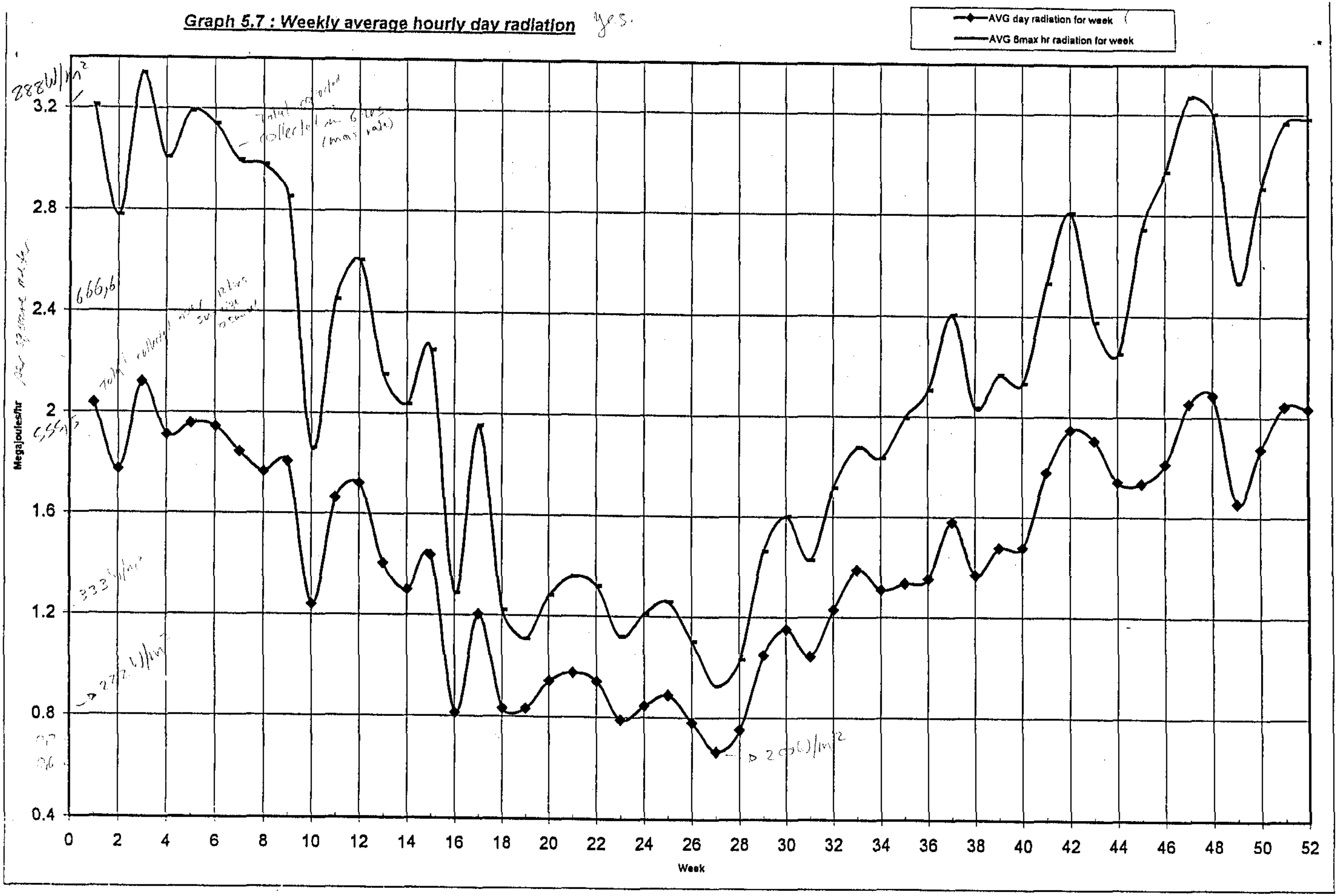


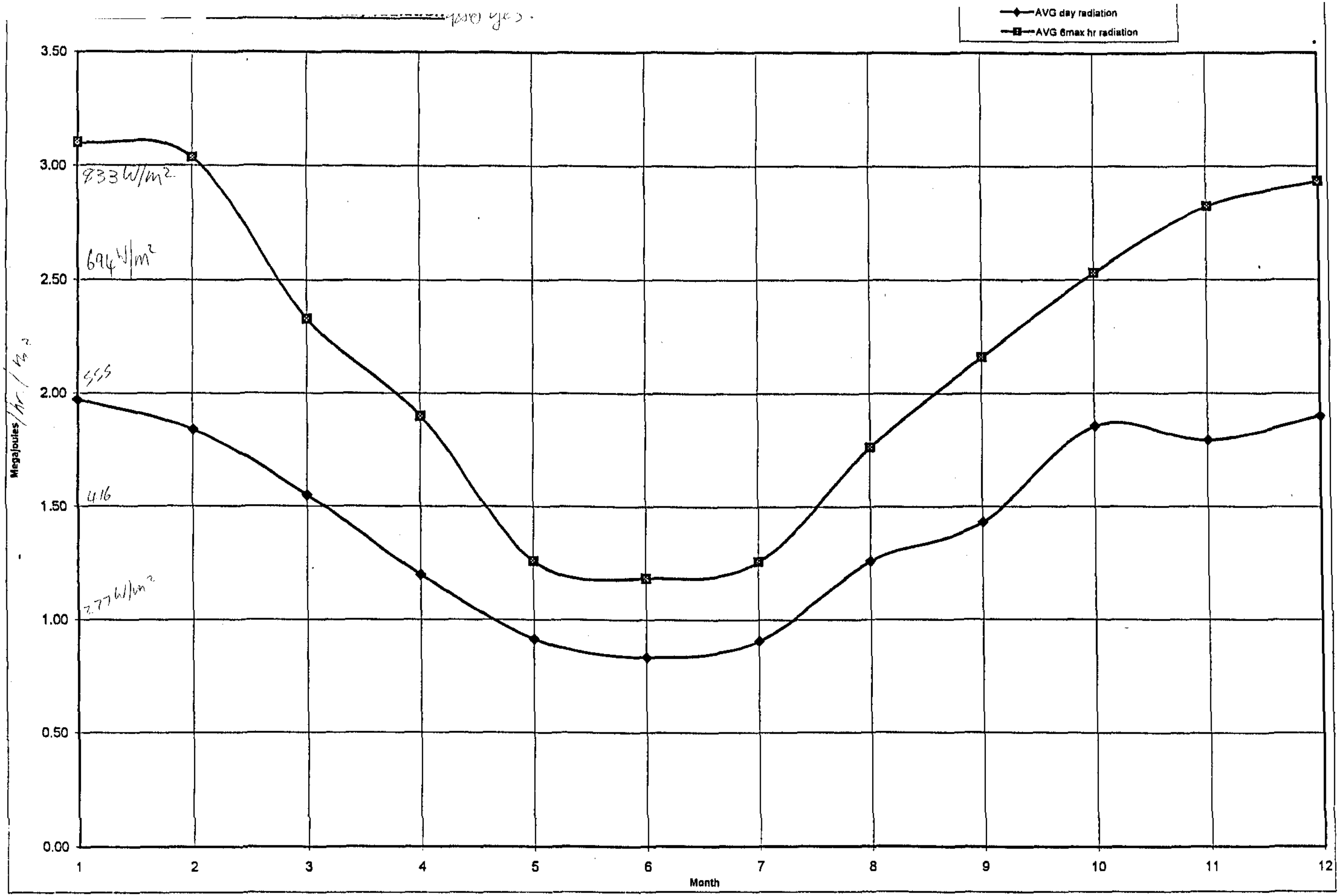
Graph [illegible] : Weekly average daily temperatures yes.

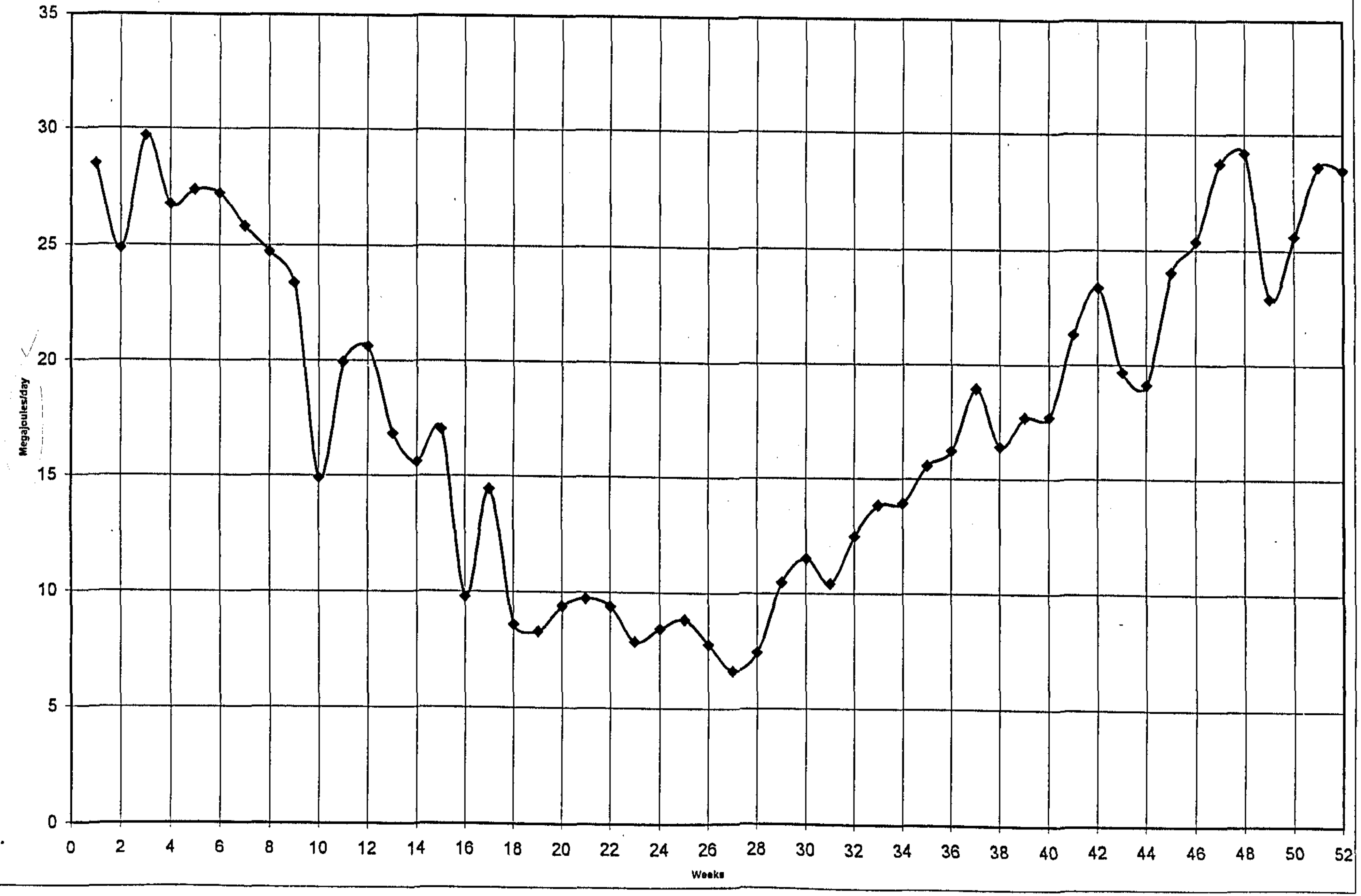

Monthly average daily temperatures
106
Month temp average while max rad.
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
degree Celsius
1
2
3
4
5
6
7
8
9
10
11
12
Month

Graph 5.7 : Weekly average hourly day radiation

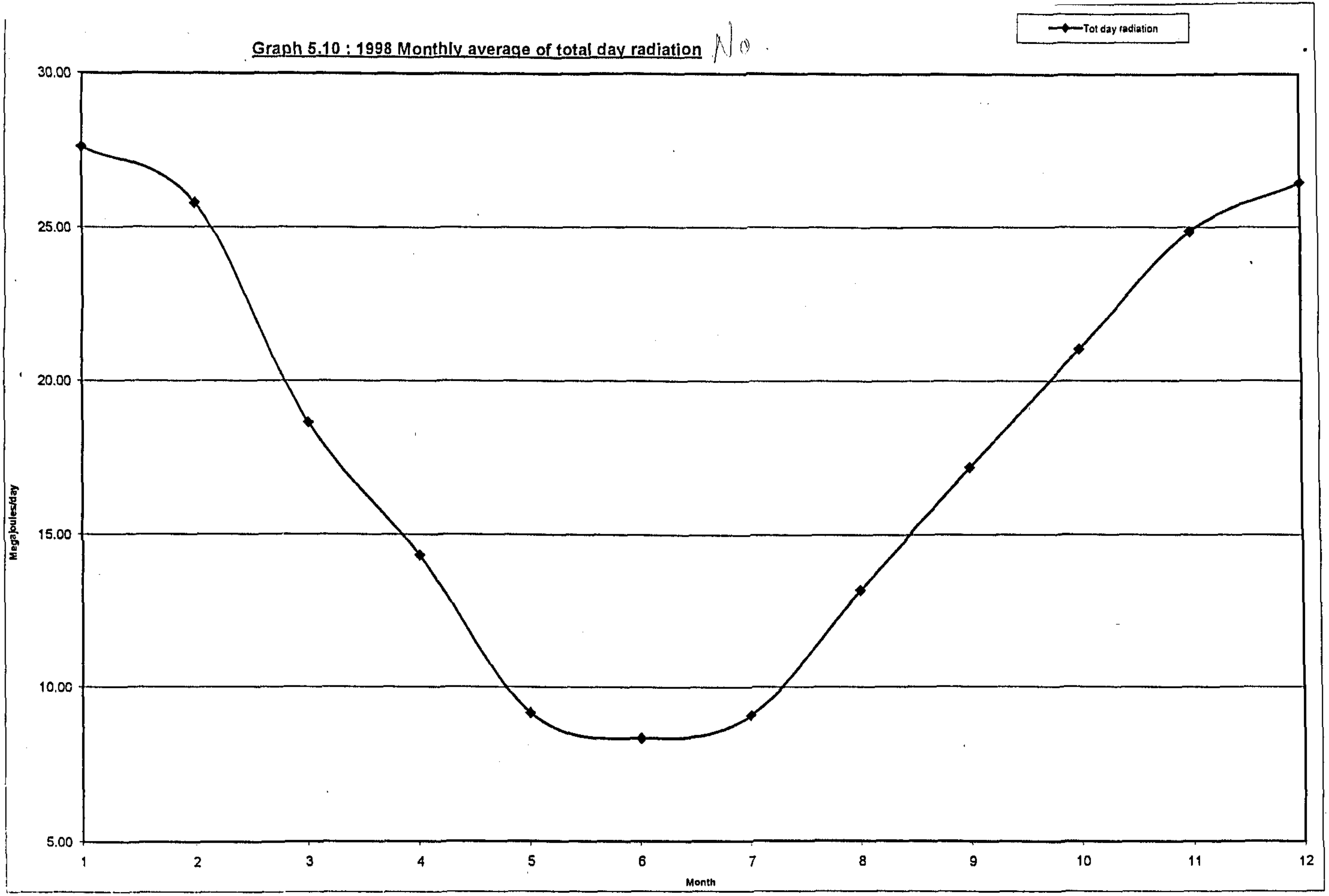
yes.




AVG day radiation
AVG 6max hr radiation
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Megajoules/hr/m²
833 W/m²
694 W/m²
555
416
277 W/m²
1
2
3
4
5
6
7
8
9
10
11
12
Month



35
30
25
20
15
10
5
0
Megajoules/day
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Weeks



Graph 5.10 : 1998 Monthly average of total day radiation No

5.6 PILOT PLANT PERFORMANCE

As explained under experimental methods there were two models tested.

The first model with the one continuous channel as in figure 4.6 produced good results in the absorption of solar heat. This model was two meters in length and one point five meters wide. When testing it on a day with a temperature of approximately 22 °C the following was obtained. The temperature difference between the input to the heater and that exiting it, was 0.3 °C. If taken into account that a pool is normally at least four meters in length and three meters wide we can expect a dramatic increase in this temperature difference.

Although this model provides good absorption it was discarded for reasons explained in section 5.4.

The second model containing one-pass channels was one meter in length and one point five meters wide. Although this model is half the size of the previous model it gave exactly the same results. Also, it did not have the negative aspects of the previous model and therefore this model is recommended.

A few test runs were taken during the month of August. August is a relatively cold month and normally pool temperatures never rise above 18 °C in this period. Occasionally, one or two hot days are experienced during this time of the year. Days like these were tested to see whether pool temperatures could be raised adequately. The following data was obtained during a test run taken.

Table 5.1 Wednesday 16 August 2000

Time	Air Temperature (°C)	Non Heated Container Temperature	Heated Container Temperature	Temperature difference (°C)
09:50	21	17.4	17.4	
10:20	22	18	20	0.5
10:50	22.9	18.5	20.6	0.3
11:20	23	19	20.9	0.3
11:50	23.7	19.1	21.4	0.5
12:20	24	19.1	21.8	0.4
12:50	25	19	22.5	0.4
13:20	26	19.8	23.3	0.2
13:50	25	19.9	23.6	0.2
14:20	24.4	20	23.9	0.2
14:50	24.4	19.9	24.1	0.2
15:20	22.3	19.8	24.3	0.1

The Non Heated Container Temperature in Table 1 is the temperature of a similar 1000-liter container to that used in the Heated Container. It is a reference container used to measure what the temperature of the water would be if a solar heated system were not connected to it. The water is agitated before measurements to ensure that the temperature taken is the overall temperature. The temperature difference in Table 1 is the temperature difference between the water leaving the tank and the water entering the heated tank.

From Table 1 the following observations are made:

- Although it was a hot day the temperature of the non-heated container did not rise above 20 °C.
- The temperature of the heated container rose much faster and to an adequate swimming temperature of 24 °C.
- During mid-day the heater receives most radiation.
- Although only a thousand liters is heated, it must be noted that only 1.5 square meters of absorbent material is used. In normal situations on a five by three meter pool it will be at least 15 square meters, hence able to heat a larger volume of water.

5.7 THE INFLUENCE OF THE SUN ON BOTH MATERIAL AND ADHESION AREAS

Influence of sun on both the material and glued material strength.				
a) Plain sample as described in section 4.1				
b) Glued sample as described in Figure 4.1 of section 4.2				
c) Glued sample as described in Figure 4.2 of section 4.2 (Pulled in opposite directions)				
	Maximum load (N)			
	Month 1	**Month 2**	**Month 3**	**Month 4**
a) Solid sample	176.5	167.6	151.3	162.6
b) Glued sample	199.1	*244.1*	*230*	*229.6*
c) Glued sample	32.81	31.56	32.96	32.81

Table 5.7a

Influence of the sun on the material colour over a four-month period.						
	L*	**a***	**b***	**delta L***	**delta C***	**delta E***
Standard	26.52	0.04	-19.18			
Month 1	26.54	0.01	-18.88	0.02	0.3	0.3
Month 2	26.57	-0.16	-18.34	0.05	0.87	0.87
Month 3	26.08	0.25	-18.72	-0.45	0.51	0.68
Month 4	*27.09*	*-0.56*	*-16.34*	*0.57*	*2.91*	*2.96*

Table 5.7b

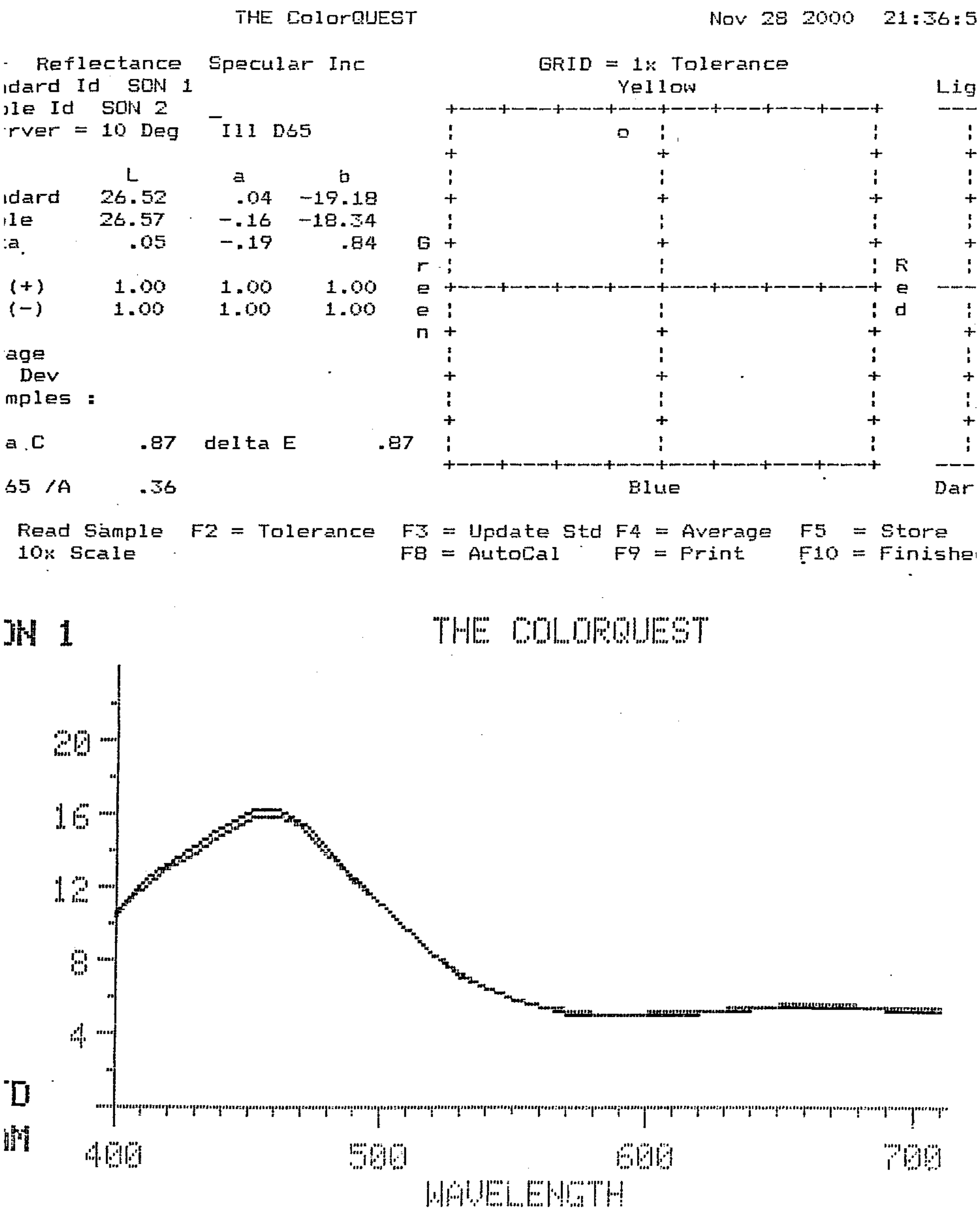
Table 5.7a indicates that the sun does not have any real effect on the strength of either the material or adhesion. The minor differences in maximum load experienced can be ascribed to experimental errors and the fact that the material used is never completely homogeneous. Thus, it can be concluded that the strength of the material selected is adequate for the proposed application.

From Table 5.7b the following observations were made. The longer the material is exposed to the sun the lower the a* value becomes. This indicates that the material turns *greener.* The b* value is also decreasing, therefore the material is slowly turning from blue towards yellow. The delta L* values are also increasing, thus indicating that the material becomes lighter in colour.

Graph 5.7.1 is an illustration of the results obtained when the colour *measurement is taken on the material after two months in the sun. The graph* shows how much light is reflected. Graph 5.7.2 and graph 5.7.3 shows that the material becomes less reflective the longer it is exposed to the sun. The material loses some of its shine, thus although the material slowly becomes lighter in colour its reflectiveness decreases. This phenomenon counter acts the loss of colour.

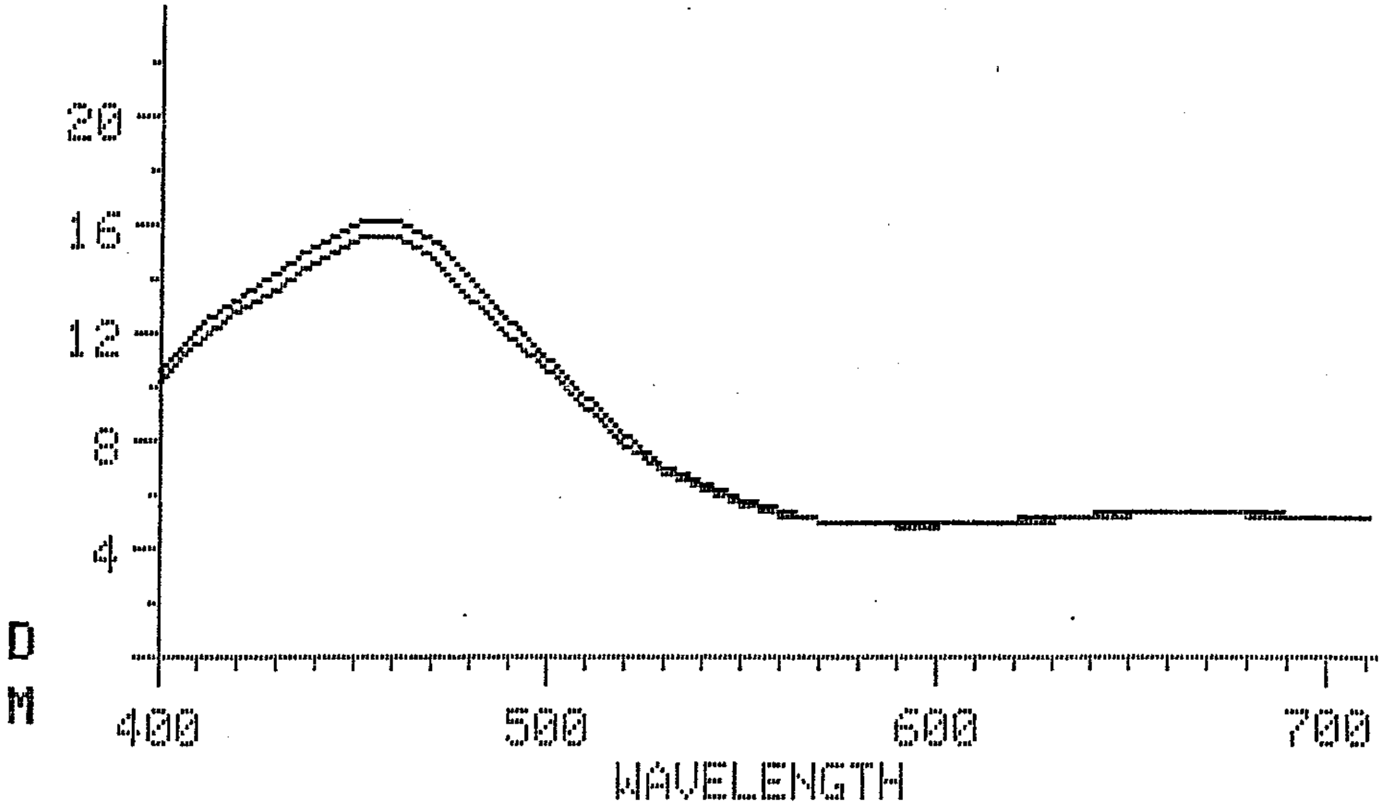
Thus, it is concluded that, although there is a slow change in colour, the absorption of radiation does not necessarily decrease due to the decrease of *reflectiveness by the material.*

Graph 5.7.1 Colour measurement printout

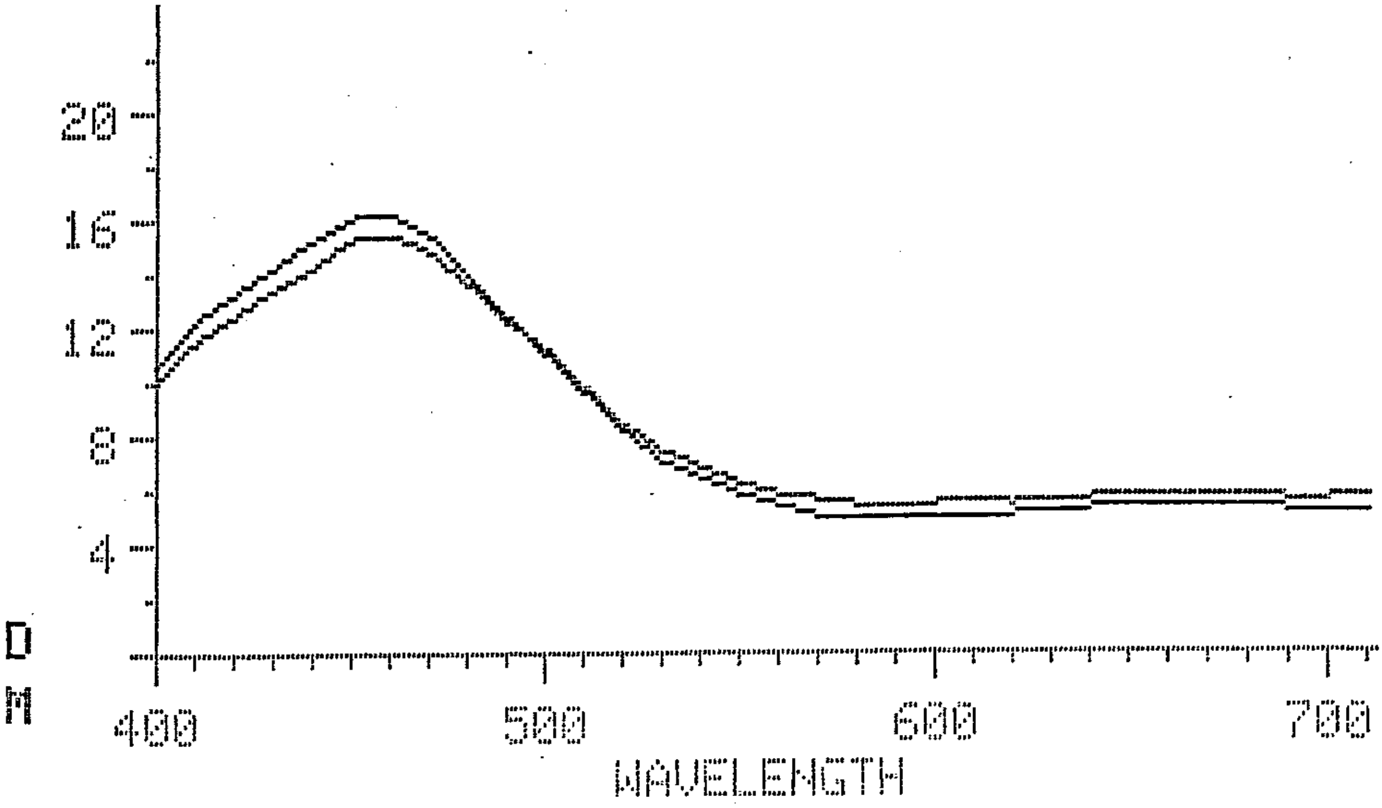


```
                THE ColorQUEST                              Nov 28 2000   21:36:5

-  Reflectance  Specular Inc
dard Id  SON 1
le Id  SON 2
rver = 10 Deg   Ill D65

           L          a          b
dard     26.52       .04    -19.18
le       26.57      -.16    -18.34
a          .05      -.19       .84

(+)       1.00      1.00      1.00
(-)       1.00      1.00      1.00

age
 Dev
mples :

a C         .87   delta E        .87

65 /A       .36

 Read Sample   F2 = Tolerance   F3 = Update Std F4 = Average   F5  = Store
 10x Scale                      F8 = AutoCal    F9 = Print     F10 = Finishe
```

Graph 5.7.2 Reflectivity of material after 3 months in the sun



Graph 5.7.3 Reflectivity of material after 4 months in the sun



5.8 THE INFLUENCE ACIDIC WATER ON BOTH MATERIAL AND ADHESION AREAS

Influence of strong acidic water on both the material and glued material.				
a) Plain sample as described in section 4.1				
b) Glued sample as described in Figure 4.1 of section 4.2				
c) Glued sample as described in Figure 4.2 of section 4.2 (Pulled in opposite directions)				
	Maximum load (N)			
	Month 1	Month 2	Month 3	Month 4
a) Solid sample	194.3	186	157.3	192.3
b) Glued sample	212.9	203.7	208.5	210.6
c) Glued sample	31.28	32.85	30.56	32.04

Table 5.8a

Influence of strong acidic water on the material colour over a four-month period.						
	L*	a*	b*	delta L*	delta C*	delta E*
Standard	26.52	0.04	-19.18			
Month 1	27.84	-2.4	-16.36	1.32	3.73	3.96
Month 2	26.71	-1.1	-15.97	0.19	3.41	3.41
Month 3	26.79	-0.41	-17.71	0.27	1.54	1.56
Month 4	27.29	-1.49	-16.13	0.77	3.41	3.5

Table 5.8b

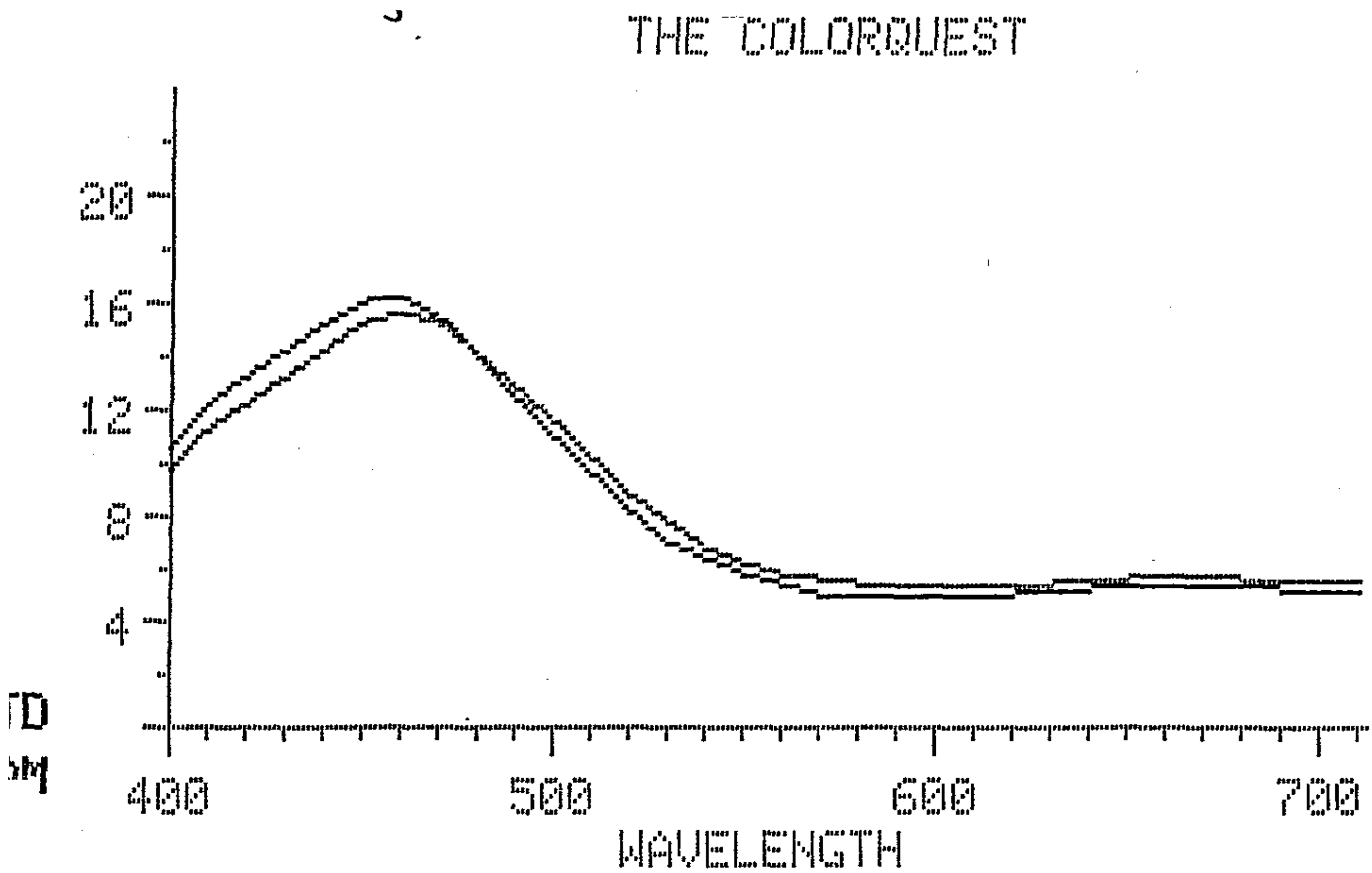
Table 5.8 indicates that the acid water does not have any real effect on the strength of either the material or adhesion. There is no noticeable decline in the strength of the material. The experiment with the solid sample shows a drastic material weakening during month three. However, this is ascribed to an experimental error since month four yields and acceptable strength.

Table 5.8b indicates that the a* values stay more or less the same while the b* slowly decreases. Thus, the material is turning more _yellowish_ in colour. This change is very slow since neither the delta L* nor the delta C* or delta E* values show major changes.

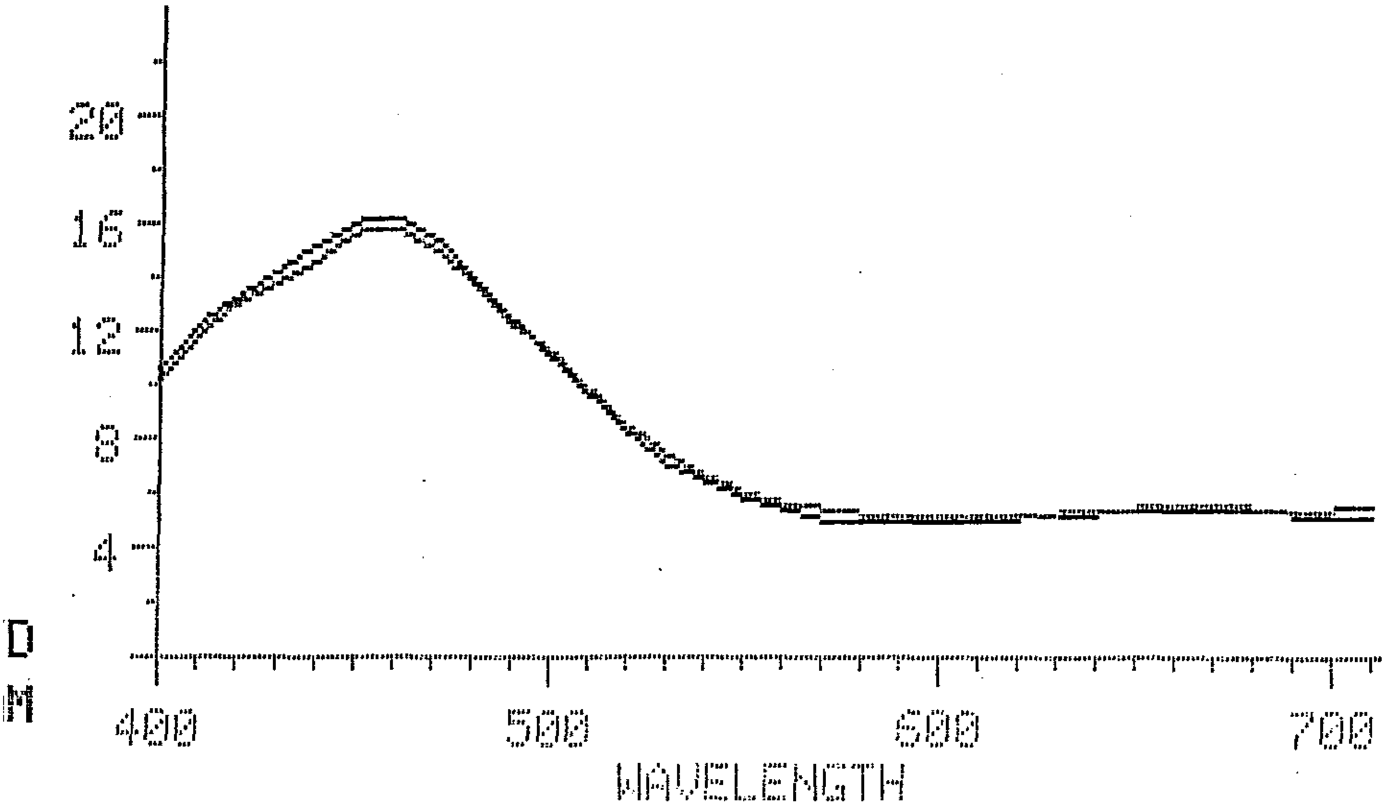
Graph 5.8.1 indicates that in the beginning strong acidic water takes the shine off the material and therefore the material reflects less light after month one. Graph 5.8.2 – 5.8.4 indicates that the material gradually becomes lighter, increasing reflectivity. However, this change is small.

The *strength of the material is of more importance in these experiments,* since water contact with the absorbing surface would be minimal.

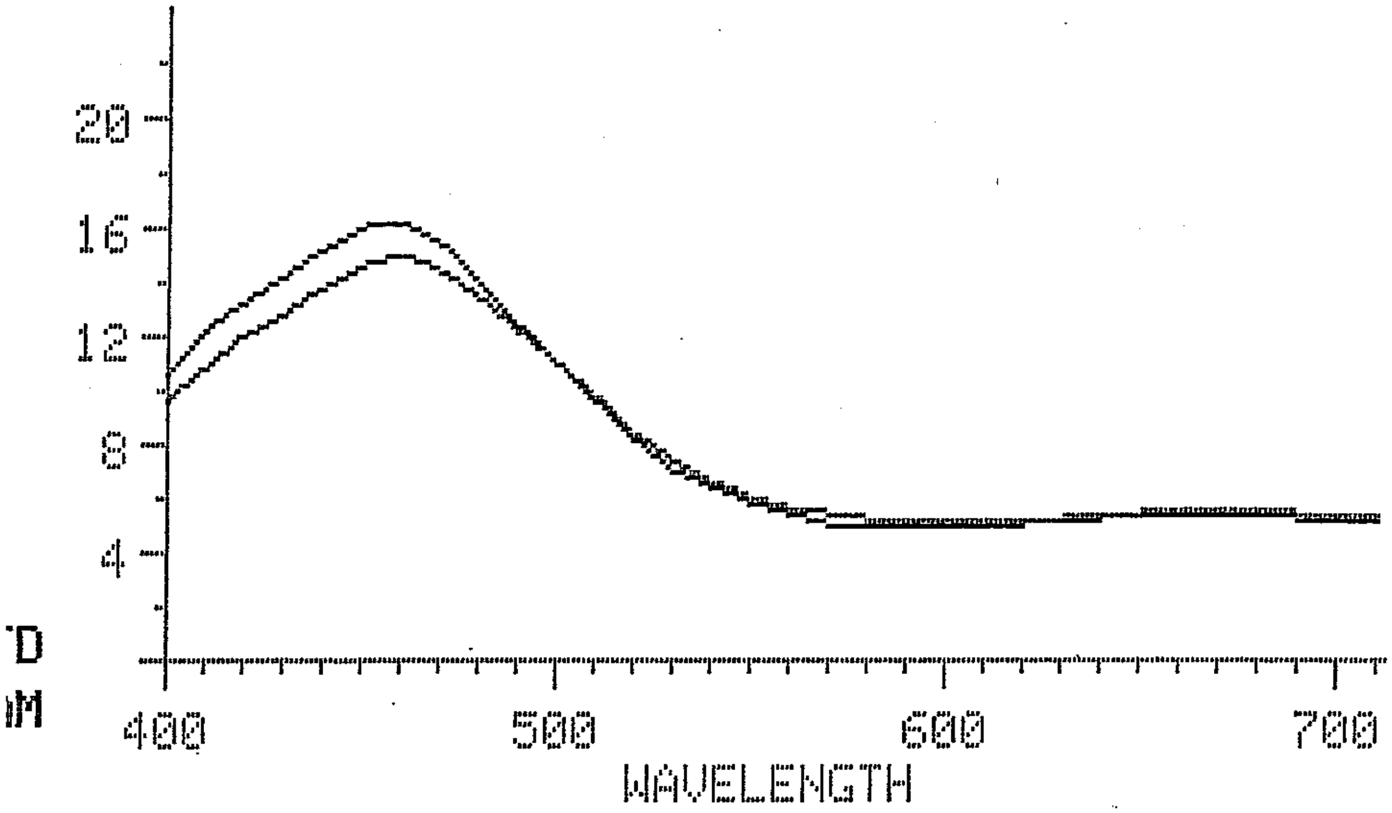
Graph 5.8.1 Reflectivity of material after 1 month in acidic water



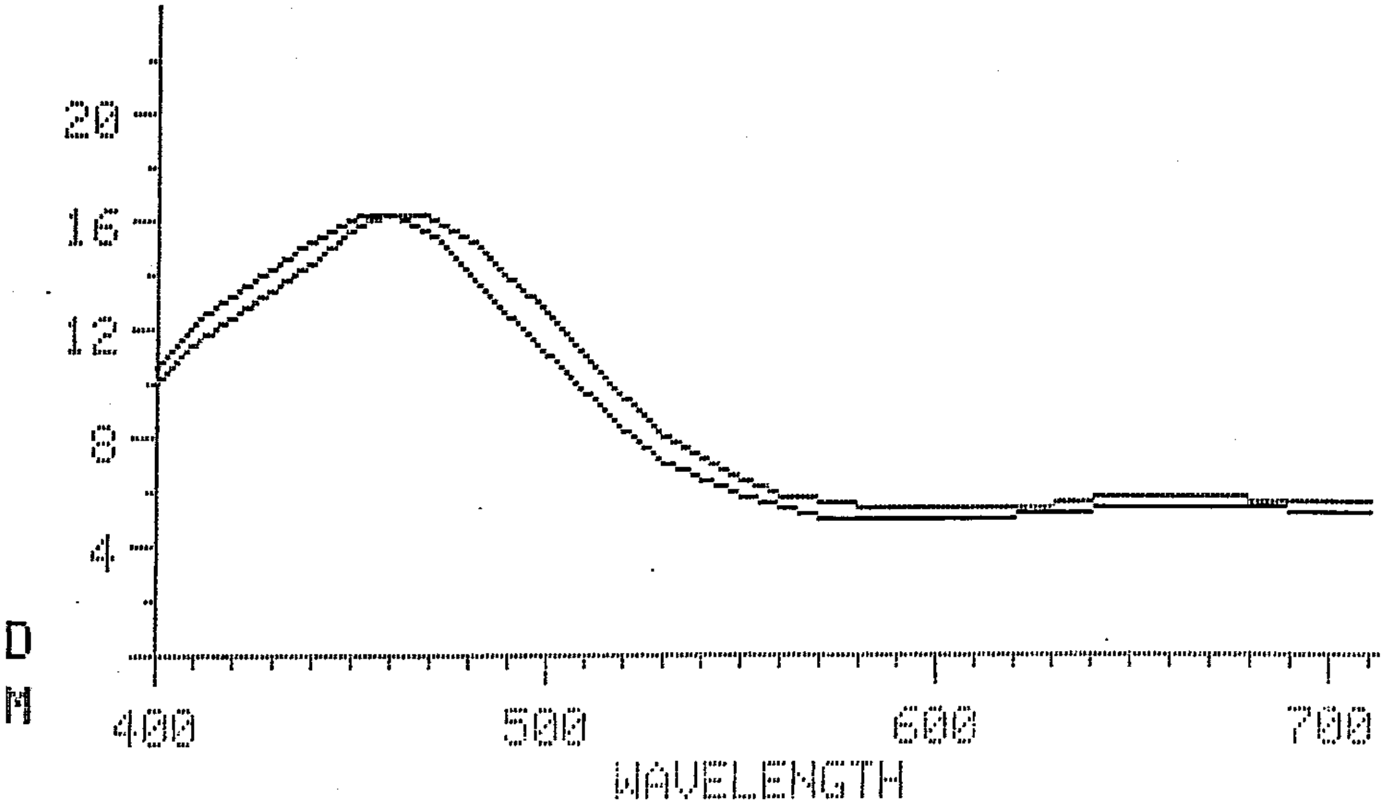
Graph 5.8.2 Reflectivity of material after 2 months in acidic water



Graph 5.8.3 Reflectivity of material after 3 months in acidic water



Graph 5.8.4 Reflectivity of material after 4 months in acidic water



5.9 THE INFLUENCE OF CHLORINE WATER ON BOTH MATERIAL AND ADHESION AREAS

Influence of strong chlorine water on both the material and glued material.

a) Plain sample as described in section 4.1

b) Glued sample as described in Figure 4.1 of section 4.2

c) Glued sample as described in Figure 4.2 of section 4.2 (Pulled in opposite directions)

	Maximum load (N)			
	Month 1	Month 2	Month 3	Month 4
a) Solid sample	167	159.3	177	183.6
b) Glued sample	243.4	246.4	230.5	215.9
c) Glued sample	33.57	31.48	34.68	30.52

Table 5.9a

Influence of strong chlorine water on the material colour over a four-month period.

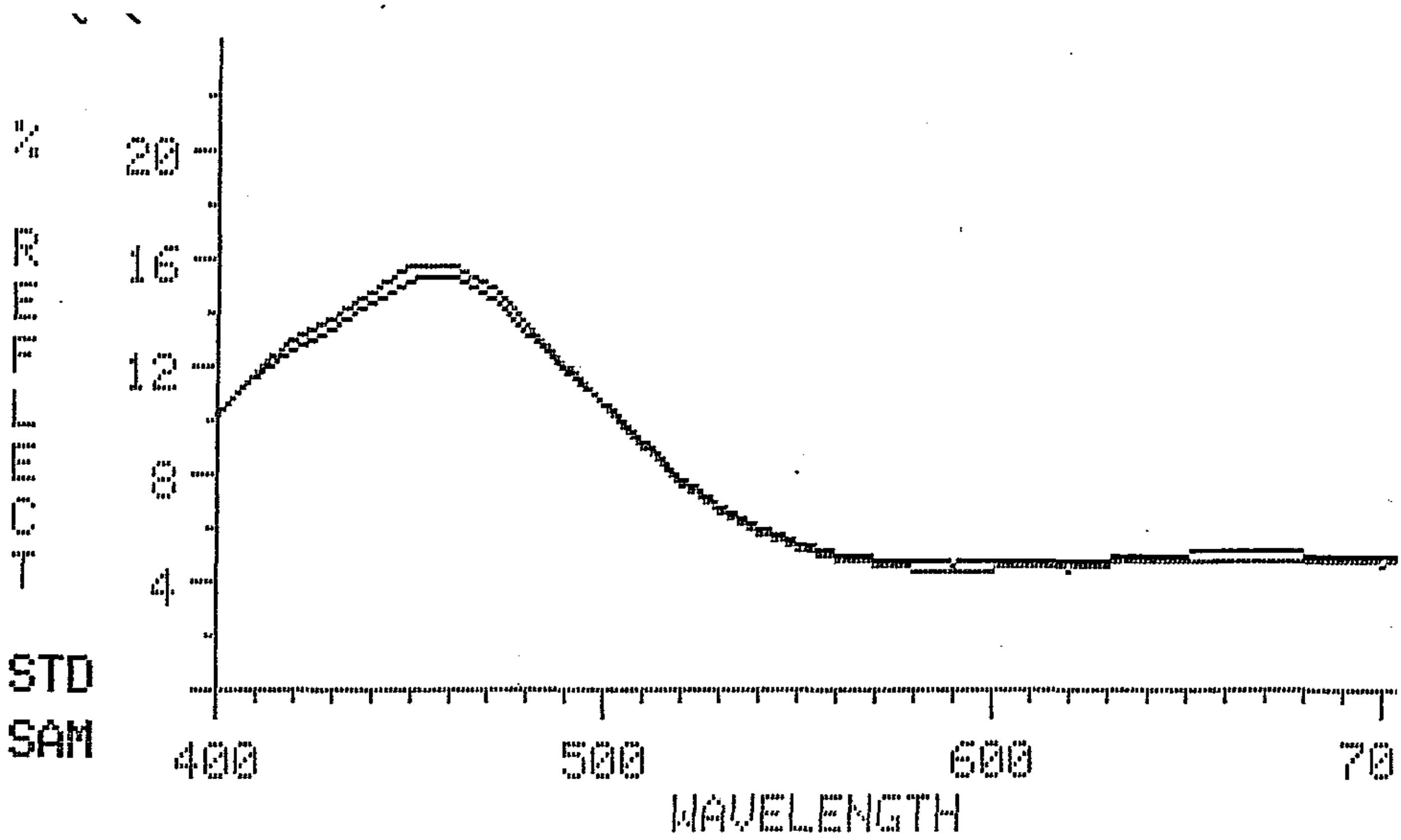
	L*	a*	b*	delta L*	delta C*	delta E*
Standard	26.52	0.04	-19.18			
Month 1	26.16	0.14	-20.91	-0.36	1.73	1.76
Month 2	26.37	-0.02	-19.66	-0.15	0.48	0.5
Month 3	29.89	-7.64	-13.9	3.37	9.32	9.91
Month 4	32.82	-10.6	-10.65	6.29	13.64	15.02

Table 5.9b

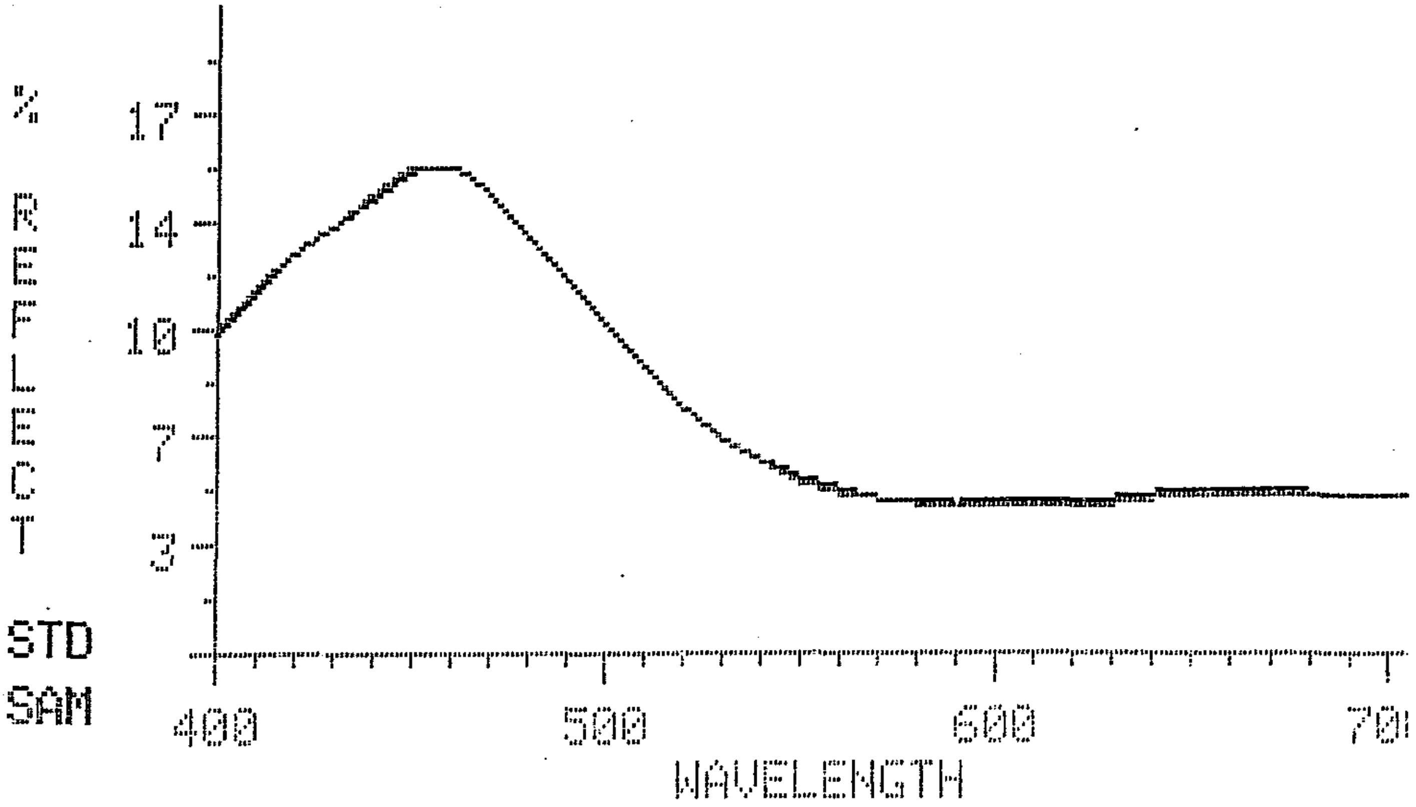
The data in Table 5.9(a) indicates that free chlorine has no noticeable effect on the strength of the material.

Table 5.9b indicates that the colour lightness of the material definitely increases. The material's colour also changes substantially towards green and yellow. These changes in colour drastically influences the reflectivity of the material as indicated on graphs 5.9.3 and 5.9.4. The material reflectivity increases drastically. However, this is not seen as a major negative aspect since the absorbing surface is not exposed to swimming pool water continuously.

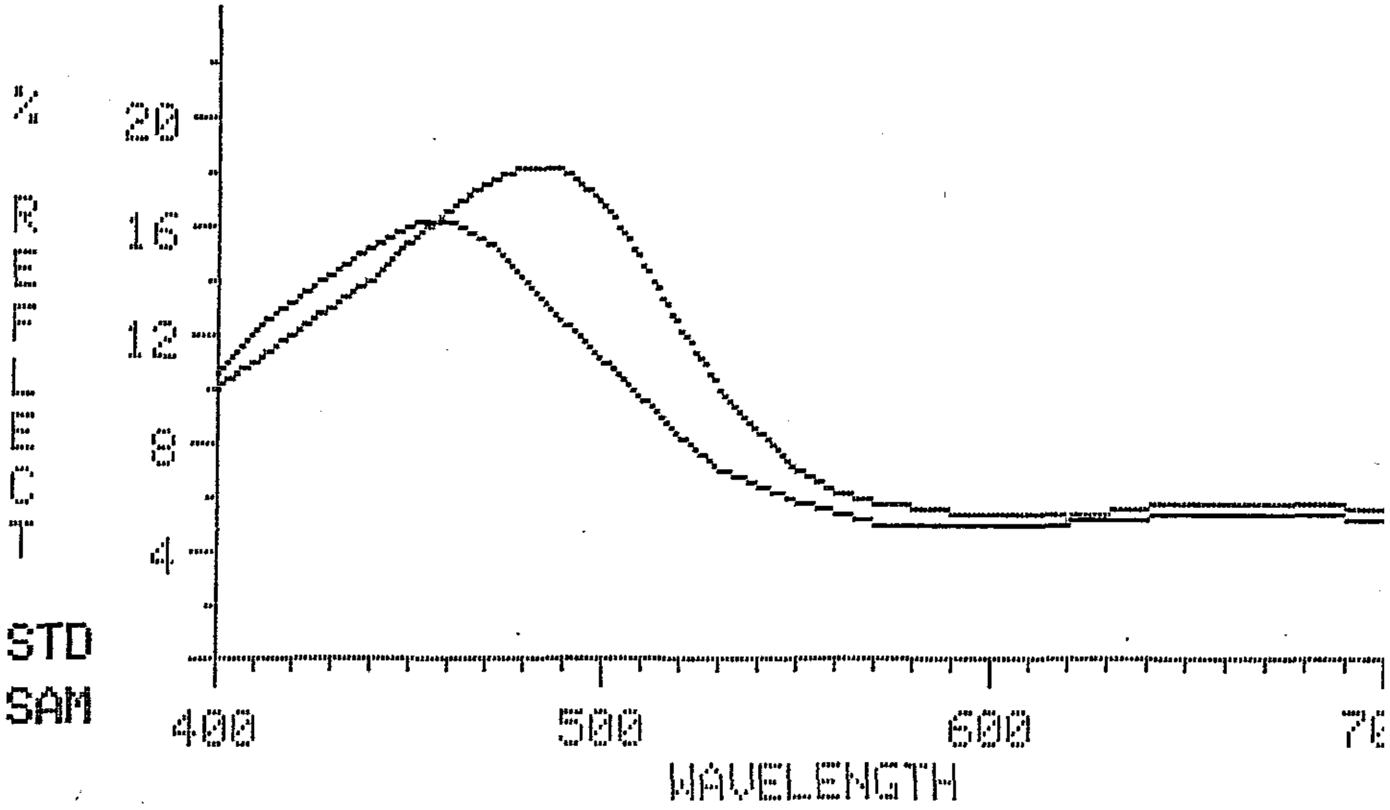
Graph 5.9.1 Reflectivity of material after 1 month in chlorine water



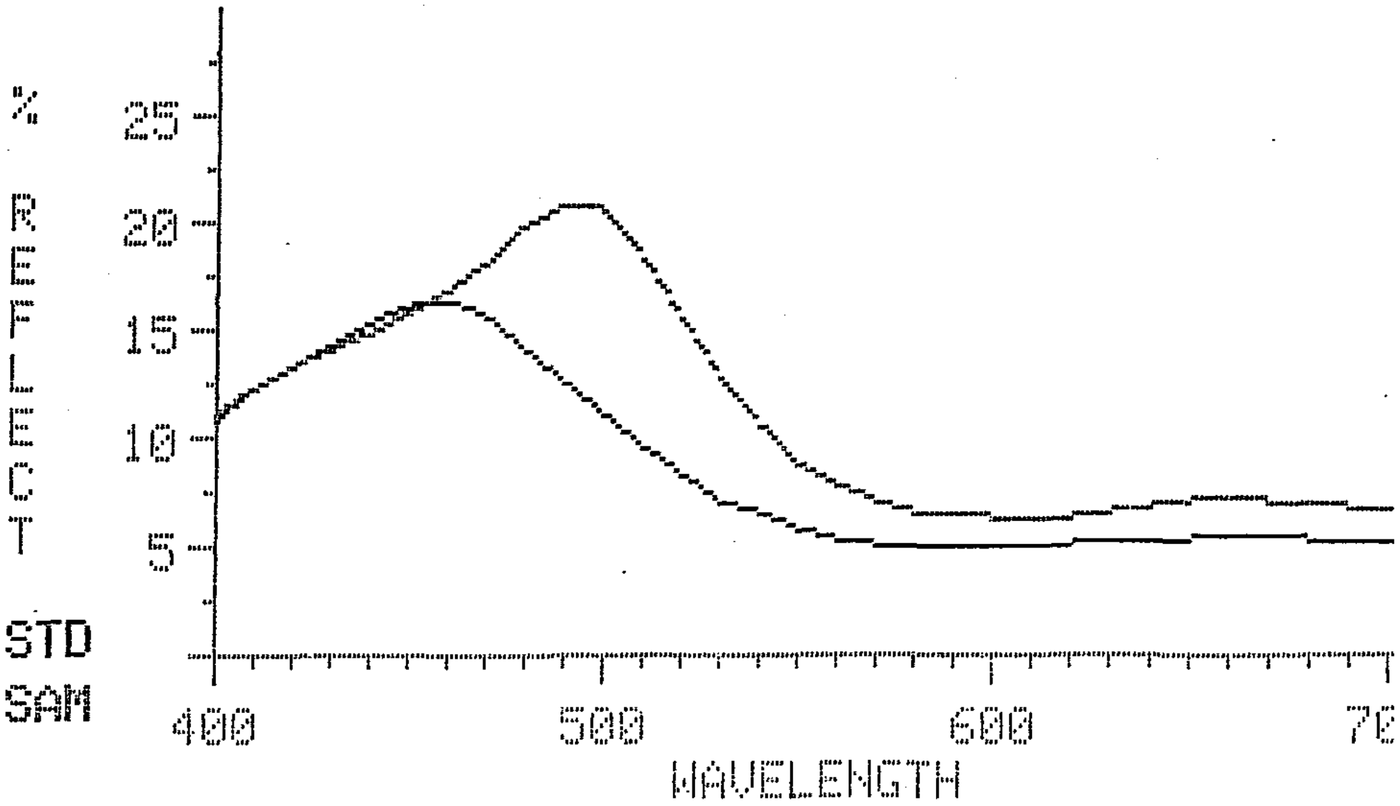
Graph 5.9.2 Reflectivity of material after 2 months in chlorine water



Graph 5.9.3 Reflectivity of material after 3 months in chlorine water



Graph 5.9.4 Reflectivity of material after 4 months in chlorine water



5.10 THE INFLUENCE OF IDEAL SWIMMING POOL WATER ON BOTH MATERIAL AND ADHESION AREAS

Influence of ideal pool water on both the material and glued material.				
a) Plain sample as described in section 4.1				
b) Glued sample as described in Figure 4.1 of section 4.2				
c) Glued sample as described in Figure 4.2 of section 4.2 (Pulled in opposite directions)				
	Maximum load (N)			
	Month 1	***Month 2***	***Month 3***	***Month 4***
a) Solid sample	188.6	196	182.6	171.6
b) Glued sample	203.7	228.9	230.5	235
c) Glued sample	36.62	37.85	38.52	39.67

Table 5.10a

Influence of normal pool water on the material colour over a four-month period.						
	L*	**a***	**b***	**delta L***	**delta C***	**delta E***
Standard	26.52	0.04	-19.18			
Month 1	28.82	-3.65	-20.66	2.3	3.97	4.59
Month 2	31.4	-8.17	-15.75	4.88	8.9	10.15
Month 3	31.06	-8.2	-15.02	4.54	9.23	10.29
Month 4	31.08	-8.37	-16.02	4.56	8.98	10.07

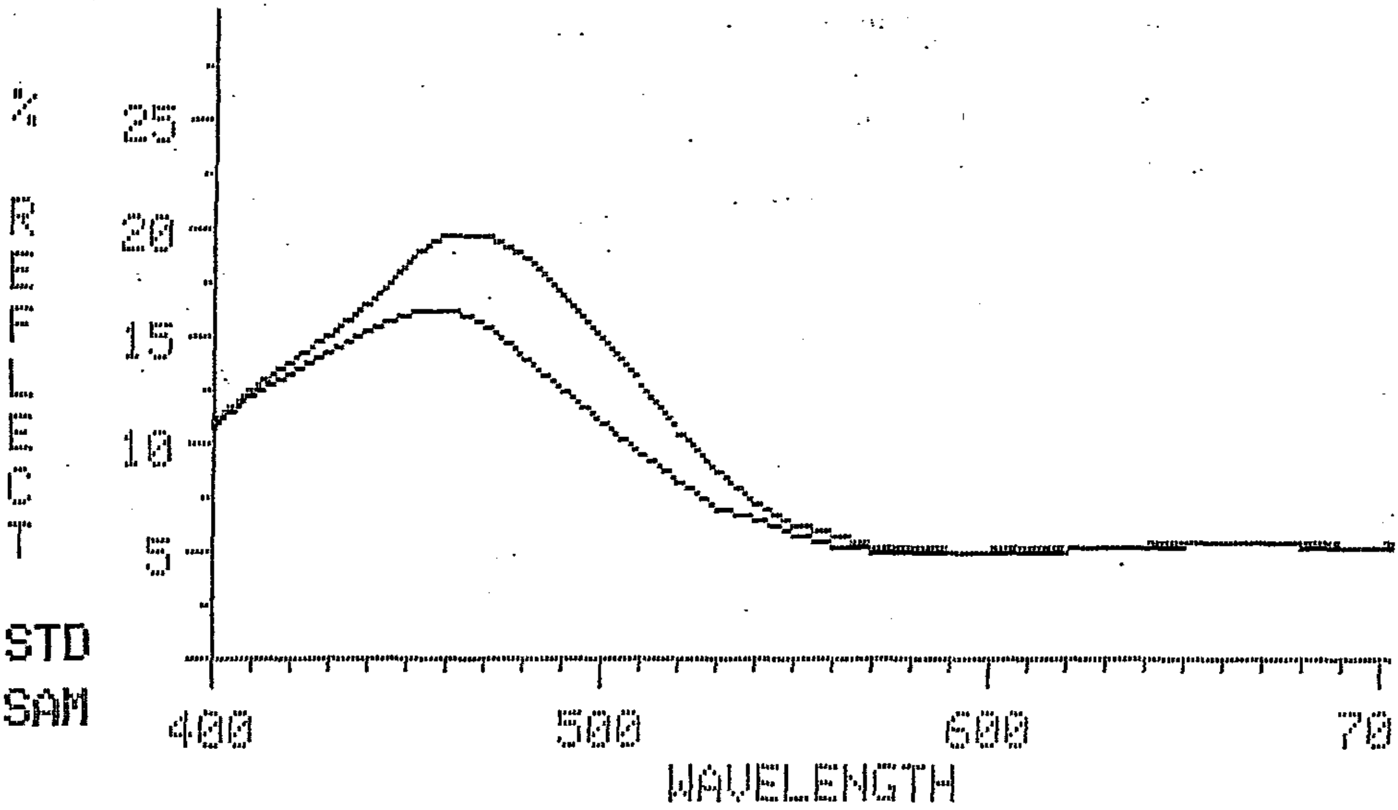
Table 5.10b

The data in Table 5.10(a) indicates that no weakening of the material occurred over the four-month test period. Random changes in material strength is observed but this is again ascribed to non uniformity of the material and/or experimental errors

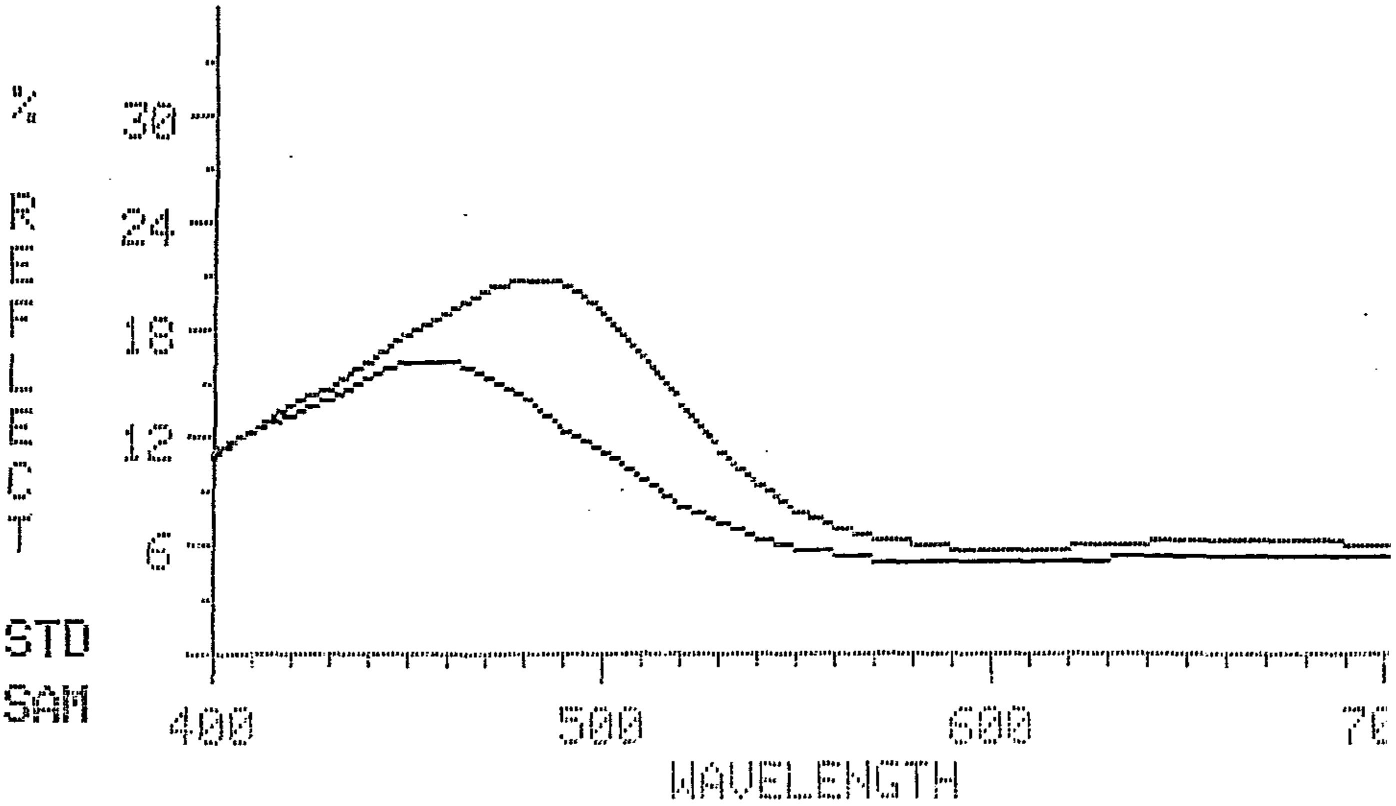
Table 5.10b gives similar results to that of table 5.9b. Again the material colour fades and changes colour. As indicated before, this will not affect the pool heating systems performance.

Graphs 5.10.1 – graphs 5.10.4 confirms the results on the changing of the colour. More light is reflected but since it is at the bottom it does not affect the absorbency.

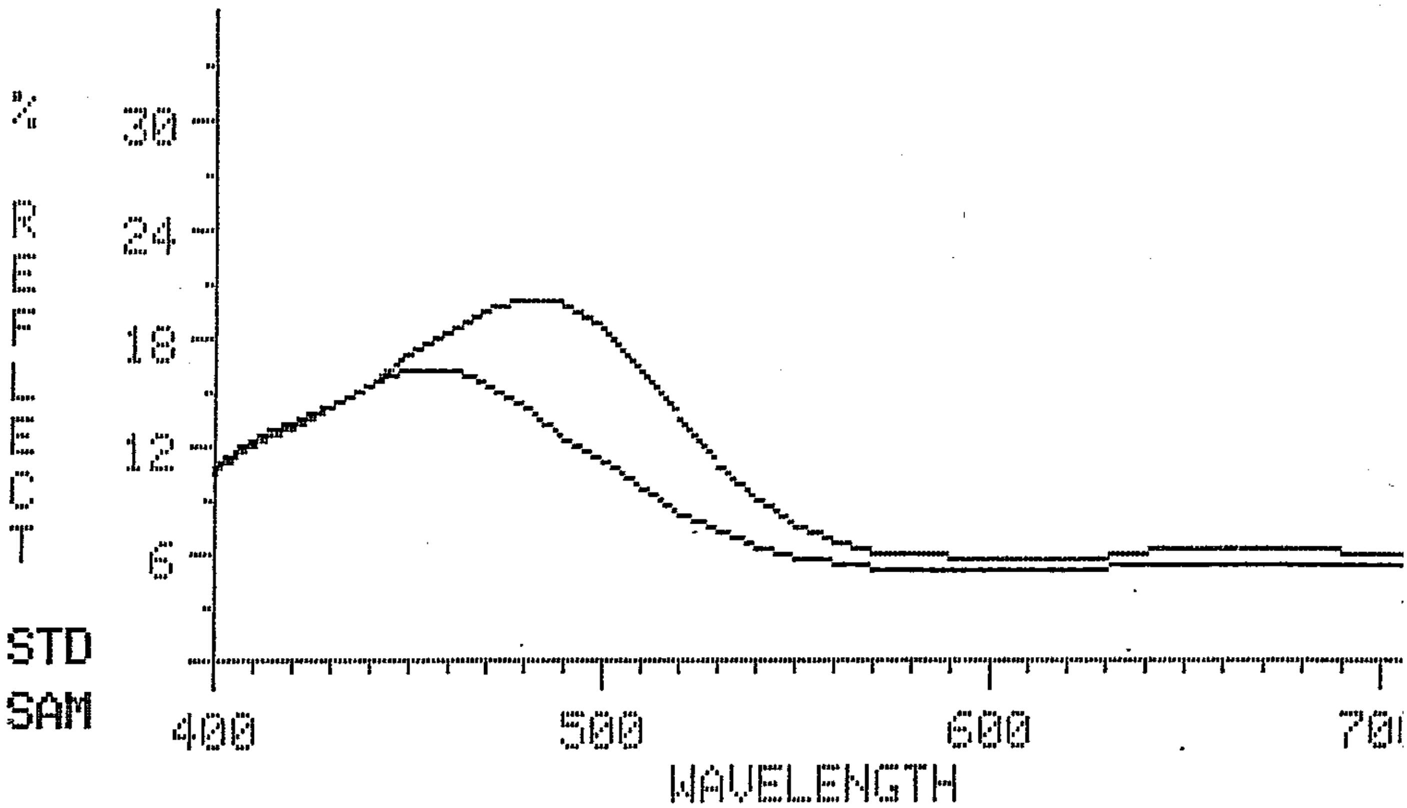
Graph 5.10.1 Reflectivity of material after 1 month in normal pool water



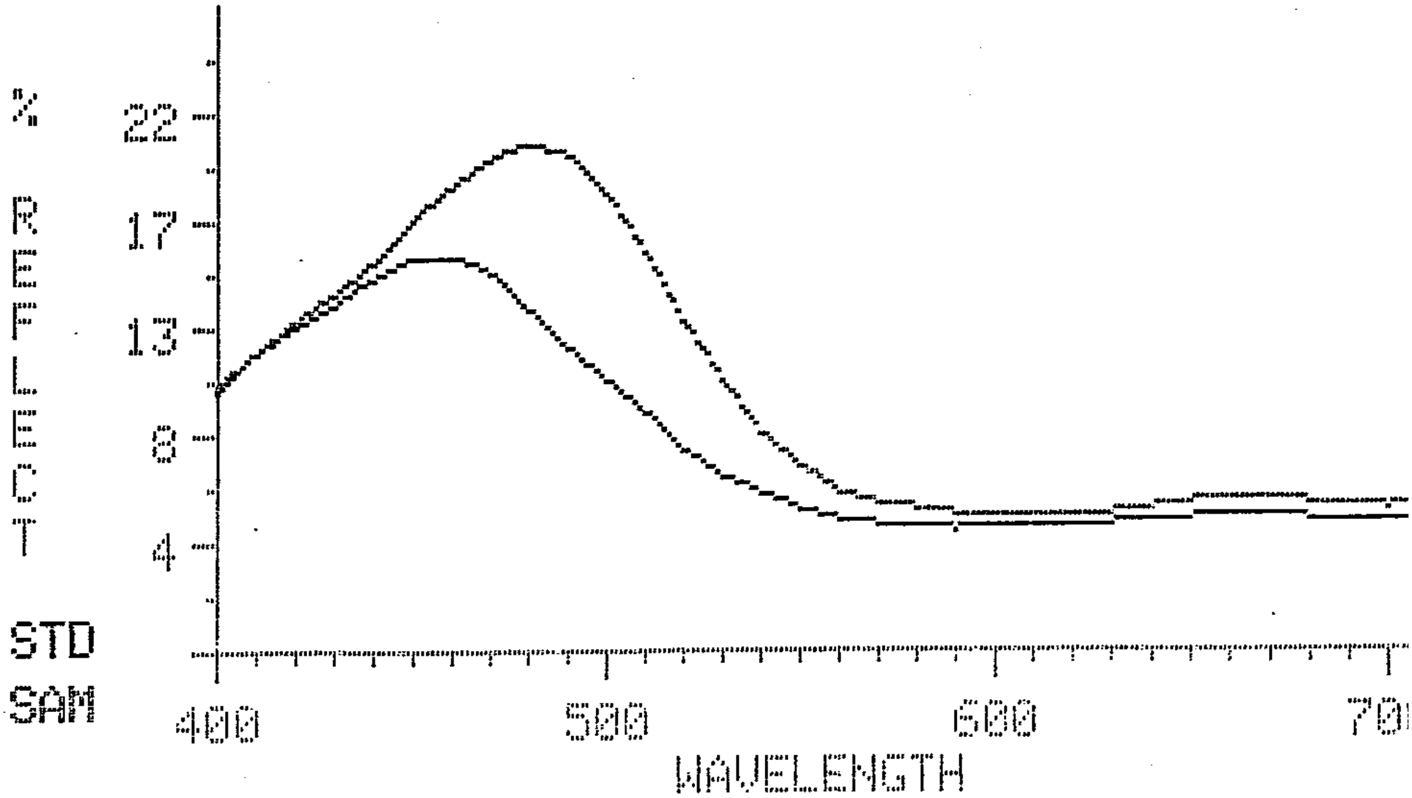
Graph 5.10.2 Reflectivity of material after 2 months in normal pool water



Graph 5.10.3 Reflectivity of material after 3 months in normal pool water



Graph 5.10.4 Reflectivity of material after 4 months in normal pool water



CHAPTER 6

FULL SCALE MODEL

In this chapter practical considerations in the design and operation of a full scale model is explained.

6.1 Placing

One advantage of this solar heater is that it is mobile. When the pool is not in use for swimming, the solar heater will be covering and heating the pool. When the pool is use for swimming purposes and the pool temperature is still to be increased, the system may be placed where it will absorb maximum solar radiation while still in operation. This means placement where it is exploited to the sun most of the day.

If it is not preverbal to cover the pool, say for instance in the summer months, the system could be placed on the roof of a house over that period. Here it can be in operation in heating the pool. During the cold winter months, the system could be placed over the pool to act as a safety mechanism, prevent dirt from entering the pool and minimise evaporation losses.

6.2 Piping and Instrumentation

The piping and instrumentation is very important in this system to eliminate the probability of damage to either the pump or heater. In the pilot model there were no pressure release valves or bypass systems. The reason for this is that these valves are expensive and during operation of the pilot model the system was monitored continuously. In practice the system will not be monitored continuously, hence some safety measures are incorporated.

A typical swimming pool system is shown below:

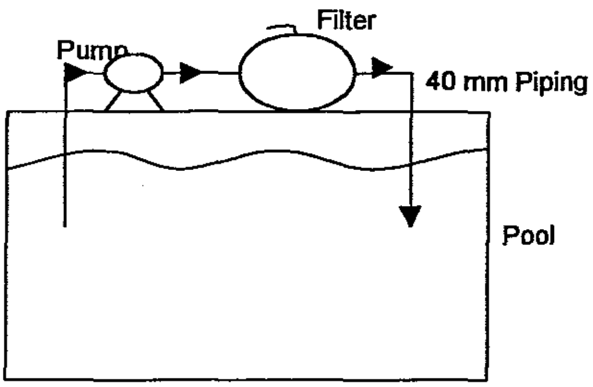


Figure 6.1 A typical pool system

6.2.1 Heater system off the pool

To implement the solar heater away from the pool, the system would be fitted after the filter. A T-junction insertion would be made in the pipeline going back to the pool. Here, a valve would be inserted to either let the water flow through the heater system or else bypass it. An important safety measure would be the implementation of a pressure valve bypass system back to the pool. This is a safety mechanism in cases of clogging or a too high water throughput. The new solar heated pool system in this case is illustrated in Figure 6.2.

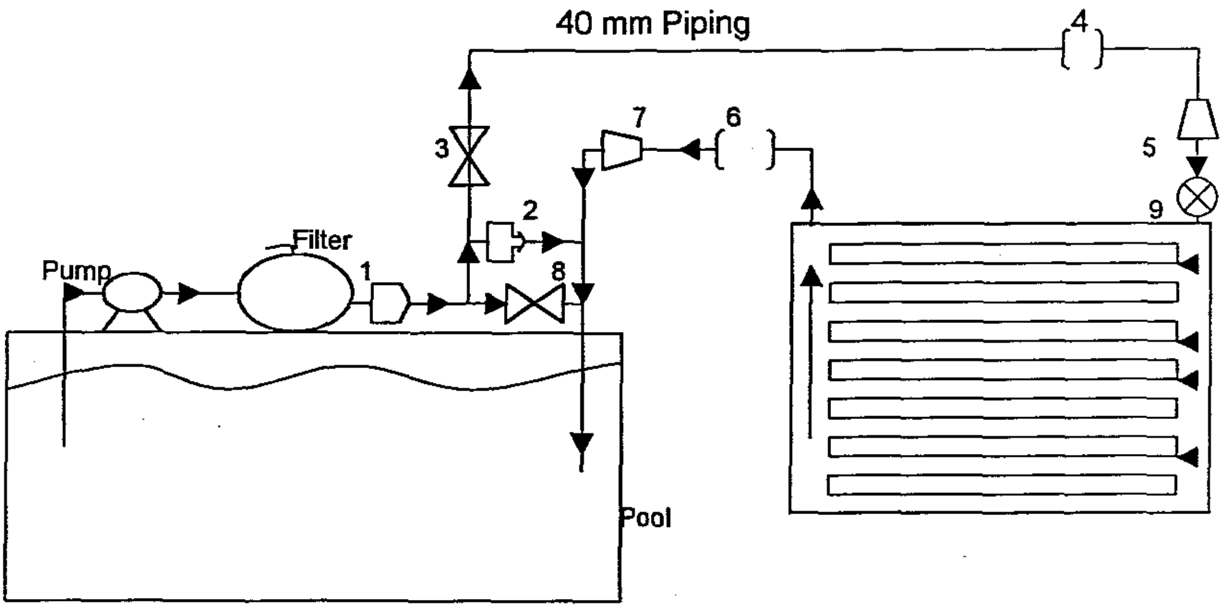


Figure 6.2 *A pool system with a added solar heater off the pool*

Explanation of diagram:

- All the piping in practice will be 40 mm black pipe
- Valve 1 (▷) is a non-return valve. This is to ensure that if the heater is higher than the filter level and the pump is switched off that the water does not drain back into the filter. This will cause the filter to backwash into the piping
- Valve 2 (▷)is a pressure release valve that will only open once the system pressure rises to levels out of specification. When this valve opens, the bypass system is opened and water will flow directly to the pool and prevent damage.
- Valve 3 (⧗) will be a normal globe valve in order to close the water flow to the heater system. When this valve is closed, valve 8 must be opened so that normal water flow can continue directly back to the pool. Whenever the heater system must be moved this valve will also be closed to ensure water flow into the pool.

- Coupling 4 ([ ]): This coupling connects/disconnects the heater system from the original pool system. When the system must be moved, it is loosened to ensure mobility of the system. This coupling would be similar to those used in fire hoses.
- Valve 5 (⏢) is a non-return valve. This valve ensures that the water flows in the right direction when the system is prepared for storage.
- Coupling 6 ([ ])is similar to coupling 4.
- Valve 7 (▷) is a non-return valve that ensures water flow in the correct direction. Secondly, if valve 2 is leaking then valve 7 will ensure that the water is not forced through the couplings.
- Valve 8 (⋈) is a very important globe valve. This valve, together with valve 2 regulates whether the water runs through the heater system or whether it runs directly from filter to pool.
- Valve 9 (⊗) is an air valve. Air always accumulates at the highest points. For this reason an air valve is placed at the highest point. The placing of this valve will be different for each system.

6.2.2 Heater system on the pool

When the pool heater is operated on the pool area, minor changes are made. The junction on the main pool line is not used. The heater will be rolled open over the pool. The inlet to the heater will be connected to the inlet of the pool water. At the exit side of the heater a fitting is added to guide the water to the bottom of the pool.

For this system to work properly valve 3 is closed and valve 8 opened.

6.3 Practical considerations

6.3.1 The material structure

The magnified material surface is illustrated below.

Figure 6.3 Magnified material surface

This type of surface assist with the maximum absorption of energy, due to deflection back to the surface. On a flat surface the heat that is not absorbed, is reflected back into the atmosphere. Figure 6.4 illustrates how this surface improves absorption.

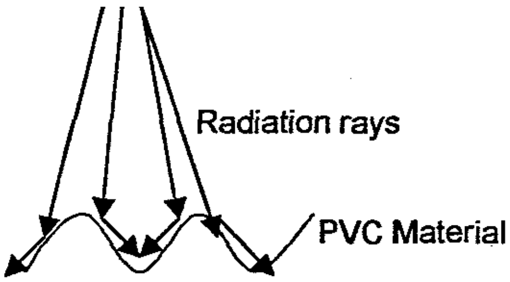


Figure 6.4 Illustration of reflected radiation rays on material surface

This is a magnified version of the material surface. It shows how radiation rays are deflected back to the surface areas. This improves the amount of absorption dramatically. This is an added advantage of this system when compared to conventional solar heating units.

6.3.2 The material colour

The darker the colour, the better the absorption. During this study dark blue was selected. However, for increased performance a black material can be used.

6.3.2 The System absorbency

In order to absorb the maximum radiation available the use of small channels was decided on. This gave an increased surface area.

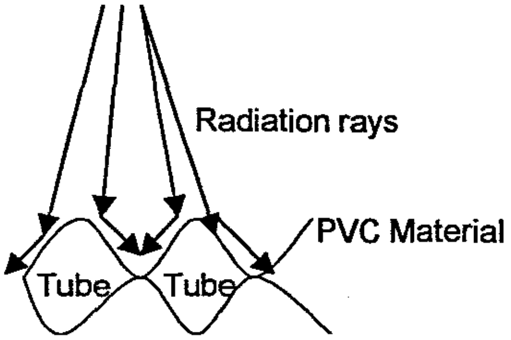


Figure 6.5 A cross sectional view of the heater unit

Most of the radiation rays are reflected back to the absorbing surface, which will improve the amount of absorption considerably. It is known that the best absorption is obtained when radiation beams are directly perpendicular with a surface. The reason for this is that in this case the least reflection takes place. If a flat surface is used, there will be maximum absorption for a small time per day only. With the tubular model direct radiation beams are experienced much longer in the day. Figure 6.6 and figure 6.7 explains this phenomena graphically.

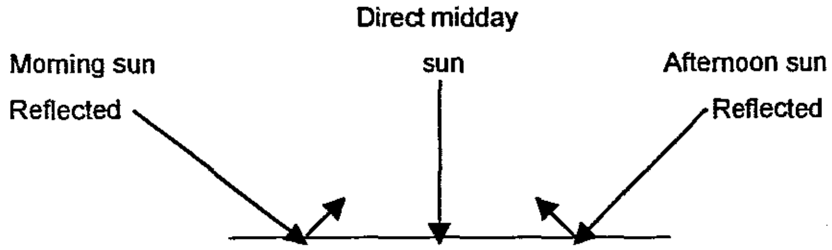


Figure 6.6 Flat surface absorption

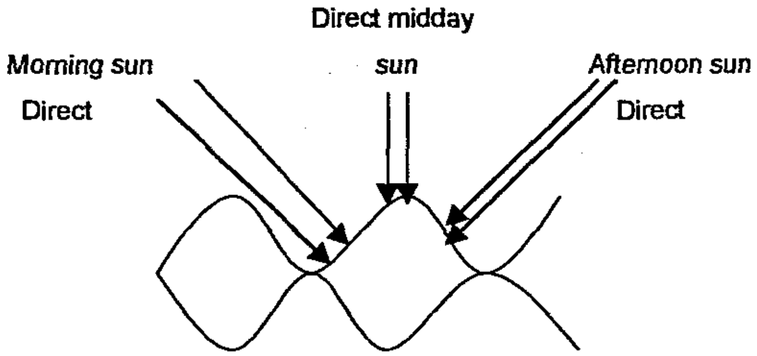


Figure 6.7 Tubular Absorption

Figure 6.7 illustrates that for most of the day the radiation beams fall perpendicular onto some part of the absorbing surface. Therefore, it will be much more efficient than the flat surface.

The absorption area is also much more on the channeled surface than on the flat surface. This will increase the amount of absorption.

6.4 Comparisons between the new and available solar units

The models currently available all consist of rigid models that have to be placed either on a roof or on a man made stand. These models are normally produced from copper tubes or moulded plastics.

Some other models consist of a pool cover that will reduce evaporation and therefore prevent heat loss from the pool. These models are flexible, but will only help while covering the pool. Once off the pool it is of no use. Also, these do not provide a water flow through the system, hence inefficient absorption rates

The model that was developed in this study is a combination of the available products on the market. The following is a list of all positive features that this new model has:

- This model is mobile. It can be placed on the roof, lawn, man made stand or the pool itself and still be working once the pump operates.
- The system comes with a handy roll up trolley for easy mobility. Therefore, no folding up and carrying heavy equipment.
- The system acts as a safety net for children when placed on the pool. This system is sufficiently strong to carry the weight of at least two adults.
- While covering the pool the system will prevent evaporation, hence prevent water loss.
- Evaporation is one of the main factors for water-cooling. In minimising it heat loss due to evaporation is prevented.
- In covering the pool foreign objects are kept out of the pool, thus decreasing maintenance costs.
- Direct sunlight destroys chlorine. In covering the pool the amount of chlorine use is decreased. This will have result in savings on the use of chemicals.
- In the marketing of normal pool covers it is said that it will heat a pool up to 8 °C. This is only true for the top layer of the water. At equilibrium the amount of

heat leaving and entering the pool is the same. When heat is absorbed by the new system while on the pool, the heat is placed back near the bottom of the pool. This will ensure a more evenly spread heat load and extend the time before equilibrium is reached.

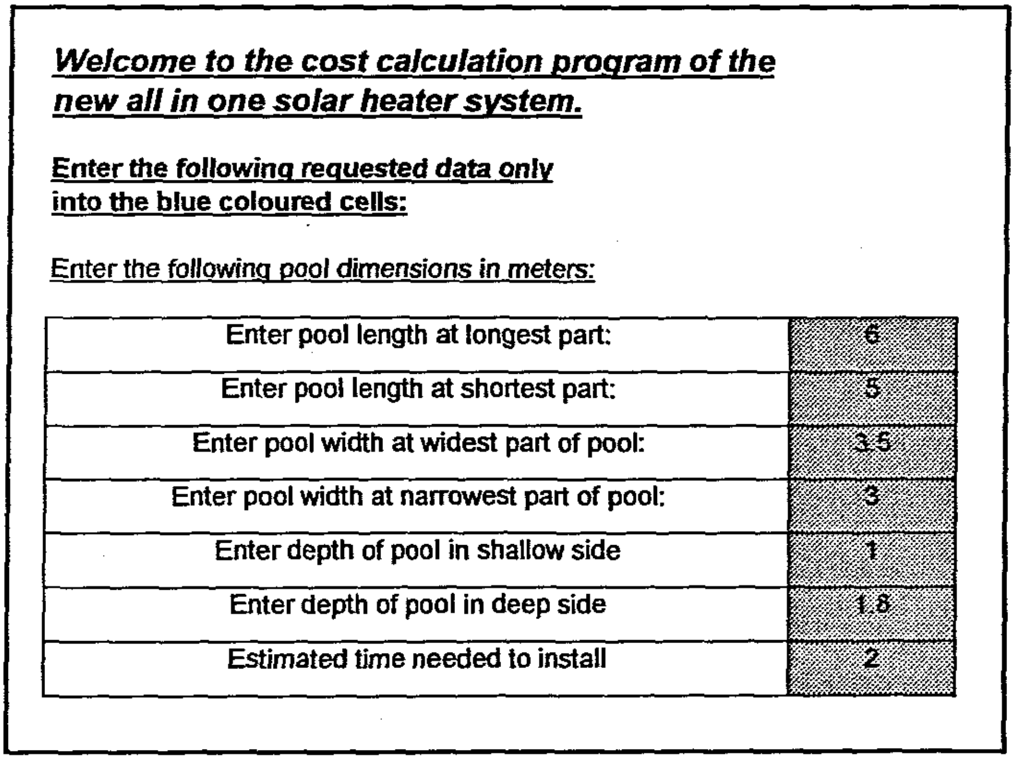
- When the system is not on the pool but in operation on the lawn or roof, at least double the normal heat is absorbed. This is ascribed to the pool still receiving its normal amount of radiation and the system also absorbs heat, which is released into the pool again. It is recommended that the system be only off the pool on warm days when swimming takes place. Otherwise, cover the pool to ensure minimum heat loss.

CHAPTER 7

COST CONSIDERATIONS

System Cost:

In order to calculate the cost timelessly and effectively a spreadsheet was set up. The spreadsheet is shown below:



Welcome to the cost calculation program of the new all in one solar heater system.

Enter the following requested data only into the blue coloured cells:

Enter the following pool dimensions in meters:

Enter pool length at longest part:	6
Enter pool length at shortest part:	5
Enter pool width at widest part of pool:	3.5
Enter pool width at narrowest part of pool:	3
Enter depth of pool in shallow side	1
Enter depth of pool in deep side	1.8
Estimated time needed to install	2

Enter the following prices in Rands **if it has changed.**

Enter installation labour cost per hour	100
Enter price of sail per running meter (1.5m wide)	30
Enter price of sail pipe per running meter (40mm diameter)	8
Enter price of glue per 5L bucket	100
Enter price of zip per running meter	4
Enter price of a pair of male female coupling	80
Enter price of a air valve	50
Enter price of black 40 mm PVC piping per meter	4
Enter price of 40mm T- bends	2
Enter price of 40mm 90°- bends	2
Cost of minor fittings (straps, hooks, rings)	70

The following is all the calculations in order to determine the right sizes for each part of the system. **Don't enter any data in this section!**

Amount of 1.5m main absorption sheets needed	2
Length of main absorption sheet in centimeters	4.7
Width of side panels needed	1.2
Sheets needed for side panels	1

<u>*The following is the cost of a solar heater system for poolsize as given above in Rands:*</u>

Cost of main absorption system:	898.6
Cost of side panels and main fittings:	285.68
Cost of roll-up trolley:	350
Cost of minor fittings (straps, hooks, rings)	75
Total cost for heater system	1609.28

Installation cost (Labour):	200

OVERALL COST FOR FULL SYSTEM	1809.28

From the above demonstration it can be seen that an average sized system will cost less than R2000 to produce.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

1. The correct adhesion methods must be used when the material is joined. Failing to do this will result in premature fatigue.

2. The adhesion process is time consuming and alternative means must be considered.

3. The material was found to be suitable for use in South African conditions and that water containing chlorine and acid did not affect the material performance drastically.

4. The material durability can be improved by adding more UV stabilizers to it.

5. More tests can be done on the channeling of the water through the system. This might improve the efficiency of the system.

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