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GAS TURBINE POWER AUGMENTATION BY USING TURBINE INLET AIR COOLING

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DEDICATION

To my parents, brothers, wife, Mohammed and Musaab with love

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Nomenclature

BNG	Blue Nile grid
C_p	Specifics heat at constant pressure kJ/kg °C
EG	Eastern Grid
gpm	Gallon per minute
GT	Gas Turbine
H	hour
Hz	Hertz
ICDH	Inlet Cooling Degree Hour
ISO	International Standardization Organization
kg	Kilo gram
kJ	Kilo joule
km	Kilo meter
kW	Kilo Watt
l	Liter
m	meter
mg	Milligram
mm	millimeters
MW	Mega Watt
NEC	National Electricity Cooperation
NG	National Grid
NOx	Nitric oxides
P	Pressure in bar
ppm	Part per million
RH	Relative Humidity
rpm	revolution per minute
s	second
S	Entropy kJ/kg °C
SFC	Specific Fuel Consumption
m^2	Square meter
T	Temperature in °C
T.D.S	Total disslvd Solid
TDB	Dry Bulb Temperature in °C
TES	Thermal Energy Storage
TIAC	Turbine Inlet Air Cooling

TWB	Wet Bulb Temperature in °C
V	Volume m^3
η	Thermal efficiency
$	U.S. Dollar
°C	Degree Celsius

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ABSTRACT

Combustion gas turbines are constant-volume engines for which shaft horsepower is proportional to the combustion air mass flow, their output and efficiency decrease as the ambient temperature increases.

The present study investigates the technical and economical feasibility of using turbine inlet air cooling in the performance of gas turbine in Khartoum area. The study results indicated that refrigerated cooling appear as the technically feasible, it can give the maximum benefits of turbine inlet cooling since it achieves the lowest inlet air temperature. While wetted media evaporative cooling is economically feasible, it is passive option that can utilize readily available potable water with lowest parasitic load.

Based on the study results, it is recommended that, for Khartoum area as hot and dry region with availability of water, wetted media evaporative cooling can be used to improve gas turbine performance.

Chapter One

Introduction

1. Introduction

Area wise Sudan is the largest country in Africa, and the tenth largest country in the world. Sudan covers an area of 2,5 million square km (around one million sq miles), has a population around of 34 million. A peace agreement was signed on 9 January 2005 between the Government of Sudan and the Sudan People's Liberation Movement. This is a good chance to rebuild and develop the country, by using Sudan's natural and human resources. The expected fast growth in economy requires increase in power demand. The increase in power demands will require additional power plants in the Sudan or any other source of power supply to meet the demand. The Gas turbine power plants appears to be most suitable type of power plant that can meet the fast demand in power, as it take the least time from signing the contract up to supplying the power to the end consumer. Also the least initial cost for all power plant types, although the operational cost is highest, but when both costs considered together gas turbine can appear as least cost solution to meet the variation of load profile.

The actual electrification of Sudan began in the year 1925 with small British power plants, their generating capacity were about 3 MW, during 1956 - 1965 Burri power plant was added (Steam turbine and Diesel units) with capacity of 30 MW. The first Hydropower plant, Sennar, 15 MW capacity, was introduced in 1970, then Roseires power station followed with installed capacity of 280 MW. In 1985 phase-1 of Khartoum North steam power plant was completed with 60 MW, and extended its capacity after few years up to 180 MW. In 2003 Gerri power plant with 277 MW (combined and open gas turbine cycles), was introduced to the system [1]. Energy is supplied to the Sudanese interconnected System from Blue Nile grid (BNG) and the Eastern Grid (EG). These two systems were interconnected in 1990 to form the National Grid (NG), which covers the most significant areas (urban and rural) of central and Eastern Sudan, presently receiving nearly 98% of its power from the BNG.

1-1 <u>Gas turbine applications in Sudan</u>

The history of gas turbine in Sudan dated back to 1985 with two 15 MW units (one installed at Old Burri Station, and another in Kilo X). Two more gas turbine power plants were installed at Kuku station with 10 and 13.5 MW installed capacity. These units were followed by another four gas turbines installed at Khartoum North power plant in 1992 with installed capacity of 20 MW each. The most recent and significant gas turbines are installed at Gerri (two units combined cycle) with 92 MW each and 3 open cycle GT with 31 MW each.

Gas turbines in Sudan can be divided into two groups according to the period of installation.

First group, All units installed before 2003, which include all open cycle gas turbines with capacities not exceeding 20 MW and considered as Peak generating units in the NG. The unit of this group faced many major problems which caused some units to be out of service for long periods.

Second group, All units installed in 2003 and after, including Garri power plant turbines (7 gas turbines 31 MW each). This group was used as base load units in the NG especially for combined cycle with its thermal efficiency reaching 45%.

Many difficulties faced gas turbines application in Sudan, appeared in the First group. The main problem was that the units output was always less than the installed capacity for all units of this group. The Engineers of NEC refer this drop of power output to Khartoum climate, which is true if compared to the output at ISO condition (15°C at sea level). But the installed capacity should be compared to the guaranteed performance values, output at the guarantee temperature, which is corrected to the ISO at site condition (Khartoum). The guarantee temperature value should be taken as the average of maximum temperatures for period of time in the city, temperature less than this will give power more than installed and vice versa, higher temperature will give power less than guaranteed capacity. Other factors may also cause turbine to degrade from the guaranteed capacity such as fuel used, pollution of compressor due to air dust, vibration and unit control problems.

The load profile curve of NEC showed that the maximum demand occurs when hydroelectric power is at its minimum level, which means that the thermal plant should carry the remainder of the load with its maximum capacity during the summer and with much reduced load or even stand-by during the winter. This mode of operation will lead to selection of gas turbine to meet this condition due to the following advantages:

1. Gas turbine units have the advantage that the number of machines on line can be increased or decreased in only few minutes. They are therefore ideal whenever peak demands, whether daily or seasonal, have to be met.
2. The Gas turbine is the most power plant that is available to meet the variation of load profile and the best economical option for plant operating at capacity factor of 20% and below or around 2,000 hour per year. Although in some areas like Saudi Arabia gas turbine running as base load operation with yearly service hours of 8,000.
3. The installation costs for gas turbines per megawatt are relatively low and the turbines can be operational in a very short time.
4. Gas turbine power plants require less highly specialized operation and maintenance staff than other types of power plants, an advantage which is important in the developing Countries.
5. Gas turbine power plants are operated with many available modifications that increased its output significantly according to the site condition.

1-2. **Project Objectives**

The overall objective of this study is to investigate the technical and economical feasibility of different means available for cooling inlet air to the compressor of a Gas Power Plant. The specific objectives include:

1. Investigation of the influence of compressor inlet temperature on the plant efficiency.
2. Investigating the technical feasibility of each mean of cooling inlet air to the compressor.
3. Investigating the economical feasibility of each mean of cooling inlet air to the compressor.
4. Selection of the technically and economically viable option for Gas turbine Power Plants in Khartoum area, Sudan.

Chapter Two

Literature Review

2-1. Literature Review

The gas turbine is an internal combustion engine which produces energy through the Brayton Cycle, a cycle invented by George Bialy Brayton, similar to that of a Gasoline or Diesel engine cycles in its working medium and consists of same four processes: compression, combustion, expansion and exhaust.

The characteristics of this cycle differ from the Otto and Diesel cycle in that the compression, combustion, expansion and exhaust processes for the gas turbine are continuous, rather than intermittent as with the reciprocating engines. Power is produced only during the expansion stroke. The expansion process is not limited by the stroke of a piston and proceeds to ambient pressure. Combustion and exhaust occur at constant pressure. It is similar to the steam turbine with respect to the steady flow of the working medium [2].

The compression and expansion processes are both carried out in turbomachines, that is, by means of rotating elements in which the energy transfer between fluid and rotor is affected by means of kinetic action, rather than by positive displacement as in reciprocating machinery [3]. There are, however, differences in the details of the cycles that make turbine operation in many respect the most satisfactory. Gas turbines are small in size, mass, initial cost per output, available in short delivery time and are quick to install. They are quick starting, by remote control, not consuming lubricating oil, cooling water not required often, offer flexibility in supplying process needed, such as compressed air, hot water and steam as well as power [4].

The first practical success was obtained by the Societe Anonyme des Turbomoteurs French Company, which built a gas turbine in 1905. This engine, the first constant pressure gas turbine to run under its own power, had an efficiency of 3%. That is only 3% of the energy put into the engine as fuel came out as useful shaft power. This engine also had a multistage centrifugal compressor (20 stages or more) with a pressure ratio of 4 and compressor efficiency not more than 60 % and the maximum gas temperature that could be used was about 393ºC [5].

However there was an elapse of many years, until in 1939, a Brown Boveri (BBC) unit for emergency electrical-power supply was put into operation in Neuchatel, Switzerland, see Fig. 2-1. The output being 4,000 kW and the efficiency 18%. Rotating at 3,000 rpm, the turbine with inlet temperature 550ºC, provided 15,400 kW, of which 11,000 kW was absorbed by the compressor with an air inlet temperature 20ºC. [6].

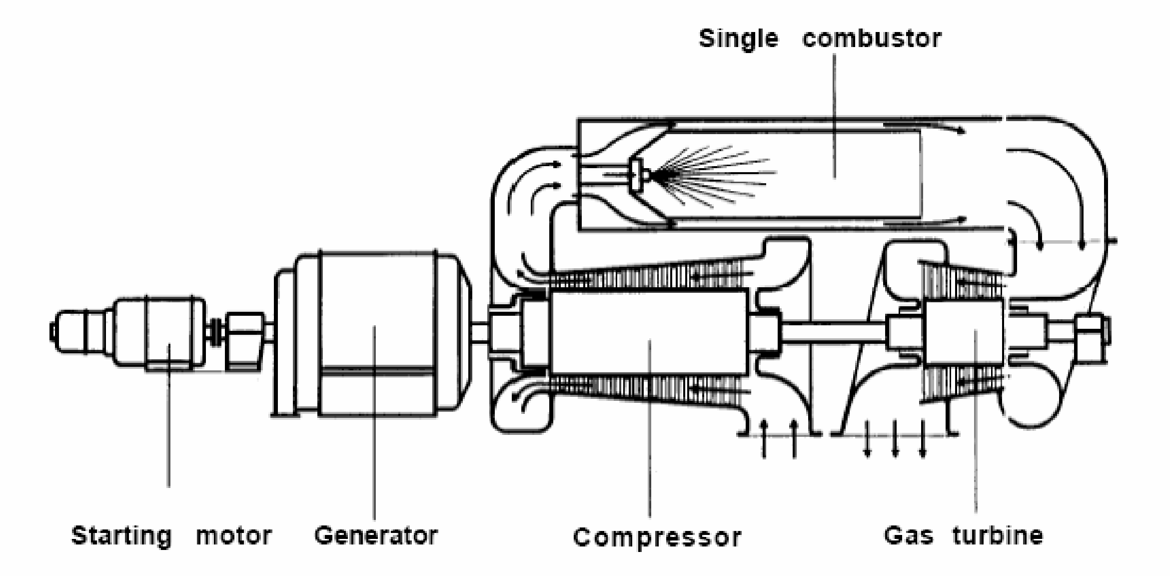

Fig. 2-1 The world's first industrial gas turbine set (Single Combustor) [6].

The attention was soon transferred to the Turbojet engine for aircraft propulsion and some of the proposed schemes utilized the gas turbine as the source of high-velocity gas. Frank Whittle shows the limitation of the piston driven engines for high speed air craft. He showed that a continuous flow turbine based engine in which combustion occurred at constant pressure could overcome these limitations [7]. The gas turbine began to compete successfully in other fields only in mid 1950s, as economic and environmental winds began blowing against coal, hydro, and nuclear. Gas turbines were looked at more seriously as an answer to meet new capacity needs, and since then it has made a progressfully greater impact in an increasing variety of applications. Combined gas and steam cycles are now widely used for electric power generation, with thermal efficiencies approaching 60 % [8].

The three main components of the gas turbine are a compressor, combustion chamber and turbine connected together as shown in Fig. 2-2 which represents the gas turbine or internal combustion turbine (IC) in its simplest form. In practice, losses occur in both the compressor and turbine which increase the power absorbed by the compressor and decrease the power output of the turbine. The maximum fuel/air ratio that may be used is governed by the working temperature of the highly stressed turbine blades. The performance of the gas turbine is affected by component efficiencies and turbine working temperature and the higher they can be made, the better the all- round performance of the plant. The effect of temperature is very predominant, for every 56ºC increase in temperature, the work output increases approximately 10% and give about 1.5% increase in efficiency [9]. Overall efficiency of the gas turbine cycle depends primarily upon the pressure ratio of the compressor. It is important to realize that in the gas turbine the processes of compression, combustion and expansion do not occur in a single component as they do in a reciprocating engine. They can be designed, tested and developed individually, and these components can be linked together to form a gas turbine unit in a variety of ways. The possible number of components is not limited to the three already mentioned. Other compressor and reheat combustion chamber may also be introduced. The way in which these components are linked together not only affects the maximum overall thermal efficiency, but also the variation of efficiency with power output, torque and rotational speed. The details will be discussed later in this study.

2-2. Types of Gas Turbines

Gas turbines can be classified according to the working cycle, components arrangements and the field of application.

2-2-1. Classification according to cycle.

(a) Open cycle

Open cycle is the most used cycle for simple or combined units. Fresh atmospheric air is drawn into the circuit continuously and energy is added by the combustion of the fuel in the working fluid itself. The products of combustion are expanded through the turbine and exhausted to the atmosphere as shown in fig. 2-2.

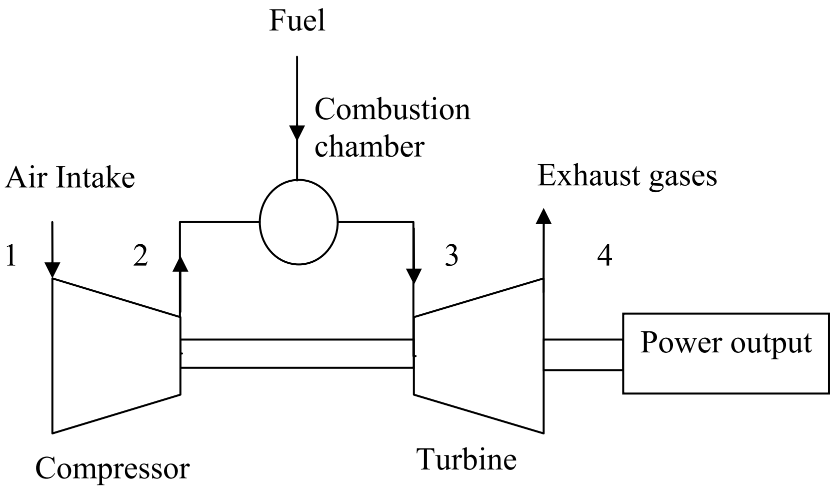

Fig. 2-2: A Simple Gas Turbine system (open cycle)

(b) Closed cycle

In principle same as open cycle, the same working fluid, air or some other gas, is repeatedly circulated through the machine, the necessary energy must be added in a heater or 'gas-boiler' wherein the fuel is burnt in a separate air stream supplied by an auxiliary fan. The closed cycle is more a kin to that of steam turbine plant in that the combustion gases do not themselves pass through the turbine as shown in fig. 2-3.

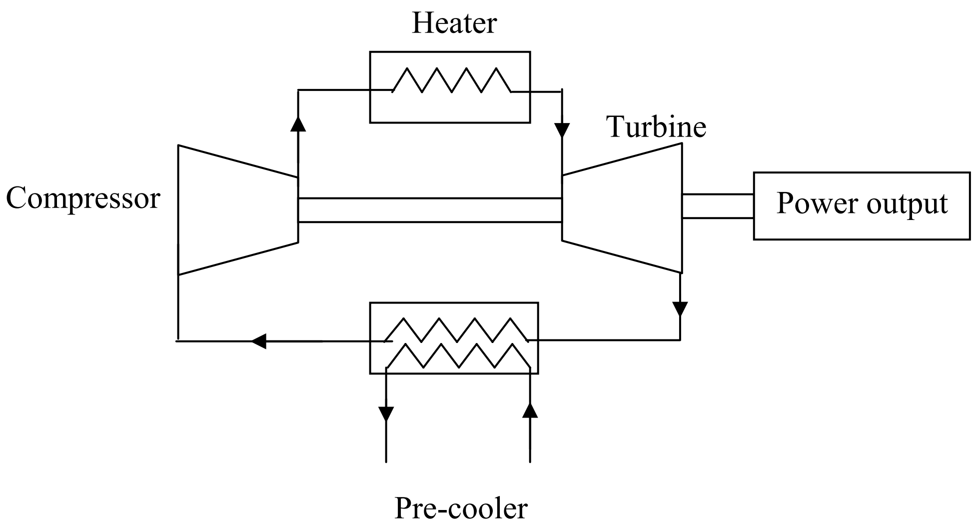

Fig. 2-3 Simple Closed Cycle

2-2-2 Classification according to the components arrangement.

(a) Gas Turbine with single-shaft arrangement

Suitable for base-load power generation, this is required to operate at fixed speed and fixed load condition.

(b) Gas Turbine with twin shaft arrangement (free turbine)

Used when flexibility in operation is required, e.g. when driving a variable speed load such as pipe line compressor, marine propeller or road vehicle. In this type the high pressure turbine drives the compressor and the combination act as a gas generator for the low-pressure turbine. Free turbine has a significant advantage in ease of starting compared to a single shaft unit, disadvantage is that, a shedding of electrical load can lead to rapid over speeding of the turbine.

2-2-3 Classification according to the field of application

(a) Aircraft propulsion

The greatest impact of the gas turbine has been in the field of aircraft. The capability of producing high output power at low engine weight (power-to-weight ratio) has made it a common propulsion system in aviation for both civilian and military applications. Also became a common propulsion system in both marine and armored military ground applications [10].

The term thermal jet engine refers to any jet-propulsion device which utilizes air from its surrounding together with combustion of the fuel to produce the fluid jet for propulsion purpose. The basic development of the jet engine took place during the period of the Second World War with parallel development being carried out by Whittle in England and Von Ohain in Germany. The application of gas turbine in the field of aircrafts takes many designs: Turbojet, Turboprop, Turboshaft, Turbofan (or by pass) and Ramjet engine. The most designed engine similar to that of the simple cycle is turbojet which is designed to produce just enough power to drive the compressor. The gas leaving the turbine at high pressure and temperature is then expanded to atmospheric pressure in the propelling nozzle to produce a high velocity jet [11].

(b) Industrial application

These gas turbines were designed shortly after the Second World War and introduced to the market in the early 1950s. The early heavy-duty gas turbine design was largely an extension of the steam turbine design. Restriction of weight and space were not important factors for these ground based units, and so the design included heavy-wall casings split on horizontal centerlines, sleeve bearing, large-diameter combustors, thick airfoil sections for blades and stators, and large frontal areas. The life time required of an industrial plant is of the order of 100,000-200,000 hours [12], where as this is not expected of an aircraft gas turbine. The kinetic energy of the gases leaving the turbine is wasted in simple cycle without heat recovery steam generator. The industrial heavy-duty gas turbine most widely used with axial-flow compressors and turbines. In most U.S. design can-annular combustors is used and single-stage side combustor is used in European design. Industrial applications can be built with either a fixed turbine or free power turbine. Gas turbine design for industrial applications depends also on the type of the driven load. Some designs are built to drive the load directly such as alternators or pipelines compressors, while other design drive the load through reduction gearbox which is required to match the power turbine speed to that of the driven load, e.g. a marine propeller.

The use of gas turbines for electrical power generation in the beginning were primarily for peak loads and emergency applications, since it can generate full power from cold start within two minutes. Although this capability should be used only for emergencies, because thermal shock on the hot parts will greatly reduce the period between inspections and overhauls. In Saudi Arabia due to abundant cheap fuel, heavy-duty gas turbines are used for base-load duty. A particular advantage of the gas turbine in desert conditions is its freedom from any requirement for cooling water. Nowadays the principal manufacturers of large gas turbines are Alstom (BBC), General Electric and Siemens-Westinghouse, all of whom design single-shaft machines, which are capable of delivering power in the range of 3 to 268 MW per unit as shown in Table2-1 for electric power generation. Single-shaft units running at 3,000 to 3,600 rpm respectively can drive 50 or 60 Hz generators directly without the need for an expensive gearbox. Many heavy-duty units have run well in excess of 150,000 hours, with a substantial number have exceeded 200,000 hours. Table 2-1 shows today's gas turbines of the most gas turbine manufacturers.

Table 2-1: Gas Turbine Engines for Electric Power Generation 2004 [13]

Company	Model Number	Output at ISO Condition (kW)	Heat Rate (kJ/kWh)	Pressure Ratio	Mass Flow (kg/s)	Exhaust Temp(C)	Out put Shaft Speed (r/min)
Alstom	GT26	268,000	9222	32	630	615	3000
Ansaldo Energia	V94.3A	265,000	9351	17	-	585	3000
GE Power Systems	PG9351(FA)	255,600	9757	15.4	624	609	3000
Kawasaki Heavy Industries, Ltd.	GT13E2	165,100	9560	14.6	532	524	3000
NPO Saturn	GTD-110	114,500	9883	14.7	362	517	3000
Nuovo Pignone	PGT16	137,200	10300	20.2	473	491	3000
Nuovo Pignone	MS9001E	126,100	10650	12.6	418	543	3000
Siemens Westinghouse	V94.3A	265.9	9323	17	656	584	3000

2-3. Gas Turbine Cycles

2-3-1. The Ideal Cycle

The gas turbine works ideally on the Brayton Cycle. This cycle is composed of two reversible adiabatic (and hence isentropic) and two constant pressure processes. Assuming no pressure drop during the heat addition processes, and no mechanical losses, for simple calculation, a mean value of specific heat C_p can be assumed [14]. Fig. 2-4 shows that the gas (mainly air) is drawn into the compressor, and compressed isentropically from point 1 to 2, heated at constant pressure from 2 to 3 in combustion chamber for the open cycle or heat exchanger for the closed cycle, the resulting hot gases expand isentropically through the turbine from point 3 to 4, cooling occur from point 4 to 1, in the open atmosphere for the open cycle, or in heat exchanger for the closed cycle to complete the cycle.

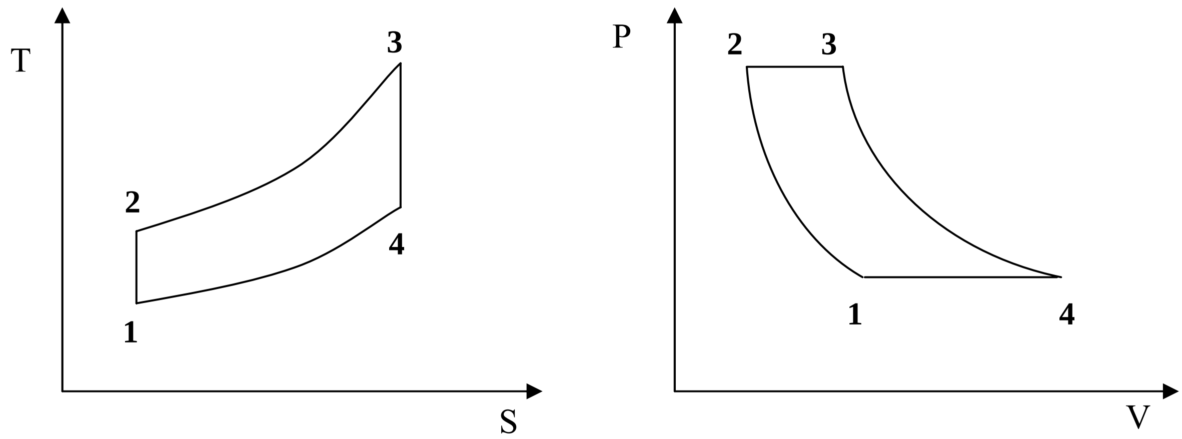

Fig. 2-4 P-V and T-S diagrams for the ideal Brayton cycle

From Fig.(2-4) the major processes encountered are:-

1- Air intake at point (1) reversible adiabatic compression (process 1-2)
   The work input $= mc_p (T_2 - T_1)$
2- Constant pressure heat supply in the combustion chamber (process 2-3)
   Heat supplied $= mc_p (T_3 - T_2)$
3- Ideal isentropic expansion process between pressure P_2&P_1, (Process 3- 4)
   The work output $= mc_p (T_3 - T_4)$
4- Gases exhausted at point (4) to atmosphere in a simple cycle.

The thermal efficiency = $\frac{\text{net work output}}{\text{Heat supplied}} = \frac{mc_p (T_3 - T_4) - mc_p (T_2 - T1)}{mc_p (T_3 - T_2)}$

$$= \quad 1- \frac{T_1\text{-}T_4}{T_3\text{-}T_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}1)$$

$$\text{but } \frac{T_2}{T_1} = r^{\frac{k-1}{k}} = \frac{T_3}{T_4}$$

$$\text{where pressure ratio, } r = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

Assume m = (k-1)/k

$$\text{Then } \eta_{ideal} = \quad (1 - \frac{1}{r^{m}}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}2)$$

When referring to the thermal efficiency of actual gas turbines, manufacturers often prefer to use the concept of heat rate rather than efficiency. The reason is that fuel prices are normally quoted in terms of Dollars or Pounds Sterling per megajoule, and the heat rate can be used to evaluate fuel cost directly. Heat rate is defined as specific fuel consumption (SFC) multiplied by the net calorific value at constant pressure (Qnet,p), and thus expresses the heat input required to produce a unit quantity of power. It is normally expressed in kJ/kWh and the corresponding Thermal efficiency = 3600/ (heat rate) kJ/kWh [15].

2-3-2. Actual gas turbine cycle

The actual cycle (Fig. 2-5) involves a chemical reaction in the combustion chamber (open cycle) and results in high-temperature products which are chemically different from the reactants that cause in an increase in enthalpy of the working fluid. The compressor used is either a centrifugal or an axial flow compressor and the compression process is therefore irreversible but approximately adiabatic. Similarly the expansion process in the turbine is irreversible but adiabatic. Due to these irreversibilities, the turbine must develop more gross work output than is required to drive the compressor and to overcome the mechanical losses in the drive.

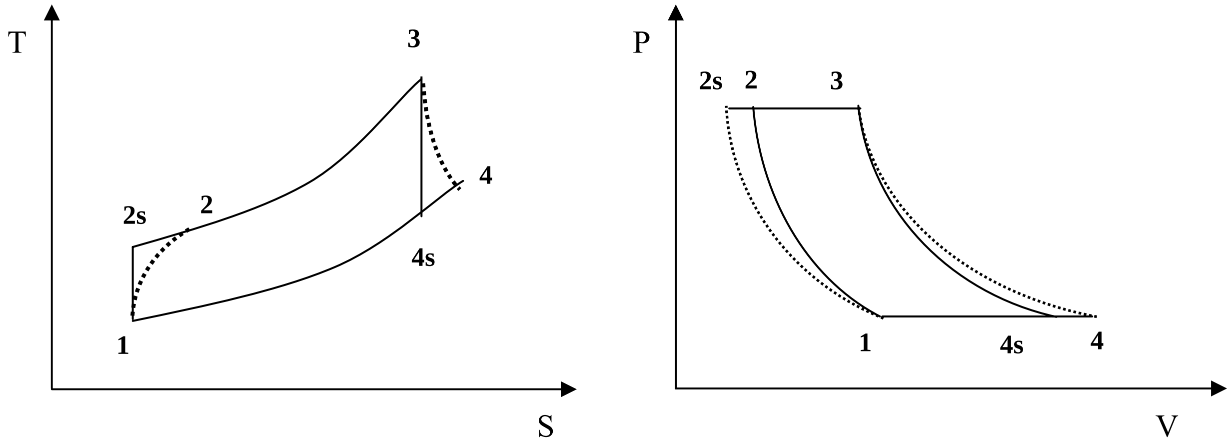

Fig. 2-5 P-V and T-S diagrams for the actual GT cycle

The differences between the Ideal and actual gas turbine cycles are due to the following:

1- Compression is not isentropic (irreversible) due to the pressure losses from inlet air filters, friction in ducts & silencer and inlet guide vane and turbine inlet cooling coils or evaporative cooling media.

2- Expansion is not isentropic (irreversible) due to the blade clearance and blade and vane service conditions.

3- Exhaust pressure losses due to the exhaust housing, silencer and stack. The exhaust pressure is slightly higher than atmospheric pressure, i.e. P_4 is greater than P_1.

4- Variation of specific heat with temperature and fluid composition.

5- Variation of amount of the working fluid through the cycle.

6- Pressure drop through the combustor and Losses due to incomplete combustion of fuel, and slight pressure drop between discharge and combustor inlet, i.e. P_2 is greater than P_3.

7- Losses due to bearings and auxiliaries, classed as mechanical losses.

8- Loss of heat to surroundings, resulting in non-adiabatic compression and expansion and direct loss in the combustion chamber(s).

The first and second points are the most important, which in turn, result in the largest deviation from the ideal performance. The others are usually small under normal conditions, although the mechanical losses may vary considerably with size and operation of the plant [16]. So the turbine efficiency depends mainly on compressor and turbine efficiencies.

$$\text{Compressor efficiency} = \eta_c = \frac{\text{Ideal work}}{\text{Actual work}} = \frac{T_{2s}-T_1}{T_2-T_1} \quad .....(2\text{-}3)$$

$$\text{Then } T_2 = \frac{T_{2s}-T_1}{\eta_c} + T1$$

$$\text{Compressor work Wc} = \frac{\text{Ideal work}}{\eta_c} = mc_p \frac{T_{2s}-T_1}{\eta_c} \quad ....(2\text{-}4)$$

$$\text{Turbine efficiency} = \eta_t = \frac{\text{Actual work}}{\text{Ideal work}} = \frac{T_3-T_4}{T_3-T_{4s}}$$

$$\text{Then } T_4 = T_3 - \eta_t\,(T_3-T_{4s})$$

$$\text{Turbine work } W_t = \eta_t\,(\text{Ideal work}) = \eta_t mc_p\,(T_3-T_{4s}) ....(2\text{-}5)$$

$$\text{Net work} = \text{Turbine work- Compressor work} = W_t - W_c$$

$$\text{Net work} = W_{net} = mc_p[\eta_t\,(T_3-T_{4s}) - \frac{T_{2s}-T_1}{\eta_c}] \quad ....(2\text{-}6)$$

$$\text{Heat added} = Q_A = mc_p(T_3-T_2) = mc_p(T_3-T_1) - (T_{2s}-T_1)/\eta_c \quad ....(2\text{-}7)$$

$$\text{Actual Efficiency } \eta_{actu} = \frac{\text{Net work}}{\text{Heat added}} = \frac{\eta_t\,(T_3-T_{4s}) - (T_{2s}-T_1)/\eta_c}{(T_3-T_2) - (T_2-T_1)/\eta_c} \quad .....(2\text{-}8)$$

$$\text{Actual Efficiency } \eta_{actu} = [\frac{(T_3/T_1)\eta_t\,\eta_c - r^m}{((T_3/T_1)\text{-}1)\,\eta_c + 1 - r^m)}]\ (1 - \frac{1}{r^m}) \quad ....(2\text{-}9)$$

$$\text{But } \eta_{ideal} = (1 - \frac{1}{r^m})$$

$$\text{Then the Actual Efficiency } \eta_{actu} = [\frac{(T_3/T_1)\eta_t\,\eta_c - r^m}{((T_3/T_1)\text{-}1)\,\eta_c + 1 - r^m}] \times \eta_{ideal} \quad ...(2\text{-}10)$$

2-3-3. Effect of Dust on the gas turbine performance

Khartoum, which lies in sub-Saharan Africa, is directly affected by aerosols originating from the Sahara desert, as can be seen from Fig. 2-6.

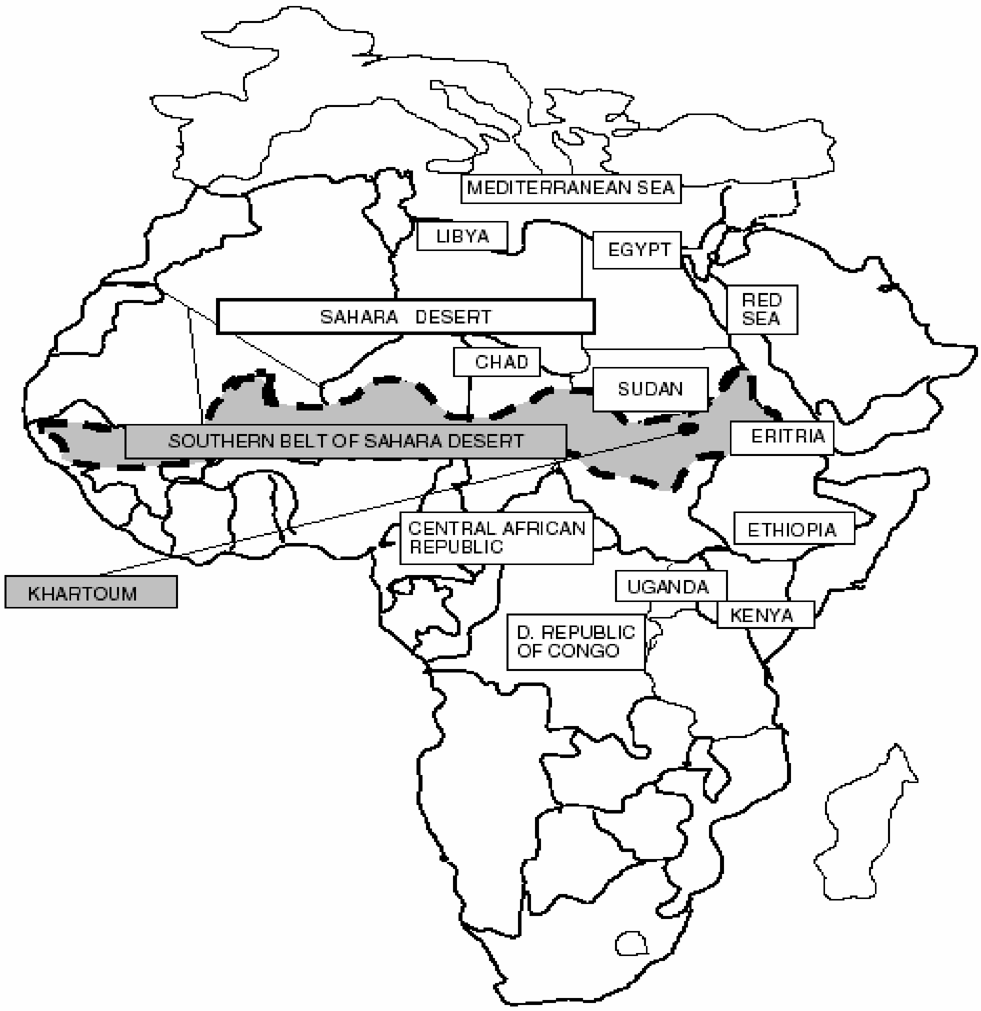

Fig. 2-6 Khartoum, site location showing the southern belt of the Sahara desert [44]

Deserts, which occupy most of the Northern part of Sudan, are the main sources of dust aerosols. Sahara desert is believed to be responsible for increasing levels of dust storm activity in a great belt from Mauritania to Sudan [44]. As the dust particle has hazardous effect on the human health it has also considerable effect on the gas turbine operation and out put, since the gas turbine performance and reliability are a function of the quality and cleanliness of the inlet air entering the turbine. Gas turbine is a breathing engine, the compressor acts as the lung of the human and inlet air system act as the nose. If the nose is not filtering the air properly then the dust will pass to the Lung causing hazardous to the health of the humanbeing unless it banish out by sneeze.

2-3-3-1. Effect of dust on the gas turbine performance

Khartoum is classified as dusty area (dust load is >0.1 ppm by weight). The effect of the air contaminant depends on the amount of this contaminant, its size, mechanical properties and its chemical composition, this effects can be explained as follows:-

1- Erosion of compressor and turbine components from the sand and mineral dust, because it cut away a small amount of the metal resulting in roughness of the stationary and moving blades.
2- Fouling, since submicron of dust is too small to be trapped by conventional filtration systems, it can enter the compressor and deposit on the blades this process can be increased by oil mist from the bearings and cause fouling of the compressor.
3- Corrosion of compressor blades causes pitting of the blade surface, which lead to surface roughness.
4- Cooling passage plugging, since the cooling air flow is extracted from the compressor, contaminant in the inlet air may also be present in the cooling air. If these contaminant cause a build up in the cooling passage heat transfer is degraded and temperature may increase to levels which give rise to cracking. Fig. 2-7 shows the effect of cooling passage plugging in the first stage nozzle (the cost of new first stage nozzle is around $426,667).
5- The presence of sodium, potassium, vanadium and lead in the inlet air after combining with sulfur and/or oxygen during the combustion process deposit on the surfaces of the hot gas path cause protective oxides film on the hot gas path part to be disrupted so that the parts oxides several times faster than in the presence of gases free of them.[45]

Fig. 2-7 The effects of plugging first stage nozzle cooling passage.

All the previous mentioned factors can lead to compressor and turbine blades roughness either by metal losing or deposit precipitation, and both can lead to reduction of Gas turbine output as much as 20 % in case of significant fouling. If compressor airflow is reduced by 2.5%, the output will be reduced by 7% and increase heat rate by 2.75% [45].

2-3-3-2. Air treatment for gas turbine installed in Khartoum

Due to the dusty weather of Khartoum the filters type that gas turbine manufacturers recommend for dusty areas should be one of the following:-

a) **Self cleaning filter**

   This type use compressed air to make back-pulse to banish out the dust from the filter (sneeze), when the differential pressure is above the set point. This type of filtration is installed in the second group of gas turbine in Khartoum (Garri gas turbines). But this type can not remove submicron particles. Fig. 2-8 shows the fine dust that can bypass this filter.

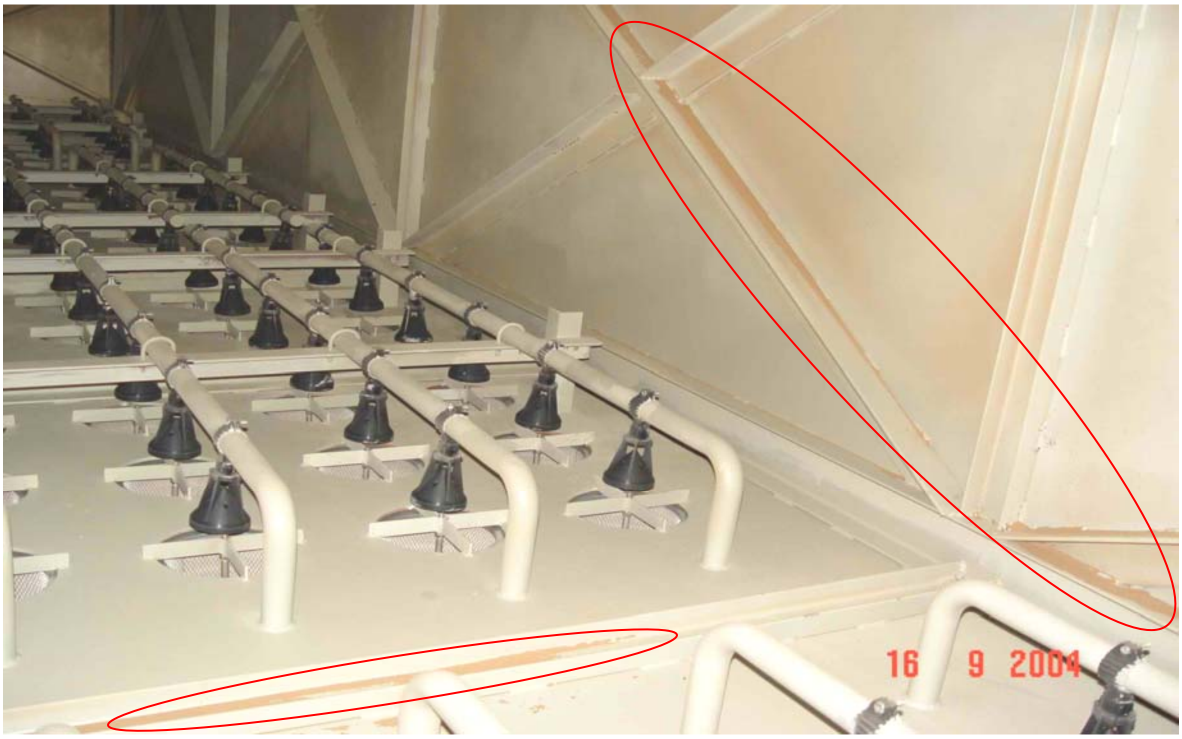

Fig. 2-8 Dust passing the GT 7 self cleaning filter system, Garri power plant.

b) Passive filter with prefilter

The first group of gas turbine in Khartoum (installed before Garri) using passive filtration only (Box type) without prefilter which lead to quick dust loading on the filter, resulting in drop of the pressure through the inlet and hence reduce output and increase heat rate and this requires frequent outage of the unit from service to clean the filters. This problem is one of the major problems that face this group of gas turbines. Fig. 2-9 shows the type of the first group and its elevation close to the ground. At the ground level the concentration of dust is the highest and the particles tend to be coarser than at higher elevations. Most of the gas turbine manufacturers recommend for desert and dusty areas the elevation from the ground should not be less than 6 m.

Fig. 2-9 Kilo X South of Khartoum, gas turbine plant box type filter location

In addition to the filtration system, compressor washing is usually used to remove the fouling of the compressor. On-line compressor wash systems are available that are used to maintain compressor efficiency by washing the compressor while on load, before significant fouling has occurred. Offline systems are used to clean heavily fouled compressors when the unit is shutdown.

2-4. Gas turbine Performance improvement

The simple gas turbine cycle efficiency is low compared to that of diesel and steam turbine. Many modifications were carried out to improve GT performance, the following are the most used methods:

1. Regeneration
2. Compressor intercooling
3. Turbine reheat
4. Turbine inlet air cooling

2-4-1. Regeneration

Regenerator is simply a surface-type heat exchanger used to preheat the compressed air by exhaust gases. The result of this process is reduction of the amount of fuel to be injected into the combustor, increasing the efficiency with decrease in the pressure ratio. The specific work output is unchanged by addition of regenerator. Regeneration used in a turbine is in the range of 3 to 7 MW, above this limit regenerator becomes less advantagous.

2-4-2. Compressor Intercooling

In compressor intercooling the air is first compressed to some intermediate pressure, and then the fluid is passed through an intercooler, where it is cooled down to a lower temperature at essentially constant pressure. Then, it passes through another stage of the compressor, where its pressure is further raised to the final pressure. The overall result is a lowering of the net work input required for a given pressure ratio. Cooling or to have much heat transfer through the compressor casing is not possible or practical. In order to obtain the benefits of intercooling, another physical arrangement is required which result in added complexity to the design.

2-4-3. Turbine Reheat

Reheat can be performed in two separate turbine stages, high and low power turbines (HP & LP). The HP turbine drives the compressor and the LP turbine provides the useful power output. The work output of the LP turbine can be increased by raising the temperature at inlet to this stage. This can be done by placing a second combustion chamber between the two turbine stages in order to heat the gases leaving the HP turbine. The use of reheat increases the turbine work output without changing the compressor work or the maximum limiting turbine inlet temperature.

2-4-4. Turbine Inlet Air Cooling

Cooling turbine inlet air by using different means of cooling equipment increases the combustion turbine air flow rate, result in increasing the power and net efficiency of power generating equipment with less modification on gas turbine compared to the above mentioned methods. There are many designs available for gas turbine inlet air cooling, these designs and its effect will be discussed in details in this study.

Chapter Three

Gas Turbine Inlet Air Cooling

3. Gas Turbine Inlet Cooling

3-1. Background:

The use of gas turbines for driving electric generators is becoming more popular as the range of size available increases. More power out of a gas turbine is achieved by simply increasing the mass flow rate of air into the compressor. Turbine inlet air cooling (TIAC) systems are commonly used to cool the inlet air. This process increase the air density which increase the total mass flow rate and therefore increase the power produced and net efficiency.

Kraneis [17] shows that evaporative cooling for TIAC has relatively lately gained importance for the power output increase, especially at higher ambient temperatures, though the principle has been known for a long time and also the relevant weather data have been accessible since long. The installation of gas turbine and combined cycle power plants has particularly increased in North America during the past two years, 35% to over 50% of the delivered stationary gas turbines are already equipped with an evaporative cooler.

Saravanamuttoo, Rogers and Cohen [18] gave brief description of the TIAC for industrial gas turbines used to generate electricity in regions with high summer temperature. These turbines are expected to meet high peak demand due to the large air-conditioning loads for about 25% of the year (this condition is same as that of Saudi Arabia summer loads). It is possible to increase power by cooling the air entering the compressor, and electric utilities have found this to be an economical solution compared with the alternative of buying a more powerful gas turbine, which would need to run at reduced power for 75% of the year.

According to Stewart [19] the parameters that affect the design of TIAC installations and operations include the type of turbine, climate, hours of operation, the ratio of airflow rate to power generated, and the value of the power generated. The power produced by the turbine is nearly a linear function of air mass flow rate, for an ideal gas, the mass flow rate is: $m = PV / RT$

Hence, power output is a linear inverse function of temperature. As the inlet air is cooled to a lower temperature, the power increases, along with increased efficiency (decreased heat rate). Nebraska Company, taken as a case study for Stewart, has an ISO rating (15ºC and 1.103 bar) with distillate fuel oil of 59.8 MW, TIAC system with ice storage, cool the inlet air from an air ambient temperature of 38°C to 4°C produces a net power increase of approximately 12 MW or about 21%.

Evaporative cooling can be used effectively in drier climates, to cool gas turbine inlet air. This system uses a cooling fluid, usually water that is brought into contact with the incoming air in the cooling media. The system is equipped with drift eliminators which separate the water droplets from air stream. Some manufacturers as Munters [20] provides an evaporative cooling system that can achieve 95% of cooling efficiency increasing GT out put by 20% as much as 0.8% per one degree Celsius. The greatest benefit can be obtained from evaporative cooling during summer after-noon's. Increasing the water vapor in air stream tends to lower the amount of oxides of nitrogen produced in the combustion process at the same time. The air scrubbing effect of evaporative cooling media contributes to the removal of many airborne contaminants and particulates before they enter the turbine.

A pilot test for evaporative cooling [21] was conducted for six months, from January to June 2000 with Munters evaporative system, to prove the suitability of the air-cooling technology to the Jamaican climatic conditions in Hunts Bay Power Station in Jamaica (668 MW two GT John Browns and one GE Frame 7 combustion turbines). The plant owned by Jamaica Public Services Company Ltd. Gas Turbine no. 4 John Brown Engineering MS5001 (Frame 5) unit with an ISO rating of 25.5 MW inlet air and site rating of 21.750 MW at 31ºC and 1.013 bar was selected. The result was found to be:-

1. Maximum load achieved during the test was 24.6 MW at ambient DBT of 31ºC, this represents an increase of 2.4 MW or about 11%.
2. An average reduction in heat rate of 1.6 %.

3. Low inlet pressure drop.
4. NOx Emission reduced.

Sanjeev, Josive and Donald [22], studied two basic methods of inlet air fogging, high-pressure impingement (HP) nozzles and ultrasonic nozzles (US). In the first method, the HP impingement type nozzle, water supplied at a high pressure in the range of 68.9 to 206.8 bar are used to produce a fine mist or fog. The supply water to the nozzles is controlled and pressurized by a high pressure pump. Typically, a plunger-type, fixed displacement pump is utilized. The droplet size varies with water pressure. The second method is ultrasonic nozzles (US), in an ultrasonic nozzle, compressed air and water at relatively low pressures, are used to maintain small water droplet size (droplets ranging from 0.5 to 10 microns). The water under pressure is directed through an ultrasonic shock wave of air to break down the water particles into a finer mist / fog. The water is supplied at a much lower pressure than that of the impingement nozzle. The orifice in the ultrasonic nozzle is much larger than the impingement nozzle making it much less susceptible to clogging. In addition, lower operating pressure means that normal piping, valves, hoses, gauges are used. The ultrasonic nozzles can vary the amount of air and water reaching the nozzle, uniform distribution of fog in the air stream is possible, thus eliminating any stratification in the air stream. However, an ultrasonic wave is set up with compressed air and this adds to the complexity of the system. The main drawback of this system is the compressed air requirement, which results in an auxiliary power consumption of up to 3 times that of the HP impingement nozzles.

Valenti [23] studied cogeneration plant operated by Kalaeloa Partners L.P., a joint venture formed between ABB Energy Ventures and Kalaeloa Investment Partners to provide process steam for Tesoro Hawaii Corp (one of two oil refineries based in the Aloha State) and electricity for Hawaiian Electric Co. Inc. The power plant is equipped with two ABB 11N gas turbines capable of generating 74.6 MW each, an ABB extraction/condensing steam turbine that generates 51.5 MW, and two Deltak heat recovery steam generators. In 1997, Kalaeloa Partners examined their plant's design, and determined that evaporative cooling was an economical way to improve its output and efficiency. Munters installed a Turbidek evaporative cooling system at the inlet of each ABB 11N gas turbine. The evaporative cooling systems began operating in 1998, with the following results: -

1. Actual power increases have been higher than anticipated (2.1-MW) closer to a 5-MW total increase, the steam turbine's output has improved by nearly a full megawatt because the heat recovery steam generator produced more steam and thus more power.
2. The system also reduced the maintenance costs.

Swanekamp [24] discussed the advantages and disadvantages of evaporative and fogging inlet cooling systems, and claimed that the reason for their popularity is their low capital cost. This can usually be recovered within the first six months to one year. While capital costs are low, operational costs for fogging systems are higher, as they consume demineralized water. Another limitation is that, like evaporative coolers, they cannot drop the air temperature lower than about 1 degree Celsius above ambient wet-bulb. Gas turbine users also have expressed concerns about nozzle plugging, large amount of ductwork gets wet, which can cause corrosion, and contaminants on the ductwork can get washed into the turbine, resulting in increasing foreign object damage (FOD), increased CO emissions, and degradation of inlet plenum material and compressor blades that may result from the water droplets. But evaporative and fogging systems suppliers report that these problems can be avoided through proper design and operation.

The use of mechanical refrigeration systems to produce chilled water for inlet air cooling of gas turbine, is much more effective and reliable. Inlet chilling systems can cool the air to less than 10ºC regardless of the ambient wet-bulb temperature. While it is significantly more expensive on a first-cost basis than evaporative cooling and inlet fogging, but the system can be installed at half the cost of installing new turbine. Refrigeration-based chilling technologies can produce significantly more power over the course of a year than can evaporative or fogging systems. Refrigerated cooling can be used to provide continuous cooling throughout the day or on-peak cooling using thermal energy storage (TES) technology [25]. With continuous cooling, the inlet air can be cooled instantaneously whenever needed. There are several ways of providing continuous cooling through direct refrigeration, absorption chillers, and electrical chillers. This type of cooling is most suitable for base load plants or whenever cooling is required for more than 6-8 hours a day.

Sundaram [26] highlighted the subsequent applications of the technologies developed as part of thermal energy storage (TES). A model was developed at Pacific Northwest National Laboratory (PNNL) 1978-1998 as part of the gas turbine inlet air cooling activity. The model can be used to assess the benefits of installing the inlet air cooling systems both in existing and new gas turbine plants. A preliminary screening of the available technologies shows that the 20 % increase in gas turbine capacity can be obtained at an average cost of $150/kWe. This represents a 65 % reduction in the cost of adding peak capacity by installing new gas turbine at an estimated cost of $380/kWe.

Vapor compression systems are usually driven by electric motors, which have a significant parasitic load on the power output of the site. Polar Group [27] use a rule of thumb which states that for every 7 kW incremental station power made by the refrigeration system, about 1 kW is going back to the electric vapor compression system. Vapor compression systems can also be driven by steam turbines and natural gas engines. The choice of a gas engine makes sense for a peaking plant, the choice of a steam turbine makes very good sense for a combined cycle plant.

Hwang, Ohadi and Radermacher [28], discussed the importance of natural refrigerants on big systems of cooling like TIAC. Because of the environmental issues, there is an increase in interest towards natural refrigerants like ammonia, carbon dioxide, hydrocarbons, etc. Ammonia is the most used refrigerant in electrical chilling systems which is selected as the refrigerant for the refrigeration cycle because of its low cost, higher efficiency, non-polluting properties, and ease of use. Ammonia is considered highly efficient for reciprocating and rotary screw compressors in the medium to low temperature ranges because of small compressor displacement per ton of refrigeration produced, high latent heat and low kW/ton. In addition, ammonia is hard to ignite, has limited explosive potential, but is irritant to humans.

Wang [29] gave a comparison between the two thermal storage media that are widely used in air conditioning, ice storage and chilled water storage. At temperature difference of 10 ºC, 1 kg of chilled water can store 41.9 kJ of thermal energy, where same mass of ice can store 391.6 kJ if the density of water is 997 kg/m^3 and the density of ice is only 920 kg/m^3. For the same storage capacity the storage volume for ice is only about 0.12 that of chilled water. In addition to the ice storage and chilled water systems, phase change material storage systems are sometimes used. The most common phase-change material used for cooling thermal storage is a mixture of inorganic salts, water, nucleating and stabilizing agent, which melts and freezes at 8.3 ºC. Phase-change materials have high discharge temperature and a high storage tank volume of 0.048 m^3/kWh instead of 0.019 to 0.027 m^3/kWh for Ice.

In Qassium Power Plant, located in central region, Saudi Arabia, where the average increase in demand annually is about 7% during the last 10 years in the peak period from 12:00 to 17:00 hrs daily. Inlet air cooling (ammonia-based) with ice harvesting to store ice in thermal storage tank (TES) was selected to meet the high and short demand. The system was installed in Qassium power plant extension (six GE frame 7EA units) with total capacity of 342 MW. 13,000 cubic meters above ground concrete tank designed to store 165,000 ton of thermal power equivalent to 460 MWh. The system work all days of the week by using load shifting procedure, producing ice in 19 hours during off-peak between 17:00 to 12:00 hrs next day and use the ice to cool inlet air during peak period. This period can be increased two hours more for two days only, in case of emergency. The inlet air can be cooled down from 50º C dry bulb to 10º C, thus increasing the density of inlet air from 1 kg/m^3 to $1.17kg/m^3$ resulting increase mass flow rate by 15% which increase turbine output from 57.8 MW to 75,8 MW. An increase of 18 MW for each unit and 108 MW as total. Thus an increase of 30-35% in power is obtained with drop of inlet air pressure not more than 309.4 Pa. During the peak period the system consume 1 MW electric power only for recycling chilled water pumps for all units, during off-peak the refrigeration plant consume 16 MW to produce ice for 19 hours, the system have 10% reserve power stored in storage tank that can be used during abnormal increase in ambient temperature. In case of any failure of one or two compressors the system can work as a continuous system by using load leveling procedure rather than using load shifting.

Sanjeev, Joseph and Donald [30], discusses the feasibility study and design for a Thermal Energy Storage System (TES) based inlet chilling system to provide peaking capacity enhancement for ABB 11N1 gas turbine. The system design is based on cooling the inlet air for 4 hours a day, 5 days a week. Each of these systems includes a 3,400 ton refrigerant plant, 9,092 cubic meters tanks, and 2,600 tons of ice-making capacity. The instantaneous cooling load for each set of 4 turbines is 16,200 tons. With this TIAC, a total gain of more than 112 MW (approximately 17%) was expected for the two plants. The system was operated in June 1999 just before the start of the summer peak season. During July 1999 using this system, Wisconsin Electric was able to realize a total gain of 112 MW in rated power.

Raquel, Luis, and Antonia [31] analyzed the different type of cooling systems. Absorption system is considered as one of the best options for Combined Cycle Technologies. Absorption chillers use thermal input to produce cooling for space conditioning or for refrigeration. These machines commonly use lithium bromide (LiBr)/water or ammonia (NH3)/ water as their working fluid. Absorption chillers tend to have long life. Absorption systems usually have a higher initial cost than vapor compression systems, and typically have a lower Coefficient of Performance (COP) too. Several plants have already used absorption systems successfully. Present commercial absorption chillers are either directly fired by natural gas /other fuel or indirect fired by low-pressure steam or hot water, single or double-effect. The single-effect chiller typically uses steam or hot water as the heat source. Natural gas-fired absorption chillers are a good choice for peaking stations. Steam-fired absorption chillers are a good choice for combined cycle plants, in particular, older cogeneration plants, which typically have an intermediate-pressure (10.3 bar) steam header available to them. One minor drawback of absorption chillers is that they are typically larger than an equivalent vapor compression system. As space is typically at a premium on most power plant sites, this can be a disadvantage to the selection of absorption technology. Most new absorption chillers, in particular the double-effect models, have a smaller footprint than older models, some what alleviating this concern.

Polar Works [32] provides Turbo-Absorption technology, which uses a turbine-driven vapor compression system for part of the chilling load. The turbine is a backpressure design, typically operating from a high pressure of at least 8.6 bar, and exhausting to a low pressure of 1.03 bar. The low-pressure steam exhaust is fed to an absorption chiller to provide the remainder of the chilling load. Most cogeneration plants have intermediate 10.3 – 17.2 bar extraction line and low pressure 1.03 bar pegging steam headers, it relieves the increased summer time steam load on the back end of the steam turbine and condenser.

Dharam, Tom and James [33] discussed the results of some of the analysis performed for a 316.8MW cogeneration plant in Clear Lake, Texas. The plant was retrofitted with a hybrid cooling system incorporating absorption chillers, an electric centrifugal chiller and a chilled water storage system. The TIAC system was started up in May 1999. The plant uses three Westinghouse 501D5 gas turbines, each with a rated capacity of 105.6MW. The plant produces steam as a co-product and sells it to the adjacent chemical plant. The plant was built in 1982 and a fogging system was added later for cooling inlet air to the turbine system. In August 1998, management decided to use chillers to cool the inlet air to much lower temperatures than that is possible with the fogging system. The results showed the following:-

1- The TIAC systems with absorption chillers enhance power capacity up to about 49MW above what was possible at 35ºC ambient. This increase was about 33MW more than that using evaporative cooling, 31MW more than that using fogging, and 11 MW more than those using electric chillers.
2- TIAC systems using chillers achieve the highest reduction in heat rate of 505.3kJ/kWh. In comparison, evaporative cooling and fogging achieve heat rate reductions of only 151.9kJ/kWh and 160.4kJ/kWh, respectively.
3- The parasitic power need of a direct-fired double-effect absorption chiller is the lowest while that for an electric chiller is the highest. TIAC system that incorporate a direct fired double effect (DFDE) achieves greater power capacity enhancement than that incorporating a hot-water single-effect (HWSE) chiller.
4- The results show that TIAC systems with chillers achieve incremental capacity enhancement at nearly half the capital cost of installing an additional gas turbine without TIAC.

Kohlenberger [34], investigated and modeled TIAC syetems on a Dallas, Texas site based on the American Society of Heating and Air conditioning Engineers, (ASHRAE) and U.S. International station Meteorological Climate Summary (U.S. ISMCS) ambient temperature data. This gives a very broad range of temperature and humidities for analysis and comparison. A gas turbine generator (GTG) system using a Westinghouse 501D5 open cycle combustion turbine with nominal ISO rating of 118.5 MW at a heat rate of 10,568 kJ/kWh was used. The comparison based on uncooled, and evaporative cooled and refrigerated cooled turbine. The evaporative cooling with cooler effectiveness in the range of 80-90%, is only effective at temperature greater than 10 –12.8 ºC. The added pressure drop due to the resistance of the media and water spray loading further reduces the turbine output in all the GT units. The inlet air can be cooled to 8°C in three stage (1^{st} ,2^{nd}, 3^{rd} stage coils) for refrigerated systems. The advantages of using one stage (1^{st} stage coil) system only, is in the possibility of using the refrigerant directly in the coils, instead of using secondary refrigerant (chilled water, brines), thus utilizing only a single heat exchanger, and reducing pump recirculation power. The comparative study showed for evaporative cooling and refrigerated cooling, the following results

1- Output gain (MW) are 11.1 for evaporative and 25.2 for refrigerated cooling system.
2- GT heat rate (kJ/kWh) are 10,616 for evaporative and 10,198 for refrigerated cooling system.
3- The net system installed Budget estimate ($) are 300,000 for evaporative 5,950,000 for refrigerated.

Kenji, Katsuo, Minoru and Akira [35], from Mitsubishi heavy industries developed new technology for TAIC with Liquid Air storage Energy system (LASE). The system stores energy as liquid air by using cheaper electricity at night, and discharge this energy during the day by combusting the pressurized stored air. LASE, based on liquid rocket engine technology is starter-less, more efficient, and enjoys power balancing. A pilot plant of generator of LASE was designed and demonstrated such key technology as its starting and stability characteristics. As a result, the feasibility of the system was confirmed. Also this new TIAC system was tested by injecting liquid air at an existing 150 MW class gas turbine, and it successfully gave an improved performance.

Thomas [36], discussed the result of the Emissions tests performed on a GE-7EA turbine, which has a fog system installed downstream of an existing media-type evaporative cooler (fog intercooling technique). The fog system is capable of injecting water at the rate of 0.6% of the inlet air mass flow. When the airflow reaches the fog nozzles it is already nearly saturated, due to the water vapor added by the evaporative cooler, so only a small portion of the fog spray evaporates before being pulled into the compressor. The GE-7EA turbine normally produces about 140 ppm of NOx. However, this turbine is fitted with a steam injection system, which injects steam directly into the primary zone of the combustors, and with a media type evaporative cooling system. Both these systems reduce NOx emissions. The tests performed with the inlet fogging system in operation showed a further reduction in specific NOx of about 18%.

3-2. TIAC theoretical approach

The basic idea of turbine inlet air cooling is to reduce the work of the adiabatic compression by reducing compressor inlet temperature. The compression of air to the same pressure ratio and mass flow requires less energy at low temperature than at high temperature as shown in fig. 3-1, assuming that compressor efficiency will not change with an isentropic condition.

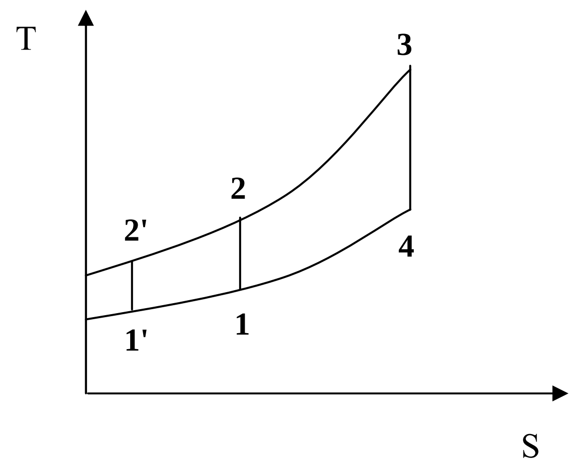

Fig. 3-1 T-S diagrams for TIAC ideal cycle

Irreversible adiabatic compression without cooling (process 1-2)

The work input without cooling $= mc_p (T_2 - T_1)$

Irreversible adiabatic compression with cooling (process 1'-2')

The work input with cooling $= mc_p (T_{2'} - T_{1'})$

Since the pressure lines diverge from left to right [38] then:

$mc_p (T_{2'} - T_{1'}) < mc_p (T_2 - T_1)$

The net work output will increase by the value $mc_p (T_2 - T_1) - mc_p (T_{2'} - T_{1'})$

The heat supplied to the combustion chamber with cooling to the same maximum temperature $T_3 = mc_p (T_3 - T_{2'})$ then:

The heat supplied will increase by the value $mc_p (T_2 - T_{2'})$

The thermal efficiency $= \dfrac{\text{net work output}}{\text{Heat supplied}} = \dfrac{mc_p (T_3 - T_4) - mc_p (T_{2'} - T_{1'})}{mc_p (T_3 - T_{2'})}$ .. (3-1)

Then from equation (3-1) it appears that thermal efficiency will increase if the increase in the net work output is greater than the additional heat supplied i.e.

$[mc_p (T_2 - T_1) - mc_p (T_{2'} - T_{1'})] > mc_p (T_2 - T_{2'})$.

Parasitic load of the inlet cooling system should be considered because it can decrease the net work output.

The practical designs for TIAC systems mainly concentrate on the increase of air mass flow to simulate the winter condition. The actual winter condition shows that the decrease of compressor inlet air temperature increases air density, pressure ratio and all turbine components efficiency, resulting in higher expansion process in the turbine, with no change in the turbine inlet temperature (maximum cycle temperature) as shown in fig. 3-2.

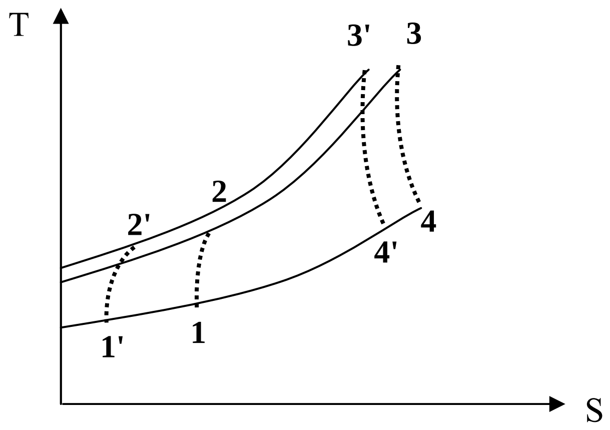

Fig. 3-2 T-S diagrams for TIAC actual cycle

The following reading was taken from two GE MS7111EA gas turbine reading, which shows increase in compressor pressure discharge (CPD), output and decrease in exhaust temperature.

Date	Temp.(°C)	GT #	Load (MW)	CPD (Bar)	Exhaust Temp.(ºC)
12/01/2005	6	1	77	10.7	525
11/08/2004	46	1	62	9.0	550
14/01/2005	8	2	78	10.8	519
11/08/2004	45	2	62	9.2	559

Chapter Four

Performance calculations

4-1. The Study Site –Khartoum

Based on the gas-turbine inlet cooling options, there is no one best technique. The best option for a particular gas turbine will depend on its design, location, and operating cycle In order to study the effect of ambient temperature on the performance of the gas turbine, the site should be first studied.

Khartoum, (384 m altitude) is the capital of Sudan lies in the centre of the country, at the point where the White Nile coming from lake Victoria in Uganda meets the Blue Nile coming from lake Tana Ethiopia. The city has a population of around 4.8 million inhabitants, distributed in Khartoum, Khartoum North and Omdurman. Table (4-1) shows that even in winter, the maximum temperature is high, then Khartoum can be considered in general as hot and dry region. Table (4-2) shows the average wet bulb temperature depression of 12.2, which indicate low humidity ratio throughout the year. Khartoum is consuming around 80% of the energy generated in the NG. In 2003 the NG total installed capacity was 1,016 MW and the available is 689 MW. The Maximum peak at 2003 summer was 570 MW and the maximum winter peak was 480 MW [47]. The daily peak hours are between 7 to 10 PM. During the period from April to June all generating units of NG were on full load operation.

4-1-1. Meteorological data of Khartoum city.

The weather data (Meteorological data) dry and wet bulb temperatures are the major consideration in this study to investigate the influence of compressor inlet temperature on the plant efficiency. The technical and economical feasibility of each mean of cooling inlet air to the compressor will decide the suitable system for Khartoum based on these data. The Meteorological data for Khartoum city were abstracted from Khartoum station for one year, details of this data in appendix A.

Table 4-1: The maximum dry bulb temperatures in Khartoum [48].

Day	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	35.5	28.0	40.5	37.0	43.5	38.5	39.5	39.5	39.0	38.0	36.0	36.0
2	35.5	27.3	39.5	38.5	44.0	40.5	40.0	41.5	32.5	40.5	36.5	36.0
3	35.0	24.0	39.5	41.5	44.7	39.0	41.0	40.0	36.5	41.5	37.0	36.0
4	35.0	21.0	40.0	41.0	45.0	38.5	37.5	37.5	40.0	40.0	37.5	35.5
5	37.0	20.5	40.0	42.5	45.6	39.5	39.5	39.5	35.0	39.5	37.0	36.0
6	38.5	22.0	37.0	42.5	41.0	39.0	40.5	39.0	38.0	40.5	36.0	35.0
7	38.0	25.0	41.0	38.5	39.5	41.5	38.6	34.5	39.5	40.5	36.5	35.0
8	31.0	25.5	41.5	37.0	41.5	40.5	39.0	37.0	38.5	39.5	36.5	37.0
9	27.5	28.0	40.0	38.3	43.0	39.5	38.0	38.0	38.5	40.5	38.5	32.0
10	26.0	28.0	38.5	39.0	43.0	40.0	40.5	36.5	38.0	40.5	37.0	32.0
11	26.0	27.0	39.0	38.5	41.0	39.5	38.0	37.0	39.0	40.0	37.5	30.5
12	23.5	31.0	37.5	38.0	37.0	40.0	39.5	37.7	38.5	40.0	37.5	30.0
13	24.0	31.5	34.5	37.5	37.5	42.0	38.5	35.0	40.5	40.5	37.5	28.5
14	25.5	31.5	36.0	37.5	38.5	43.5	38.5	38.0	40.5	41.0	36.0	28.5
15	27.0	32.0	38.0	39.0	41.5	42.5	38.0	33.5	38.0	40.0	35.0	31.5
16	28.0	33.0	37.5	40.0	42.5	42.0	38.5	37.0	38.5	39.5	35.0	32.5
17	29.0	33.8	36.0	40.0	44.0	43.5	35.0	35.0	39.5	40.0	34.0	32.5
18	28.0	37.0	30.0	40.0	40.0	44.5	37.5	36.0	41.5	40.5	34.5	37.0
19	26.4	39.5	30.0	39.5	41.0	38.0	37.5	37.5	39.0	41.0	35.0	34.0
20	25.0	37.5	29.5	41.5	36.0	41.5	39.5	39.0	40.5	40.5	35.0	33.0
21	25.0	33.0	29.0	42.0	36.5	39.0	37.5	39.0	39.0	38.0	38.0	31.0
22	27.0	31.5	31.0	44.5	39.5	40.5	41.0	36.5	38.5	38.0	37.5	30.5
23	27.0	31.5	35.0	44.0	39.5	43.0	43.5	37.0	40.0	38.5	36.5	27.0
24	26.5	32.5	36.5	43.5	41.3	43.5	37.5	39.5	40.0	38.5	36.0	26.0
25	26.5	35.0	34.4	42.5	41.0	42.3	37.5	39.0	41.0	37.0	36.5	28.0
26	28.0	37.0	35.0	39.0	42.0	39.0	38.0	39.0	40.5	38.0	36.0	31.0
27	30.5	39.0	37.5	38.0	40.0	38.5	40.5	36.0	41.0	37.0	35.0	33.5
28	32.5	40.5	37.0	37.5	37.0	38.5	37.5	35.0	38.5	38.0	35.0	34.0
29	33.5	0.0	38.0	41.0	34.5	41.5	39.0	38.5	39.0	37.4	35.5	34.0
30	35.0	0.0	37.8	43.0	36.5	35.0	40.0	36.0	40.5	39.0	35.5	36.0
31	28.5	0.0	35.0	0.0	36.5	0.0	39.5	38.0	38.7	36.0	0.0	37.0
Max.	**38.5**	**40.5**	**41.5**	**44.5**	**45.6**	**44.5**	**43.5**	**41.5**	**41.5**	**41.5**	**38.5**	**37.0**

Table 4-2: The average monthly wet bulb temperature depression in Khartoum

Month	Average wet bulb depression
January	9.6
February	10.7
March	14.7
April	16.0
May	14.5
June	14.7
July	11.6
August	9.6
September	11.3
October	12.5
November	11.6
December	10.1
Average	12.2

4-2-2. Site correction factors

Gas turbine output is depends on the air density. Air density is affected by the altitude, temperature and humidity. ISO condition for Gas turbine, refer to the following:

1. Altitude is sea level (zero altitude).
2. Dry bulb temperature is 15ºC.
3. Relative Humidity is 60%.

The density of air at this condition is 1.212 kg/m^3

To drive the output of gas turbine in Khartoum it is necessary to correct the ISO condition to site conditions according to the following equation [37]:

Gas turbine output (site) = output (ISO) x altitude Correction factor x temperature correction factor x humidity correction factor…..(4-1)

Site maximum dry bulb of 45.6ºC and 21.0ºC wet bulb temperatures will be used for correction factors calculation.

Density of air at altitude of 484m with barometric pressure of 0.9722 bar, temperature of 15ºC and 60% humidity = 1.161kg/m^3

Then altitude correction factor = density at 484m / density at sea level

=1.161(kg/m^3)/1.212 (kg/m^3) = 0.958

Density of air at dry bulb of 45.6ºC (maximum), at sea level and 60% humidity

= 1.043kg/m^3

Then temperature correction factor = density at 45.6ºC / density at 15ºC

= 1.043 (kg/m^3) / 1.212(kg/m^3) = 0.860

Density of air at humidity of 9.7% at 15ºC and sea level

= 1.222 kg/m^3

Then humidity correction factor = density at 9.7% / density 60%

= 1.222(kg/m^3) / 1.212(kg/m^3) = 1.008

The above correction factors show that, in Khartoum, the temperature correction factor is most effective factor in the turbine output. Altitude correction factor will be constant for all calculation, but temperature and humidity factors will depend on the weather condition (dry, wet bulb temperatures and relative humidity). In this thesis, manufacturer's correction factors for out put and heat rate will be taken for all calculations related to output and heat rate.

4-1-3. Performance derivation for MS 7111EA at Khartoum – Sudan at 50 ºC

At ISO rating base load condition using natural gas as a fuel the unit has the following specifications.

Output at 60 Hz = 83.5 MW

Rated speed = 3600 RPM

Heat Rate = 11,025kJ/kWh.

Air mass flow = 300 kg/s.

Khartoum condition

Altitude = 484 m

Barometric pressure = 0.9563 bar

Temperature dry (max) = 50 ºC

Wet bulb = 27.8 ºC

Output correction factors for Khartoum from the manufactures document [37] are as follows:

Altitude Correction factor = 0.9575

Temperature Correction factor = 0.78

Humidity Correction factor = 0.999

Corrected Output at Khartoum = 83.5 x 0.78 x 0.9575 x 0.999

= 63.09 MW

Heat rate correction factors for Khartoum.

Heat rate and thermal efficiency are not affected by altitude.

Temperature Correction factor = 1.06

Humidity Correction factor = 1.0027

Corrected heat rate at Khartoum = 11,025x 1.06x1.0027 = 11,718kJ/kWh

4-1-4. Garri power plant

Garri power plant as shown in Fig 4-1 is located 70 km north of Khartoum. The site is near to the refinery of Khartoum in order to take advantage of direct fuel supply. The total power installed of the power plant is 277 MW, Garri 1 consists of 2x92 MW combined cycle (2x31 gas turbine with 30MW steam turbine for each cycle). Garri 2 consist of 3x 31 MW open cycle gas turbine, there is plan for NEC to add one open gas turbine to Garri 2 and converted to combined cycle operation.

Fig. 4-1 Garri Power plant, 330 MW

The gas turbine installed in Garri is turbine and generator package type PG6581B 50 HZ cycle, 42 MW output and 11,260 kJ/kWh heat rate at ISO condition. 31MW output and 12,300 kJ/kWh heat rate at dry bulb temperature 40°C and 18.4% relative humidity at site conditions.

4-2. Gas Turbine Inlet Air Cooling Systems

There are two main systems for TIAC, namely evaporative cooling and refrigerated inlet air cooling.

(a) Evaporative cooling

Make use of evaporation of water to reduce the gas turbine inlet air temperature, but the system is limited by wet bulb temperature. There are two basic systems for achieving evaporative cooling:-

1. Conventional Evaporative cooling system (use wetted media)
2. Fogging system.

(b) Refrigerated system

There are several systems that are used to cool the inlet air, through a heat exchanger placed in the turbine inlet. Unlike the evaporative cooling, turbine inlet air can be cooled below the ambient air wet-bulb temperature. The following are the systems used in this field.

1. Direct mechanical refrigeration system.
2. Indirect mechanical refrigeration system using secondary fluid.
3. Mechanical refrigeration with ice storage tank.
4. Mechanical refrigeration with chilled water storage.
5. Mechanical absorption chiller – single effect.
6. Mechanical absorption chiller – double effect.

This thesis will study and investigate the technical feasibility of turbine inlet air cooling by evaporative and refrigrative cooling using vapor compression chillers (with or without thermal storage tank). Although other types of refrigerated cooling system are now used successfully in wide range of power plants in the world.

4-2-1. Evaporative cooling systems

Evaporative cooling is one of effective and commonly used systems that are used in drier climates for cooling gas turbine inlet air, since large amount of cooling is accomplished with expenditure of relatively small amount of electric power needed to drive small pumps as shown in fig. 4-2.

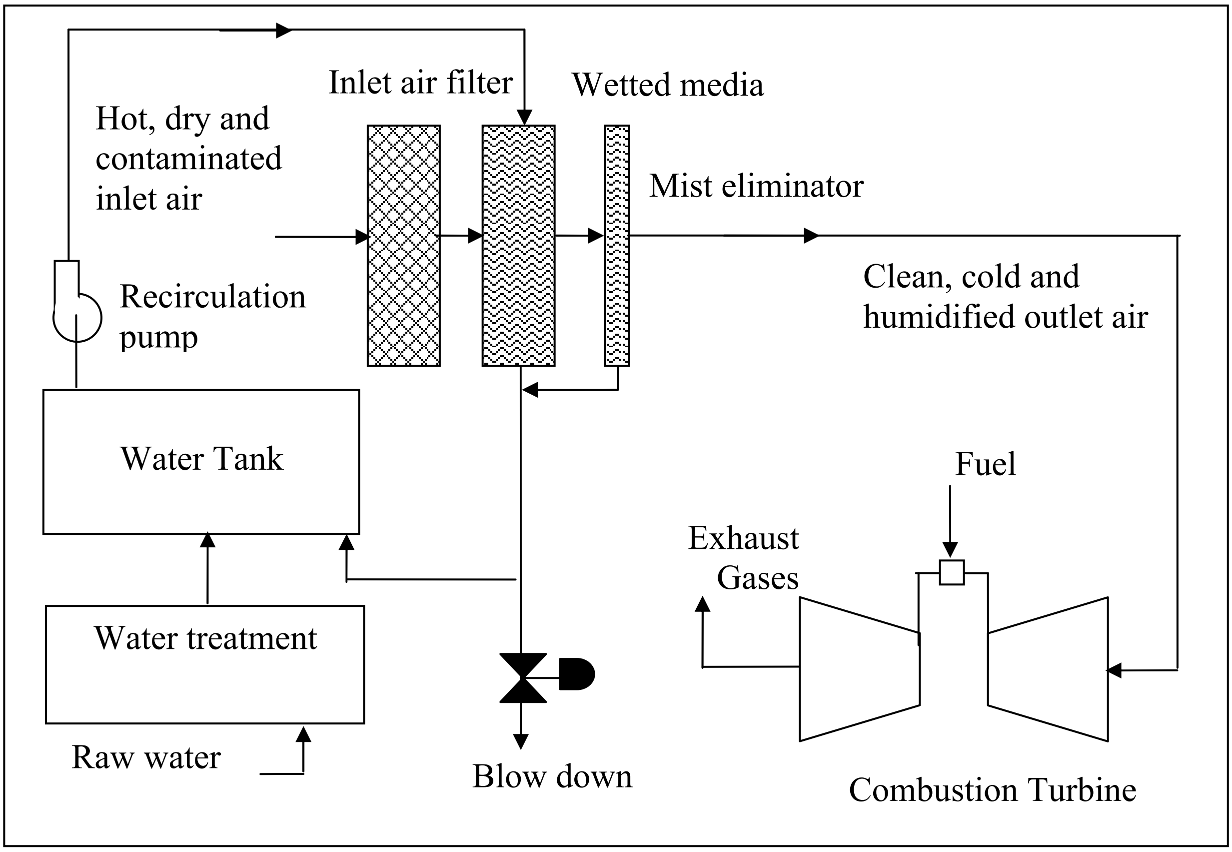

Fig. 4-2 Schematic drawing of Wetted media Evaporative cooling.

4-2-1-1. Evaporative cooling theory

Evaporative cooling is idealized as an adiabatic saturation according to the law of saturation which states that "as adiabatic saturation of an air water-vapor mixture occurs in an isolated compartment, the sensible heat loss equals the latent heat gain" this can be explained as follow [39]:

1- The only heat transfer is internal (sensible heat loss equals latent gain, and total heat of the air passing through the cooler remains constant).

2- Wet-bulb temperature is constant, (dry bulb temperature decrease, dew point rises, and the leaving air approaches saturation)
3- Recirculated water adjusts itself to the wet-bulb temperature. If it enters the cooler at a temperature lower than the wet-bulb, it is first warmed to the wet bulb and then evaporates. If the initial water temperature is higher than the wet bulb, it will be cooled to the wet bulb by its own evaporation. The initial water temperature has very little effect on the efficiency of the cooler, since the heat involved in cooling 1kg is usually less than 23 kJ while the heat it will absorb as it evaporate is of order of 2460 kJ. In most cases in hot weather, it is sufficiently accurate to assume that the water supply temperature approximates the air wet-bulb temperature. This is because the temperature of many water sources is naturally close to or slightly lower than the wet bulb temperature. However the temperature of water in long runs of sun-struck pipes can be significantly increased.
4- The amount of air cooling accomplished is directly proportional to the amount of water evaporated.
5- If complete saturation occurs, the leaving –air dry-bulb temperature equal wet bulb and dew point temperatures. However, 100 percent saturation is rarely obtained, and the leaving –air temperature approaches the wet bulb as a lower limit but does not reach that temperature. Practical experience shows that 100 percent level of cooling (complete saturation) is difficult to achieve but can be 85% to 95 % depending on the effectiveness of an evaporative cooling system and its design.

From what was stated above we can conclude the following:-

Wet bulb depression is the deference between dry bulb and wet bulb temperatures.

The effectiveness is cooling efficiency of the system to transfer water vapor into the air stream and is defined as the drop in dry-bulb temperature produced in the air passing through the cooler divided by the wet-bulb depression of the entering air. The effectiveness of an evaporative cooling system depends on the surface area of water exposed to the air stream (media type and thickness) and the residence time (airflow face velocity).

Wet bulb depression = (TDB1 – TWB) X effectiveness (%) ………………….(4-2)

Assuming adiabatic condition and water recirculation then:

TDB2 = TDBI - (TDB1 – TWB) X effectiveness (%.)

Where:-

- TDB1 refer to dry bulb temperature of air entering.
- TWB refer to air wet bulb temperature.
- TDB2 refer to dry bulb temperature of air leaving.

Fig. 4-3 shows that, the maximum average wet bulb depression for Khartoum area in the period from March to June and the minimum is during the raining season from July to September due to the increase in the Humidity.

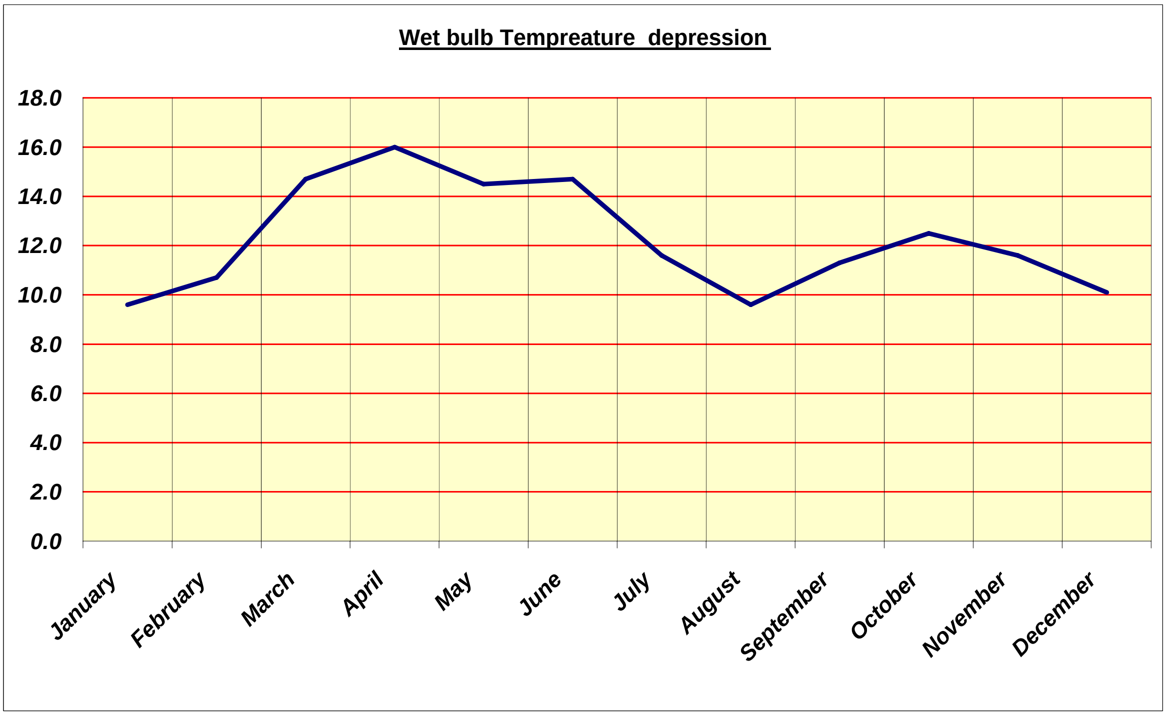

Fig. 4-3 Wet bulb temperature depression chart in Khartoum – Sudan.

4-2-1-2. Wetted media types and thickness

Evaporative cooling wetted media types and designs have big effect on the cooling effectiveness and the following are most used types:

(i) Rigid media sheets are sheets of rigid and corrugated material made from plastic, impregnated Cellulose, or fiberglass with 45/15 degree transverse flutes. The depth of the rigid media is typically 300 mm in the direction of the airflow but may be vary from 200 to 400 mm. Rigid media have lower pressure drops and can easily be cleaned by water flushing.

(ii) Aspen pads manufactured from literally wood fibers and packed together.

For most of the gas turbines applications with evaporative cooling rigid media type is used, the media is typically 300 mm or more thick and covers the entire cross-section of the inlet air duct or filter house. The media and drift eliminator result in a pressure drop in the inlet air duct. Typical values are approximately 1.25 mm of water column. This increase in inlet pressure drop decreases the plant output and efficiency for all ambient temperatures and loads even when the system is off. Retrofit installation often requires substantial ducting modifications. The effectiveness of the system is fixed by the media selection and condition so the inlet air temperature can not be controlled (the system is either on or off). This is not typically an issue because the operator desires the maximum possible increase in plant output.

4-2-1-3. Wetted media location

The media are positioned, according to the site dusty conditions, in the filter housing in the following different locations.

- In front of filter
- In between stages
- Down stream of the filter

4-2-1-4. Water requirement

Water quality and quantity in the site to be used in evaporative cooling will be the main factor to select this system of turbine inlet air cooling especially in Sudan, where the Nile water is suitable without treatment as in the analysis presented in table 3-3, the analysis which was conducted by Water Project Saudi Arabia company.

Table 4-3 Nile water sample analysis.

Parameters	Unit	Sample Result
Temperature	°C	31.6
pH		7.44
Conductivity	µs/cm	231
T.D.S	mg/l	183
Total alkalinity	mg/l as $CaCO_3$	108
Total hardness	mg/l as $CaCO_3$	98
Sodium	mg/l	0.34
Potassium	mg/l	0.05
Calcium	mg/l	34.4
Magnesium	mg/l	6.81
Iron (Total)	mg/l	0.86
Chloride	mg/l	6
Nitrate	mg/l	1.6
Bicarbonate	mg/l	119.5
Sulphate	mg/l	1
Silica (as SiO_2)	mg/l	14.8

The Langelier saturation index (I_s) will be used to determine the suitability of water with these properties for recirculation in the evaporative cooler. The water will be circulated and makeup water will be added to replace the water that has been evaporated and bleed off. Bleed water will be used to reduce the concentration of the dissolved solids in the water. The Langelier saturation index [40] is determined by the following equation:-

$I_s = pH - pH_s$ ……………………………...…………...……………….………..(4-3)

pH = pH from the test = 7.44

pH_s = Total hardness + alkalinity + Total dissolved solids

By taking the value of the Total hardness, alkalinity and Total dissolved solids from Table 4-4 then:

I_s =7.44 -2.95-2.70-2.72 = -0.93

Table 4-4 Langelier equivalent value for Nile water sample values.

Parameter	Sample value	Langelier equivalent value
T.D.S	183	2.72
Total alkalinity	98	2.70
Total hardness	108	2.95

According to the characteristic of Langelier, the water is slightly corrosive and non scale forming and indicates no water treatment is required. Nile water may need physical treatment when taken from the River if the turbidity is high during autumn season.

4-2-1-5. Blow-down

Blow-down is required for recirculation system to limit the concentration of solids and the rate depends on the total hardness of the water and evaporation rate. With 108 hardness as Ca CO3 the blow-down ratio to evaporation is equal to unity i.e.

Blow-down ratio = (blow-down gpm)/(water evaporation gpm) =1

4-2-1-6. Mist eliminator

Mist eliminators are designed in shape of S, to separate the water droplets from the air stream, depends on inertial forces and therefore droplet size and velocity when the air passes through the 'S' turns of the drift eliminators, the heavy water droplets impinge on the out side of each turn. They are drawn out of the air stream into the drainage channels. This should be done with high efficiency and low pressure drop, because the media and drift eliminator result in a pressure drop in the inlet air duct result in gas turbine output decrease.

4-2-1-7. Dust removing by evaporative system

Evaporative cooling media work as second stage filter that remove dust and other contaminants that bypass the main filter. The water is directed toward the air entering face of the media, where it flushes dust and dirt from the surface and removes it from the system with the blow down water. The cross-fluted design media increase the surface area and makes a strong self-supporting media with high evaporative efficiency and low pressure drop (resistance to air flow).

4-2-1-8. Effect of dust on the cooling media

Airborne dust and other contaminants especially when there is dust storm tend to clog the airflow passages of the cooling media, which required increase in the rate of blow down water and hence more water to be consumed. To eliminate this effect on the media life time and water quantity, recirculation should pass through clarification tank before circulating the water again to the cooling pad as shown in fig. 4-4.

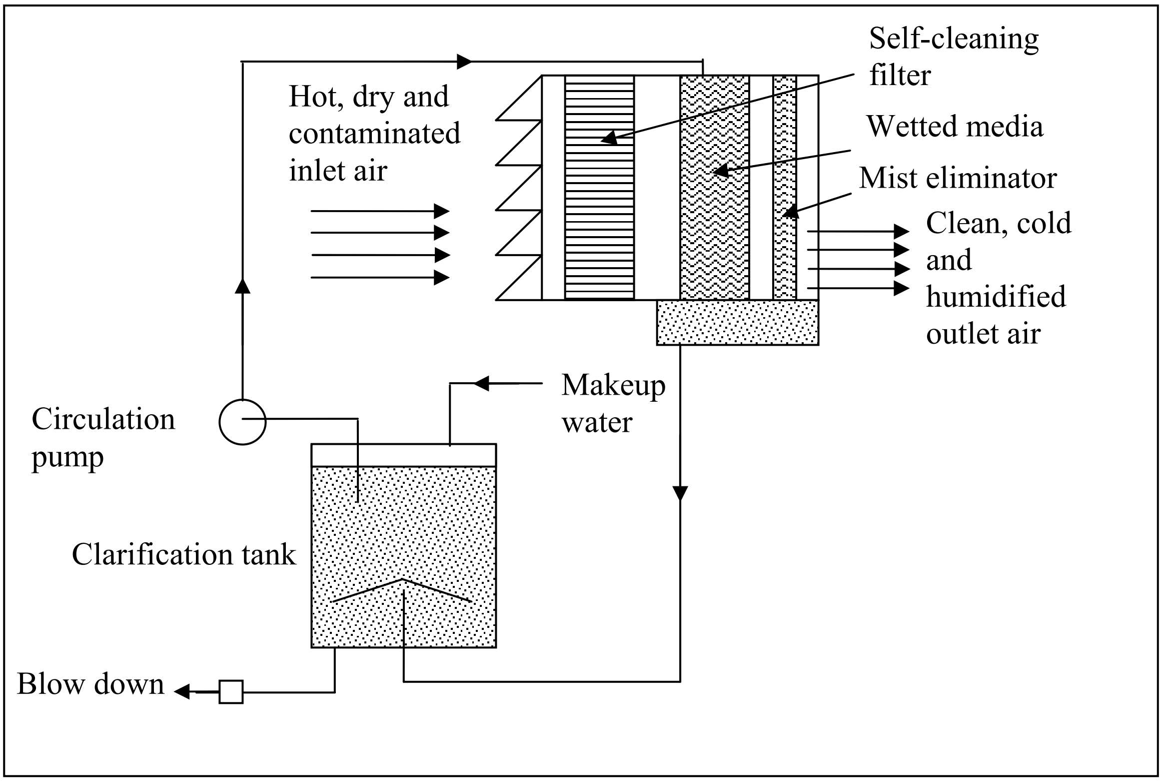

Fig. 4-4 the proposed system to remove dust from the inlet air

4-2-1-9. The minimum inlet air temperature

The inlet air under-goes an acceleration process increasing the air velocity while traversing through the inlet housing as shown in fig. 4-5, and if this process occur adiabatically, there will be further decrease in the inlet air temperature depending on the speed. However, the turbine inlet air cooling systems should not cool inlet air below the minimum recommended temperature, based on the fact that, if cooling (especially evaporative) is permitted at too low temperature, this could cause icing. From the available data, the possibility that the dry bulb temperature will fall below freezing cannot happen in Khartoum.

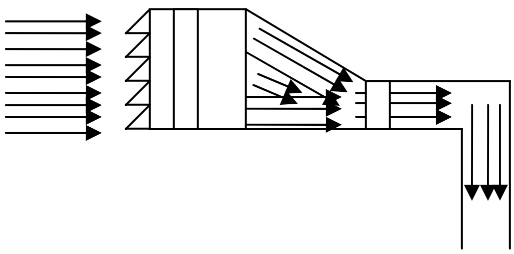

Fig 4-5 The movement of inlet air through inlet ducting

4-2-1-10. Gas turbine Power output calculations without inlet air cooling (base case unit).

In order to study the effect of TIAC on performance, calculation will be done for gas turbine with and without TIAC in the maximum dry bulb temperature recorded (45.6ºC).

Correction factor for 45.6ºC and 85 % relative humidity at Khartoum as follows:

Output correction factors

Altitude Correction factor	= 0.9575
Temperature Correction factor	= 0.81
Humidity Correction factor	= 0.9999
Corrected Output at Khartoum	= 83.5 x 0.81 x 0.9575 x 0.9999
	= 64.75 MW

Heat rate correction factors

Heat rate and thermal efficiency are not affected by altitude.

Temperature Correction factor = 1.05

Humidity Correction factor = 1.0001

Corrected heat rate at Khartoum = 11,025x 1.05x1.0001

= 11,577 kJ/kWh

4-2-1-11. Gas Turbine Performance calculation with evaporative cooling

Using evaporative cooler with 85% effectiveness the calculation will be as follows:

Wet bulb depression = 45.6ºC – 21.0ºC = 24.6ºC

Cooler outlet temperature = 45.6ºC - 24.6ºC x 0.85 = 24.7ºC

Moisture content at cooler inlet = 0.0052 kg/kg dry air

Moisture content at cooler outlet = 0.015 kg/kg dry air

Air density at 45.6ºC = 1.06 kg/m3

Power output with evaporative cooling

Correction factor for 24.7ºC and 85 % relative humidity at Khartoum

Output correction factors

Altitude Correction factor = 0.9575

Temperature Correction factor = 0.94

Humidity Correction factor = 0.9989

Corrected Output at Khartoum = 83.5 x 0.94 x 0.9575 x 0.9989

= 75.04 MW

According to the manufacturer performance characteristic [41], 10.16 mm of water column inlet pressure drop produce 1.42 % power output loss and increase heat rate by 0.45 %.

Assume insertion of evaporative media will cause pressure drop of 1.27 mm of w.c. which will drop output by 0.18 %

media losses on turbine output = 0.0018 x 75.04 = 0.14 MW

Net turbine output = 75.04 – 0.14 = 74.90 MW

Power capacity enhancement = 74.90 - 64.75 MW = 10.15 MW

Heat rate correction factors for Khartoum.

Heat rate and thermal efficiency are not affected by altitude.

Temperature Correction factor = 1.0083

Humidity Correction factor = 1.0032

Corrected heat rate at Khartoum = 11,025x 1.0083x1.0032 = 11152 kJ/kWh

The gas turbine inlet air mass flow rate at 45.6ºC = 300 x1.0608/1.225 = 260 kg/s

The evaporation flow rate (gpm) = (0.015 -0.0054)kg $_w$/kg $_a$ x 260 kg $_a$

= 2.496 kg/ s x 0.001 m3/kg $_w$

= 0.0025 m3/s = 40 gpm

4-2-2. Fogging system

Fogging system as shown in Fig. 4-6, is considered as an evaporative cooling using the same idea of evaporation theory descried in evaporative cooling using wetted media. The dry bulb temperature of inlet air decreases by losing its sensible heat to the liquid water droplets generated by the fogging system. This sensible heat is enough to provide the latent heat necessary to evaporate and diffuse these droplets into the surrounding air stream resulting in an increase in its density. The difference between the two systems is that; evaporation in fogging will continue up to saturation line, and some time may exceed the saturation point causing over saturation. The idea of fogging is the same as for air washer in the way of direct contact between water droplets and air, but the difference is in the diameter of the water droplet size. Also fogging system creates a large evaporative surface area by atomizing the supply of water into billions of super-small spherical droplets. Droplet diameter plays an important role with respect to the surface area of water exposed to the air stream and, therefore, to the speed of evaporation. For instance, water atomized into 10-micron droplets yields 10 times more surface area than the same volume atomized into 100-micron droplets. Water droplets of less than 40 microns in diameter make up a fog. When droplet sizes are larger than this, they are called a mist. Fogs tend to remain longer time in air than the mists. In still air, for example, a 10-micron droplet falls at a rate of about one meter in five minutes, while a 100-micron droplet falls at the rate of about one meter in three seconds [42].

Fig. 4-7 shows fogging system in operation, Fig. 4-8 shows the Location of fogging nozzle in filter house.

Foggers were first applied to gas turbine inlet air cooling in the mid-1980s. It was applied in Sudan in Kilo 10 power plant Fiat gas turbine but there is no data or report about the effect of the system on the turbine output and hardware. The system is out of service now.

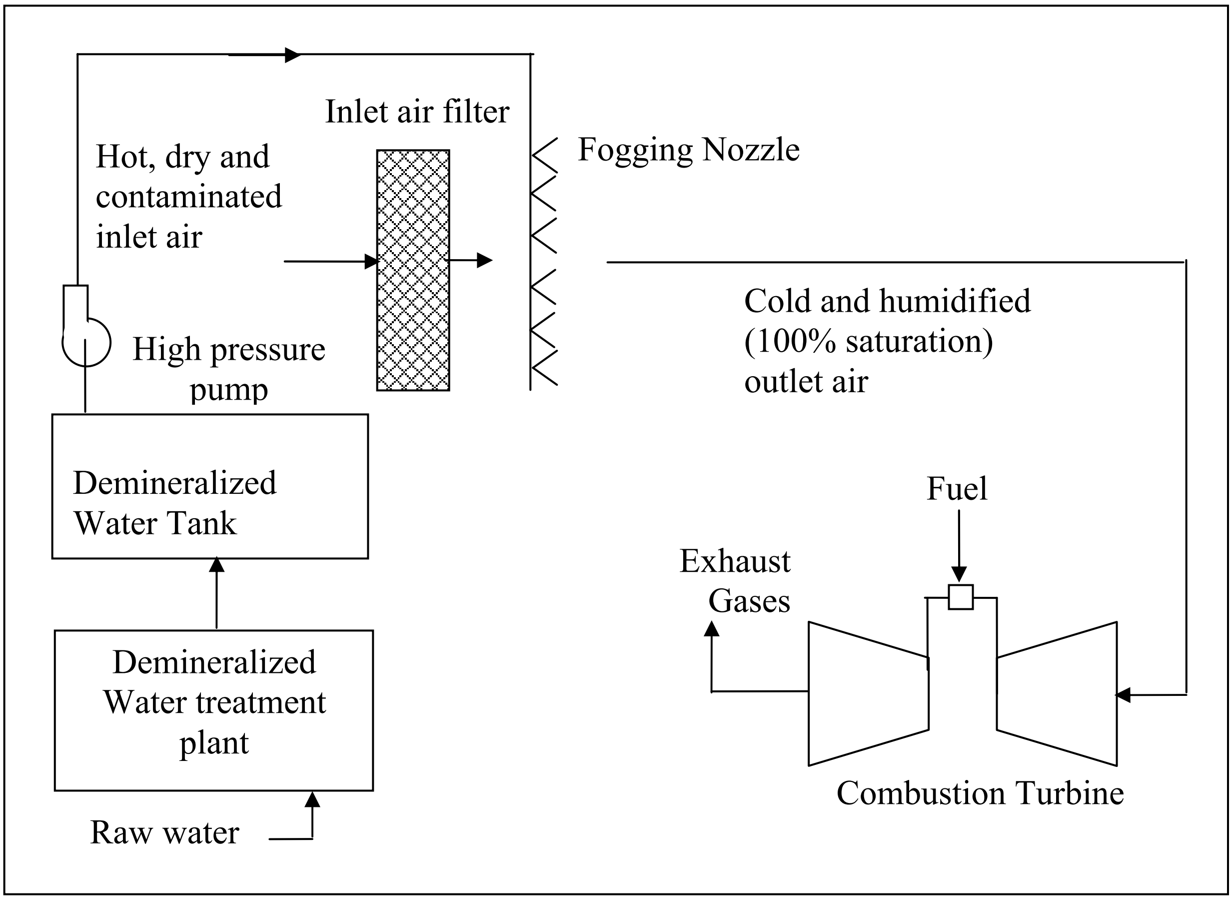

Fig. 4-6 Schematic Drawing of Fogging System.

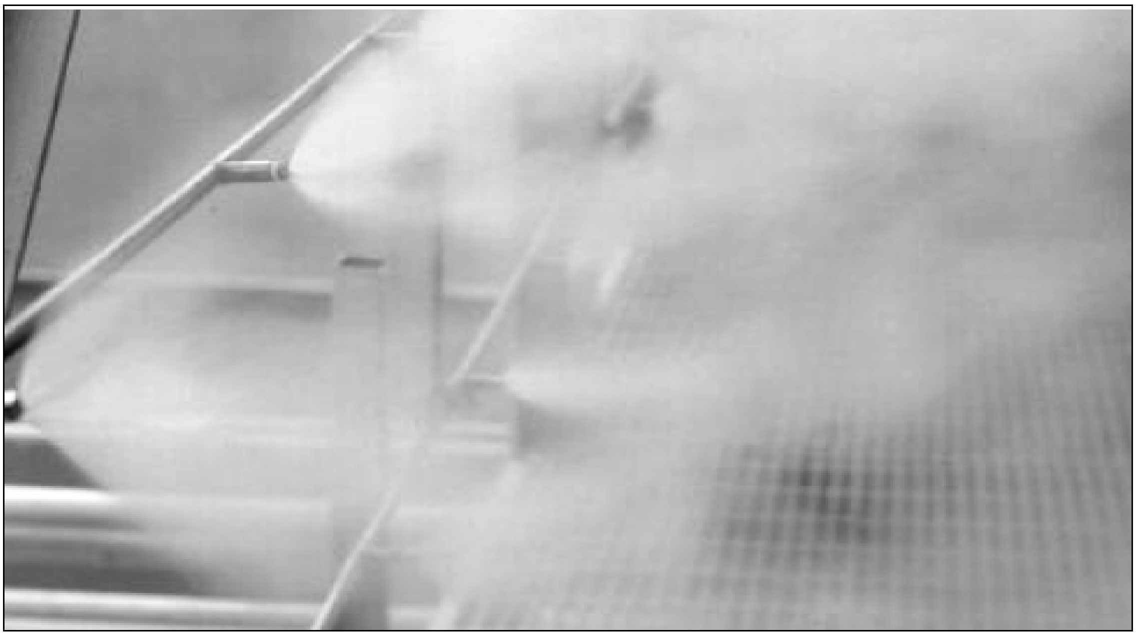

Fig. 4-7 Fogging system with high pressure impingement Nozzle [22]

Fig. 4-8 Location of fogging nozzle in filter house

4-2-2-1. Gas Turbine Performance Calculation with Fogging System

The same calculation for evaporative cooling will be done for fogging at the same maximum dry bulb temperature recorded, 45.6 ºC with 21.0 ºC wet bulb temperature.

Using Fogging with 100% effectiveness the calculation will as followed:

Wet bulb depression = 45.6ºC – 21.0ºC = 24.6ºC

Cooler outlet temperature = 21.0ºC

Moisture content at inlet = 0.0054 kg/kg dry air

Moisture content at outlet = 0.0206 kg/kg dry air

Air density at 45.6ºC = 1.06 kg/m3

Power output with Fogging System

Correction factor for 21.0ºC and 100 % relative humidity at Khartoum

Output correction factors as follows:

Altitude Correction factor = 0.9575

Temperature Correction factor = 0.96

Humidity Correction factor = 0.9988

Corrected Output at Khartoum = 83.5 x 0.96 x 0.9575 x 0.9988

= 76.66 MW

Assume insertion of fogging will cause pressure drop of 0.25 mm w.c. which will drop output by 0.04 %.

Fogging losses on turbine output = 0.0004 x 76.66 = 0.03 MW

Net turbine output = 76.66 – 0.03 = 76.63 MW

Power capacity enhancement = 76.63 - 64.75 MW = 11.88 MW

Heat rate correction factors for Khartoum.

Heat rate and thermal efficiency are not affected by altitude.

Temperature Correction factor = 1.0049

Humidity Correction factor = 1.004

Corrected Heat rate at Khartoum = 11,025x 1.0049x1.004 = 11123kJ/ kWh

The gas turbine inlet air mass flow rate at 45.6ºC = 300 x1.0608/1.225 = 260 kg/s

The evaporation flow rate (gpm) $= (0.0156 - 0.0054)kg_w \times 260kg_a/s$

$= 2.65\ kg_w/s \times 0.001\ m^3/kg_w$

$= 0.00265\ m^3/s = 42$ gpm

4-2-2-2. Inlet air fogging temperature control

The moisture content of air and its dry bulb temperature can provide accurate information on the system path and how well it approximates the adiabatic saturation process and determining system efficiency. The deviation from the adiabatic saturation process is attributed to several factors, such as external heat gain or loss, water temperature, etc. The measurement of moisture content can enable the fogging system control logic to control the measurement of actual moisture content of air upstream and downstream of a fogging system and hence the required water flow rate through the system to obtain maximum performance without over spraying excessive water or under cooling inlet air.

4-2-3. <u>Refrigerative inlet air cooling system</u>

Refrigerative inlet cooling systems are used to cool the inlet air through the heat exchanger coils installed in gas turbine inlet filter house, by using direct refrigerant in the cooling coils or by secondary cooling fluid (usually water). Refrigeration systems are much more effective and reliable, hence it can cool the air to less than 10ºC regardless of the ambient wet-bulb temperature. While it is significantly more expensive on a first-cost basis than evaporative cooling and inlet fogging, but the systems can be installed at half the cost of installing new turbine [43]. Refrigeration-based chilling technologies can produce significantly more power over the course of a year than can evaporative or fogging systems.

Refrigerated cooling can be used to provide continuous cooling throughout the day or on-peak cooling using thermal energy storage (TES). With continuous cooling, the inlet air can be cooled instantaneously whenever needed. This type of cooling is most suitable for base load plants or whenever cooling is required for more than 8 hours a day. Refrigeration system ensures that the power output will be maximized during the hottest hours of the year. It can be accomplished with Thermal Energy Storage technology (TES), which build energy (ice or chilled water) at off-peak hours when electrical demand and costs are low, and store it in thermal storage tank, to cool inlet air during daylight hours, when electrical demand and costs are high, which can significantly improve the economics of a peaking power plant.

4-2-3-1. Mechanical vapor Compression

Mechanical vapor compression systems operate like a standard air conditioner as shown in Fig (4-9). A refrigerant is compressed, condensed, expanded in an evaporator, and recompressed. The evaporator may be a cooling coil in the inlet air stream, or it may be a heat exchanger that makes chilled water, which in turn is pumped to a cooling coil in the inlet air stream.

Vapor compression systems are usually driven by electric motors, which have a significant parasitic load on the power output of the site. Vapor compression systems can also be driven by steam turbines and natural gas engines. The choice of a gas engine makes sense for a peaking plant. The choice of a steam turbine makes very good sense for a combined cycle plant.

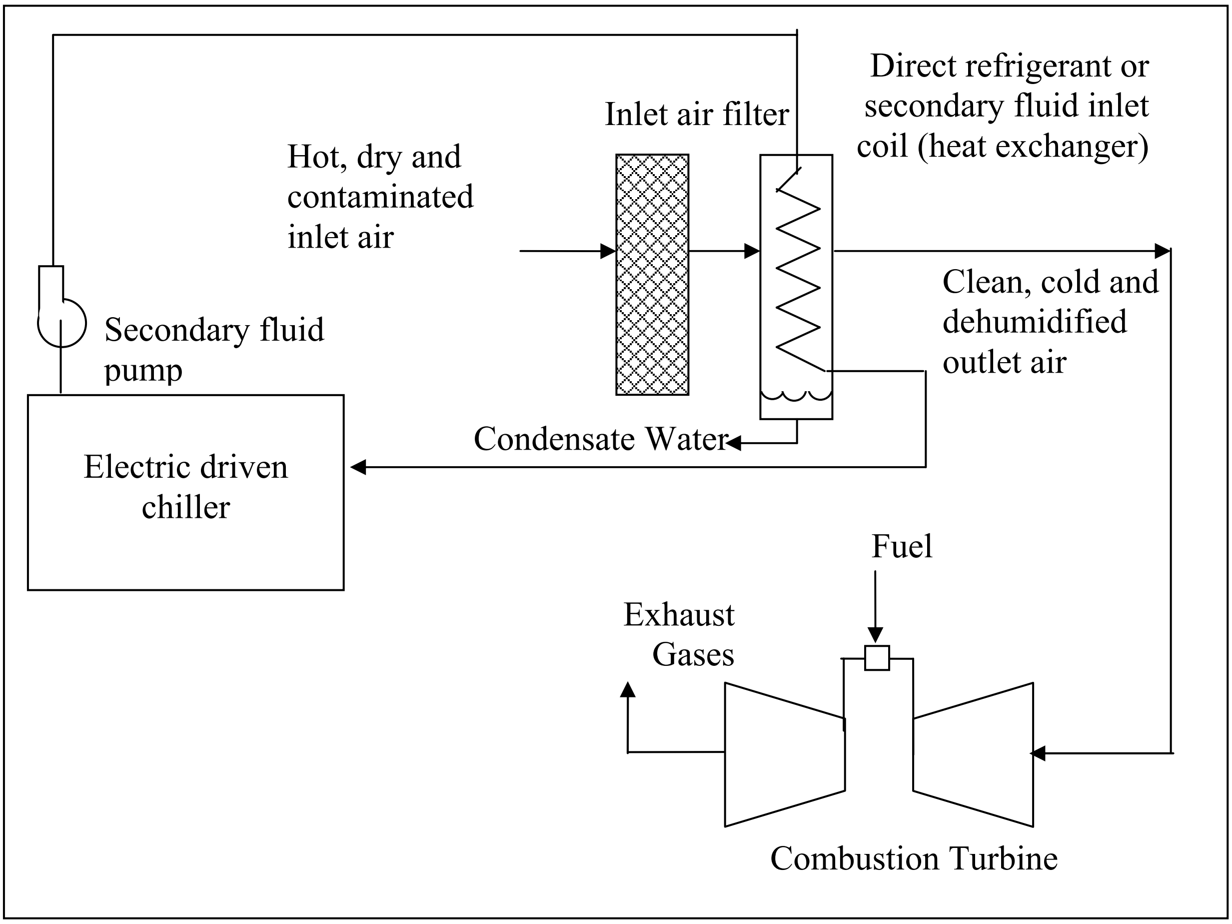

Fig. 4-9 Schematic of refrigeration system using direct Mechanical chiller.

4-2-3-2. Absorption Chillers

Absorption chillers (see Fig. 4-10) usually have a higher first cost than vapor compression systems, and typically have a lower Coefficient of Performance (COP) too, but higher electricity revenues very quickly compensate the slightly higher first cost of the system. Several plants have already used absorption systems successfully. Absorption systems have very low parasitic electrical load. They can be "fired" by natural gas or by low-pressure steam. This system is suitable in cogeneration plants have intermediate 10 - 17 bar extraction line and low pressure steam headers.

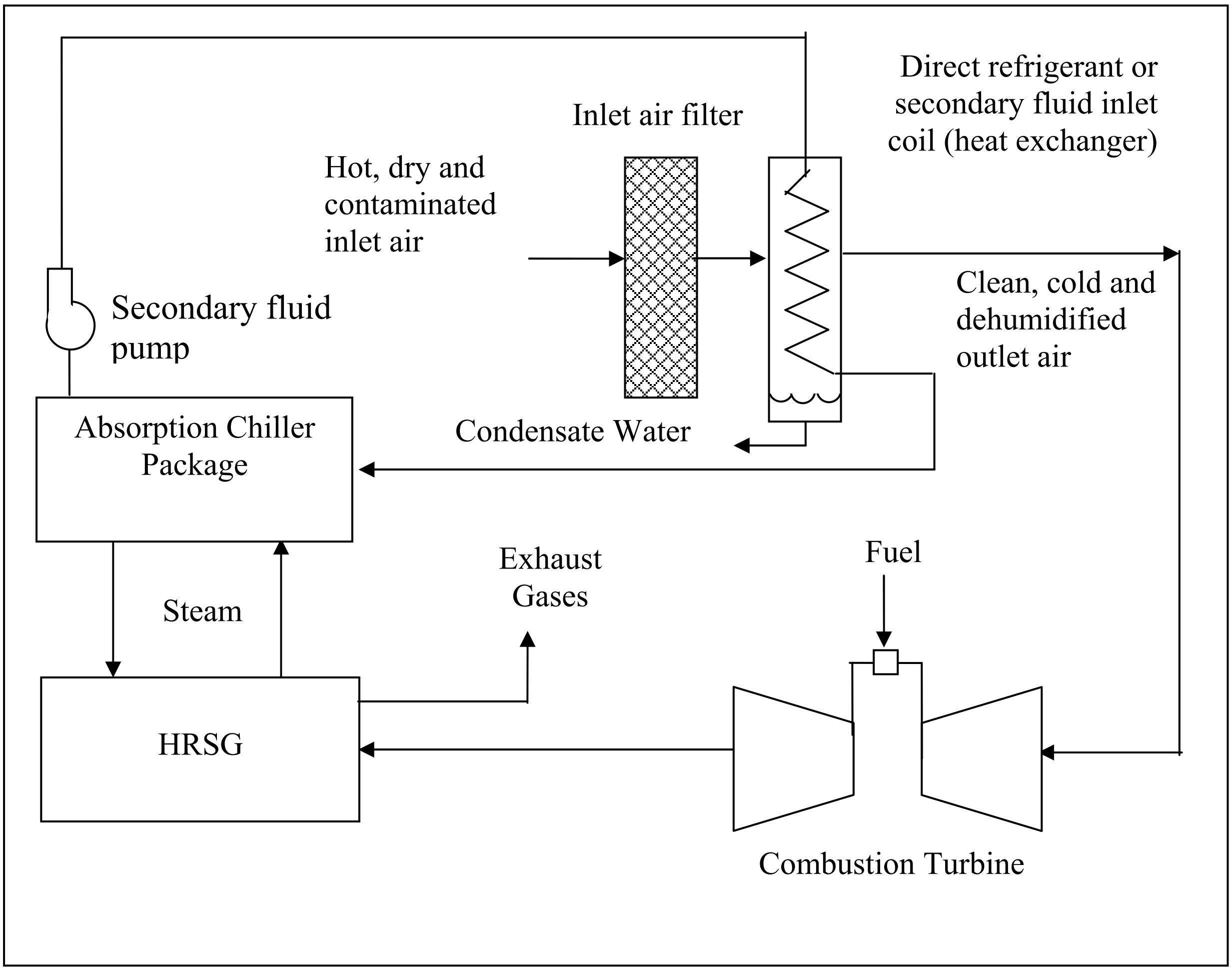

Fig. 4-10 Schematic of refrigeration system using direct absorption chiller.

4-2-3-3. Cooling load calculations for refrigeration system

The calculation will be based upon the new installation without the need for generator, lube oil and transformer cooling to accommodate the increase in load. The calculation will be based on constant coil outlet dry temperature of 10ºC.

4-2-3-4. Turbine heat exchanger load

$Q = mc_p (T_{1n} - T_{out})$ kW ……………………………………………………(4-4)

Q = 275 kg/s x1.005 kJ/kg ºC (45 – 10) ºC = 9673 kW

Q = 2,756 Ton of refrigeration (1 T.O.R =3.57 kW)

Where :

Q = Turbine cooling load (kW).

m = Mass flow to the turbine (kg/s).

Tin = Inlet coil dry bulb temperature (ºC)

Tout = Outlet coil dry temperature (ºC).

Cp = Specific heat of inlet air (kJ/kg ºC).

4-2-3-5. Gas Turbine Performance Calculation with refrigeration System

The performance will be always on 10 ºC as constant outlet temperature

Altitude Correction factor = 0.9575

Temperature Correction factor = 1.03

Humidity Correction factor = 1.00

Corrected Output at Khartoum = 83.5 x 1.05 x 0.9575 x 1 = 83.94 MW

Assume Insertion chilling coils will cause pressure drop of 1.0 inch of w.c. which will drop output by 0.36 %.

Fogging losses on turbine output = 0.0036 x 83.94 = 0.03 MW

Net corrected turbine output = 83.94 – 0.03 = 83.91 MW

Heat rate correction for Khartoum.

Heat rate and thermal efficiency are not affected by altitude.

Temperature Correction factor = 0.995

Humidity Correction factor = 1.00

Corrected heat rate at Khartoum = 11,025x 1 x 0.99 = 10,915 kJ/kWh

4-2-3-6. On line Refrigerative inlet cooling system

Online refrigeration use chillers to remove the cooling load directly when the turbine is running on peak hours more than 8 hours per day. On line refrigeration can use liquid refrigerant directly in the inlet air cooling coils, or it can use secondary fluid between the chiller and inlet coil. The direct refrigerant coils have a relatively large capacity to cool than the secondary fluid coils.

Chiller capacity = 2,756 ton.

Corrected Output at Khartoum = 83.91 MW

Power capacity enhancement = 83.91 - 64.75 MW = 19.16 MW

power required for the chiller will be taken as 0.8 kW/ton of refrigeration

Parasitic load for online cooling = 2,756 x 0.8 = 2.20 MW

The net out put for online cooling = 19.16 – 2.20 MW = 16.96 MW

4-2-3-7. Refrigerative cooling with Thermal Energy Storage (TES).

Thermal storage used when there is variation in power demand and/or electricity prices between peak hours and off peak hour and the peak period is less than 8 hours normally 5 to 6 hour is used. We will take 6 hour for our calculations. The system is shown diagrammatically in Fig 4-11, Fig. 4-12 shows Ice Thermal Storage Tank with Ice harvester.

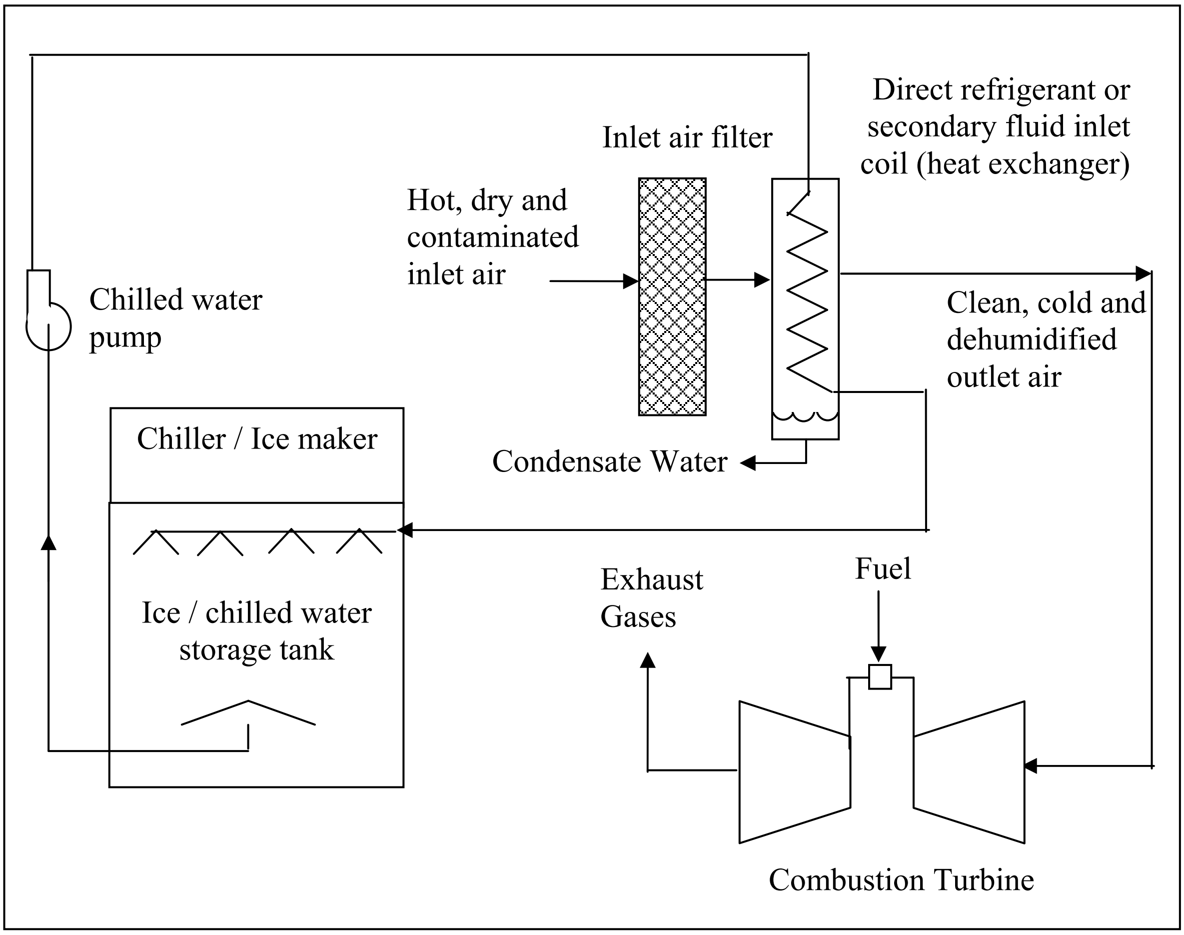

Fig. 4-11 Schematic of refrigerative system using Mechanical chiller with TES.

Fig. 4-12 Mueller Avalanche Ice Thermal Storage Tank with Ice harvester on the top of Tank, Lincoln, Nebraska U.S.A [25].

The build cycle - 18 hour

The chiller(s) capacity = cooling load x burn hours

= 9673 kW x 6 hrs = 58041kW-hr

Chiller capacity for 18 hour operation at build cycle = 58041kW -hr/ 18 hr

= 3225 kW = 918 ton

The increase in unit out put = 19.16 MW

Parasitic load at burn cycle is required for chilled water pump and system auxiliaries = 323 kW

The power capacity enhancement = 19.16 – 0.32 MW = 18.84 MW

It appears that the chiller capacity of the TES is one third of the online cooling chiller capacity plus the difference of electricity price if applicable. But the cost of the tank and piping connection may eliminate part of this advantage.

Chapter Five

Technical and Economical Feasibility

5-1. Technical Feasibility of cooling systems

5-1-1. Investigation of influence of TIAC on the output

Because of the wide usage and high demand for gas turbine engines, several companies produce such engines. As a result, there is global competition among gas turbine manufacturers. Companies are continually striving to improve the efficiency and performance of their engines. This is accomplished through the development and implementation of advanced compressor, combustor and other turbine components. General electric gas turbine PG7111EA was chosen to be the experimental unit in this study because an enormous amount of data is available about it. This unit has the following features:

i. Design

   17 stage axial compressor, 3 stage impulse turbine (high-energy stage), 10 slot cooled combustion liners and 1105 ºC turbine inlet temperature.

ii. Usual power

   60 Hz electric generator rated 83.5 MW at ISO condition.

iii. High availability, 90% during the last 5 years in Saudi Arabia.

iv. Long plant life time without major turbine failure up to 20 years.

v. Good efficiency (31%) compared to the other gas turbines.

vi. Using wide range of fuel grade and type.

vii. Longer gap between major overhaul about 48,000 hrs for base unit operation (natural gas as a fuel and operation of 1000 hrs per one start)

5-1-2. Actual Data

In order to determine the effect of increase of one degree Celsius of ambient air temperature on the gas turbine performance and output, a period of 9 months from 23/05/2002 to 24/02/2003 was selected and 24 hour per day data was taken from the reading of 10 gas turbines of same model, capacity and operation condition (using natural gas as fuel) through the Distribution and Control System (DCS) used for this units. DCS collect the data through a set of thermocouples for temperature reading and a wattmeter for the load reading with accuracy of ± 1.0. This devices were well calibrated after the conversion project of these units from using crude oil to natural gas as a fuel. The units data which satisfy the base load equation (max output) was selected for the temperatures from 7°C to 43ºC as in Table 5-1, the curve was drawn as in Fig. 5-1, It is depicted that decrease of 1 ºC of inlet air temperature will increase output by 0.623 %, this value is approximately equal to the manufacturer value of 0.616 % as shown in performance curve Fig. 5-2. Heat rate manufacturer curve Fig. 5-3 shows that decrease of 1 ºC will decrease the heat rate by 0.09 %.

Table 5-1 Gas turbine out put vs. inlet temperature

Compressor inlet temperature (°C)	Output (MW)
7.3	80.0
11.3	78.0
13.3	77.0
15.5	76.0
17.8	75.0
20.1	74.0
22.0	73.0
24.1	72.0
26.1	71.0
28.3	70.0
30.6	69.0
32.2	68.0
34.2	67.0
36.5	66.0
38.6	65.0
40.8	64.0
43.0	63.0

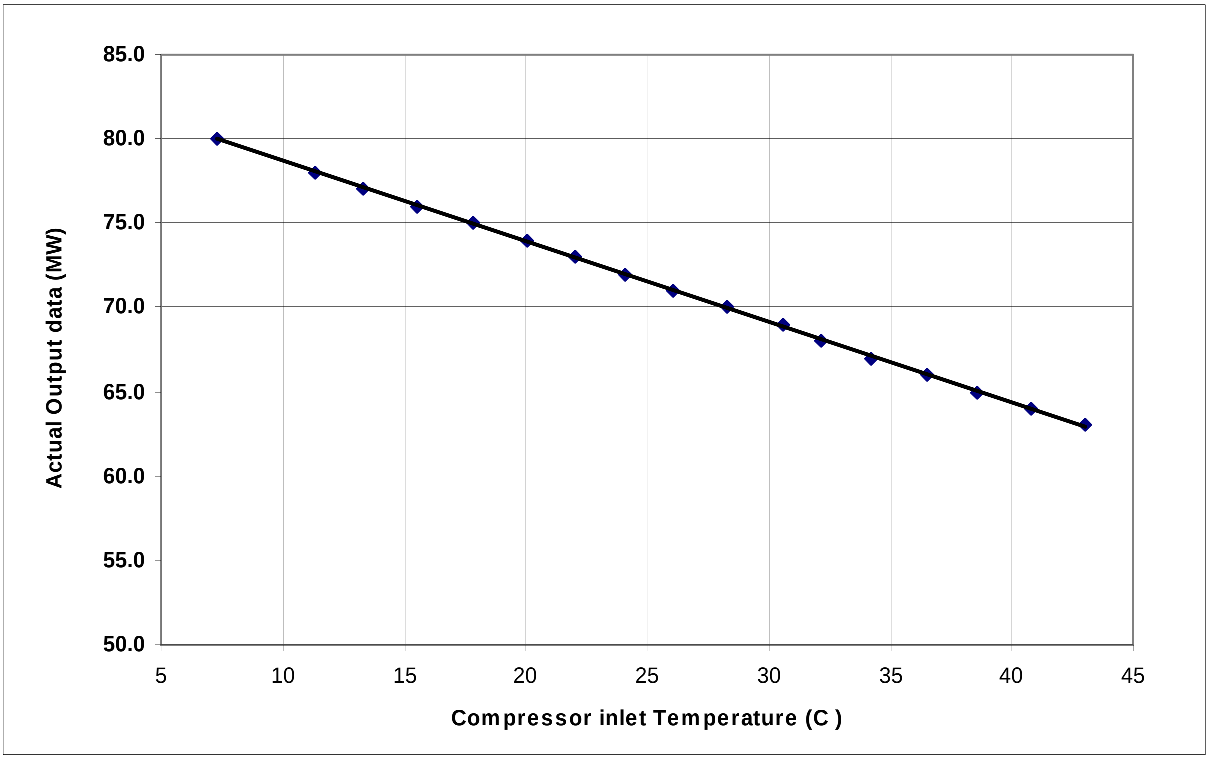

Fig. 5-1 Effect of compressor inlet temperature on the output for the actual data.

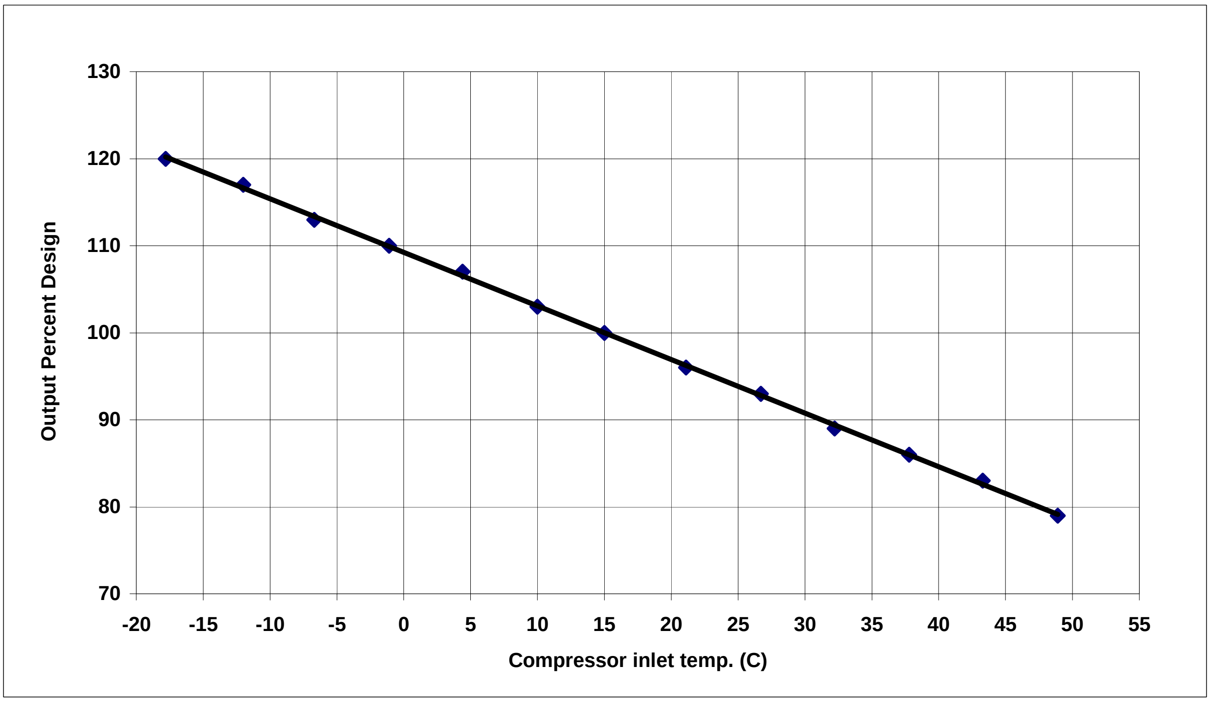

Fig. 5-2 Effect of compressor inlet temperature on output (manufacturer curve [37]).

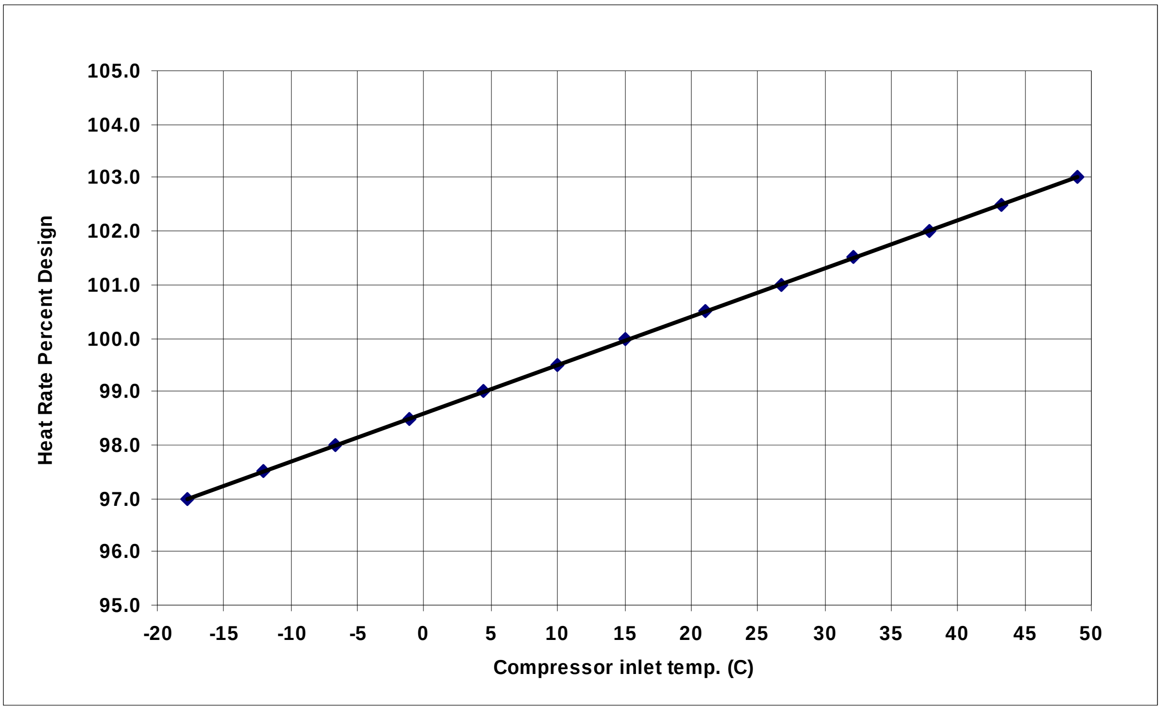

Fig. 5-3 Effect of compressor inlet temperature on heat rate (manufacturer curve [37]).

5-1-3. Cooling options assessment

In order to select the suitable system for Khartoum city the following analysis tables and figures are a result of a computer program [Appendix B1] that can calculate the required data according to the user selection of the operating period required, hour per day, minimum inlet temperature, minimum ambient temperature to run the system and evaporative cooling effectiveness. Gas turbine performance calculations for the cooling options were done according to the following factors:

- Gas Turbine is assumed to be continuous running 8760 hour / year, using natural gas as a fuel with zero degradation.
- For performance calculations 45.6 ºC dry bulb (maximum in the year) and 21.0 ºC wet bulb temperature at maximum dry temperature were considered.
- The minimum inlet cooling temperature of refrigrative cooling was selected to be 10ºC and the minimum economical ambient temperature to start the system was found to be 13 ºC. When running the system with temperature difference less than 3 ºC, the chiller load will be greater than the output enhancement.

5-1-3-1. Inlet Cooling Degree Hour (ICDH)

This term of degree-hour is used in inlet cooling to define the total amount of cooling that can be expected in a particular climate zone. The total estimated annual increase in turbine output in that zone can then be calculated by multiplying the annual ICDH by the megawatt output increase per degree of inlet cooling. This calculation gives the total annual kilowatt Hours of additional power that can be produced by the inlet cooling option [46]. For further evaluation of Evaporative cooling system (Wetted media and Fogging) two more definitions for ICDH are given below:

a) Available ICDH

Available ICDH is total degree of cooling from dry bulb temperature to wet bulb temperature with 85% for wetted media and 100% effectiveness for fogging system without limiting the output temperature by minimum manufacturer recommendations for evaporative cooling, i.e the wet bulb depression multiplied by media effectiveness (85 % for wetted media) or cooling down to the wet bulb temperature (saturation condition) in case of Fogging system (100% effectiveness). For one year, it was found to be 107,180 and 91,103 for fogging and wetted media respectively, for Khartoum city.

b) Useful ICDH

The useful degree hour of inlet cooling can be defined as the presence of effective wet bulb temperature depression which can give drop in temperature when evaporative cooling is used for one hour with the condition that the temperature leaving the cooler not less than minimum design temperature (value for evaporative cooling according to recommendations taken to be 15°C). Fig. 5-4 shows useful ICDH for Khartoum city of 103,349 and 88,902 which represent 96.4% and 97.6% for fogging and wetted media respectively. These values indicate that Khartoum is hot and dry area and evaporative cooling can be one of the best options.

For refrigrative cooling it can be defined as the drop of temperature from ambient dry bulb temperature to the design inlet cooling temperature which was selected to be 10°C, the ICDH was found to be 180,275 ICDH.

Fig. 5-5 and 5-6 show that the maximum useful hour through the year can be achieve during the period from April to November, and through the day it can be achieved from 9 – 22 hrs. This can be one of the guidance for the system operational policy.

5-1-3-2. Power Capacity Enhancement

The Net Power Capacity enhancement using TIAC cooling option shown in Fig. 5-7 shows 16.97, 11.88, 10.26 MW which represent percentage enhancement of 26.2%, 18.3%, 15.8% for refrigrative, Fogging and wetted media respectively. Refrigrative enhance the capacity by 7.9% more than evaporative and 10.4% more than fogging system. Refrigrative cooling can give the maximum benefit of cooling options due to ability of the system to cool the inlet air below the wet bulb temperature which is not possible for evaporative cooling systems, but on other hand the parasitic power for refrigrative cooling using electric chiller is highest.

5-1-3-3. Total Heat Rate Reduction, MJ/MWh

Figure 5-3 shows that decrease in ambient temperature improve, the heat rate by 0.09% per one degree Celsius, Fig. 5-8 shows that refrigrative cooling achieve highest reduction of 667kJ/kWh compared to 454kJ/kWh and 425kJ/kWh for fogging and wetted media evaporative cooling respectively. These values increase the fuel efficiency by 5.8, 3.9 and 3.7 for refrigrative, fogging and wetted media evaporative cooling respectively.

The total fuel consumption per year can be calculated by using the following equation [46].

Total fuel consumption Reduction = ICDH x heat rate reduction per one degree of inlet cooling (0.09%) **[46]**…..……....(5-1)

Using the above equation the reduction of fuel consumption found to be 162 MJ, 92MJ and 80MJ for refrigrative, fogging and wetted media evaporative cooling respectively.

5-1-3-4. Total Electric Energy Production Enhancement, MWh

Figure 5-9 shows the effect of cooling options on the total net gas turbine energy production. The calculation based on hourly weather data of Khartoum city, assuming that the unit is running 8760 hour per year. Wetted media evaporative and fogging cooling getting use of all useful ICDH which represent 96.4% and 97.6% of the available ICDH for fogging and wetted media respectively. The refrigrative cooling can cool the inlet air to 10°C whenever the ambient temperature is greater than 13°C. The following equation is used to calculate total energy enhancement

Total gain in megawatt hour = ICDH x megawatt increase per one degree of inlet cooling (0.62%) ……………………(5-2)

by using the above equation, fig. 5-9 shows 77,348 MWh, 51,255 and 44,028 for refrigrative, fogging and wetted media evaporative cooling respectively. Fig. 5-10 shows that the maximum MWh can be achieved for all the cooling option on 15:00 hr per day. Fig. 5-11 shows that in month April maximum output achieved from fogging and wetted media evaporative cooling, where in month May the maximum MWh achieved for refrigrative cooling using electric chillers.

5-1-3-5. Water required for fogging and wetted media

One of the main advantages of gas turbine is its ability to run with the minimum water requirement among the other types of power producing machines. Fogging and wetted media evaporative cooling require high quantity of water with special properties as discussed in chapter 3. Nile water sample analysis shown in Table 3-3 prove that it can be used as raw water for wetted media evaporative cooling without any chemical treatment unlike fogging which required demineralized water. The total water required was found to be 72,760 M^3 and 42,459 M^3 per year for wetted media and fogging cooling system respectively. This quantity can be met without any difficulties for Khartoum city. Fig. 5-12 shows the water requirement per month, where April, May and June are the highest.

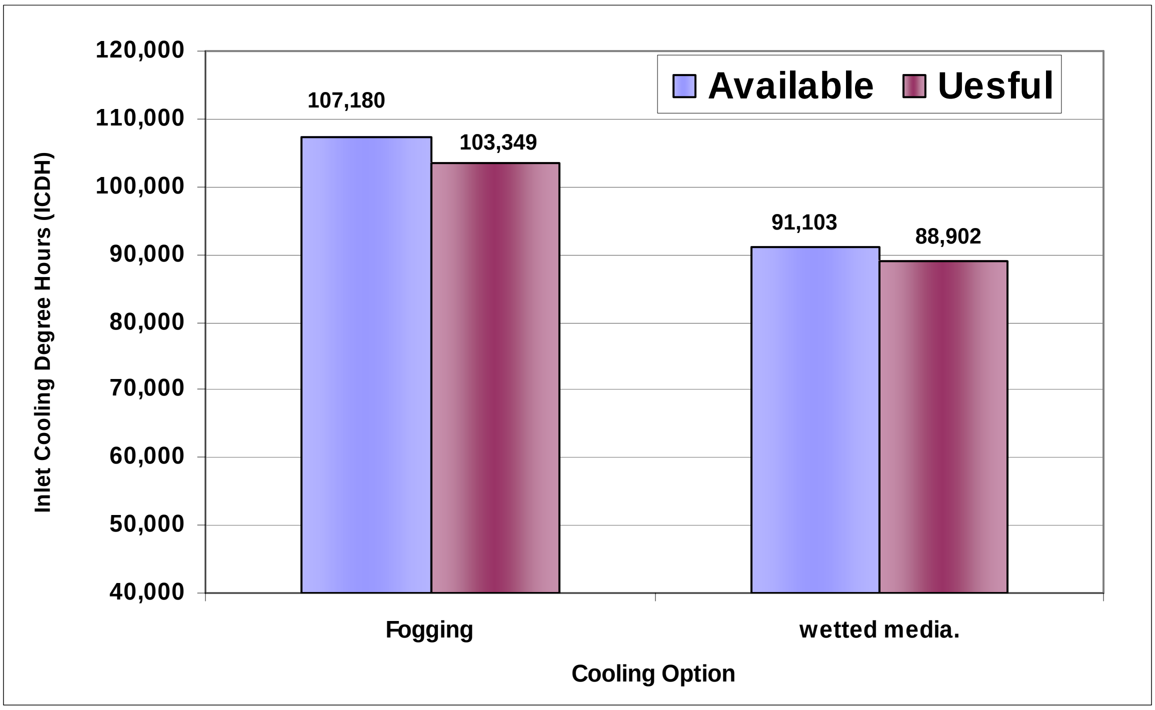

Fig. 5-4 Inlet Cooling Degree Hours Available and Useful

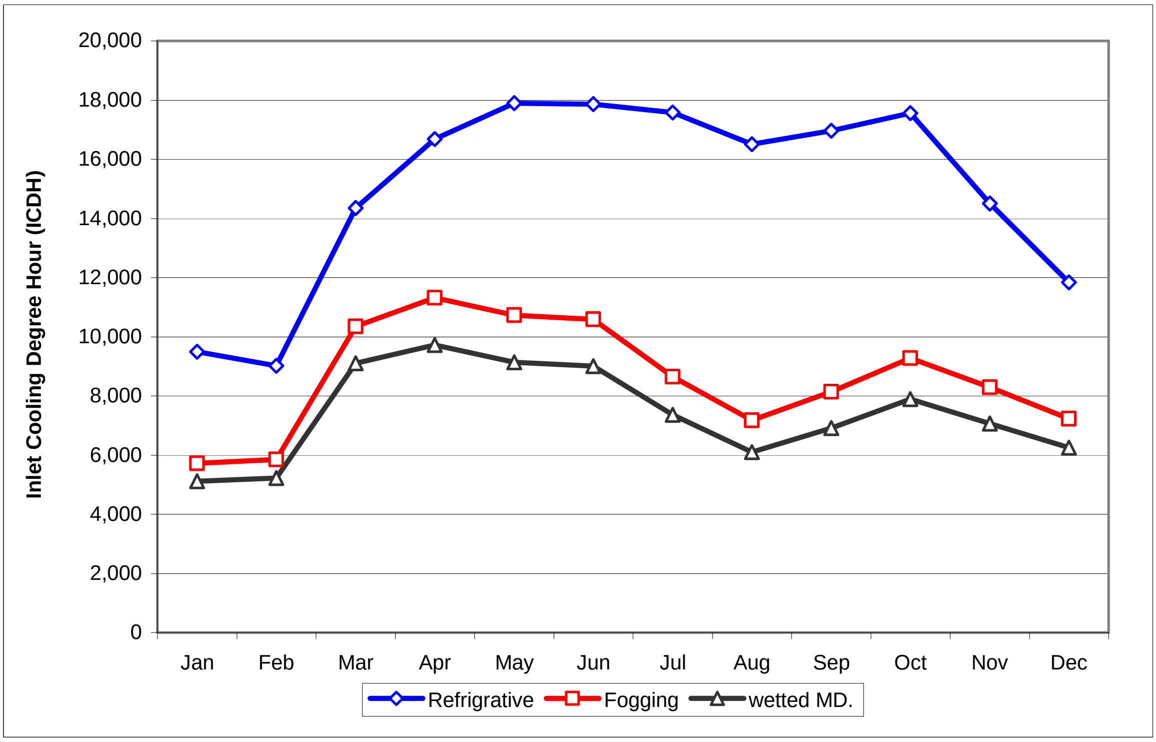

Fig. 5-5 Useful Inlet Cooling Degree Hour per month for one year.

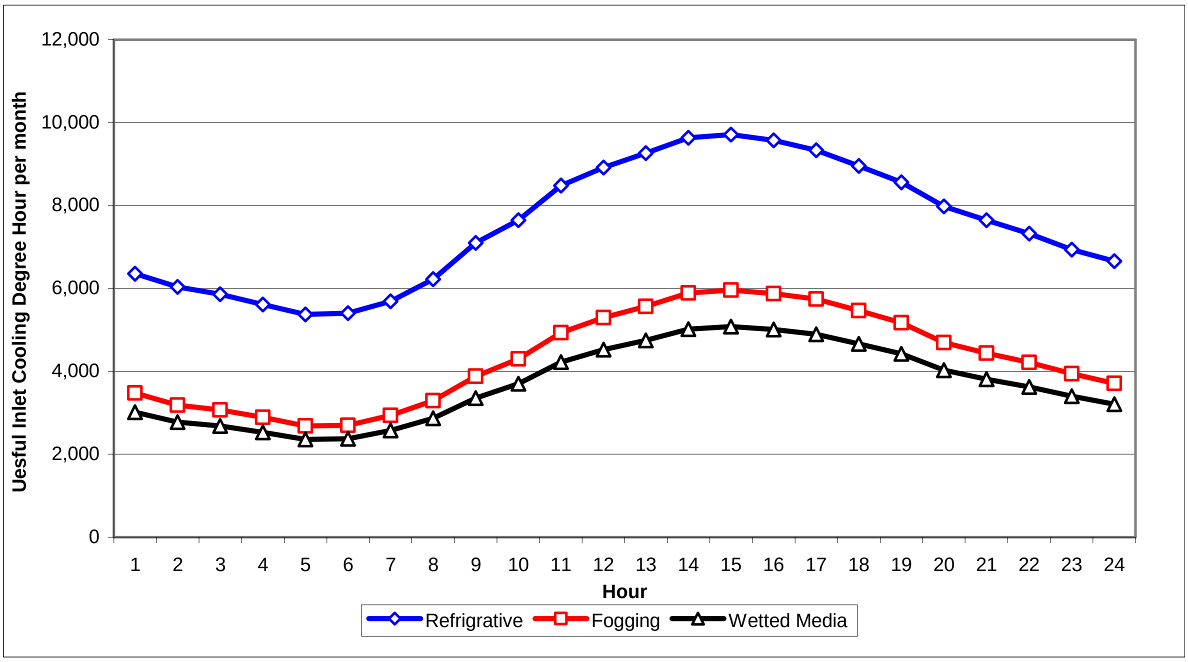

Fig. 5-6 Useful Inlet Cooling Degree for 24 Hours.

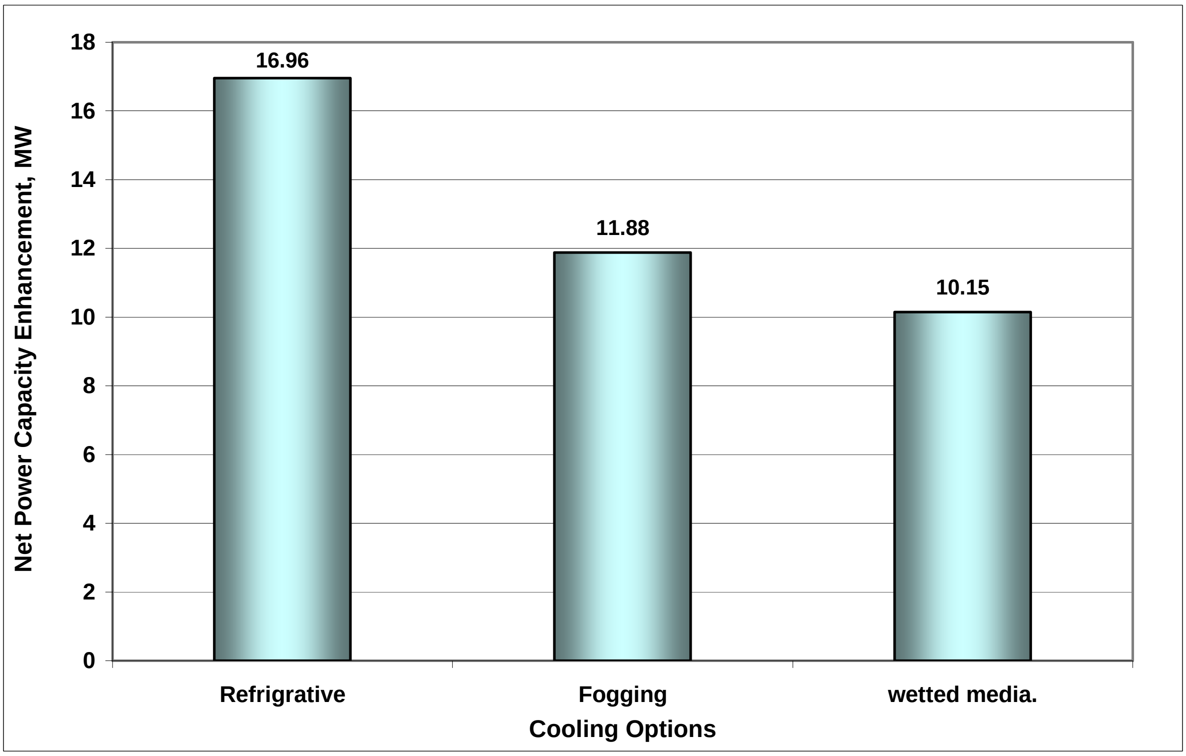

Fig. 5-7 Effect of TIAC on Net Power Capacity Enhancement (MW)

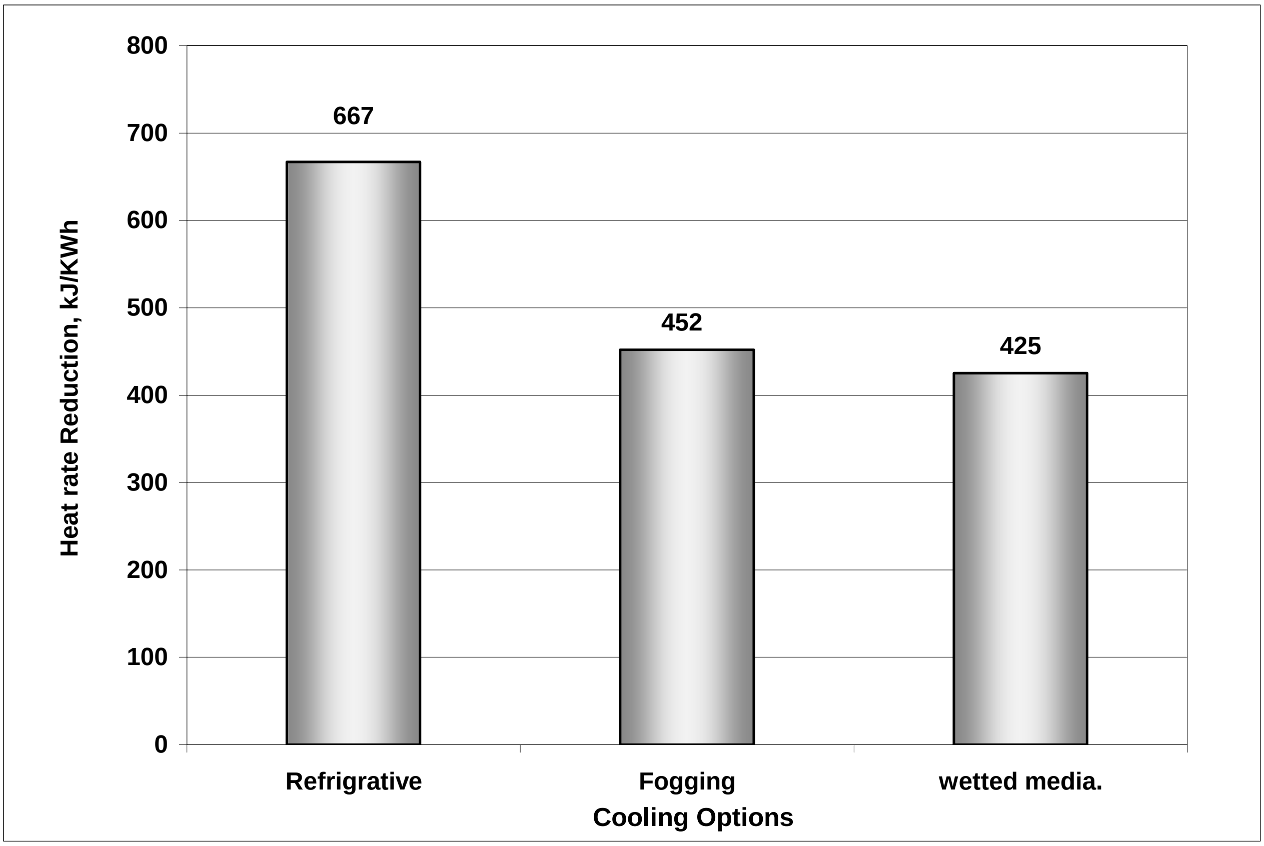

Fig. 5-8 Effect of TIAC on Heat Rate Enhancement (KJ / KWh)

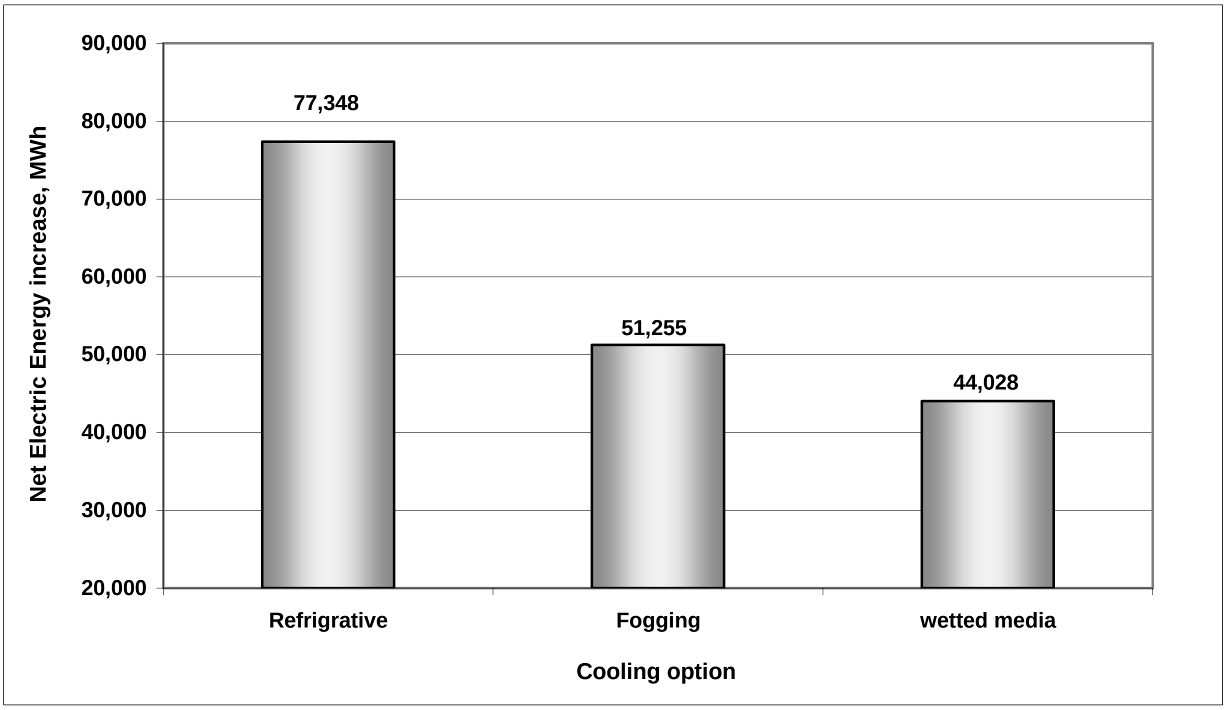

Fig. 5-9 Effect of TIAC on Net Electric Energy Enhancement (MWh)

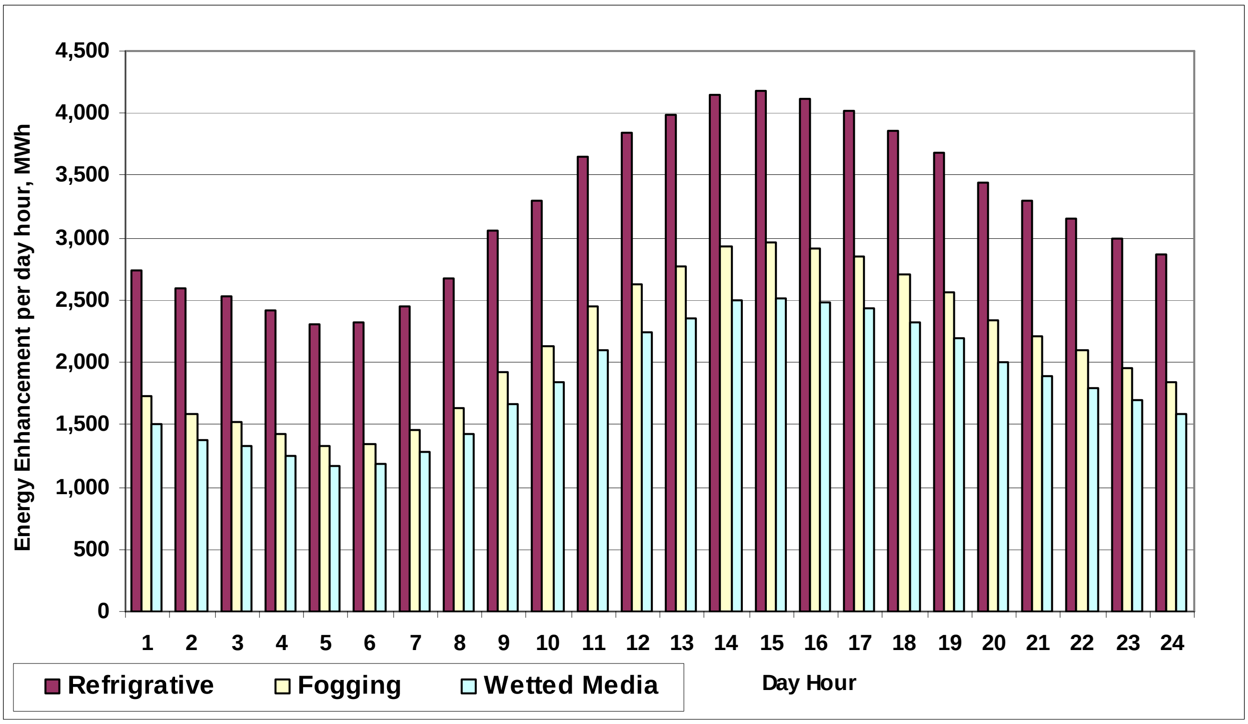

Fig. 5-10 TIAC Daily Net Electricity Energy Enhancement

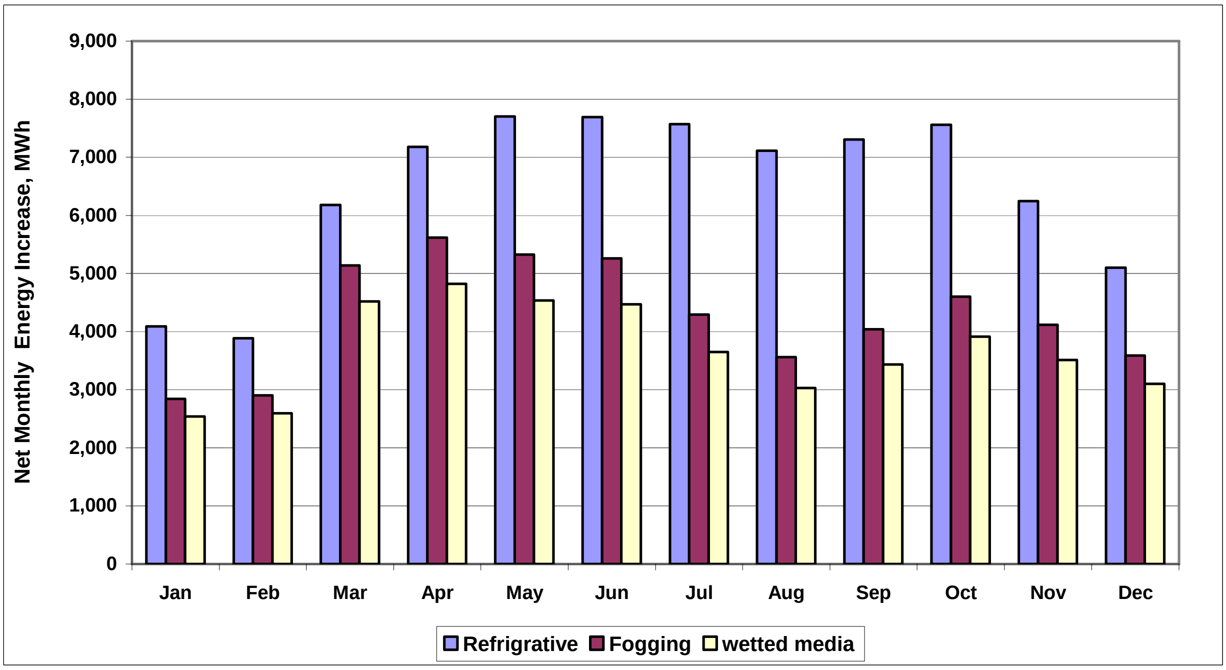

Fig. 5-11 TIAC Monthly Net Electricity Energy Enhancement

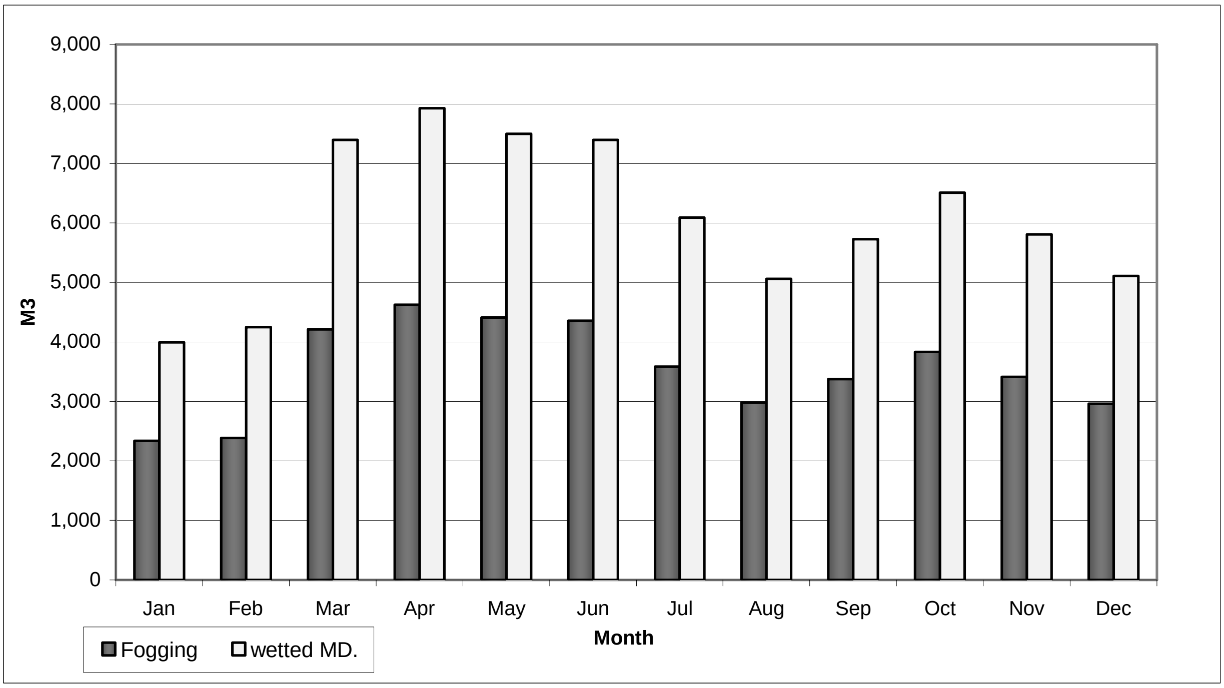

Fig. 5-12 Total Water required for wetted media and Fogging cooling per year.

(For wetted media total water required = Evaporation + Blow down)

Table 5-2: Summary of Gas turbine performance with different cooling options.

Cooling option	Evaporative cooling		On line Cooling (10°C)
	wetted media	**Fogging**	
Useful inlet cooling degree hour	88,902	103,349	180,275
Net output enhancement (MW)	10.15	11.88	16.96
Gain in power output (%).	15.8	18.3	26.2
heat rate improvement (kJ/kWh).	405	432	631
Heat rate improvement (%).	3.7	3.9	5.7
Water evaporation rate (gpm).	40	42	N/A
Total water required (gpm). Evaporation = Blow down	80	42	N/A
Total water required per year (M^3).	72,760	42,459	0
Total Energy production enhancement (kWh/year)	44,028,000	51,255,000	77,348,000

5-2. Economical feasibility

A cost benefit analysis is required to determine the economic feasibility of an inlet cooling options. Refrigrative cooling shows maximum benefit of TIAC options, energy generated times 1.51 and 1.75 of the energy that can be generated from fogging and wetted media evaporative cooling respectively. The installation cost of refrigrative cooling is nearly half that of installing new units, but it is 4 and 5 times more expensive than the cost of fogging and wetted media evaporative cooling respectively as shown in figure 4-13. The maintenance cost is high compared to the other options, the payback period found to be 2.2, 0.6 and 0.4 for refrigrative, fogging and wetted media respectively as shown in table 5-3.

Evaporative cooling (fogging and wetted media) appears to be the best economical solution according to the weather condition of Khartoum city. In order to calculate the revenues, energy production price was taken to be \$0.107/kWh, the selling price was taken to be \$0.136/kWh, which represent the commercial selling price of Sudanese National Electricity Corporation (NEC), The effect of heat rate improvement on the fuel price was not taken in the cost analysis.

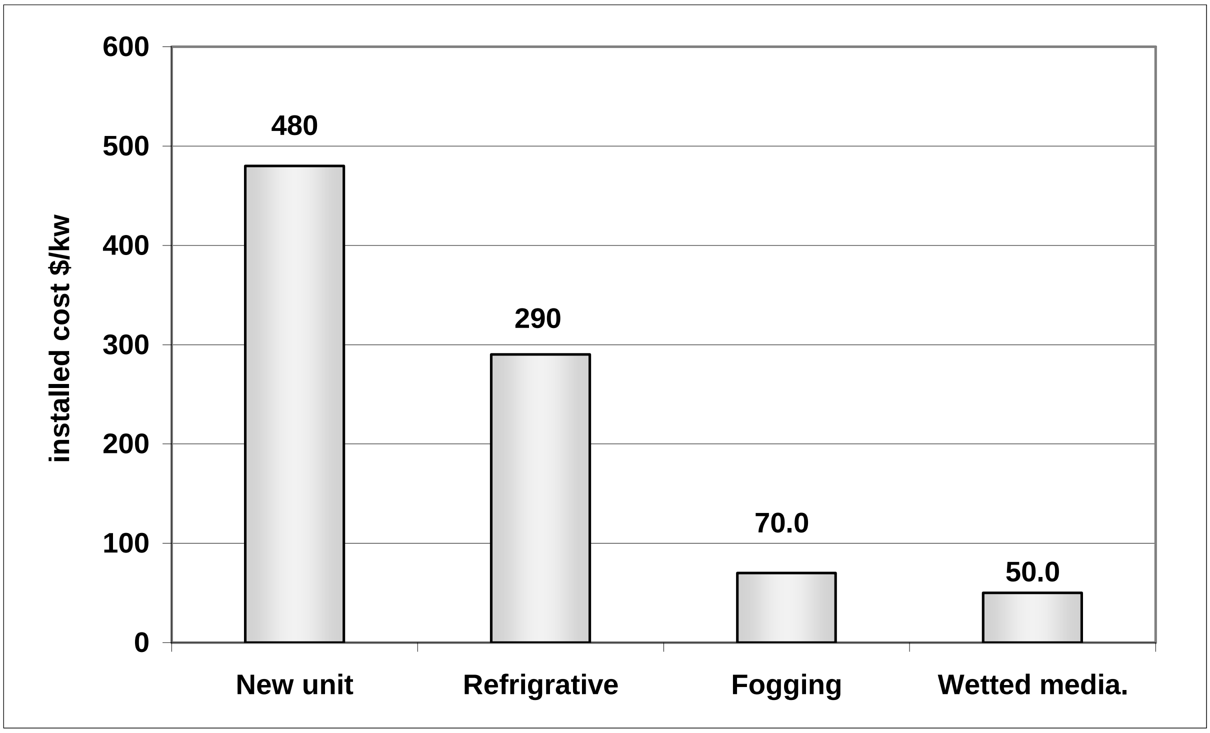

Fig 5-13 Installed cost of cooling options per kWh.

Table 5-3: Cost summary of the TIAC options.

Cooling option	Base case	Evaporative cooling		On line Cooling (10°C)
		wetted media	fogging	
Total Energy production enhancement kWh/year	0	44,028,000	51,255,000	77,348,000
Installation cost $/kW	480	50	70	290
Output MW	64.75	10.15	11.88	16.96
Operating / Maintenance cost	high	low	low	high
Total installation cost $	20,708,000	550,000	840,000	4,930,000
Total enhanced energy production cost (0.107$/kWh)	0	4,710,996	5,484,285	8,276,236
Total enhanced Energy Sold cost ($0.136/kWh)	0	5,987,808	6,970,680	10,519,328
Total Revenue $ / year	0	1,276,812	1,486,395	2,243,092
Payback period / (year)	0	0.4	0.6	2.2

For Khartoum area, hot and dry region with availability of water, the feasibility study showed that evaporative cooling (wetted-media or fogging) is less expensive compared to others. The selection of evaporative method should be according to the comparison of the two methods as shown in table 5-4.

Table 5-4: Comparison between wetted media and fogging systems.

Criteria	Wetted media	Fogging
Effectiveness	85%	100%
ICDH Available	91,103	107,180
ICDH Useful	88,902	103,349
Total kWh can be produced	44,028,000	51,255,000
GT'S manufacturer recommendations	Old and proven technology, approved by all GT'S manufacturer.	Several GT'S manufacturers, but not all approved this technology. Some of them not recommended it up to date.
Over spray	System with mist eliminator is less risk.	Risk of over spray is high.
Water requirement	Potable water at low pressure, Nile water can be used directly as raw water without treatment according to the analysis shown in chapter 2.	Required demineralized water (water treatment plant)
Pressure drop	Add pressure drop due to the media and mist eliminator even when the system is off.	minimal pressure drop and no pressure drop when it off

Criteria	Wetted media	Fogging
Inlet area modification	Need modification for media and mist eliminator.	Less duct space is required
Corrosion In The Inlet Duct	Standard material can be used with Nile water.	The use of demineralized water can deteriorate inlet ducts. Stainless steel or special coating is required
Power consumption	Less power is required to circulate the water.	Moderate power is required to drive the high pressure pump that operate at 130 to 207 bar to ensure that at least 90% of the water mass is composed of droplets less than 20 microns in diameter.
Compressor Erosion	85% effectiveness, system with mist eliminator will catch non-vaporized droplets and then prevent corrosive and erosive effect on the compressor blade.	Droplets coalesced on downstream components into larger droplets, can cause compressor blades erosion. Needs proper design and drainage.
Compressor Coating Distress		Some gas turbines manufacturer experienced coating distress in the first few stages of the axial flow compressor, for the units that use fogging system.

Criteria	Wetted media	Fogging
Compressor fouling	System can remove dust and contaminate that can foul the compressor and works as second stage filter as shown in the proposed system in chapter 3.	Corrosive and erosive effects can cause roughness of the blades, this effect can cause fouling on the compressor and hence reduce the benefits of the system on the output
Initial cost	25 to 50 $/kW	40 to 70 $/kW
Running cost	Lowest operational cost.	Operational costs for systems are high, because they consume demineralized water.
maintenance	Low pressure pump, sump cleanliness, and periodic media replacement (approximately every 6 years)	Maintenance is required to nozzles (prevent plugging), high pressure pumps, valve, GT inlet system components and compressor blades if carry over is excessive.
System location	Due to the dust concentrations in Khartoum, the system should be installed after the filters.	Same as wetted media system, should be installed after the filters with careful location of fogging nozzles, to avoid excessive water accumulation on ducts and inlet cones, and the use of appropriate drain systems.

Chapter six

Conclusion and Recommendations

6-1. Conclusions:

The technical and economical feasibility of different means available for cooling inlet air to the compressor of Gas Turbine Power Plants in the Khartoum area is investigated. The two main cooling systems, evaporative cooling and refrigerated inlet air-cooling, were considered in this study. Based on the study results, the following conclusions can be drawn:

1. Turbine inlet cooling enhanced the GT (GE-PG7111EA) output by 26.2%, 18.3% and 15.8% for refrigerative, fogging and wetted media evaporative cooling respectively and showed an improvement in the efficiency by reducing the heat rate (5.8%, 3.9% and 3.7% for refrigerative, fogging and wetted media evaporative cooling respectively).
2. Refrigerated inlet air-cooling is found to be the most feasible technical option, since it can reduce the inlet air temperature below the wet bulb temperature (cooling to 10°C). The energy generated from refrigerative cooling equals 1.51 and 1.75 times of the energy that can be generated from fogging and wetted media evaporative cooling respectively. But it is 4 and 5 times more expensive than the cost of fogging and wetted media evaporative cooling respectively
3. The wetted media inlet air-cooling is found to be the most feasible economical option (50, 70 and 290 $/kW installation cost for wetted media, fogging and refrigrative cooling respectively). Operation of wetted media is simple, safe and economical. Unlike operation of other systems, it requires less maintenance cost and less experience.
4. The wetted media inlet air-cooling system can eliminate major problems such as compressor fouling and cooling passage plugging of turbine blades that result in reduced power output. Wetted media acts as second stage cleaning filter in this regard.
5. Evaporative cooling increases the water vapor contents of the combustion air and hence, cause significant decrease in NOx emissions.

6. Wetted media evaporative cooling increases the mass flow rate of the exhaust gasses. Hence, it can be installed in combined cycles as well as open cycles. The increase in mass flow rate of the exhaust gasses, results in steam production enhancement.

6-2. Recommendations

Based on the study results, the following recommendations are made:

1. Any new installations of gas turbines in Khartoum area should be combined with wetted media evaporative cooling system. The site location should have raw water that can be used directly or with minimum treatment.
2. The technical and economical feasibility of retrofitting existing gas turbines with inlet air-cooling systems should be looked into.
3. The feasibility of using absorption chillers for cooling inlet air to the compressor of Gas Turbine Power Plants with heat recovery steam generator in a combined cycle in Khartoum area should be investigated.
4. The minimum ambient temperature to start the system, the number of working hours per day, the number of working days per year, and the shutdown period for preventive and corrective maintenance based on the actual climatic data at the installation site should be studied.
5. The effect of humidity and water droplets on compressor blades erosion and hence performance is to be investigated.

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Appendix A

Weather Data

(Source: Sudan Meteorology department 1993)

Table A1: Dry bulb temperature sbtracted from Khartoum Station (January)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jan	25.5	22.0	21.5	21.0	21.5	21.5	21.0	21.5	23.0	25.0	30.0	30.5	31.5	35.5	35.5	35.0	34.0	32.0	28.5	28.5	23.0	27.5	25.0	24.0
2-Jan	24.0	23.0	22.5	21.5	21.5	21.0	21.5	22.5	25.0	26.5	31.0	32.5	34.0	35.0	35.5	35.0	34.0	33.0	32.0	29.0	28.0	27.0	28.0	27.0
3-Jan	26.5	25.5	24.5	23.0	22.5	21.5	21.5	22.0	26.3	30.0	31.5	32.5	34.5	35.0	35.0	33.5	32.5	31.5	29.5	29.5	29.0	24.0	26.0	25.0
4-Jan	24.2	23.5	23.0	22.0	21.0	21.0	20.5	23.5	26.0	26.0	30.0	31.0	32.5	34.5	35.0	34.5	33.0	31.0	30.5	28.5	27.5	27.0	25.5	25.0
5-Jan	24.0	23.5	22.0	21.0	20.5	20.5	22.5	22.5	28.5	31.5	32.5	34.0	34.0	36.5	37.0	37.0	36.0	35.0	32.0	29.0	28.0	27.0	26.0	25.5
6-Jan	24.2	23.5	23.0	22.0	22.0	22.0	24.0	26.0	28.5	31.0	33.5	34.0	35.0	38.0	38.5	37.5	36.5	35.0	32.5	31.5	31.0	30.0	29.0	29.0
7-Jan	28.5	28.5	28.0	27.0	25.0	24.5	25.0	24.0	25.0	34.0	35.0	38.0	35.5	38.0	37.5	36.5	35.0	32.5	31.5	31.0	30.0	28.0	28.5	28.5
8-Jan	28.5	28.0	27.0	25.0	24.5	24.0	25.0	26.5	27.5	28.5	29.0	31.0	31.0	30.0	29.0	27.5	25.0	24.5	23.5	22.0	21.5	20.5	20.0	19.0
9-Jan	18.5	18.0	18.5	18.0	17.0	17.0	18.5	20.5	21.5	24.0	25.0	27.5	26.5	26.0	25.0	24.0	23.0	22.5	22.0	21.0	20.0	19.5	18.5	17.5
10-Jan	17.5	16.5	16.0	16.0	15.5	17.5	18.8	21.7	22.5	25.0	25.2	26.0	26.0	26.0	25.0	24.0	22.0	21.5	20.0	19.5	19.0	18.5	17.5	17.3
11-Jan	16.0	15.0	15.5	15.0	15.5	18.0	19.5	21.5	22.5	23.5	26.0	26.0	25.2	24.5	23.5	23.0	22.5	22.0	21.0	19.8	19.5	18.5	17.5	16.0
12-Jan	15.0	15.0	15.5	15.5	17.5	19.0	20.5	22.0	22.0	23.5	23.5	23.0	22.0	21.0	20.0	19.0	18.0	17.5	16.5	16.0	15.5	14.5	14.0	13.0
13-Jan	12.5	12.0	12.5	12.5	14.0	15.0	15.0	15.5	21.0	15.5	19.0	19.5	20.4	23.0	23.0	23.0	24.0	23.0	21.0	19.0	18.5	18.0	16.0	15.5
14-Jan	15.0	15.0	14.0	13.0	13.0	14.0	14.0	14.0	16.5	17.5	21.5	22.5	24.5	25.5	25.0	24.5	24.0	22.7	22.4	20.0	19.0	17.5	16.0	15.0
15-Jan	14.5	15.0	15.0	14.0	13.0	14.0	13.0	15.0	16.5	18.0	22.5	24.0	26.0	27.0	27.0	26.5	25.5	24.2	22.0	20.0	19.0	18.0	17.0	16.5
16-Jan	15.5	14.5	14.0	14.0	13.0	13.0	14.0	15.0	19.5	21.0	24.0	26.0	27.0	28.0	28.0	27.0	27.5	25.0	25.0	22.5	21.5	20.5	19.0	18.0
17-Jan	17.5	17.5	16.5	16.0	15.5	14.0	16.0	17.0	20.5	21.5	25.0	26.0	27.0	28.5	29.0	29.0	29.0	27.0	25.0	23.5	22.5	23.0	21.6	20.5
18-Jan	19.5	19.5	19.0	18.0	16.5	16.0	16.0	16.5	20.0	21.5	24.0	25.8	26.5	27.5	28.0	27.0	26.0	25.0	23.5	22.0	21.0	20.0	19.0	18.0
19-Jan	17.5	16.5	16.0	15.0	14.0	14.0	14.0	14.5	17.5	19.5	22.0	23.5	25.0	25.5	26.4	26.0	26.0	25.0	24.0	22.5	21.5	20.5	19.0	18.5
20-Jan	18.0	16.0	15.0	14.5	14.0	13.5	13.2	14.0	16.5	18.0	21.0	22.5	24.0	25.0	25.0	24.0	24.0	22.0	20.5	19.0	18.0	17.5	17.0	17.0
21-Jan	16.0	14.5	14.0	13.5	13.0	13.0	12.0	13.0	17.0	20.5	23.5	24.5	25.0	25.0	25.0	24.5	24.5	23.0	21.5	20.0	19.5	18.0	18.0	17.0
22-Jan	16.0	14.0	13.0	13.0	12.5	12.0	12.5	13.5	18.5	20.0	21.5	23.0	24.0	26.5	27.0	26.5	25.0	24.0	23.0	21.0	20.0	19.5	17.5	17.0
23-Jan	16.5	15.5	15.0	15.0	14.0	13.0	13.5	24.5	17.0	19.0	22.0	23.5	25.0	26.5	26.5	27.0	25.5	24.0	23.0	21.0	20.0	19.0	18.5	18.0
24-Jan	17.5	16.0	15.0	15.0	14.0	14.0	14.5	24.5	18.0	20.5	23.5	25.0	26.0	26.5	26.5	26.0	25.5	25.0	24.0	22.0	21.0	20.0	18.0	17.5
25-Jan	16.5	16.0	15.0	14.5	13.5	12.0	14.3	15.0	19.5	22.0	23.5	24.0	25.0	26.5	26.0	26.0	26.0	25.0	24.0	22.5	21.5	20.0	19.0	18.5
26-Jan	17.5	16.5	16.0	15.5	15.0	15.0	16.0	16.5	20.0	20.5	23.0	26.0	27.0	27.5	28.0	27.5	26.5	26.0	25.5	21.5	21.0	20.0	19.0	18.5
27-Jan	18.0	18.0	17.0	16.0	15.0	15.0	16.5	18.0	20.0	21.5	25.0	26.5	27.0	29.5	30.5	30.0	30.0	29.0	26.5	24.5	23.5	23.0	20.5	20.0
28-Jan	19.0	18.5	18.0	17.0	16.5	16.5	18.0	20.0	22.0	24.0	27.0	29.0	30.0	32.0	32.5	32.0	32.2	31.0	30.0	28.0	27.0	25.5	24.5	24.0
29-Jan	22.0	22.0	21.5	21.0	20.0	19.5	19.5	20.5	24.0	26.5	28.8	31.0	33.0	33.5	32.5	33.5	33.5	32.0	31.0	29.0	28.0	27.5	27.0	26.0
30-Jan	25.5	25.0	24.0	24.0	23.0	22.5	22.7	23.0	25.0	26.5	30.0	31.5	33.0	34.0	35.0	34.0	31.0	30.0	29.0	27.5	26.5	26.0	24.0	23.0
31-Jan	22.5	21.0	21.0	20.0	18.0	17.3	16.8	17.9	17.5	21.0	24.0	25.5	27.0	28.5	28.5	28.0	28.0	26.5	25.0	24.0	23.0	22.0	21.0	20.0

Table A2: Dry bulb temperature sbtracted from Khartoum Station (February)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Feb	19.0	18.0	17.0	16.0	16.0	15.5	16.0	17.5	19.5	21.0	21.0	25.5	26.5	27.0	28.0	28.0	27.5	26.0	25.0	23.5	23.0	22.5	20.5	19.5
2-Feb	19.5	18.5	17.5	17.5	16.5	15.5	16.0	17.0	18.5	19.5	23.5	25.0	26.0	27.3	27.3	27.0	26.5	25.0	23.5	22.0	21.0	20.5	20.0	19.5
3-Feb	18.0	17.0	16.0	15.5	15.0	15.0	16.0	14.0	16.5	18.0	19.7	21.0	22.0	23.5	24.0	24.0	23.0	22.3	21.5	19.0	18.0	17.5	16.0	15.5
4-Feb	15.0	14.5	14.0	13.0	12.0	11.5	11.5	12.5	14.5	15.5	17.5	19.0	20.0	20.0	21.0	21.0	19.5	16.5	17.5	16.0	15.0	14.0	13.5	13.0
5-Feb	12.5	12.0	11.0	11.0	10.0	9.5	10.0	11.5	14.0	15.0	17.0	18.0	19.5	20.0	20.5	20.5	20.0	19.0	18.0	16.5	16.0	15.0	13.0	12.5
6-Feb	12.0	11.5	11.0	10.0	9.0	8.5	9.0	12.0	14.3	15.0	18.5	20.0	21.5	22.0	22.0	21.5	21.5	21.0	20.0	18.0	17.0	16.0	14.5	14.0
7-Feb	13.0	12.5	12.0	11.0	10.0	9.5	10.0	12.0	16.5	18.0	21.0	22.0	24.0	24.3	25.0	25.0	24.2	23.5	22.5	19.5	18.5	17.5	17.0	16.0
8-Feb	15.0	14.0	13.0	12.5	12.0	11.5	11.5	15.5	16.0	19.5	21.0	23.0	24.0	25.0	25.5	25.5	25.0	24.5	23.0	20.5	20.0	19.5	17.0	16.0
9-Feb	15.5	14.5	14.0	13.0	13.0	12.5	12.5	14.5	19.0	20.5	22.5	24.0	25.0	27.0	28.0	28.0	26.0	25.8	24.0	24.5	20.5	19.5	18.0	17.0
10-Feb	16.0	15.5	15.0	14.0	13.0	13.0	14.0	15.5	20.5	22.0	23.5	25.0	25.5	27.5	28.0	27.5	26.0	25.0	23.5	22.5	21.0	20.0	19.0	18.0
11-Feb	17.0	16.0	15.5	14.5	14.5	14.0	15.0	16.5	18.0	20.0	22.0	23.0	24.5	26.5	27.0	26.5	26.5	25.0	24.0	24.5	20.5	18.0	17.5	17.0
12-Feb	16.5	15.5	15.0	15.0	14.0	15.0	16.5	17.0	20.5	22.0	25.0	27.0	28.5	30.5	31.0	31.0	29.5	28.0	26.5	24.0	23.0	22.0	24.0	20.0
13-Feb	19.5	19.5	19.0	18.0	17.0	16.0	16.5	19.0	22.5	26.0	29.0	30.0	31.5	31.5	31.5	31.5	30.5	30.0	29.3	25.0	24.0	23.5	21.5	21.0
14-Feb	20.5	19.0	18.5	18.0	18.0	17.5	18.0	20.0	24.0	26.0	28.0	30.0	31.0	31.5	31.5	31.0	30.0	29.0	28.0	25.0	24.0	22.5	24.0	21.0
15-Feb	20.5	20.0	20.0	19.0	18.0	18.0	19.0	19.0	23.0	25.5	28.5	29.5	30.0	32.0	32.0	31.5	31.0	30.0	28.5	27.0	26.0	25.0	22.5	21.5
16-Feb	21.0	20.5	20.0	19.0	18.5	18.0	19.0	19.5	21.5	25.0	28.5	31.0	33.0	32.5	33.0	33.0	32.5	31.5	29.5	28.0	27.0	25.5	24.5	24.0
17-Feb	23.5	22.0	21.0	20.0	20.0	19.5	20.5	20.5	23.0	26.5	27.5	29.0	31.5	33.0	33.8	32.5	32.5	31.0	29.5	28.0	27.0	26.0	25.5	25.0
18-Feb	23.5	22.0	21.5	21.0	20.0	20.0	21.5	22.4	26.5	28.0	23.0	35.0	35.5	36.5	37.0	36.7	36.0	35.5	34.5	30.7	29.5	28.0	27.0	26.5
19-Feb	26.0	23.5	22.5	21.5	21.5	21.0	21.0	23.5	28.5	29.5	35.5	35.0	37.0	39.5	39.5	39.0	39.0	37.5	35.6	33.0	32.0	37.5	30.0	29.0
20-Feb	28.0	27.0	26.0	25.0	24.5	23.5	24.5	24.5	27.0	28.0	32.5	33.5	34.0	37.0	37.5	37.0	35.5	35.0	34.5	31.5	30.5	29.5	27.5	26.5
21-Feb	26.0	25.0	24.0	23.5	23.0	22.5	23.0	22.5	24.5	25.5	29.0	30.5	31.0	32.0	33.0	33.0	32.0	31.0	29.5	29.0	28.0	26.5	24.5	25.5
22-Feb	23.0	22.0	24.0	24.0	20.0	20.0	20.5	24.0	23.0	24.0	26.5	29.0	30.0	31.0	31.5	31.0	30.5	21.0	28.0	27.0	25.5	24.5	22.5	21.0
23-Feb	20.0	19.5	19.0	18.0	17.5	17.5	18.0	20.5	23.5	25.0	28.0	20.5	30.0	31.0	31.5	31.0	31.0	30.0	29.0	27.0	25.5	24.7	23.5	23.0
24-Feb	22.0	20.0	19.5	18.0	18.0	18.0	18.5	19.0	22.5	23.5	29.0	30.5	31.0	32.0	32.0	32.0	32.5	32.0	31.0	29.0	28.5	28.0	26.5	25.0
25-Feb	23.0	22.0	21.0	20.0	18.0	18.0	19.0	20.5	24.0	28.0	31.0	32.0	34.0	35.0	35.0	34.5	34.0	32.5	30.5	23.5	26.5	24.5	24.0	23.0
26-Feb	22.0	21.0	20.0	19.5	19.5	19.0	21.0	22.5	25.0	27.0	30.5	32.5	34.0	36.0	37.0	37.0	35.0	33.5	32.5	30.0	29.0	28.0	25.0	24.0
27-Feb	23.0	22.5	22.0	21.5	21.5	21.0	22.0	23.5	27.5	29.5	33.0	36.5	38.0	38.5	39.0	38.0	37.5	36.5	35.5	31.5	31.0	29.5	27.0	26.0
28-Feb	25.0	25.0	24.0	23.0	22.0	22.0	22.0	23.5	25.0	30.0	32.0	35.0	39.5	40.5	40.5	40.0	39.3	38.0	35.5	32.0	31.0	30.0	29.0	28.0

Table A3: Dry bulb temperature sbtracted from Khartoum Station (March)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Mar	27.0	26.5	26.0	25.0	23.0	23.0	24.0	25.5	29.0	32.0	36.0	37.5	39.5	40.5	40.5	40.0	40.0	39.0	37.0	35.0	34.0	32.5	31.0	30.0
2-Mar	29.0	27.0	26.0	25.0	23.5	23.0	25.0	26.0	30.5	31.5	36.0	37.5	38.5	39.5	39.5	39.0	38.0	36.5	35.0	34.5	33.0	32.0	32.0	31.0
3-Mar	30.0	27.0	26.0	24.5	22.5	22.0	23.5	25.5	31.3	33.0	36.0	38.0	39.5	39.0	39.5	39.0	37.5	36.0	34.5	34.0	32.0	31.5	31.5	30.5
4-Mar	29.5	29.5	28.5	26.5	24.0	24.5	25.0	27.0	30.0	30.7	31.0	32.7	36.7	40.0	40.0	39.5	39.5	38.0	37.5	34.5	33.5	32.0	29.0	28.0
5-Mar	28.0	27.0	26.0	25.0	24.0	24.5	24.0	25.5	31.8	34.5	37.0	38.5	39.0	39.5	40.0	39.5	38.0	37.5	37.0	32.5	31.0	30.0	28.5	27.0
6-Mar	26.3	26.0	25.5	25.0	23.0	24.5	25.2	25.5	30.5	32.5	34.0	35.5	36.0	36.5	37.0	37.0	36.0	35.0	34.0	32.0	30.5	29.5	28.0	27.0
7-Mar	26.5	26.0	25.0	24.0	22.5	23.0	24.5	26.5	31.5	33.0	37.5	38.0	39.0	40.5	41.0	40.5	39.5	38.5	37.0	35.0	31.0	30.0	28.5	27.0
8-Mar	26.0	26.0	25.0	24.0	22.0	22.5	24.5	27.5	31.0	36.0	38.5	39.0	40.0	41.3	41.5	41.0	40.0	39.0	37.0	34.0	32.0	30.5	30.0	29.5
9-Mar	28.5	27.5	26.0	25.0	25.0	24.0	25.0	27.0	28.5	31.0	35.0	36.0	37.0	39.5	40.0	40.0	38.5	37.5	36.0	32.5	31.5	30.5	28.0	27.0
10-Mar	26.0	26.5	26.0	25.0	25.0	25.5	25.5	25.6	29.5	31.5	35.0	36.0	37.5	38.0	38.0	38.5	38.0	37.5	35.7	33.5	32.0	31.0	30.0	29.5
11-Mar	26.6	26.0	25.5	25.0	23.0	23.5	25.0	26.0	29.5	31.5	34.5	36.0	37.0	39.0	39.0	38.5	39.0	38.0	36.5	34.0	32.5	31.0	30.0	29.0
12-Mar	28.0	27.0	26.0	24.5	24.0	23.0	23.0	25.0	28.0	29.5	33.5	35.0	36.5	37.0	37.5	37.0	34.5	33.0	32.0	30.5	29.5	28.0	26.5	25.0
13-Mar	25.0	24.0	23.5	22.5	21.0	20.0	21.0	22.0	26.0	28.0	29.5	31.0	32.5	34.0	34.5	34.0	33.5	32.0	31.9	29.5	29.0	28.0	26.5	26.0
14-Mar	24.5	23.0	22.5	21.5	20.3	20.0	20.5	22.0	27.5	28.0	32.0	33.0	34.5	36.0	36.0	35.5	35.5	33.5	32.5	31.0	30.5	29.0	28.0	27.4
15-Mar	25.0	24.0	22.0	22.5	21.0	20.5	21.5	24.5	29.5	32.0	35.0	37.0	37.0	37.5	38.0	37.0	36.0	34.0	33.0	31.0	30.0	29.0	28.0	27.4
16-Mar	26.5	25.0	24.5	24.0	23.0	22.0	23.0	25.5	28.0	32.0	35.5	36.0	37.0	37.5	37.5	37.0	35.5	34.0	32.0	30.0	29.0	28.5	28.0	27.0
17-Mar	25.5	23.5	22.5	22.0	21.5	23.0	23.5	27.0	28.5	30.0	32.0	33.0	34.0	35.5	36.0	35.0	34.5	33.0	32.0	30.0	29.0	27.0	25.5	24.0
18-Mar	22.5	21.5	21.0	20.0	19.5	19.0	20.5	20.0	25.0	25.0	26.0	27.5	29.5	30.0	30.0	29.5	29.5	29.0	28.5	27.0	26.0	25.0	23.5	23.0
19-Mar	23.5	21.5	21.0	20.5	20.0	19.5	19.5	20.0	22.5	25.0	25.0	26.5	28.0	30.0	30.0	29.5	29.5	28.5	27.5	26.5	26.0	25.0	23.5	23.0
20-Mar	22.5	24.0	22.0	20.0	19.0	18.0	19.0	21.0	22.0	22.0	23.0	24.5	26.0	29.0	29.5	29.0	28.0	27.0	26.4	25.0	24.4	24.0	22.0	21.0
21-Mar	20.8	20.3	20.0	19.0	19.0	18.0	19.0	21.0	22.5	24.5	25.5	26.5	27.5	29.0	29.0	28.5	28.0	27.0	26.0	25.0	24.0	23.0	22.2	21.5
22-Mar	21.0	20.5	19.5	18.5	18.5	18.0	18.5	20.5	22.5	25.0	26.0	26.5	28.0	30.5	31.0	30.5	30.5	29.0	28.0	27.5	26.5	25.0	24.5	24.0
23-Mar	23.0	22.5	21.5	21.0	21.0	21.0	21.5	22.5	27.0	28.0	29.5	30.5	31.0	34.0	35.0	35.0	34.5	33.5	32.5	30.0	29.0	28.0	28.0	27.5
24-Mar	26.5	26.5	25.5	24.5	24.0	24.5	25.5	25.5	29.5	31.0	33.0	34.8	26.0	36.4	36.5	36.5	25.0	33.0	32.0	31.0	30.0	29.5	29.0	28.0
25-Mar	27.0	27.0	26.5	26.0	25.5	25.5	26.0	27.0	27.0	29.0	30.0	31.0	33.0	33.0	34.0	34.0	34.4	33.5	32.5	32.0	30.0	34.0	27.5	33.5
26-Mar	26.0	24.0	23.5	23.0	23.0	24.5	23.0	23.0	26.5	28.0	31.5	33.0	33.5	34.5	35.0	34.0	34.5	34.0	33.0	31.0	29.5	28.5	27.5	26.0
27-Mar	25.0	24.0	24.0	23.0	21.5	22.5	24.0	25.5	28.0	28.0	33.0	34.0	35.0	37.5	37.5	37.0	36.5	35.0	34.0	32.0	31.0	29.5	27.0	26.0
28-Mar	24.0	23.0	22.5	22.5	21.0	22.5	24.0	26.5	29.0	30.5	33.0	34.0	35.0	37.0	37.0	37.0	35.5	34.5	33.5	31.0	30.0	29.5	27.5	26.5
29-Mar	26.0	23.0	23.0	22.0	22.0	22.0	23.0	26.0	30.0	30.5	34.5	35.0	36.0	37.0	38.0	37.5	37.0	36.0	35.0	31.5	30.5	29.5	27.5	26.5
30-Mar	26.0	24.0	23.0	22.0	22.0	21.0	23.5	26.0	29.0	30.5	34.0	35.5	37.0	37.0	37.8	37.0	35.5	34.0	33.7	30.0	29.0	28.0	27.0	26.2
31-Mar	25.5	24.0	24.5	23.0	21.0	21.5	23.5	24.0	27.5	29.5	33.5	33.0	35.0	35.0	34.5	34.5	34.5	33.5	31.5	29.5	28.5	27.5	26.5	25.5

Table A4: Dry bulb temperature sbtracted from Khartoum Station (April)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Apr	24.8	23.5	23.0	22.0	21.5	22.0	23.0	25.0	29.5	31.0	34.0	35.5	36.5	37.0	37.0	36.5	36.0	34.5	33.0	31.0	30.0	29.5	27.5	27.0
2-Apr	26.0	24.0	23.5	25.0	23.0	22.5	24.0	25.0	29.5	31.0	36.0	33.5	38.0	38.5	38.5	38.0	37.6	36.5	35.0	33.0	37.0	31.0	28.0	24.5
3-Apr	26.0	20.0	20.0	23.0	23.0	23.0	24.0	27.5	32.0	34.5	37.5	38.5	35.5	41.0	41.5	41.0	35.5	38.5	37.0	35.0	34.0	32.0	30.0	29.5
4-Apr	28.5	23.5	23.0	27.5	26.0	27.0	27.5	30.0	35.0	37.0	37.0	40.0	40.5	41.0	41.0	40.0	40.5	39.0	38.5	35.0	34.0	33.0	30.5	29.5
5-Apr	29.5	29.0	28.0	27.5	26.0	27.5	29.0	32.5	36.5	39.5	40.5	41.5	42.0	42.0	42.5	42.5	41.5	40.0	39.0	36.0	34.5	33.5	33.0	32.0
6-Apr	30.0	28.5	27.0	26.5	26.5	26.0	27.0	31.0	36.5	38.5	40.0	40.5	41.0	41.3	42.5	42.0	41.0	42.0	38.5	36.5	35.0	34.5	34.5	33.5
7-Apr	32.0	32.0	25.0	28.0	27.0	27.0	28.0	30.5	32.0	30.0	30.5	38.0	38.0	38.5	38.0	38.5	36.5	35.0	34.0	33.6	32.0	31.0	30.5	25.5
8-Apr	29.0	28.5	27.0	26.5	26.5	27.0	27.0	29.5	32.0	33.7	34.5	36.0	36.5	36.8	37.0	37.0	35.0	34.0	33.5	31.5	30.5	30.0	29.5	28.0
9-Apr	27.5	27.5	27.0	27.0	26.5	26.0	27.0	28.0	30.5	32.0	36.5	37.5	37.5	38.0	38.3	37.5	37.0	35.6	34.6	33.0	31.5	30.0	29.0	28.0
10-Apr	27.5	26.0	25.5	25.0	24.0	24.0	25.6	28.0	30.0	31.5	35.0	36.5	37.0	38.0	39.0	38.0	35.5	34.5	33.5	32.0	31.0	30.0	29.5	28.5
11-Apr	27.5	26.5	25.5	25.0	25.0	26.0	26.5	28.5	31.0	32.0	35.0	37.0	38.0	38.0	38.5	38.0	36.5	35.0	34.0	31.5	30.0	29.5	28.0	27.0
12-Apr	26.0	25.0	24.5	24.0	23.0	24.0	26.5	27.0	30.3	32.5	35.0	36.0	37.0	38.0	37.5	37.0	36.0	36.0	36.0	31.5	30.0	29.0	27.0	26.5
13-Apr	25.0	24.0	23.5	23.0	22.0	22.0	23.0	26.0	31.0	33.0	34.0	36.0	37.0	37.5	36.5	36.5	36.5	35.5	34.0	31.0	30.5	25.5	27.0	26.0
14-Apr	25.5	24.4	23.5	23.0	22.0	23.0	24.5	27.5	31.0	33.0	34.5	35.5	36.5	37.5	37.0	37.0	37.0	36.0	35.0	33.0	31.5	30.0	28.0	27.5
15-Apr	27.5	27.5	27.0	26.0	25.0	25.0	25.3	29.5	33.0	35.0	37.0	38.5	38.5	38.5	39.0	39.0	38.6	38.0	36.0	34.7	33.8	33.0	31.6	31.0
16-Apr	31.0	31.0	30.0	29.0	28.5	29.0	29.0	33.0	32.0	34.0	35.0	38.0	39.0	40.0	40.0	39.5	38.5	36.5	35.0	35.5	34.5	34.0	33.5	32.5
17-Apr	31.0	29.5	28.5	27.0	26.5	26.5	27.0	29.5	32.0	35.0	36.0	37.5	38.5	39.0	40.0	39.0	38.0	37.0	36.0	34.5	33.5	32.0	32.0	31.5
18-Apr	31.0	30.0	29.5	29.0	27.0	27.0	28.5	29.0	31.5	33.0	36.0	35.5	40.0	40.0	40.0	39.5	39.0	37.0	36.0	34.0	32.5	32.0	31.0	30.0
19-Apr	30.0	28.5	28.3	27.0	27.0	27.5	28.0	31.0	33.5	35.5	37.0	39.0	39.5	35.8	39.0	39.5	39.5	38.5	37.0	36.0	36.0	34.0	33.0	32.0
20-Apr	32.0	30.0	35.5	29.0	28.0	28.0	29.5	32.5	34.5	39.0	39.5	39.5	40.5	41.0	41.5	41.5	40.5	38.5	37.0	36.5	36.5	35.0	33.0	32.0
21-Apr	31.5	31.5	30.5	29.5	29.0	25.5	30.7	33.6	36.5	38.0	39.5	40.0	41.0	42.0	42.0	41.5	41.0	39.5	37.5	37.0	36.0	35.0	34.0	33.0
22-Apr	32.0	31.0	33.0	29.0	29.0	29.5	31.5	34.0	37.0	38.0	41.5	42.0	42.0	44.0	44.5	44.0	43.0	42.0	39.0	38.0	36.5	36.0	35.5	35.0
23-Apr	34.0	33.5	32.0	31.0	30.0	31.0	32.0	34.5	37.0	38.0	41.0	42.0	32.0	44.0	44.0	44.0	43.0	42.0	41.5	39.0	38.0	38.0	35.0	34.0
24-Apr	33.5	32.0	31.5	31.0	30.0	31.0	32.5	33.0	35.5	37.0	40.0	41.0	41.0	42.6	43.0	43.5	42.0	41.5	41.0	38.0	37.0	35.5	35.0	35.5
25-Apr	35.0	32.5	32.0	31.0	30.0	30.5	32.0	34.0	35.0	37.0	38.5	39.5	40.5	42.5	42.5	41.0	41.0	40.0	39.0	38.0	36.5	38.0	35.0	34.0
26-Apr	31.5	31.5	31.0	30.0	29.0	30.0	31.0	31.0	34.0	35.0	37.0	39.0	39.0	39.0	39.0	38.5	38.5	37.5	36.0	35.0	34.0	33.5	32.0	31.0
27-Apr	30.0	29.0	28.0	27.0	25.5	26.0	27.5	30.0	31.5	33.0	35.0	35.5	37.0	37.5	38.0	38.0	37.0	36.0	35.0	33.5	32.0	31.0	29.5	29.0
28-Apr	28.0	26.0	25.5	24.0	22.0	23.0	24.0	26.5	31.5	32.5	35.0	36.5	36.7	37.5	36.5	36.5	36.4	35.5	34.5	32.0	31.0	30.0	29.0	27.5
29-Apr	27.0	25.7	25.0	24.0	23.0	23.0	25.0	28.0	32.5	35.5	38.0	39.0	40.0	41.0	41.0	40.9	39.5	38.5	37.0	34.5	33.5	32.8	31.0	30.0
30-Apr	29.0	28.0	28.0	27.5	26.0	26.0	28.5	32.5	36.0	37.5	41.0	42.0	42.5	43.0	43.0	42.0	41.0	40.0	38.5	36.5	34.0	33.0	31.5	30.0

Table A5: Dry bulb temperature sbtracted from Khartoum Station (May)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-May	29.5	28.5	27.5	27.5	27.5	28.0	30.0	34.5	38.0	39.0	42.0	42.0	42.5	43.0	43.5	43.0	42.0	40.5	38.5	36.0	34.6	33.5	32.5	32.0
2-May	31.5	29.0	28.0	27.0	27.0	27.5	29.5	34.0	39.0	40.0	43.0	43.5	44.0	44.0	44.0	43.5	43.5	42.0	42.0	37.5	37.5	36.0	35.5	33.0
3-May	32.0	30.5	30.0	29.0	27.5	30.0	32.0	34.0	36.6	37.0	42.5	43.0	44.5	44.4	44.7	44.0	44.0	42.0	40.0	38.5	37.5	36.0	35.0	35.0
4-May	33.5	32.0	31.0	30.5	30.0	31.0	32.0	34.0	38.0	39.5	43.5	43.5	44.5	44.5	45.0	44.0	43.7	42.5	41.5	39.0	38.0	37.0	35.7	34.0
5-May	33.0	31.5	31.0	30.5	32.0	33.0	34.0	34.0	37.5	39.0	42.0	43.0	44.5	45.6	45.5	44.5	43.5	42.0	40.5	38.0	37.5	36.0	34.0	33.0
6-May	32.5	31.0	30.5	30.0	29.0	29.0	29.5	32.5	35.0	37.0	38.0	39.0	40.5	41.0	41.0	40.0	39.5	38.5	37.5	35.0	34.0	33.5	32.0	31.0
7-May	29.5	28.0	27.5	23.0	25.5	25.5	26.5	30.0	33.0	34.5	36.0	38.0	38.5	38.5	38.5	39.5	39.5	38.0	36.0	34.5	34.0	33.0	32.0	31.0
8-May	30.0	28.5	29.0	29.0	27.5	27.5	28.5	31.0	36.0	36.5	39.5	40.0	40.5	41.5	41.5	41.5	40.5	39.5	37.0	35.0	34.5	33.0	32.0	31.0
9-May	30.0	29.0	28.5	28.0	27.5	28.0	29.5	30.5	36.6	38.0	41.0	42.0	43.0	43.0	43.0	43.0	42.5	41.5	40.0	37.0	36.0	34.5	32.0	31.0
10-May	30.0	29.0	29.5	29.5	29.0	29.5	29.0	31.5	34.5	36.0	38.5	40.5	41.5	43.0	43.0	42.5	42.0	40.0	39.0	37.5	35.5	39.0	35.0	34.0
11-May	33.5	31.5	30.5	29.0	29.0	29.0	30.0	31.5	34.0	36.0	33.0	40.0	41.0	41.0	41.0	40.5	39.0	37.5	36.0	35.0	34.0	33.5	32.5	31.5
12-May	30.5	29.0	28.0	27.5	26.0	26.0	28.0	29.5	30.0	33.0	33.5	34.5	35.0	36.5	37.0	37.0	36.0	35.5	33.5	32.0	31.0	29.5	28.0	27.0
13-May	26.0	25.0	25.0	24.0	23.5	24.5	25.5	27.5	31.0	32.5	33.7	34.5	35.5	37.5	37.5	37.0	36.0	35.5	35.0	31.0	30.5	29.5	28.0	27.0
14-May	26.0	25.0	25.0	24.0	23.5	24.0	25.0	29.0	33.0	31.5	35.6	36.5	38.0	38.5	38.5	38.0	38.0	37.0	35.0	33.0	32.0	31.5	30.0	29.5
15-May	28.5	27.5	27.0	26.5	24.5	26.0	27.0	30.0	32.5	34.5	37.0	38.5	39.5	41.0	41.5	41.0	40.0	39.5	38.0	36.0	35.0	34.5	33.0	31.8
16-May	30.0	28.5	27.5	26.5	26.5	27.5	28.0	32.0	37.0	38.5	41.0	41.5	41.5	42.0	42.5	42.0	41.5	42.5	38.0	36.5	35.5	35.5	33.0	32.0
17-May	30.0	28.5	28.0	27.5	29.0	30.0	31.0	33.5	37.0	38.5	41.0	42.0	42.5	43.5	44.0	43.5	42.5	41.5	38.5	37.0	36.0	35.0	33.0	32.0
18-May	31.0	30.5	30.0	28.5	28.5	30.0	30.0	31.5	33.0	34.5	36.0	37.5	38.5	40.0	40.0	40.0	39.5	38.5	37.0	36.0	35.0	34.0	34.0	32.5
19-May	32.0	32.0	31.0	30.0	30.0	30.5	31.5	33.0	35.0	36.0	37.7	38.5	39.5	40.5	41.0	40.5	39.5	38.5	37.0	35.0	34.5	34.0	31.0	30.5
20-May	29.5	28.0	27.5	27.0	27.0	27.0	27.5	29.0	29.0	30.0	31.0	33.5	34.0	36.0	36.0	35.5	32.0	31.5	30.5	30.0	29.5	29.5	29.0	28.5
21-May	27.5	26.5	26.0	26.0	26.0	26.5	27.5	29.0	30.3	31.5	34.5	35.0	36.0	36.5	36.0	35.5	35.5	35.0	34.0	34.0	33.5	32.5	32.5	32.0
22-May	31.5	31.5	31.5	31.0	31.0	32.0	32.0	33.0	33.0	35.5	37.5	38.0	39.0	39.0	39.5	39.0	39.0	37.5	36.0	32.0	31.5	30.5	30.0	29.5
23-May	29.0	28.0	27.0	26.0	26.0	25.5	27.5	29.0	31.3	34.3	35.5	36.5	39.5	39.0	39.5	39.0	39.0	38.0	37.0	37.0	35.0	32.0	32.0	31.0
24-May	30.0	33.0	31.0	30.0	31.0	30.5	31.5	34.0	35.0	36.5	38.5	39.5	40.0	40.5	41.0	41.3	40.5	40.5	37.5	35.0	34.0	33.0	30.5	29.5
25-May	30.0	30.0	29.0	29.0	29.0	28.5	30.0	32.0	34.0	36.5	38.5	40.0	40.5	40.5	41.0	40.0	40.0	39.0	37.0	35.5	34.5	34.0	34.0	33.5
26-May	33.5	33.0	32.0	31.5	31.5	32.0	33.0	33.5	35.5	37.0	39.0	41.0	41.5	42.0	42.0	42.0	41.0	39.6	38.5	38.0	37.0	35.5	33.0	32.0
27-May	31.0	30.0	30.0	29.5	39.5	30.0	32.0	32.5	35.0	37.0	37.5	38.5	39.5	40.0	40.0	40.0	38.5	37.0	36.0	36.0	35.5	35.0	33.5	33.0
28-May	37.0	31.0	30.5	30.5	30.5	35.0	31.0	33.0	33.0	33.5	36.0	36.5	28.5	26.5	26.0	25.0	24.0	24.0	24.0	24.0	23.5	23.0	25.0	25.5
29-May	25.0	23.0	25.5	25.0	24.5	24.5	25.0	26.0	28.0	29.5	30.0	30.5	30.5	32.0	34.0	34.5	34.5	34.0	33.0	33.0	31.5	30.5	30.0	30.0
30-May	29.5	29.5	29.0	29.5	28.5	29.0	29.7	31.5	32.0	31.5	33.0	34.5	35.0	36.5	36.5	36.5	36.5	35.0	34.0	33.0	33.5	33.0	33.0	31.0
31-May	30.0	30.0	30.0	29.0	28.0	30.0	31.0	30.0	32.0	31.5	33.0	34.5	35.0	36.5	36.5	36.5	36.5	33.0	34.0	33.0	33.5	33.0	33.0	31.0

Table A6: Dry bulb temperature sbtracted from Khartoum Station (June)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jun	30.0	30.0	30.0	29.0	28.0	30.0	31.0	30.0	32.0	33.0	34.5	35.0	35.5	38.0	38.5	38.5	36.5	35.5	34.5	34.0	33.5	33.0	32.5	31.5
2-Jun	31.0	31.0	30.5	30.0	29.5	29.5	30.5	32.0	33.5	35.0	37.0	38.0	39.5	40.0	40.5	40.5	40.0	39.0	38.0	36.0	35.5	35.0	33.0	32.0
3-Jun	31.0	30.0	29.0	28.0	28.0	29.0	29.5	32.0	33.0	34.0	37.0	38.0	38.3	38.5	38.5	38.5	39.0	38.5	37.5	35.0	34.5	34.0	32.0	31.5
4-Jun	30.5	30.0	29.0	29.0	28.0	28.5	27.3	29.0	31.0	33.0	34.5	37.0	38.0	38.0	38.5	38.5	38.0	36.5	35.0	35.0	34.0	33.5	32.5	32.0
5-Jun	31.0	30.0	29.3	29.0	28.5	28.5	30.0	31.0	33.0	34.5	36.0	38.0	38.5	39.0	39.5	39.0	39.0	38.0	37.0	36.5	35.5	35.0	33.5	32.5
6-Jun	31.0	30.0	29.0	29.0	27.0	27.0	28.0	30.0	32.0	34.0	35.0	36.5	37.0	38.5	39.0	39.0	38.5	37.5	36.5	36.0	35.5	35.0	33.5	33.0
7-Jun	32.0	31.5	30.5	30.5	30.0	30.5	31.0	32.0	35.5	36.0	38.0	38.5	39.0	41.0	41.0	41.0	41.5	41.0	39.0	37.5	36.5	35.0	32.5	31.0
8-Jun	31.5	31.0	31.0	30.0	30.0	31.0	31.5	31.5	34.5	36.0	37.0	38.4	39.7	40.5	40.5	40.5	40.0	39.5	39.0	36.0	35.0	34.0	34.0	33.5
9-Jun	33.0	32.0	31.5	30.0	28.0	29.0	29.7	32.5	34.0	35.0	37.5	38.5	39.0	39.0	39.5	39.5	39.0	38.0	37.0	34.5	33.5	33.0	32.5	31.5
10-Jun	30.5	29.5	29.0	28.5	28.0	28.5	29.0	31.0	33.0	34.5	36.0	37.0	38.0	39.5	40.0	39.5	39.0	38.0	37.0	35.0	34.0	33.0	32.0	31.0
11-Jun	30.0	29.0	29.0	28.5	27.0	27.5	28.5	31.5	35.0	36.5	37.0	37.5	38.0	39.5	39.0	39.0	39.0	38.0	37.0	35.5	33.5	32.0	31.0	30.0
12-Jun	29.5	29.5	29.0	29.0	29.0	30.0	30.5	32.0	35.0	36.0	38.0	39.4	40.0	40.0	40.0	39.5	39.0	38.0	37.5	36.0	35.0	33.5	33.0	32.5
13-Jun	32.0	31.0	30.5	30.0	30.0	30.0	31.0	33.0	36.5	37.5	39.5	39.5	40.2	41.5	42.0	41.0	41.0	40.0	38.5	36.0	35.5	34.8	34.3	33.5
14-Jun	32.5	32.0	30.5	30.5	30.5	31.0	31.0	33.0	33.0	36.0	40.0	41.0	42.0	43.0	43.5	42.0	42.0	41.0	39.5	36.5	37.0	36.0	34.7	34.0
15-Jun	33.5	33.0	32.0	31.0	29.0	29.5	31.0	33.0	35.5	37.0	39.5	41.0	41.0	42.0	42.5	42.0	41.5	40.5	39.0	37.5	36.0	35.0	39.5	39.0
16-Jun	33.0	32.5	32.0	31.5	29.0	29.0	30.0	31.5	34.5	36.0	38.0	39.0	39.5	41.5	42.0	42.0	41.5	40.0	38.5	38.0	37.5	35.0	34.5	33.5
17-Jun	33.0	32.0	31.5	30.0	29.0	29.0	30.0	33.5	35.5	37.0	40.5	41.5	42.0	43.5	43.5	42.5	43.0	42.5	40.5	38.5	37.0	35.5	34.0	33.5
18-Jun	33.0	32.0	31.5	31.0	30.0	30.0	31.5	32.5	36.0	37.5	39.0	41.0	42.0	43.5	43.5	44.5	44.0	43.0	41.5	38.5	37.5	36.0	35.3	34.0
19-Jun	32.0	36.0	36.0	29.0	28.5	28.0	28.5	29.5	30.0	30.5	33.5	33.5	34.0	37.5	38.0	38.0	38.0	37.0	35.5	35.5	35.0	34.5	34.0	33.0
20-Jun	32.0	32.0	31.0	30.0	30.0	30.5	31.0	32.0	33.5	35.0	37.5	39.5	40.5	41.5	41.0	40.5	40.0	39.0	38.5	37.0	36.0	35.0	34.0	33.0
21-Jun	32.0	31.0	30.0	29.5	29.0	29.5	30.0	31.0	32.0	33.5	35.0	36.5	37.5	38.5	39.0	38.5	38.5	38.0	37.0	35.0	33.5	32.5	31.5	30.5
22-Jun	30.5	29.0	28.5	28.0	27.5	28.0	28.5	31.5	35.0	36.5	38.0	39.5	40.0	40.0	40.5	39.5	40.0	39.0	37.5	35.5	35.0	33.5	33.0	32.0
23-Jun	31.5	32.0	31.0	29.5	29.5	29.5	30.0	33.0	36.5	38.0	40.0	41.0	41.5	43.0	42.5	42.5	42.5	41.3	39.5	38.0	38.0	37.0	35.5	34.5
24-Jun	34.0	34.0	34.0	33.0	31.8	31.5	32.8	34.0	36.0	38.0	40.0	41.0	41.0	43.0	43.0	43.5	43.5	42.5	41.5	38.0	38.0	37.0	36.0	35.0
25-Jun	33.5	32.0	32.0	31.5	31.5	31.0	32.0	34.0	36.0	37.5	39.0	40.5	41.0	42.3	42.0	41.0	41.0	40.0	39.0	37.5	36.0	35.0	34.0	33.0
26-Jun	32.0	31.0	30.0	30.0	29.0	29.0	29.0	34.0	36.0	33.0	34.5	36.0	37.5	38.0	38.5	39.0	38.5	38.0	37.0	35.5	34.0	33.0	32.0	31.0
27-Jun	30.0	30.0	29.0	28.5	28.0	28.0	29.0	30.5	32.0	33.5	35.0	35.5	36.5	38.2	38.0	38.5	38.0	37.0	36.0	36.0	35.0	33.5	33.5	33.0
28-Jun	32.5	32.0	31.0	27.0	28.0	29.0	30.5	32.0	32.5	34.0	35.5	36.5	37.5	38.5	38.5	38.5	38.5	38.0	37.0	36.5	35.0	34.0	34.0	33.0
29-Jun	32.0	31.0	30.0	29.0	30.5	31.5	32.0	32.5	34.0	36.0	37.5	38.5	40.0	41.0	41.5	40.5	40.5	39.5	39.0	38.5	37.0	36.0	33.0	32.0
30-Jun	31.0	30.0	30.0	29.5	29.5	29.0	28.0	27.5	28.5	29.5	31.5	33.0	34.5	35.0	35.0	34.5	34.5	33.5	33.0	32.5	32.0	31.5	30.5	30.0

Table A7: Dry bulb temperature sbtracted from Khartoum Station (June)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jul	30.0	30.0	29.5	29.5	28.0	28.0	29.0	29.5	31.0	32.0	35.5	37.0	38.0	38.5	39.0	39.5	39.5	39.0	38.0	36.5	34.0	33.0	33.0	32.0
2-Jul	32.0	31.0	30.5	30.5	30.5	29.0	29.0	30.5	34.0	34.0	37.0	37.5	39.0	40.0	40.0	39.5	39.5	38.5	37.5	36.5	35.5	34.0	33.5	32.0
3-Jul	31.5	30.5	30.0	30.0	29.0	29.0	30.5	30.5	33.7	38.0	38.0	39.5	40.0	41.0	41.0	40.5	41.0	41.0	39.0	37.0	36.0	35.5	35.5	35.0
4-Jul	34.0	33.0	32.0	30.0	28.5	28.5	28.0	29.5	31.0	32.5	34.0	34.5	35.0	35.5	36.5	37.5	37.0	36.0	35.5	35.0	34.0	33.5	33.0	32.0
5-Jul	31.0	31.0	30.0	29.5	29.0	29.0	29.5	31.5	33.0	34.5	36.0	37.0	38.5	39.5	39.5	39.5	39.5	38.5	38.5	37.0	37.0	36.0	34.5	33.5
6-Jul	32.5	31.0	31.0	30.0	30.0	30.0	30.5	32.0	33.5	34.5	36.0	37.0	38.0	40.5	40.5	40.5	37.0	35.0	33.5	31.5	30.5	30.0	30.0	29.5
7-Jul	29.0	28.5	28.0	27.0	26.5	26.5	27.0	29.0	30.5	32.0	34.5	36.0	37.0	38.6	38.5	38.5	38.0	37.0	37.0	35.5	34.5	34.0	34.0	33.5
8-Jul	33.0	32.5	32.0	31.5	31.0	31.0	31.5	32.0	34.0	35.0	36.7	38.0	39.0	39.0	39.0	39.0	39.0	38.0	33.5	34.0	33.0	32.0	31.7	31.0
9-Jul	31.5	30.5	30.5	31.5	31.5	27.0	27.5	28.5	31.0	32.5	34.5	35.5	36.0	37.5	38.0	38.0	38.0	37.5	37.0	36.5	36.0	35.0	34.0	33.0
10-Jul	32.0	32.0	31.0	31.0	30.5	31.0	32.0	32.0	33.7	34.5	37.5	38.5	40.0	40.5	40.5	40.5	40.5	39.5	38.5	37.5	36.0	35.5	33.5	32.5
11-Jul	31.5	29.0	29.0	28.5	29.0	29.0	30.0	31.0	32.0	33.5	35.0	36.5	37.0	37.0	38.0	38.0	37.5	36.0	34.5	33.5	32.5	32.0	31.5	31.0
12-Jul	30.5	29.5	29.0	28.0	27.5	28.0	28.5	30.5	31.5	32.0	35.0	36.5	37.0	39.5	39.5	39.0	39.0	38.5	37.5	37.5	36.5	36.0	36.0	35.0
13-Jul	32.5	31.0	29.5	29.5	29.5	29.5	30.0	30.0	32.0	33.5	35.0	36.5	37.5	38.5	38.5	38.5	38.5	38.0	37.5	36.0	35.0	32.0	31.5	31.0
14-Jul	30.5	30.0	30.0	29.0	29.0	30.0	31.0	33.0	33.5	35.0	35.5	36.0	37.0	38.0	38.5	38.5	38.5	37.5	36.5	33.5	33.0	32.0	30.0	29.0
15-Jul	28.0	27.0	27.0	27.0	27.0	28.0	28.0	29.5	32.5	34.0	35.5	36.5	37.0	38.0	38.0	33.0	33.0	32.5	32.0	31.0	30.5	29.0	28.0	30.5
16-Jul	30.0	30.0	28.0	28.0	28.0	28.5	28.5	30.0	31.0	32.5	34.0	35.0	36.5	38.0	38.5	37.5	35.0	33.0	32.5	30.5	30.0	30.0	31.5	30.5
17-Jul	28.5	27.5	27.0	26.5	25.5	25.0	26.0	27.0	30.0	30.5	32.0	32.5	33.0	35.0	35.0	34.0	34.0	33.0	33.0	33.0	32.0	31.0	31.0	30.5
18-Jul	30.0	29.4	29.0	28.5	28.0	28.0	29.0	29.0	30.5	32.0	33.5	34.2	35.5	37.0	37.0	37.5	37.0	36.5	36.0	34.5	34.0	32.7	31.0	31.0
19-Jul	30.0	29.0	28.5	28.0	27.5	28.0	28.5	29.5	32.5	34.0	35.0	36.0	37.0	37.0	37.0	37.5	37.0	36.0	35.0	35.0	34.5	33.5	32.5	32.0
20-Jul	31.0	30.0	29.0	28.0	28.0	28.5	29.0	29.0	31.5	33.0	35.5	36.5	38.0	39.0	39.5	39.5	38.5	37.5	37.0	36.5	36.0	35.0	34.0	33.0
21-Jul	32.0	30.0	30.0	29.5	27.0	27.5	28.0	29.5	32.0	33.0	35.5	37.0	37.0	37.0	37.5	37.5	37.0	36.5	36.0	35.0	34.5	33.5	33.0	32.5
22-Jul	32.0	31.0	31.0	30.0	29.0	29.5	30.0	31.0	32.5	35.0	36.5	37.5	38.0	40.0	40.5	41.0	40.5	39.5	38.5	38.0	37.0	35.5	35.0	34.0
23-Jul	33.0	33.0	33.0	32.0	31.0	31.0	32.0	32.5	35.0	36.0	39.0	40.0	41.0	43.5	43.5	42.0	42.5	42.0	41.0	40.0	39.5	38.0	36.0	35.0
24-Jul	34.0	32.0	32.0	30.0	28.0	29.0	29.0	29.5	31.5	32.0	34.5	34.5	35.0	37.0	37.0	37.0	37.5	36.5	36.0	35.5	34.5	33.5	33.0	32.0
25-Jul	31.0	30.0	29.0	28.0	27.5	27.5	28.0	28.5	31.0	32.0	34.0	35.0	36.5	36.5	36.5	37.5	36.5	36.0	35.0	34.5	34.0	33.5	33.0	32.0
26-Jul	31.0	30.0	30.0	28.0	27.0	27.0	28.0	28.0	29.5	31.5	33.5	35.0	36.0	37.0	38.0	38.0	36.0	36.0	35.5	35.0	34.0	33.5	33.0	32.0
27-Jul	32.0	31.0	30.5	30.0	29.5	29.5	30.0	32.0	34.0	35.5	36.0	37.5	39.0	39.5	40.0	40.5	40.0	39.5	38.5	37.5	36.5	35.5	35.5	34.5
28-Jul	33.5	32.5	31.5	30.0	27.0	27.0	27.0	27.5	30.0	31.0	33.5	34.5	36.0	37.5	37.5	37.5	37.0	36.5	36.0	35.0	33.5	31.7	30.0	29.0
29-Jul	28.0	30.0	29.5	29.0	27.5	27.5	28.0	29.5	31.5	33.5	34.5	35.5	36.5	38.0	38.0	38.5	39.0	38.0	37.0	36.5	36.0	34.5	32.5	32.0
30-Jul	31.0	30.0	30.0	29.0	29.5	29.5	30.0	32.0	34.0	35.5	37.0	38.5	39.0	40.0	40.0	40.0	40.0	39.5	38.0	36.5	35.5	35.0	34.5	32.5
31-Jul	31.0	30.0	29.5	29.0	27.0	27.0	28.0	29.0	31.0	32.5	35.0	36.0	37.5	39.0	39.5	39.0	38.5	38.0	37.0	35.5	35.0	34.0	33.0	32.0

Table A8: Dry bulb temperature sbtracted from Khartoum Station (Augest)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Aug	30.5	29.0	28.5	27.5	27.0	27.0	28.0	30.0	31.0	32.0	36.5	37.0	38.0	39.5	39.5	39.5	39.5	39.0	38.0	36.0	35.0	34.0	33.0	32.0
2-Aug	31.5	31.5	31.0	30.0	30.0	30.0	30.0	32.0	34.5	35.5	38.0	39.0	40.0	41.5	41.5	41.0	41.0	39.0	38.0	37.0	36.0	35.0	34.0	33.0
3-Aug	33.0	32.0	32.0	31.0	30.0	30.0	30.0	31.0	32.5	33.5	35.5	37.0	38.0	40.0	40.0	39.0	39.0	38.0	38.0	36.5	35.5	34.5	33.5	33.0
4-Aug	32.0	31.0	30.0	29.5	29.5	29.5	29.0	29.0	30.0	33.0	33.0	34.0	35.5	37.0	37.5	37.5	37.5	37.0	36.5	35.5	35.0	34.0	33.5	33.0
5-Aug	32.0	31.0	30.5	30.0	29.0	29.0	30.0	30.5	33.0	34.0	35.5	36.0	37.5	39.0	39.5	39.5	39.0	38.5	37.5	37.0	33.0	27.0	29.5	29.5
6-Aug	29.5	29.5	28.5	27.5	27.0	27.0	28.0	28.0	32.5	33.0	35.7	36.0	37.5	38.5	39.0	39.0	38.5	38.0	37.5	32.0	31.0	31.0	31.0	31.0
7-Aug	31.0	29.0	29.0	28.0	27.0	27.0	26.5	26.5	26.5	27.5	29.0	30.0	31.8	33.0	33.5	34.5	33.7	33.5	33.0	30.5	30.0	29.5	27.0	26.0
8-Aug	25.6	25.0	25.0	25.0	25.0	25.5	26.5	27.0	29.5	30.5	32.5	34.0	36.0	36.5	37.0	37.0	36.5	36.0	35.0	34.0	33.0	31.6	31.0	30.5
9-Aug	30.0	29.0	29.0	28.0	28.0	28.5	29.0	29.5	31.5	33.0	35.5	36.5	37.5	37.5	38.0	37.5	37.0	37.0	36.0	35.0	34.5	34.0	34.0	33.0
10-Aug	32.0	30.5	30.0	29.5	29.0	29.0	29.5	29.0	28.0	29.5	33.0	34.0	35.0	35.5	36.0	36.5	36.5	35.0	34.5	34.0	33.0	32.0	31.0	32.0
11-Aug	30.0	29.0	28.5	28.5	28.0	28.0	29.0	30.0	29.5	30.0	33.0	33.5	34.0	36.5	37.0	37.0	37.0	36.0	35.0	34.0	33.5	33.0	32.5	31.5
12-Aug	31.0	30.5	30.0	30.0	29.0	29.0	30.5	32.0	33.5	34.5	35.0	36.0	36.5	37.0	37.5	37.7	35.5	34.0	34.0	34.0	33.0	32.0	32.0	31.0
13-Aug	30.0	29.5	29.0	28.5	29.0	29.5	30.0	30.0	32.0	27.0	30.5	32.5	33.0	35.0	33.5	32.0	29.0	28.0	27.0	27.0	26.5	26.0	26.0	25.0
14-Aug	24.0	24.0	24.0	25.0	25.0	25.0	25.0	26.0	27.5	32.5	35.0	36.0	36.5	38.0	37.0	34.8	31.5	31.0	30.0	30.0	29.5	29.5	29.0	27.0
15-Aug	25.5	24.5	23.0	22.5	22.5	23.0	23.0	23.0	25.5	28.5	30.0	31.0	32.0	33.0	33.0	33.0	33.5	32.5	31.5	31.5	31.0	31.0	30.5	30.0
16-Aug	29.5	29.0	28.5	28.5	28.5	28.5	29.0	29.5	30.5	33.0	33.5	33.7	35.5	36.5	37.0	36.0	37.0	36.5	34.0	34.0	33.5	32.0	30.6	29.5
17-Aug	28.0	26.0	24.0	24.0	25.0	25.5	26.0	25.0	27.5	28.0	29.0	30.5	33.0	35.0	35.0	35.0	35.0	34.0	33.0	30.0	29.5	28.5	27.0	26.5
18-Aug	26.0	26.0	26.0	25.5	25.5	25.5	26.0	27.0	29.5	30.0	32.5	33.0	33.5	35.5	36.0	36.0	35.5	35.0	34.0	33.0	31.0	31.0	29.5	29.0
19-Aug	28.5	28.0	27.0	27.0	26.0	26.0	27.0	28.5	30.5	32.0	34.0	35.5	36.0	37.5	37.0	37.0	37.0	36.0	36.5	35.5	35.0	34.0	33.0	32.0
20-Aug	31.0	30.0	30.0	29.5	30.0	30.0	30.0	31.0	32.0	33.5	34.5	35.5	36.0	38.5	39.0	39.0	39.0	38.5	37.5	36.5	36.0	35.5	34.5	33.5
21-Aug	32.0	30.5	30.0	30.0	30.0	30.0	31.0	29.5	30.5	32.5	35.0	35.5	37.0	38.5	38.5	38.5	39.0	38.0	37.0	36.5	35.5	34.5	34.0	33.5
22-Aug	33.0	31.0	30.5	30.0	29.5	30.0	30.0	29.0	30.0	32.0	33.0	34.0	35.5	36.5	36.5	36.5	36.5	35.5	35.0	32.0	31.0	30.5	29.0	28.0
23-Aug	27.0	27.0	27.0	36.0	25.5	27.0	27.0	27.8	27.0	31.0	32.5	34.0	36.0	36.0	36.0	36.5	37.0	36.5	35.0	33.5	32.0	31.5	30.0	29.5
24-Aug	29.0	28.5	28.5	28.0	28.0	28.5	29.0	29.5	32.0	33.0	35.5	37.0	38.0	39.0	39.5	39.5	39.5	38.5	37.0	36.5	36.0	35.0	33.5	33.0
25-Aug	32.0	31.0	31.0	30.0	28.0	28.5	28.5	30.0	31.0	33.0	35.5	36.0	37.0	38.5	39.0	39.0	39.0	38.0	37.0	35.0	34.0	33.5	33.5	33.0
26-Aug	32.0	30.0	29.5	29.5	29.5	30.0	31.0	31.0	32.0	35.0	36.5	37.5	38.5	39.0	39.0	39.0	38.5	37.5	35.5	32.5	32.0	31.5	30.5	30.0
27-Aug	29.5	28.5	28.5	27.0	26.0	26.0	26.0	24.5	26.0	27.5	32.0	34.5	36.0	36.0	35.0	34.0	33.0	32.0	33.0	30.0	29.0	28.0	27.0	27.0
28-Aug	26.0	25.5	25.5	25.5	25.0	26.0	26.0	27.5	29.5	30.0	32.0	33.0	33.5	35.0	35.0	34.0	34.0	33.0	33.0	33.0	32.0	31.0	31.0	30.5
29-Aug	29.5	29.5	29.5	29.0	29.0	29.0	29.5	32.0	32.5	34.0	35.5	36.5	37.5	38.5	38.5	38.0	38.5	38.0	37.0	36.5	35.5	34.5	33.0	32.0
30-Aug	31.0	30.0	30.0	29.5	22.5	21.0	23.5	26.5	28.0	28.5	30.5	32.0	33.5	36.0	36.0	36.0	36.0	35.5	34.5	34.0	33.0	32.0	32.0	31.5
31-Aug	30.5	29.5	29.0	29.0	28.0	27.5	27.5	29.0	31.0	33.0	35.0	35.5	37.0	38.0	38.0	38.0	38.0	35.0	35.0	35.0	34.0	33.0	31.0	31.0

Table A9: Dry bulb temperature sbtracted from Khartoum Station (September)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Sep	31.0	30.5	30.3	30.0	30.0	30.0	30.5	31.0	32.0	34.0	35.0	36.0	37.0	39.0	39.0	38.5	39.0	38.0	37.0	36.0	35.5	35.0	35.0	34.0
2-Sep	33.0	28.0	29.0	28.5	28.5	28.0	27.5	27.5	29.5	30.0	30.0	31.5	32.0	32.0	32.5	32.5	32.5	32.0	31.0	29.0	28.5	27.5	26.5	26.5
3-Sep	26.0	26.0	26.0	25.0	25.0	25.0	26.0	27.0	29.0	30.0	32.0	33.0	35.0	36.5	36.5	36.5	36.5	35.0	34.5	31.5	31.5	30.0	30.0	28.5
4-Sep	28.0	27.5	27.5	27.0	27.0	28.5	29.0	30.0	34.0	35.0	36.5	37.5	38.0	39.0	40.0	40.0	39.0	37.5	35.0	34.0	33.5	33.0	32.0	32.0
5-Sep	31.5	31.0	30.0	29.0	27.5	27.5	28.0	28.0	29.5	31.5	32.0	32.0	32.5	34.5	35.0	35.0	35.0	34.0	33.0	31.0	30.5	30.0	28.5	28.0
6-Sep	27.5	27.5	26.5	26.0	26.0	26.0	26.5	28.0	30.5	32.0	34.0	35.0	36.5	37.0	38.0	36.5	36.5	36.0	36.0	34.0	33.0	32.5	31.0	30.5
7-Sep	30.0	29.0	29.0	29.0	28.0	28.0	28.7	30.5	32.5	33.0	36.5	37.0	37.5	38.0	39.0	39.0	39.5	38.0	37.0	35.5	34.5	33.5	32.5	32.0
8-Sep	31.0	31.0	29.0	27.0	25.5	26.0	27.0	28.0	30.5	21.5	34.0	36.0	37.0	38.5	38.5	38.5	37.5	36.5	35.0	34.5	34.0	34.5	33.0	32.0
9-Sep	31.0	31.0	31.0	30.0	28.0	28.0	29.0	29.0	31.0	32.5	34.2	38.5	37.0	37.5	38.0	37.5	36.5	35.0	34.0	33.5	33.0	32.0	31.5	31.0
10-Sep	30.0	29.0	28.0	28.0	28.0	28.0	29.0	30.0	31.5	32.5	34.5	36.5	37.0	38.0	38.0	37.5	36.0	37.0	36.5	30.0	29.5	29.0	28.0	28.0
11-Sep	27.5	26.5	29.5	29.5	29.5	29.5	30.0	30.0	33.0	34.5	36.0	37.5	38.2	39.0	38.5	38.5	38.5	38.0	37.5	34.2	34.0	33.0	32.0	32.0
12-Sep	31.0	30.0	30.0	29.5	28.5	29.5	30.5	32.0	32.5	32.0	35.5	36.5	37.0	38.0	38.0	38.0	38.5	37.5	36.5	36.0	35.5	34.5	33.0	33.0
13-Sep	32.0	31.0	32.0	31.5	31.5	32.0	32.5	34.5	34.5	36.0	38.0	39.0	40.0	40.5	40.5	40.5	40.0	39.0	36.5	36.0	35.5	34.0	32.5	32.0
14-Sep	32.0	32.0	32.0	31.5	31.0	31.0	32.0	32.5	34.5	35.5	37.0	38.0	39.0	40.5	40.5	40.5	40.5	39.0	38.0	36.5	36.0	35.0	33.5	32.5
15-Sep	31.0	30.0	29.5	29.0	28.0	29.0	29.0	29.0	30.0	31.0	34.5	35.5	36.5	37.0	38.0	38.0	38.0	37.0	36.5	35.0	34.0	33.0	31.0	30.5
16-Sep	30.0	30.0	30.0	29.5	26.5	29.0	30.0	30.5	31.5	32.5	34.0	35.0	36.0	37.0	37.0	36.0	38.5	38.0	37.0	35.0	34.5	34.0	32.0	32.0
17-Sep	31.5	30.5	30.0	29.5	28.5	29.0	29.0	29.5	30.5	32.0	34.5	36.0	38.0	39.0	39.5	39.0	38.5	38.0	37.0	36.0	35.0	34.0	33.0	33.0
18-Sep	32.0	31.0	30.0	29.0	29.0	29.0	30.5	31.0	33.8	34.5	38.0	39.0	39.5	41.5	41.5	41.0	40.5	39.0	38.0	35.0	34.5	34.0	33.0	37.5
19-Sep	31.0	30.5	30.5	30.0	29.0	27.5	28.0	28.0	30.0	31.5	35.0	36.5	37.0	38.5	39.0	39.0	38.5	37.5	37.0	36.0	35.0	34.0	32.0	31.5
20-Sep	31.0	31.0	31.0	30.0	29.0	29.0	30.0	31.0	35.5	36.0	37.5	38.0	39.0	40.5	40.5	39.0	39.5	38.0	37.5	36.5	35.0	33.0	31.0	30.0
21-Sep	30.0	30.0	30.0	29.5	31.5	31.5	31.5	31.0	34.0	35.0	37.0	38.0	39.0	39.0	39.0	39.0	38.0	36.5	35.0	34.0	33.0	37.0	31.0	30.0
22-Sep	29.0	28.0	28.0	28.0	28.0	28.5	28.5	29.5	31.0	32.0	34.5	35.5	36.5	38.0	38.5	38.0	38.0	37.0	35.5	34.8	34.0	33.0	32.5	31.5
23-Sep	30.5	30.0	30.0	29.5	29.5	29.5	30.0	32.0	33.5	34.5	36.5	37.5	38.0	40.0	40.0	40.0	40.0	39.0	36.0	34.5	34.0	33.0	34.0	33.0
24-Sep	30.5	30.0	30.0	29.5	29.5	29.5	30.0	32.0	33.5	34.5	36.5	37.5	38.0	40.0	40.0	40.0	40.0	39.0	36.0	34.5	34.0	33.0	34.0	33.0
25-Sep	32.5	32.5	32.0	31.0	31.0	30.5	30.5	32.5	34.0	35.5	38.0	39.0	40.0	41.0	41.0	41.0	40.5	40.0	39.0	38.0	36.5	36.0	36.0	36.0
26-Sep	35.5	33.0	32.0	31.5	31.0	31.0	32.0	32.0	34.0	36.5	37.5	38.4	39.5	40.5	40.5	40.5	40.5	39.0	38.0	37.0	36.0	35.0	35.0	35.0
27-Sep	34.5	31.0	31.0	31.0	29.0	29.0	29.0	31.5	33.5	35.0	37.0	38.0	39.0	40.0	40.5	41.0	41.0	40.0	38.0	35.5	34.5	33.0	32.0	31.0
28-Sep	31.0	30.0	29.0	29.0	29.0	29.0	30.0	30.5	32.5	34.0	35.5	36.5	38.0	38.5	38.5	38.5	38.0	36.5	36.0	35.5	34.5	34.0	33.0	33.5
29-Sep	32.5	32.0	32.0	31.0	31.0	30.5	31.5	32.0	33.0	34.5	36.5	38.0	38.5	38.5	39.0	38.5	38.0	37.0	35.0	32.5	32.0	31.0	30.0	29.5
30-Sep	29.0	28.0	28.0	28.0	28.0	28.0	31.0	31.0	34.0	35.0	38.0	38.5	39.5	40.5	40.5	40.0	40.0	39.0	38.0	35.0	34.0	33.0	31.5	30.5

Table A10: Dry bulb temperature sbtracted from Khartoum Station (October)

S'LT DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Oct	29.0	28.5	28.0	28.0	28.0	28.0	31.0	31.0	34.0	33.0	34.5	35.5	36.0	38.0	38.0	38.0	37.0	37.0	36.0	34.0	33.0	32.0	32.0	31.5
2-Oct	31.0	29.5	29.0	28.0	27.5	27.5	28.0	33.0	35.0	36.0	37.0	38.0	39.0	40.0	40.5	39.5	38.0	37.0	35.5	33.0	34.0	33.0	33.0	32.5
3-Oct	32.0	31.0	30.0	30.0	30.0	30.5	32.0	33.5	36.0	37.0	39.0	40.0	40.5	41.5	41.5	40.0	39.5	38.5	38.0	37.0	36.5	35.5	33.5	32.5
4-Oct	31.5	30.5	30.5	30.0	30.0	30.5	32.5	33.0	35.0	36.5	38.0	38.5	39.0	40.0	40.0	39.0	38.5	37.5	36.5	35.5	34.5	32.0	31.0	30.0
5-Oct	30.0	30.0	30.0	30.0	30.0	29.5	29.5	33.0	34.5	36.0	37.5	38.5	38.5	39.0	39.5	39.0	38.0	36.5	35.5	34.0	33.0	32.0	31.5	31.0
6-Oct	30.0	30.0	29.0	28.5	29.0	29.0	30.0	31.5	34.5	36.0	38.0	39.0	39.5	40.5	40.5	39.0	39.0	39.0	38.0	37.0	36.0	35.0	33.5	32.0
7-Oct	31.0	30.5	30.0	30.0	29.0	29.0	29.5	34.0	35.0	36.0	37.5	33.5	39.9	40.5	40.5	39.5	39.5	33.5	37.0	36.0	35.0	34.0	33.0	32.0
8-Oct	31.0	30.5	30.0	29.5	28.5	28.0	28.5	30.0	32.5	34.0	37.0	38.5	39.0	39.5	39.5	39.0	38.0	37.0	36.0	34.5	34.0	33.5	33.0	32.0
9-Oct	31.0	30.0	29.5	29.0	27.0	28.0	29.0	29.3	33.0	34.5	36.5	38.0	38.5	40.0	40.5	40.5	39.5	38.0	36.5	36.0	36.0	35.0	32.0	31.0
10-Oct	30.0	29.9	29.0	26.0	27.5	28.0	29.0	31.5	33.5	34.0	37.0	38.0	39.0	40.0	40.5	40.0	39.0	33.5	36.0	35.0	33.5	33.0	32.0	32.0
11-Oct	31.0	30.5	30.0	28.5	27.0	28.0	29.5	30.0	32.5	33.6	36.0	38.0	39.0	40.0	40.0	40.0	39.0	38.0	37.5	35.0	34.5	33.0	32.5	31.0
12-Oct	30.0	29.0	29.0	28.5	27.5	27.5	28.0	32.0	32.5	35.0	37.5	35.0	35.0	40.0	40.0	39.0	39.0	38.0	37.0	36.5	35.5	34.0	33.5	33.0
13-Oct	32.0	30.5	29.5	28.5	28.0	29.0	30.0	30.5	33.5	35.0	37.7	39.0	40.0	40.5	40.0	39.5	39.0	38.0	37.5	37.0	36.5	36.0	34.5	34.0
14-Oct	33.5	33.5	32.5	32.0	31.0	31.5	32.0	32.5	34.5	35.5	33.0	39.0	39.5	41.0	41.0	41.0	40.0	39.0	38.0	36.5	36.0	36.0	36.0	35.5
15-Oct	34.0	33.0	32.5	32.0	31.0	32.0	32.5	33.0	34.0	35.0	38.0	39.5	39.5	40.0	40.0	39.0	38.0	37.0	36.5	35.5	35.0	34.0	33.0	33.0
16-Oct	32.0	31.0	30.5	30.0	30.5	30.0	31.5	31.0	35.0	36.0	37.0	38.0	38.5	39.5	39.5	34.0	34.0	33.0	32.0	32.0	31.0	31.0	31.0	31.0
17-Oct	31.0	30.5	30.0	30.0	29.0	29.0	29.5	32.0	34.0	36.0	37.9	38.0	39.0	40.0	40.0	39.5	38.0	37.0	36.0	34.0	34.0	33.0	30.5	30.0
18-Oct	30.0	30.0	30.0	30.0	30.0	31.0	32.5	34.0	36.5	38.0	39.5	40.0	40.5	40.5	40.5	40.0	39.4	38.0	37.0	35.5	34.5	33.5	32.0	32.0
19-Oct	31.5	31.0	31.0	30.0	28.0	28.5	30.0	32.0	34.5	36.0	37.0	38.0	39.5	40.5	41.0	40.0	38.5	37.0	36.0	35.5	35.0	34.0	35.3	32.5
20-Oct	31.7	30.0	30.0	29.0	28.0	28.0	28.5	30.0	33.0	34.5	38.0	39.0	39.5	40.0	40.5	40.0	38.0	37.0	36.0	35.5	35.0	34.5	33.0	32.0
21-Oct	32.0	30.0	30.0	29.0	28.0	28.0	28.5	29.5	31.5	32.5	35.0	36.0	37.5	38.0	38.0	38.0	37.0	36.3	36.0	34.5	34.0	33.5	32.0	32.0
22-Oct	31.5	31.0	30.5	29.5	28.5	28.5	29.5	31.0	32.5	34.0	36.7	37.4	38.0	37.0	37.0	36.5	34.0	33.0	33.0	33.0	32.0	32.0	31.7	31.0
23-Oct	30.5	29.5	29.0	28.5	27.5	27.5	30.0	31.5	34.0	35.5	37.0	35.5	38.0	38.5	33.5	38.0	37.0	36.0	35.5	35.0	34.0	33.0	32.0	31.0
24-Oct	30.5	29.0	29.0	28.0	27.0	27.0	28.0	30.0	34.0	35.0	36.0	37.5	38.5	33.5	38.5	37.5	36.5	35.5	35.0	33.5	33.0	32.0	31.0	30.0
25-Oct	29.0	27.5	27.0	26.5	26.3	26.0	27.0	28.5	32.5	33.0	36.0	36.5	36.5	37.0	37.0	36.5	36.5	35.0	34.5	32.0	31.5	31.0	29.0	28.5
26-Oct	28.0	28.0	27.0	26.5	26.0	26.0	26.5	29.0	31.5	32.5	35.0	37.0	37.0	37.0	38.0	37.5	36.0	35.0	34.0	32.0	31.5	31.5	29.0	28.5
27-Oct	28.0	27.0	27.0	27.0	27.0	27.0	28.0	29.0	32.4	35.0	35.5	36.0	36.5	37.0	37.0	37.0	37.0	35.3	34.0	33.0	31.0	31.5	30.0	29.0
28-Oct	28.0	26.0	26.0	26.0	25.0	26.0	27.0	28.0	31.0	32.0	35.5	37.5	38.0	38.0	35.0	37.5	37.0	36.0	35.0	32.5	32.0	31.0	29.0	28.0
29-Oct	27.0	27.0	27.0	26.0	25.4	25.0	26.5	28.5	30.0	31.5	34.0	35.5	37.0	37.0	37.0	37.4	35.5	34.5	34.0	32.5	32.0	31.0	30.0	29.0
30-Oct	28.0	27.5	27.0	26.5	26.0	26.5	29.0	31.0	32.5	34.0	36.0	37.0	35.0	39.0	39.0	38.0	37.0	36.5	36.0	33.5	32.0	31.5	31.5	31.0
31-Oct	31.0	30.0	29.5	29.0	29.0	29.0	30.0	30.5	30.5	32.0	34.0	35.0	36.0	35.0	35.0	35.0	35.0	33.0	32.5	32.0	31.0	30.0	30.0	30.0

Table A11: Dry bulb temperature sbtracted from Khartoum Station (November)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Nov	29.0	29.0	29.0	29.0	29.0	29.0	29.5	30.0	30.5	32.0	34.0	35.0	36.0	35.0	35.0	35.0	35.0	33.0	32.5	32.0	31.0	30.0	30.0	30.0
2-Nov	29.0	29.0	29.0	29.0	29.0	29.0	29.5	30.0	30.5	32.0	33.0	34.0	34.5	36.0	36.5	35.5	35.5	34.5	33.5	32.3	31.0	31.0	30.0	29.5
3-Nov	29.0	28.0	27.0	26.0	28.0	29.0	29.0	29.0	31.0	32.0	34.5	36.0	37.0	37.0	37.0	36.5	36.0	35.0	34.0	33.5	33.0	32.5	31.0	30.0
4-Nov	29.0	29.0	28.0	27.5	25.0	25.0	25.5	28.0	31.0	32.0	34.0	36.0	36.5	37.0	37.5	37.0	35.5	34.5	34.0	33.0	32.0	31.0	30.5	28.5
5-Nov	28.4	28.0	27.5	27.0	26.0	26.0	26.0	28.0	30.6	32.5	35.0	36.0	36.0	36.5	37.0	37.0	35.5	33.5	33.0	32.0	31.0	30.5	30.0	29.5
6-Nov	29.0	28.0	27.0	26.5	25.5	25.0	25.0	27.0	29.5	30.5	34.0	35.0	36.0	35.5	35.5	35.5	35.0	34.0	33.5	31.0	31.0	30.0	30.0	29.0
7-Nov	28.5	28.0	27.5	27.0	26.0	26.0	25.0	27.0	30.0	31.0	35.0	35.0	36.0	35.5	36.0	36.5	35.5	35.0	33.5	32.5	31.5	31.0	30.5	30.0
8-Nov	29.0	28.0	28.0	27.0	26.5	26.0	26.5	28.5	31.0	31.0	35.0	36.0	36.5	36.5	36.0	35.0	35.5	34.0	34.5	32.5	32.0	31.5	31.0	30.0
9-Nov	29.0	28.0	28.0	27.5	27.0	27.0	27.0	27.5	30.0	32.5	34.5	36.5	37.0	38.0	38.5	37.0	36.0	35.0	34.0	31.5	30.0	29.5	29.5	28.5
10-Nov	28.0	27.0	26.5	26.0	25.0	25.5	27.0	28.0	31.0	32.0	35.0	36.0	37.0	37.0	37.0	36.5	35.0	34.0	32.5	31.5	31.0	30.0	27.0	26.5
11-Nov	26.0	26.0	26.0	25.5	25.5	26.0	26.5	27.5	30.0	32.0	35.0	36.0	37.5	37.5	37.5	36.0	36.0	36.0	35.0	33.0	32.0	31.5	30.0	29.0
12-Nov	28.0	27.0	27.0	26.5	25.0	23.0	25.5	28.0	30.0	32.5	34.5	34.5	36.0	37.5	37.5	37.0	36.0	34.5	33.0	32.0	31.0	30.0	29.5	28.5
13-Nov	27.5	27.0	26.5	25.5	25.0	24.0	25.0	28.0	31.0	32.0	35.0	36.0	37.5	37.0	37.0	36.5	35.5	35.0	35.5	32.0	31.5	31.0	29.5	28.0
14-Nov	27.5	26.0	26.0	25.0	24.5	25.0	26.0	27.0	29.5	31.0	33.0	34.5	35.0	35.5	36.0	35.0	35.0	33.0	32.0	30.5	29.0	28.0	27.5	26.5
15-Nov	25.0	24.0	24.0	23.5	22.0	22.0	23.0	23.5	25.0	28.0	29.5	31.0	32.0	34.0	35.0	34.0	32.5	31.0	30.5	28.5	27.0	26.5	26.0	25.5
16-Nov	25.0	24.0	23.0	22.5	22.0	22.5	23.0	34.5	27.5	31.0	31.5	33.0	34.0	35.0	35.0	35.0	33.0	31.0	30.5	29.0	28.0	28.0	26.0	25.5
17-Nov	25.0	24.5	24.0	23.0	21.0	21.0	22.0	24.0	26.5	27.0	31.0	32.0	33.0	34.0	34.0	34.0	33.0	31.0	30.0	29.5	28.5	27.5	27.0	26.5
18-Nov	25.5	25.0	24.0	23.5	22.5	22.0	23.0	25.0	27.0	30.0	31.5	33.0	33.5	34.5	34.5	34.0	33.0	32.5	32.0	30.0	29.5	28.5	28.0	27.5
19-Nov	27.0	26.5	25.0	24.5	23.0	23.0	24.0	26.0	28.5	30.0	32.5	33.0	33.5	35.0	35.0	34.0	34.0	33.5	32.0	30.5	29.5	29.0	28.0	27.0
20-Nov	26.0	25.5	25.0	24.0	23.5	23.5	25.0	26.5	29.0	29.0	33.0	33.0	34.5	35.0	35.0	34.0	34.0	33.0	32.0	31.0	29.5	29.0	28.0	27.5
21-Nov	27.0	26.0	25.0	24.0	24.0	23.5	25.0	26.0	29.0	32.0	34.0	36.0	37.0	37.0	38.0	37.0	35.5	35.0	32.0	31.0	29.5	29.0	28.0	27.5
22-Nov	27.0	26.5	26.0	25.5	24.0	24.0	24.0	27.5	30.0	31.0	35.0	36.0	36.5	37.5	37.5	36.0	35.0	33.0	31.5	30.0	29.0	28.0	28.0	27.5
23-Nov	27.0	26.5	26.0	25.0	25.5	25.5	26.0	28.0	28.5	30.0	33.0	34.5	35.5	36.0	36.5	36.0	34.5	33.0	32.5	30.5	29.0	28.0	27.5	27.0
24-Nov	27.0	26.0	25.0	24.0	23.0	23.0	24.5	28.0	31.0	32.5	34.0	35.0	35.5	36.0	36.0	35.0	34.0	34.0	32.0	30.0	30.0	29.0	27.5	26.5
25-Nov	25.5	24.5	24.5	24.0	23.5	24.0	24.0	27.0	30.0	30.0	35.0	36.0	36.0	36.5	36.5	36.0	34.5	34.0	32.0	29.0	27.0	26.0	25.5	25.0
26-Nov	24.0	23.0	22.5	22.0	24.0	19.5	21.5	24.0	27.0	30.0	32.0	34.0	35.0	36.0	36.0	34.5	33.5	33.0	32.0	30.5	28.0	28.0	28.0	27.5
27-Nov	26.5	26.5	26.0	24.0	24.0	24.0	24.0	26.0	29.0	31.0	32.5	32.5	34.5	35.0	34.5	34.0	33.0	31.5	30.0	29.5	29.0	28.0	27.5	27.0
28-Nov	26.5	26.0	25.5	25.0	24.0	24.0	24.0	26.0	29.0	30.0	32.5	33.5	34.0	34.0	35.0	35.0	33.0	32.0	31.0	29.5	29.0	29.0	28.0	27.0
29-Nov	26.0	24.0	23.0	25.0	23.0	24.0	24.5	26.0	28.5	30.0	32.5	33.5	34.5	35.0	35.5	34.5	33.5	33.0	31.5	29.0	29.0	28.0	27.0	26.0
30-Nov	26.0	25.5	25.0	24.5	23.5	23.5	23.0	25.0	27.5	30.0	31.5	33.0	33.9	34.5	35.5	35.5	32.5	32.0	31.0	29.5	28.0	27.5	27.0	26.0

Table A12: Dry bulb temperature sbtracted from Khartoum Station (December)

S'LT / DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Dec	26.0	25.0	24.5	24.0	23.5	23.0	24.0	25.0	27.5	31.0	32.5	33.0	34.0	35.5	36.0	36.0	34.5	34.0	31.8	30.5	30.0	25.0	28.0	27.0
2-Dec	26.5	26.0	25.5	25.0	24.0	24.0	25.0	26.0	29.5	31.0	34.0	35.0	35.0	36.0	35.0	34.5	34.0	33.0	32.5	30.0	29.0	28.0	28.0	27.0
3-Dec	26.0	25.0	24.5	24.0	24.0	24.5	24.5	24.5	27.0	29.0	35.5	34.0	34.5	35.5	36.0	35.5	34.0	31.5	30.5	30.0	28.0	28.0	27.0	26.5
4-Dec	25.5	24.5	24.0	24.0	24.0	23.5	24.0	25.5	27.0	31.0	33.5	35.0	35.0	35.0	35.5	35.0	33.5	33.0	31.0	30.0	29.0	28.5	27.5	26.5
5-Dec	25.5	24.5	23.5	23.5	23.0	24.0	25.0	25.5	28.0	31.0	33.0	34.0	35.0	36.0	34.5	34.5	34.5	33.0	30.0	28.0	27.0	26.5	25.5	25.0
6-Dec	24.0	23.0	24.0	23.0	22.0	22.0	24.0	24.0	25.0	27.0	32.0	34.0	34.5	35.0	35.0	34.5	33.5	33.0	30.0	29.5	28.0	28.0	27.5	27.0
7-Dec	26.0	25.0	24.5	24.0	23.0	22.0	22.5	23.0	26.0	28.0	29.0	35.0	35.0	33.0	33.0	32.0	31.5	31.0	29.0	28.0	27.5	26.5	25.0	24.0
8-Dec	23.5	22.0	24.5	21.0	19.5	21.5	22.0	20.0	22.5	23.0	25.0	27.0	29.0	31.5	37.0	31.5	30.5	30.0	28.0	28.5	28.0	25.0	24.0	23.5
9-Dec	22.5	22.0	21.5	20.0	19.0	19.0	20.0	20.0	23.0	24.0	26.5	28.0	32.0	31.0	31.0	31.0	30.0	29.0	28.0	27.0	26.0	25.0	24.5	23.5
10-Dec	22.5	22.0	21.5	20.0	20.0	20.0	21.0	22.0	24.0	27.0	28.5	30.0	31.0	32.0	32.0	30.0	30.0	29.5	28.0	27.0	26.0	24.0	24.0	23.5
11-Dec	23.0	22.0	22.0	21.0	19.0	19.0	21.0	22.0	23.0	24.5	27.0	29.0	30.0	30.5	30.5	30.0	28.5	27.0	26.0	25.0	24.5	23.5	23.0	22.5
12-Dec	21.5	20.5	20.0	19.5	19.0	19.0	18.0	19.5	21.0	22.0	25.0	26.5	30.0	30.0	30.0	29.0	29.5	28.0	27.0	25.0	24.5	24.0	23.0	22.5
13-Dec	21.0	20.0	19.5	18.5	18.5	18.0	19.0	19.0	21.5	23.5	24.5	26.0	27.0	28.0	28.5	28.5	28.0	27.0	26.0	25.0	24.0	22.0	22.0	21.5
14-Dec	20.5	19.5	19.0	18.5	17.5	17.0	18.0	18.0	20.0	21.0	24.5	26.0	27.5	28.0	28.5	28.0	28.0	27.0	25.5	24.5	23.0	22.5	22.5	22.0
15-Dec	21.5	21.0	21.0	20.0	19.5	18.0	17.0	20.0	23.0	25.0	26.0	25.0	31.0	31.5	30.0	30.0	30.5	30.0	29.0	28.5	27.5	26.5	24.0	24.0
16-Dec	23.5	23.0	22.0	21.0	21.0	20.0	20.5	22.5	25.0	26.5	28.5	25.5	31.5	32.5	32.0	32.0	31.0	29.0	28.0	27.0	26.0	25.0	24.0	23.5
17-Dec	22.5	21.5	21.0	20.0	19.0	18.5	19.5	21.0	23.5	26.0	29.0	30.0	31.5	32.0	32.5	32.0	30.5	29.0	28.0	27.0	26.5	25.5	24.5	24.0
18-Dec	23.0	21.5	21.0	20.0	20.0	21.0	22.5	21.5	25.5	27.0	30.0	31.5	37.0	32.5	33.0	33.0	31.0	30.0	29.5	27.0	26.0	25.0	25.0	24.0
19-Dec	23.5	23.5	23.0	22.0	20.5	20.5	21.0	23.5	26.0	28.0	31.0	33.0	34.0	34.0	33.0	32.5	32.0	30.5	28.0	27.0	26.0	26.0	25.0	24.0
20-Dec	24.0	24.0	23.5	23.0	22.0	21.0	22.0	22.0	24.0	26.0	29.5	31.5	32.5	33.0	32.0	32.0	31.5	30.5	28.5	27.5	26.0	25.5	24.0	23.0
21-Dec	22.0	22.0	21.5	21.0	19.0	19.0	20.0	20.0	22.5	23.0	27.0	28.0	30.0	30.5	31.0	30.5	28.0	27.5	27.0	25.0	24.0	23.5	23.0	22.0
22-Dec	21.5	21.0	20.0	20.0	19.0	18.0	19.0	19.0	21.0	23.0	25.0	26.0	27.0	30.0	30.5	30.0	29.0	28.0	27.0	25.0	24.0	24.0	22.0	21.0
23-Dec	20.0	19.5	19.0	18.0	18.0	19.0	18.0	17.5	20.0	20.5	24.0	25.5	26.0	27.0	27.0	26.5	26.0	25.0	24.0	23.0	23.0	22.0	19.0	18.0
24-Dec	17.5	17.5	17.0	16.5	15.5	15.0	15.5	16.0	19.0	20.5	22.5	23.5	24.0	26.0	26.0	25.5	25.0	24.0	23.0	22.0	21.5	20.0	19.5	19.0
25-Dec	18.0	17.0	17.0	16.0	15.0	15.0	15.5	17.0	19.5	21.5	24.5	25.0	26.0	28.0	28.0	27.5	27.5	27.0	26.0	23.5	23.0	22.5	19.0	18.5
26-Dec	18.0	18.0	17.5	17.0	15.0	15.5	16.5	17.5	21.5	22.0	26.5	27.0	28.0	31.0	31.0	30.0	30.0	29.0	28.0	26.5	26.0	26.0	25.0	24.0
27-Dec	23.0	21.5	21.5	21.0	21.0	20.5	21.0	22.0	24.0	25.0	29.0	31.5	32.5	33.0	33.5	33.0	31.5	30.5	30.0	27.0	26.0	25.0	24.0	23.0
28-Dec	22.0	22.0	21.5	21.0	20.5	20.5	21.0	21.0	24.0	25.0	28.0	29.5	31.5	33.5	34.0	33.5	33.0	32.0	31.0	29.0	29.0	28.0	25.5	25.0
29-Dec	22.0	22.0	21.5	21.0	20.5	20.5	21.0	21.0	24.0	25.0	28.0	29.5	31.5	33.5	34.0	33.5	33.0	32.0	31.0	29.0	29.0	28.0	25.5	24.5
30-Dec	24.5	23.5	23.0	22.0	20.5	20.0	20.0	22.0	26.0	27.0	31.0	32.0	33.5	36.0	35.5	35.0	35.5	34.0	33.0	31.0	30.5	30.0	28.0	27.5
31-Dec	26.0	26.0	26.0	25.0	23.0	23.0	23.0	24.0	27.0	28.0	31.0	32.0	33.0	35.5	37.0	37.0	36.5	36.5	36.0	34.0	30.5	30.0	28.5	27.5

Table A13 :Wet bulb temperature abtracted from Khartoum Station (January)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jan	14.5	14.0	13.5	13.0	13.0	13.0	13.5	14.5	16.0	17.0	19.5	20.0	20.0	19.5	19.5	19.0	19.0	18.5	18.0	17.5	17.5	17.0	16.0	16.0
2-Jan	15.5	15.0	14.5	14.0	14.0	14.0	14.5	15.0	17.5	18.0	28.0	21.0	21.0	21.5	21.5	21.0	20.0	20.0	19.5	18.5	18.0	17.5	17.0	16.5
3-Jan	16.0	16.0	16.0	15.0	15.0	15.0	15.0	14.5	15.0	17.0	19.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	19.0	17.5	17.0	16.5	16.5	16.0
4-Jan	15.0	15.0	15.0	15.0	14.0	14.0	12.0	13.5	15.0	15.0	18.0	19.0	19.5	20.0	20.0	20.0	19.0	19.0	18.0	17.0	17.0	16.5	16.5	16.0
5-Jan	16.0	15.5	15.0	15.0	14.0	14.0	14.0	15.0	18.0	18.5	19.5	19.5	20.0	21.5	22.0	22.0	22.0	21.0	20.0	19.0	18.0	18.0	17.5	17.0
6-Jan	16.5	15.5	15.0	15.0	15.0	15.0	15.0	16.0	18.5	19.0	21.5	22.0	22.0	21.5	21.0	21.5	21.5	21.0	20.0	20.0	20.0	18.5	18.0	18.0
7-Jan	17.5	17.0	17.0	16.0	15.0	15.0	15.0	13.0	13.0	22.0	22.0	21.5	21.5	21.5	21.5	21.5	21.5	21.0	20.0	20.0	20.0	18.0	17.5	17.0
8-Jan	17.0	16.0	15.0	15.0	15.0	15.0	12.5	13.0	14.0	14.0	15.0	16.0	16.0	16.0	15.0	15.0	14.0	13.5	13.0	12.5	12.0	11.5	11.0	11.0
9-Jan	11.0	11.0	10.0	10.5	10.0	10.0	10.5	11.0	12.0	13.0	13.5	14.0	14.0	14.0	12.0	13.0	12.5	12.0	11.5	11.0	10.5	10.0	9.0	8.0
10-Jan	9.0	10.0	10.0	10.0	9.5	10.0	11.0	12.0	12.5	14.5	14.8	15.0	15.0	15.0	14.0	13.5	12.0	12.5	13.0	11.0	10.5	10.5	8.5	8.0
11-Jan	8.0	8.0	8.0	8.5	9.0	9.5	10.0	11.5	12.0	13.5	14.0	14.0	14.0	13.0	12.5	12.0	11.5	11.0	11.0	10.0	10.0	9.5	9.0	8.0
12-Jan	8.0	8.5	9.0	10.0	11.0	11.5	12.0	12.0	12.0	12.5	12.5	12.0	11.0	10.5	10.0	10.0	10.0	9.5	8.5	8.5	8.0	8.0	8.0	7.0
13-Jan	7.5	7.0	7.5	7.5	8.0	8.5	9.0	11.0	11.5	8.0	10.0	10.0	11.0	12.0	12.0	12.0	11.5	11.0	11.0	10.0	10.0	9.5	8.0	7.5
14-Jan	10.0	7.0	8.0	7.5	7.5	8.0	8.0	8.0	10.0	10.5	13.5	14.0	14.5	14.5	14.5	14.0	14.0	12.0	11.0	10.0	10.0	9.0	9.0	9.0
15-Jan	9.2	8.5	8.0	7.5	7.5	7.5	7.0	9.0	10.0	11.0	13.5	14.0	14.0	15.0	15.0	15.0	14.0	13.5	13.0	11.5	10.0	9.5	9.0	9.0
16-Jan	8.5	8.0	7.5	7.0	6.5	6.5	7.0	8.0	10.5	11.0	14.3	14.0	14.0	15.5	13.5	15.0	15.0	14.5	14.0	13.0	13.0	13.0	13.0	12.0
17-Jan	10.5	10.5	10.0	10.0	9.5	9.0	10.0	11.0	12.0	13.0	14.5	15.0	15.5	16.0	16.0	16.0	16.0	15.2	15.0	14.0	13.5	13.5	12.5	12.0
18-Jan	11.5	11.0	11.0	10.0	10.0	10.0	10.0	10.0	11.5	12.0	14.0	14.0	15.0	16.0	16.0	16.0	15.0	14.5	14.0	13.0	12.0	11.0	11.0	10.5
19-Jan	10.0	8.5	8.5	8.0	7.5	7.5	7.5	8.0	10.5	11.0	12.2	13.0	13.0	13.0	14.0	14.0	13.0	13.0	12.0	11.0	11.0	11.0	11.0	10.5
20-Jan	11.5	9.0	8.0	9.0	8.5	8.0	8.0	8.0	9.5	10.0	11.5	12.0	12.0	13.5	13.5	13.0	13.0	12.5	12.0	11.0	10.0	9.7	9.5	9.0
21-Jan	8.5	7.8	7.0	7.0	7.0	7.0	7.0	8.5	10.5	12.5	12.5	13.0	14.0	14.0	14.3	13.5	13.5	13.0	12.5	12.0	11.5	10.0	11.0	9.5
22-Jan	9.0	8.0	7.0	7.5	7.0	7.0	7.0	8.0	10.0	10.0	12.0	13.0	14.0	15.0	15.5	15.0	14.5	14.0	13.5	12.0	12.0	11.5	10.0	9.5
23-Jan	9.0	9.0	9.0	9.0	8.5	7.5	7.5	8.0	10.0	10.0	12.5	13.0	14.0	15.0	15.0	15.0	15.0	14.0	13.5	13.5	13.0	12.5	11.0	11.0
24-Jan	10.5	10.5	10.2	10.0	9.2	8.5	8.0	9.0	11.0	12.0	14.0	14.5	14.2	14.5	14.5	14.5	14.5	15.0	15.0	13.5	13.0	12.0	10.5	10.5
25-Jan	10.0	10.0	9.0	9.0	8.5	8.5	9.0	9.0	11.5	12.0	13.0	13.5	13.5	13.5	13.2	14.0	13.0	13.0	12.0	11.5	11.0	10.0	10.0	9.5
26-Jan	9.0	9.0	9.0	8.5	8.0	8.0	8.0	8.0	10.5	11.0	13.0	12.5	13.5	13.5	13.5	13.5	13.5	13.0	13.0	11.5	11.0	10.0	9.5	9.5
27-Jan	9.5	9.0	9.0	8.0	8.0	8.5	9.0	10.5	12.0	12.0	13.7	14.5	15.0	17.0	17.5	17.0	16.5	16.0	15.5	14.5	14.0	13.5	12.5	12.0
28-Jan	11.0	11.0	11.0	10.5	10.0	10.0	11.0	12.5	14.0	15.0	17.0	18.0	18.0	19.0	19.0	19.0	19.0	18.5	18.0	17.0	16.5	16.5	15.0	14.5
29-Jan	14.0	13.7	13.7	13.0	12.0	12.0	12.0	13.0	15.5	16.0	16.5	17.5	18.5	19.0	19.0	19.0	19.0	18.0	18.0	16.5	16.0	16.0	16.5	16.5
30-Jan	16.5	16.5	16.5	16.0	15.0	15.0	15.0	15.0	16.0	17.0	19.0	19.0	19.5	20.5	21.0	21.0	19.0	18.0	17.8	16.5	16.0	15.5	14.0	14.0
31-Jan	13.0	17.0	11.5	11.0	10.5	10.0	10.0	9.5	11.5	11.5	13.5	14.0	15.5	15.5	15.5	15.0	14.5	14.0	13.5	12.0	12.0	12.0	11.0	11.0

Table A14 :Wet bulb temperature abtracted from Khartoum Station (February)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Feb	10.0	9.5	9.0	9.0	8.5	8.5	8.5	9.5	11.0	11.0	12.0	13.0	13.0	14.0	14.5	14.5	14.0	13.5	13.0	11.5	12.0	11.5	10.0	10.0
2-Feb	10.0	9.5	9.0	9.0	9.0	8.5	8.5	9.0	10.0	10.0	13.0	14.0	14.0	14.0	14.0	14.0	14.0	13.5	13.0	12.0	11.0	11.0	11.0	10.5
3-Feb	10.0	9.5	9.5	9.0	9.0	9.0	9.0	8.0	9.0	10.0	11.4	12.0	12.5	13.0	13.0	13.0	12.0	12.0	11.0	10.5	10.0	9.5	8.5	8.5
4-Feb	8.0	7.5	7.0	7.0	6.0	6.0	6.0	6.0	7.5	8.0	9.5	10.0	10.5	11.0	11.0	11.0	10.5	10.0	10.0	9.0	8.5	8.0	7.5	7.5
5-Feb	6.5	6.0	5.5	5.5	5.5	5.5	5.5	6.0	8.0	8.0	9.5	10.0	10.5	11.0	11.0	11.0	10.5	10.0	10.0	9.5	9.5	9.0	7.5	7.0
6-Feb	6.5	6.0	6.0	5.0	5.0	5.0	5.0	6.5	7.5	8.0	10.0	10.0	11.5	12.0	12.0	11.5	11.5	11.0	10.5	9.5	9.0	9.0	8.0	8.0
7-Feb	7.5	6.5	6.0	5.0	4.0	4.0	4.0	6.0	9.0	10.0	11.5	11.5	13.5	13.2	14.0	14.0	14.0	13.5	13.0	11.5	11.0	10.5	9.0	8.5
8-Feb	8.0	8.0	7.5	7.5	7.0	7.0	7.0	8.0	8.5	10.0	11.5	12.5	13.0	13.0	13.0	13.0	13.5	13.5	13.0	11.5	11.5	11.5	8.5	8.0
9-Feb	8.0	8.0	7.5	7.0	7.0	7.0	7.0	8.0	9.5	10.0	11.5	12.0	13.0	14.0	14.0	14.0	14.0	13.5	13.0	12.0	12.0	11.0	10.0	9.5
10-Feb	9.0	9.0	8.5	8.0	8.0	8.5	8.5	9.0	10.5	11.0	12.0	12.0	12.0	15.0	15.0	15.0	15.0	14.0	13.5	13.5	13.0	12.0	11.0	10.5
11-Feb	10.0	9.0	8.5	8.0	8.0	8.0	8.5	8.5	9.5	10.0	12.5	13.0	13.5	14.0	14.0	14.0	15.0	14.5	14.0	12.5	12.0	10.0	9.5	9.0
12-Feb	8.5	8.0	8.0	8.0	8.0	8.5	8.5	9.0	11.5	12.0	14.0	15.0	16.0	16.0	16.5	16.5	16.5	15.0	15.0	14.0	13.5	13.0	12.5	12.0
13-Feb	11.5	11.0	11.0	10.5	10.5	10.0	10.5	11.0	13.0	15.0	16.0	16.0	16.5	16.5	17.0	17.0	16.0	16.0	16.0	14.0	13.5	13.0	12.0	12.0
14-Feb	11.5	11.0	11.0	10.0	10.0	10.0	10.0	11.0	13.0	13.5	16.0	17.0	17.0	17.0	17.0	17.0	17.0	16.0	15.5	14.5	14.0	13.5	12.5	12.0
15-Feb	11.5	11.5	11.0	10.5	10.0	10.0	10.0	10.0	13.0	14.0	16.5	17.0	17.0	17.5	17.5	17.0	17.0	16.5	16.0	15.5	15.0	15.0	13.5	13.0
16-Feb	13.0	12.5	12.0	11.5	11.5	11.0	10.0	11.5	13.0	14.5	16.5	17.0	19.0	18.5	19.0	19.0	18.5	18.0	17.5	16.0	16.0	16.0	13.5	13.0
17-Feb	12.5	11.5	11.0	11.0	11.0	11.0	11.5	12.0	12.0	14.5	15.0	16.0	17.5	17.5	17.5	17.3	17.0	17.0	16.5	16.0	15.5	15.0	15.5	15.0
18-Feb	14.0	13.5	13.5	13.0	13.0	13.0	13.0	12.7	13.5	14.0	16.5	17.0	17.0	18.0	18.0	18.0	18.5	18.5	18.5	17.7	17.5	17.0	16.0	16.0
19-Feb	16.0	14.5	14.0	13.5	13.0	13.0	13.0	14.0	17.0	17.5	19.5	19.5	20.0	20.5	20.5	20.5	20.5	20.0	20.0	20.0	20.0	20.0	19.5	19.0
20-Feb	18.0	17.0	16.0	15.5	14.5	14.0	14.0	13.5	15.0	15.0	17.5	17.5	18.0	20.0	20.0	20.0	19.5	18.0	18.0	16.5	16.0	15.0	15.0	15.0
21-Feb	14.0	14.0	14.0	13.6	13.5	13.0	13.5	13.7	14.0	15.0	16.5	17.0	18.0	19.0	19.5	19.5	19.0	18.5	18.0	17.0	17.0	16.5	15.5	15.0
22-Feb	14.5	13.0	13.0	13.0	12.5	12.5	13.0	12.0	13.0	14.0	14.0	15.0	16.5	16.5	16.5	16.0	15.5	15.0	14.5	14.0	13.5	13.0	11.0	11.0
23-Feb	10.0	10.0	10.0	9.5	9.0	9.0	9.5	11.0	11.0	12.0	13.5	14.0	14.5	15.0	16.5	16.0	16.0	15.0	15.0	14.5	14.0	13.0	12.0	12.0
24-Feb	11.5	11.0	10.5	10.0	9.0	9.0	9.0	10.0	11.0	11.5	15.5	15.5	16.0	16.0	16.0	16.0	16.0	16.0	15.5	14.5	14.5	14.0	13.5	13.0
25-Feb	12.0	11.5	11.5	11.0	9.0	9.0	9.0	9.5	12.5	13.0	14.0	14.5	15.0	15.0	15.0	15.0	15.0	14.5	14.0	13.5	13.5	12.5	11.0	10.5
26-Feb	10.0	9.5	9.5	9.5	9.5	9.5	10.0	11.5	13.5	14.0	17.5	18.0	19.0	18.5	18.5	18.5	17.5	17.0	16.5	16.5	16.0	16.5	14.5	14.0
27-Feb	13.5	13.0	12.0	11.5	11.5	11.0	11.0	11.5	14.5	15.0	17.5	18.5	19.0	19.5	19.5	19.0	19.0	18.5	18.0	18.0	17.5	17.0	15.0	14.5
28-Feb	14.0	15.0	15.0	14.0	14.0	14.0	15.0	15.0	17.0	18.0	20.0	20.5	20.5	20.5	20.5	20.5	19.5	19.0	18.5	17.0	17.0	16.0	15.5	15.0

Table A15 :Wet bulb temperature abtracted from Khartoum Station (March)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Mar	14.5	14.0	14.0	13.5	13.0	13.0	13.0	15.5	17.0	18.0	18.5	19.0	19.5	19.5	19.5	19.0	19.0	18.5	18.0	17.0	16.0	15.0	15.7	15.5
2-Mar	15.0	14.5	14.0	13.5	13.5	13.0	14.0	15.0	16.5	16.5	17.5	18.0	18.0	18.5	18.5	18.5	18.0	17.5	17.0	17.0	17.0	17.0	17.0	17.0
3-Mar	16.0	15.0	15.0	14.5	13.5	13.0	13.5	15.0	17.0	18.0	18.0	18.0	18.5	18.5	18.5	18.0	18.0	18.0	17.0	17.0	17.0	16.5	15.5	15.5
4-Mar	15.0	14.5	14.5	14.0	13.5	13.5	14.5	14.5	17.0	18.0	18.0	18.0	18.5	18.5	18.5	18.0	18.0	18.0	17.0	17.0	17.0	16.5	15.5	15.5
5-Mar	14.0	13.0	13.0	12.5	12.0	12.0	12.5	14.0	15.0	15.5	17.0	17.5	18.0	18.0	19.0	19.0	18.0	18.0	18.0	16.0	16.0	15.0	14.0	14.0
6-Mar	14.0	12.5	12.0	12.0	11.0	12.0	12.0	12.0	13.5	14.5	15.0	15.5	16.5	17.5	17.5	17.5	16.5	16.0	16.0	14.5	14.0	14.0	13.0	12.5
7-Mar	12.5	12.0	11.5	11.5	11.0	11.0	12.0	13.0	15.0	15.0	17.5	18.0	18.0	19.0	19.5	19.5	18.5	17.5	17.5	16.5	16.5	16.0	15.0	14.0
8-Mar	14.0	14.0	13.5	13.0	12.5	12.5	13.0	15.0	17.0	18.0	18.7	19.0	19.0	19.5	19.5	19.5	19.0	19.0	19.0	17.0	17.0	16.0	15.0	15.0
9-Mar	15.0	14.5	14.0	13.0	13.0	12.5	13.0	12.0	14.0	15.0	17.0	17.0	18.0	19.0	19.0	19.5	18.5	18.0	17.5	15.5	15.0	15.0	14.0	14.0
10-Mar	13.5	13.5	13.0	13.0	12.5	12.5	13.0	13.5	17.0	17.5	19.0	19.0	19.0	19.0	19.0	19.0	18.0	18.0	17.0	16.0	15.0	15.0	14.5	14.5
11-Mar	13.6	13.5	13.0	13.0	12.0	12.0	13.0	13.0	15.0	16.0	17.0	18.0	18.0	19.0	19.0	18.5	18.0	18.0	17.0	17.0	16.0	16.0	15.0	14.5
12-Mar	14.0	13.5	13.0	13.0	12.0	12.0	12.0	13.0	13.5	14.0	16.5	16.5	17.0	18.0	18.0	18.0	17.0	17.0	16.0	15.0	15.0	15.0	14.0	13.5
13-Mar	13.0	13.0	13.0	12.0	10.5	10.0	10.5	11.0	13.0	13.5	18.0	15.0	16.5	18.0	18.0	18.0	17.5	17.5	17.0	15.0	14.0	14.0	14.0	13.5
14-Mar	13.0	12.0	12.0	11.0	11.0	11.0	11.0	12.0	14.0	14.5	16.5	17.0	18.0	17.5	18.0	17.5	17.0	16.5	16.0	16.0	16.0	15.0	14.0	14.0
15-Mar	13.5	13.5	13.0	13.0	12.0	12.0	12.5	13.0	15.0	16.0	16.5	16.5	17.5	17.5	18.0	17.5	17.0	16.5	16.0	16.0	16.0	15.0	14.0	14.0
16-Mar	14.0	14.0	13.5	13.0	13.0	12.0	12.0	13.0	16.5	17.0	19.5	20.0	20.0	21.5	21.5	21.0	20.0	19.0	17.5	16.5	16.0	15.5	15.0	14.5
17-Mar	14.5	14.0	13.5	13.5	13.0	13.0	13.0	14.0	14.0	14.5	15.0	15.0	16.0	17.5	17.5	17.0	16.5	16.0	16.0	13.0	14.0	13.5	12.5	12.0
18-Mar	11.0	11.0	11.0	10.5	10.0	10.0	10.5	10.5	11.5	12.5	13.2	13.5	14.5	15.0	15.0	16.0	15.5	15.0	15.0	13.5	13.0	12.0	11.5	11.0
19-Mar	11.0	10.9	10.5	10.0	9.5	9.0	9.0	10.0	11.0	11.0	12.0	12.5	13.0	14.5	14.5	14.0	15.0	14.0	14.0	13.0	13.0	12.0	12.5	12.0
20-Mar	12.0	11.0	10.0	10.0	9.0	8.7	10.0	11.0	12.0	12.0	12.0	13.5	14.0	15.0	15.0	15.0	15.0	14.0	14.0	13.0	13.0	13.0	12.0	11.5
21-Mar	11.4	11.0	11.0	10.0	10.0	9.0	10.0	11.0	12.5	13.0	14.0	14.5	15.0	15.5	15.5	15.0	14.0	14.0	14.0	13.0	12.5	12.0	11.3	11.0
22-Mar	11.0	10.0	10.0	9.0	8.5	8.0	8.5	9.5	11.5	12.5	12.5	12.5	13.0	15.0	15.0	15.0	14.5	14.0	13.5	13.0	13.0	13.0	11.5	11.5
23-Mar	11.0	11.0	10.5	10.0	10.0	10.0	10.0	10.0	13.5	14.0	15.0	16.0	16.0	17.0	17.5	17.0	17.0	16.5	16.0	15.0	14.5	14.0	14.5	14.5
24-Mar	14.0	13.5	13.0	13.0	13.0	13.0	13.5	13.5	14.5	15.5	16.5	17.0	17.5	17.5	17.5	17.5	17.0	16.5	16.0	15.0	15.0	14.0	14.0	14.0
25-Mar	13.0	13.0	13.0	12.5	12.0	12.0	13.0	13.0	13.5	14.0	14.5	15.0	16.0	16.0	16.5	16.5	16.0	16.0	16.0	15.0	15.0	14.5	14.0	14.0
26-Mar	14.0	12.0	11.5	11.0	11.0	12.0	12.0	12.0	13.0	13.5	15.5	16.0	16.0	17.0	17.0	17.0	17.0	17.0	16.0	14.0	13.5	13.5	13.0	12.5
27-Mar	12.0	17.0	11.5	11.0	11.0	11.5	12.0	12.0	12.5	13.0	15.0	15.5	15.5	17.5	17.5	17.0	17.0	16.5	16.0	15.0	14.0	14.0	12.0	12.0
28-Mar	12.0	11.0	11.0	10.5	10.5	11.5	12.0	13.0	14.5	15.0	17.0	17.5	18.0	16.0	16.0	16.0	16.0	15.5	15.0	14.5	14.0	14.0	13.0	13.0
29-Mar	13.0	11.0	11.0	10.0	10.0	10.0	11.0	13.5	14.0	14.0	16.0	16.0	16.5	17.0	17.5	17.5	17.5	17.0	16.5	15.0	15.0	14.5	13.0	12.5
30-Mar	12.5	12.0	12.0	11.5	11.0	11.0	11.5	12.5	14.0	14.5	17.0	17.5	18.0	18.0	18.0	12.0	16.0	16.0	16.0	15.0	15.0	14.0	13.0	12.5
31-Mar	12.5	11.0	11.0	10.0	10.0	11.0	12.0	12.0	12.5	13.0	14.5	15.0	15.5	15.5	15.0	15.0	15.0	15.0	15.0	14.0	13.5	13.0	12.0	11.2

Table A16 :Wet bulb temperature abtracted from Khartoum Station (April)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Apr	11.0	10.5	10.0	10.0	9.5	10.0	11.0	11.5	12.5	13.0	14.5	15.0	16.0	16.0	16.0	16.0	16.0	16.0	15.0	14.5	14.5	14.5	13.0	13.0
2-Apr	12.5	11.0	10.5	10.5	10.5	11.0	11.0	13.0	15.7	16.5	17.0	18.0	18.0	17.5	17.0	17.0	17.0	17.0	17.0	16.5	16.0	16.0	13.5	13.5
3-Apr	12.5	11.5	11.0	11.0	11.0	11.0	12.0	14.5	19.0	19.0	18.5	19.0	18.0	19.0	19.0	19.0	19.0	19.0	18.0	17.0	16.5	16.0	15.0	14.5
4-Apr	14.0	14.5	14.0	14.0	13.5	14.0	15.0	17.3	19.5	19.5	19.5	19.0	20.5	20.0	19.0	19.0	19.0	18.0	18.0	17.0	16.5	16.5	16.5	16.0
5-Apr	15.5	15.0	14.0	14.5	14.5	15.0	16.0	16.5	17.5	18.0	19.5	20.0	20.5	20.5	20.5	20.5	20.5	20.0	19.0	19.0	18.0	17.6	18.0	18.0
6-Apr	17.0	15.5	14.5	14.5	14.5	14.0	15.0	16.0	18.0	18.5	19.0	19.0	19.0	19.5	19.5	19.0	20.0	20.0	19.5	19.0	19.0	18.5	16.5	16.0
7-Apr	16.0	15.0	15.0	15.0	14.0	13.5	14.0	15.0	15.5	16.5	18.0	18.5	18.0	20.0	20.0	20.0	19.0	18.0	17.5	17.5	16.5	16.0	15.0	15.0
8-Apr	14.5	14.0	14.0	13.5	13.5	13.5	13.5	14.0	15.0	16.0	16.5	17.0	18.5	19.0	19.0	19.0	17.5	17.0	16.5	16.5	16.5	15.0	14.3	14.5
9-Apr	13.5	13.5	13.0	13.0	13.0	13.0	13.5	14.0	13.5	14.0	16.5	17.0	17.0	17.5	17.0	17.0	17.0	16.5	15.0	15.0	15.0	14.5	15.0	15.0
10-Apr	13.0	11.3	11.0	11.0	10.0	11.0	12.0	13.8	16.0	16.5	17.5	17.5	17.5	17.5	17.0	17.0	17.0	17.0	16.0	16.0	15.5	15.0	15.5	15.5
11-Apr	14.0	13.0	13.0	13.0	13.0	13.0	13.0	13.5	14.0	14.5	15.6	16.0	16.5	17.0	17.0	17.0	17.0	16.5	16.0	16.0	15.6	15.0	14.5	14.0
12-Apr	14.0	14.0	13.0	13.0	12.5	13.5	15.0	16.0	16.5	17.0	17.0	17.5	18.0	18.0	18.0	17.5	17.5	17.0	17.0	15.5	15.0	14.5	13.0	13.0
13-Apr	13.0	11.5	11.5	11.0	10.0	10.0	11.0	12.6	15.0	16.0	16.5	16.5	17.0	17.5	17.0	17.0	17.0	16.5	16.0	15.0	15.0	14.5	12.5	12.5
14-Apr	13.0	11.5	11.0	11.0	10.0	11.0	12.0	13.0	16.0	16.5	17.5	17.5	17.5	17.5	17.0	17.0	17.0	17.0	16.0	16.0	15.5	15.0	15.5	15.5
15-Apr	15.5	15.5	15.0	14.0	14.0	14.0	13.0	15.0	16.0	16.0	18.0	18.0	19.0	19.0	19.0	19.0	18.5	18.0	17.5	18.0	17.5	17.5	17.7	17.5
16-Apr	17.5	17.5	17.0	17.0	17.0	17.0	17.5	20.0	21.3	21.0	21.0	21.5	22.0	20.0	20.0	20.0	20.0	19.5	19.0	19.0	19.0	18.5	18.5	18.0
17-Apr	18.0	18.0	18.0	17.0	16.5	16.0	16.5	17.0	19.0	20.0	20.3	20.5	21.5	20.5	21.0	20.5	20.0	19.5	19.0	19.5	17.5	18.0	18.0	17.5
18-Apr	17.0	17.0	17.0	17.0	17.5	18.0	19.5	20.5	21.0	27.0	22.0	22.5	22.0	22.0	22.0	21.5	20.0	20.0	19.5	18.5	17.0	17.5	17.0	16.0
19-Apr	16.5	16.0	16.0	16.0	16.0	16.0	16.5	21.0	21.5	21.5	22.0	22.5	22.0	21.0	21.0	20.5	20.0	15.5	19.0	19.0	18.0	18.0	18.0	17.0
20-Apr	17.0	17.0	17.0	16.5	16.0	16.0	16.5	18.5	21.0	21.5	21.5	21.5	21.5	21.5	21.5	21.5	20.5	19.0	19.0	18.0	18.0	18.5	19.0	19.0
21-Apr	18.5	18.5	18.0	18.0	17.5	17.5	18.0	19.0	21.0	21.5	22.0	22.0	22.0	22.0	22.0	22.0	22.0	21.5	21.5	21.5	21.5	20.5	20.0	20.0
22-Apr	17.0	18.0	18.0	17.5	17.0	18.0	18.5	15.0	15.0	19.0	21.0	21.0	21.0	22.0	22.6	22.0	21.5	21.0	20.0	21.0	20.5	20.0	19.5	19.0
23-Apr	18.5	18.0	18.0	17.0	16.5	16.5	16.0	20.0	19.5	20.0	20.5	21.0	21.0	21.0	21.0	21.0	22.0	22.0	21.5	22.0	21.5	21.5	21.0	22.0
24-Apr	22.5	22.0	21.5	21.0	21.0	21.0	22.0	22.0	22.5	22.5	23.2	23.5	24.0	23.5	24.0	24.0	23.0	22.0	22.0	22.0	20.5	20.5	21.5	21.5
25-Apr	21.0	25.5	23.0	22.0	22.0	22.0	21.0	22.0	18.5	19.5	20.5	21.0	21.5	21.0	21.5	21.0	20.0	19.0	19.0	19.0	18.5	17.8	22.7	23.0
26-Apr	22.5	22.5	20.0	18.0	17.0	17.0	17.5	16.0	16.0	17.0	18.5	19.5	21.0	23.0	23.0	23.0	20.0	19.0	18.0	17.5	17.0	17.0	16.0	16.0
27-Apr	15.5	15.5	15.0	15.5	14.0	14.0	14.0	15.0	16.0	15.5	17.0	17.0	19.0	19.0	19.0	19.0	18.5	18.0	18.0	17.0	17.0	16.0	14.5	14.5
28-Apr	14.0	13.0	13.0	12.5	12.0	12.5	12.5	12.5	14.5	15.5	16.0	16.5	16.5	17.0	17.0	16.5	16.5	16.0	15.5	15.5	14.5	14.0	14.0	13.5
29-Apr	13.5	14.0	14.0	13.5	13.0	13.0	13.3	15.0	15.5	16.0	17.0	17.5	18.5	19.0	19.0	19.0	18.5	18.5	18.0	17.5	17.5	17.0	16.0	15.0
30-Apr	15.0	15.5	15.0	14.5	14.0	14.5	14.5	16.0	17.5	18.0	19.0	19.0	19.5	20.0	20.0	20.0	19.0	19.0	18.0	18.0	18.0	17.5	16.5	16.0

Table A17 :Wet bulb temperature abtracted from Khartoum Station (May)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-May	16.0	16.0	16.0	15.5	15.5	15.5	16.0	16.7	18.0	18.5	19.5	20.0	20.0	20.5	20.5	20.0	20.0	20.0	19.5	18.5	18.0	17.5	17.0	17.0
2-May	16.5	16.0	16.5	15.0	15.0	15.5	16.0	16.5	18.5	19.0	19.0	19.5	20.5	20.0	20.0	20.5	20.5	20.0	19.5	19.5	19.5	19.0	17.5	18.0
3-May	17.0	17.0	17.0	16.0	14.5	15.5	16.0	17.5	18.6	18.6	20.0	20.0	20.5	20.5	20.5	20.0	21.5	21.0	20.5	20.0	19.5	19.0	18.0	18.0
4-May	17.5	17.0	17.0	16.5	17.0	17.5	18.0	18.5	20.0	20.5	20.5	20.5	21.0	21.0	21.5	21.5	21.0	20.5	20.0	20.0	19.5	19.0	18.5	18.5
5-May	18.0	18.0	18.0	18.0	16.5	16.5	17.0	16.5	17.5	18.0	20.0	20.0	20.5	20.0	21.0	21.0	20.5	20.5	20.0	19.0	19.0	18.5	17.5	17.0
6-May	17.0	15.5	15.0	15.0	14.0	14.0	15.0	15.5	16.0	16.5	17.5	18.0	18.0	19.0	19.0	19.0	18.5	18.0	17.5	17.0	17.0	16.5	15.5	15.0
7-May	14.5	14.0	13.5	13.0	13.0	13.0	13.5	14.0	15.0	16.0	17.5	18.0	19.0	18.0	18.0	18.0	18.5	18.0	17.5	17.5	17.0	17.0	16.0	15.5
8-May	15.5	15.0	15.0	15.0	14.0	14.0	14.0	15.0	17.0	17.5	19.5	20.0	20.0	19.5	20.0	20.0	19.0	18.5	18.5	18.5	18.0	17.5	16.5	16.0
9-May	15.5	14.0	14.0	14.0	13.5	14.0	14.5	15.5	17.8	18.0	19.0	19.5	20.0	20.5	20.5	21.0	20.5	20.0	20.0	19.0	19.5	18.0	17.5	17.5
10-May	15.5	15.5	15.0	15.5	15.5	15.5	15.5	16.5	18.0	18.5	19.0	20.0	20.5	20.5	20.5	20.5	20.5	20.0	20.0	20.0	19.5	18.0	17.5	17.5
11-May	17.0	16.5	16.0	15.5	15.5	15.5	16.0	17.5	18.0	18.5	19.5	20.0	20.5	20.0	20.0	20.0	19.5	18.5	18.0	17.0	17.0	16.5	16.0	16.0
12-May	15.0	14.0	14.0	13.5	13.0	13.0	14.0	14.0	15.0	16.5	16.0	16.5	17.0	17.0	17.5	17.5	16.5	16.0	16.0	15.5	15.0	14.5	14.5	14.0
13-May	14.0	13.0	13.0	12.0	12.0	12.5	13.0	14.5	15.5	15.5	16.6	16.0	16.0	17.5	17.0	17.0	16.5	16.5	16.0	15.5	15.0	14.5	14.0	14.0
14-May	14.0	13.0	13.0	12.5	12.5	13.0	13.0	14.0	16.0	16.5	17.0	17.5	18.0	18.0	18.0	18.0	18.0	18.0	17.5	17.0	17.0	16.5	16.0	16.0
15-May	15.5	15.0	15.0	15.0	13.5	14.0	14.0	15.5	17.0	17.5	19.0	19.5	19.5	20.0	20.0	19.5	20.0	19.5	19.0	18.5	18.5	18.0	17.5	17.5
16-May	17.0	16.5	16.0	15.5	15.0	15.5	15.5	18.0	22.5	23.0	20.5	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.5	20.5	20.5	20.0	19.0	19.0
17-May	18.5	18.0	18.0	17.5	16.0	15.5	16.5	18.0	22.0	22.0	21.5	22.0	22.0	21.5	21.5	21.5	20.0	19.0	19.0	19.5	19.0	18.0	17.5	17.5
18-May	18.0	19.0	18.5	18.0	20.5	20.0	20.0	22.0	22.0	22.0	23.0	23.0	23.0	23.5	23.5	23.0	22.0	21.5	21.0	22.0	21.5	21.0	20.5	20.0
19-May	20.0	21.0	20.0	20.0	19.5	20.0	20.0	21.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0	23.0	22.0	21.5	21.0	20.5	20.0	20.0	22.0	22.0
20-May	22.0	22.0	22.0	21.5	21.5	21.5	21.5	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0	22.5	22.0	21.5	21.0	22.0	21.5	21.5	22.5	22.5
21-May	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	23.0	23.5	23.5	23.0	23.0	22.5	23.0	23.0	23.0	23.5	22.0	22.0	21.5	21.5	21.5
22-May	21.5	21.5	21.5	21.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	23.0	23.5	23.5	23.5	23.5	23.5	23.0	22.5	22.5	22.0	21.5	21.5	21.0
23-May	20.5	21.0	20.0	20.0	21.0	20.5	21.0	21.5	22.0	22.3	22.5	22.5	23.0	23.0	23.0	23.0	24.0	23.0	22.5	21.5	22.5	22.0	23.0	23.0
24-May	23.0	21.0	21.0	21.0	21.0	21.0	21.0	23.0	23.0	23.0	21.5	21.0	21.0	21.0	21.0	21.0	21.5	21.0	20.5	22.5	22.0	22.0	21.5	22.0
25-May	21.5	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	23.0	23.0	22.5	22.5	22.0	22.5	23.0	22.5	22.5	22.5	22.0	22.0	22.0
26-May	22.0	21.5	21.0	21.5	21.5	21.5	22.0	22.0	22.2	22.5	21.0	21.5	22.0	23.0	23.0	23.0	23.0	22.5	22.5	22.5	22.0	21.5	23.0	23.0
27-May	23.0	22.0	22.0	21.5	21.5	22.0	22.0	22.5	22.3	23.0	24.0	24.0	24.0	24.5	24.5	24.5	23.5	23.0	23.0	23.0	23.5	23.0	22.0	22.0
28-May	27.0	21.5	21.0	21.0	21.0	21.0	21.0	23.0	23.0	23.0	24.0	24.0	24.0	22.5	22.5	22.0	22.0	22.0	22.0	21.5	21.0	21.0	20.0	20.0
29-May	20.0	21.0	21.5	21.5	21.5	21.5	21.5	21.5	22.0	22.0	22.0	22.0	22.5	23.5	23.0	23.0	22.0	22.5	22.5	22.0	22.5	22.0	22.5	22.5
30-May	22.5	23.0	22.5	22.5	22.5	22.5	23.5	23.2	23.5	23.5	23.0	23.0	23.0	23.0	23.5	23.5	23.0	23.0	22.0	22.0	22.0	22.0	22.0	21.0
31-May	21.0	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0	23.5	23.0	23.0	23.0	23.0	23.5	23.5	23.0	23.0	22.0	22.0	22.0	22.0	22.0	21.0

Table A18 :Wet bulb temperature abtracted from Khartoum Station (July)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jun	21.0	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0	23.0	23.5	29.0	24.0	24.0	24.0	24.0	24.0	23.5	23.5	23.5	23.0	23.0	23.0	23.0
2-Jun	23.0	23.0	23.0	23.0	23.5	23.5	23.5	24.0	24.5	24.5	24.0	24.0	24.0	24.5	24.5	24.5	23.5	23.5	23.5	23.0	23.0	23.0	23.0	23.0
3-Jun	22.5	22.0	22.0	21.5	21.0	22.0	21.0	22.0	22.0	24.0	21.0	22.0	22.7	21.0	23.0	23.0	20.5	20.0	20.0	20.5	20.5	20.5	19.5	19.0
4-Jun	19.0	21.0	21.0	21.0	20.5	21.5	22.5	23.0	24.0	24.0	24.5	24.0	24.0	24.0	24.0	23.5	23.0	22.5	22.0	22.5	22.5	22.5	22.5	22.5
5-Jun	22.5	22.5	22.5	23.0	22.5	22.5	23.0	22.5	23.0	23.0	23.0	23.5	23.5	23.5	23.5	24.0	22.5	22.0	22.0	22.0	22.0	22.0	21.5	21.0
6-Jun	21.0	21.0	21.0	21.0	21.0	22.0	22.0	21.5	22.0	22.0	23.0	23.5	23.0	23.0	23.0	23.0	23.5	23.0	23.0	23.5	23.5	23.0	23.0	23.0
7-Jun	23.0	22.5	22.0	21.5	22.0	22.0	22.0	22.5	24.0	24.0	23.0	23.0	23.5	23.5	23.0	23.0	22.0	22.0	21.5	22.0	22.0	21.5	22.5	22.0
8-Jun	22.0	22.0	22.0	21.0	21.0	21.5	21.5	18.5	19.0	19.0	19.0	19.0	20.0	21.0	21.0	21.0	20.0	20.0	20.0	19.0	19.0	18.5	18.0	18.0
9-Jun	17.5	17.0	17.0	17.0	15.5	16.0	16.0	16.5	17.0	17.0	18.5	18.5	19.0	19.0	19.5	19.5	19.0	19.0	18.5	19.5	19.0	18.0	17.0	17.0
10-Jun	17.0	16.0	16.0	15.5	14.5	14.5	14.5	15.5	17.0	18.0	18.0	18.5	19.0	19.0	19.0	19.5	19.0	19.0	18.5	17.5	17.0	17.0	16.5	16.0
11-Jun	16.0	15.0	15.0	15.0	14.0	19.5	15.0	16.0	17.0	18.0	18.0	18.5	19.0	20.0	19.0	19.0	19.0	19.0	18.5	18.5	18.0	17.5	17.0	17.0
12-Jun	16.5	15.5	15.0	15.0	15.0	15.4	15.0	16.5	17.0	17.5	18.0	18.6	18.5	18.7	18.5	18.5	18.5	18.5	18.0	18.5	18.0	17.5	16.5	16.0
13-Jun	16.0	16.0	16.0	16.0	16.0	16.0	16.5	16.5	18.0	18.0	18.5	18.5	19.0	19.5	20.0	19.0	20.0	20.0	19.0	19.0	18.0	18.0	17.7	17.5
14-Jun	17.0	16.5	16.5	16.5	15.0	15.0	15.2	16.2	16.5	16.0	20.0	20.0	20.5	22.5	22.0	22.0	20.5	20.0	19.5	18.5	18.5	18.0	18.0	18.0
15-Jun	17.5	16.5	16.0	16.0	16.0	16.0	16.0	17.0	18.0	18.0	19.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	21.0	21.0	20.5	19.0	18.5
16-Jun	18.0	16.5	16.0	16.0	15.0	15.0	15.5	17.5	20.5	21.0	19.5	20.0	20.0	19.5	19.5	19.5	19.5	19.0	19.5	20.0	20.0	19.0	18.5	18.0
17-Jun	18.0	18.0	18.0	18.0	16.0	16.0	16.0	18.0	17.5	18.0	20.5	21.0	21.0	21.0	21.0	20.5	20.0	20.0	19.5	19.0	18.5	18.0	19.0	18.5
18-Jun	18.0	17.5	17.0	17.0	16.0	16.0	16.5	21.5	21.5	21.5	20.5	20.0	20.0	20.5	21.0	22.5	23.0	22.5	22.0	21.5	21.0	20.5	20.3	20.0
19-Jun	19.0	21.4	21.0	21.0	22.0	22.0	22.0	22.5	22.5	22.0	22.5	22.5	22.5	24.0	24.0	23.5	23.5	23.0	23.5	23.5	23.5	23.5	23.0	22.5
20-Jun	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	22.0	22.5	21.0	20.0	19.5	20.0	20.0	20.0	19.0	19.0	18.0	18.0	18.0	17.0	16.0	15.5
21-Jun	15.5	15.0	15.0	14.5	14.0	16.5	17.5	20.0	18.5	19.0	18.0	18.5	19.0	18.5	19.0	19.0	19.5	19.0	19.0	18.5	18.0	18.0	18.0	18.0
22-Jun	17.0	16.0	15.5	15.0	14.5	14.0	14.5	16.0	17.5	18.0	18.5	19.0	19.0	19.0	19.0	19.0	19.0	18.5	18.0	19.0	19.0	18.0	18.0	18.0
23-Jun	17.5	16.5	16.0	15.5	15.5	15.5	16.0	16.5	18.0	18.0	18.5	19.0	19.0	20.0	20.0	20.0	20.0	19.5	19.0	19.0	19.0	19.0	18.5	18.0
24-Jun	17.5	17.0	17.0	16.3	16.0	16.0	16.0	17.0	17.5	18.0	18.0	19.0	20.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.5	19.5	19.0
25-Jun	18.0	17.0	19.0	20.0	21.5	21.5	22.0	20.0	19.0	19.0	18.5	19.0	19.5	20.0	20.0	20.0	20.0	20.0	20.0	19.0	19.0	19.0	19.0	19.0
26-Jun	19.0	19.0	19.0	18.0	20.0	20.0	20.0	20.0	19.0	22.5	23.0	23.5	23.0	22.5	22.5	22.5	22.0	22.0	21.0	20.0	20.0	20.0	19.5	19.0
27-Jun	18.0	19.5	19.5	19.0	20.0	20.0	20.5	22.5	23.5	23.5	24.0	24.0	23.5	24.5	24.0	24.0	23.5	23.0	22.5	23.5	23.5	23.0	20.5	20.0
28-Jun	20.0	20.0	19.5	18.0	21.0	21.5	21.5	22.0	22.0	22.5	22.5	22.5	22.5	23.0	23.0	23.0	23.5	23.5	23.5	23.0	23.0	22.5	22.0	22.0
29-Jun	21.5	21.0	21.0	21.0	21.5	21.5	21.5	22.2	22.0	22.5	23.5	23.5	23.5	23.0	23.0	22.5	22.5	22.5	22.5	22.5	22.0	22.0	21.0	21.0
30-Jun	21.0	22.0	21.5	21.0	21.0	21.0	21.0	21.5	22.0	22.0	23.0	23.0	23.0	23.5	23.5	23.5	23.0	23.0	23.0	22.5	22.0	22.0	22.0	22.0

Table A19 :Wet bulb temperature abtracted from Khartoum Station (July)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Jul	22.0	22.0	21.5	21.5	22.0	22.0	22.0	23.0	23.0	22.5	22.0	23.5	22.5	23.0	23.0	23.0	22.5	22.5	22.0	21.5	21.0	20.5	20.0	20.0
2-Jul	20.0	20.0	20.0	20.0	20.0	21.0	21.0	22.0	22.0	22.0	19.5	19.5	20.0	18.5	18.5	18.0	19.0	19.0	18.5	19.0	18.5	18.5	17.0	17.0
3-Jul	16.5	16.5	16.0	16.0	15.5	15.5	16.0	16.0	22.0	22.0	21.5	21.5	22.0	22.5	22.0	22.0	21.5	22.0	22.0	20.0	19.5	19.5	20.5	20.0
4-Jul	20.0	20.0	20.0	20.5	21.5	21.5	21.5	22.0	22.0	22.5	23.0	23.0	23.0	23.5	23.5	23.0	23.0	22.5	22.0	22.0	22.0	21.5	21.5	21.5
5-Jul	21.0	21.0	20.5	21.0	21.5	21.0	21.0	22.5	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.0	22.0	22.0	22.0	22.0	21.0	21.0	21.0
6-Jul	21.0	21.0	21.0	20.0	21.0	21.0	21.0	22.5	23.5	23.5	23.0	23.0	23.0	21.0	21.0	21.0	22.0	22.0	21.5	22.0	21.5	21.0	22.0	22.0
7-Jul	22.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.5	22.0	22.0	23.0	22.0	21.5	21.5	21.0	22.0	22.0	22.0	22.0	21.5	20.5	21.0	21.5
8-Jul	21.5	21.5	21.0	21.0	21.0	21.0	21.0	21.5	22.0	22.5	21.0	21.0	22.0	22.5	22.0	22.0	22.0	22.0	23.0	22.0	21.5	21.0	22.0	22.0
9-Jul	21.5	22.0	21.5	22.0	22.5	22.5	22.5	22.5	23.0	23.0	23.5	23.5	23.5	23.0	22.5	22.5	23.5	23.0	23.0	22.5	22.5	22.0	22.0	22.0
10-Jul	21.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	24.0	24.0	23.5	23.5	23.0	22.5	22.5	22.5	22.5	22.5	22.0	21.0	21.0	21.0	18.0	18.0
11-Jul	17.5	17.0	17.0	16.5	19.0	19.0	19.5	22.0	22.5	23.0	24.0	24.0	24.0	23.5	23.0	23.0	23.0	23.0	22.5	23.0	23.0	22.5	22.5	22.0
12-Jul	22.0	22.0	22.0	22.0	22.5	22.0	22.5	23.0	23.8	23.5	23.0	23.5	23.5	23.0	23.0	22.5	22.0	21.5	21.0	21.5	21.0	21.0	21.0	20.5
13-Jul	20.0	21.5	21.0	21.0	21.0	21.0	21.0	22.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.0	22.5	22.0
14-Jul	22.0	21.5	21.0	21.5	22.0	22.5	22.5	23.0	23.0	23.5	23.5	23.5	22.5	22.5	22.5	21.5	21.0	20.5	22.5	22.0	22.0	20.5	22.5	22.5
15-Jul	21.5	21.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	22.5	22.5	22.5	23.0	23.0	23.0	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.0	22.5
16-Jul	22.5	22.5	23.0	22.0	23.0	23.0	23.0	23.5	23.5	24.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.5	23.0	23.0	23.0	21.5	23.0
17-Jul	22.0	22.0	22.0	21.0	21.0	21.0	22.0	23.0	23.5	22.5	22.5	22.0	22.0	22.5	22.5	22.0	22.0	22.0	22.0	23.0	22.0	22.0	22.0	22.0
18-Jul	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	22.5	22.5	22.5	22.0	22.0	22.0	22.0	22.0	21.5	21.5	21.5	21.5	21.0	22.0	22.5	22.5
19-Jul	22.0	22.0	22.0	22.0	22.5	22.5	22.5	22.5	23.0	23.0	23.0	23.0	23.0	22.0	22.0	22.0	22.5	22.0	21.0	22.5	21.0	22.5	22.5	22.0
20-Jul	22.5	23.0	22.5	22.5	22.5	22.5	22.5	22.0	22.5	23.0	23.3	23.5	23.5	23.5	23.5	23.5	23.0	23.0	23.0	22.5	22.5	22.5	22.0	22.0
21-Jul	22.0	22.0	22.0	22.0	20.0	20.0	20.5	21.5	21.5	22.0	22.5	23.0	23.0	23.0	23.0	23.0	23.5	23.5	23.0	23.0	23.0	22.5	22.5	22.5
22-Jul	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	23.0	23.0	24.0	24.0	24.0	24.5	24.5	24.5	23.5	23.0	23.0	22.5	22.0	21.5	22.0	22.0
23-Jul	21.5	21.5	21.5	21.0	21.0	21.0	21.0	23.0	24.0	24.0	23.5	23.0	23.0	22.5	22.5	22.5	22.0	23.0	23.0	21.5	21.5	22.0	23.0	23.0
24-Jul	23.0	22.0	22.0	22.0	22.0	21.5	21.5	21.5	21.5	21.5	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	23.0	22.5	22.0	21.5	22.0	21.5
25-Jul	21.5	22.0	22.0	22.0	21.5	21.5	22.0	22.0	22.0	22.0	22.5	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.5	22.4	22.0	21.5
26-Jul	21.5	22.0	20.0	20.0	22.0	22.0	22.4	23.0	23.5	23.5	24.0	23.5	23.0	25.0	25.0	25.0	24.5	24.0	23.0	23.0	22.5	22.0	22.0	22.0
27-Jul	22.0	21.5	21.0	21.0	21.0	21.0	21.0	22.0	24.0	24.0	24.5	24.5	24.5	25.5	25.5	25.5	25.0	25.0	24.0	23.0	23.0	22.5	23.0	23.0
28-Jul	23.0	23.0	22.5	22.0	22.0	22.0	22.0	22.5	22.0	22.0	22.5	22.5	23.0	22.5	22.5	22.0	22.0	22.0	22.0	22.0	22.5	22.5	22.7	22.5
29-Jul	22.0	22.0	22.0	22.0	22.5	22.5	22.5	22.0	22.5	22.5	21.5	21.5	21.5	21.0	21.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.5	20.0
30-Jul	22.0	23.0	23.0	22.5	22.5	22.5	21.5	23.0	21.5	23.5	23.0	22.5	22.5	22.0	22.0	22.0	22.5	22.0	21.5	20.5	20.5	20.5	20.5	20.0
31-Jul	19.5	19.0	19.0	19.0	21.0	21.0	21.0	22.0	22.5	22.5	21.5	22.0	22.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.5	20.0	21.0

Table A20 :Wet bulb temperature abtracted from Khartoum Station (Augest)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Aug	22.0	22.0	22.0	21.5	21.0	21.5	21.5	22.0	22.0	22.0	22.0	22.0	22.5	21.5	21.5	21.5	20.5	20.5	20.5	20.5	20.0	20.0	20.0	19.5
2-Aug	19.5	21.5	21.0	20.5	20.5	20.5	20.5	22.5	23.0	23.0	21.5	21.5	22.0	21.0	21.0	21.0	20.0	19.5	19.0	19.0	19.0	18.5	18.0	18.0
3-Aug	18.0	24.0	24.0	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	22.5	22.5	23.0	22.5
4-Aug	22.0	22.0	22.0	22.5	23.0	23.0	22.0	22.0	22.5	22.0	22.5	23.0	23.0	23.5	23.5	23.5	23.0	23.0	22.5	22.5	22.5	22.0	23.0	22.5
5-Aug	22.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	23.0	23.0	24.0	24.0	23.5	24.0	24.0	24.0	24.0	24.0	23.5	23.0	23.0	23.5	22.0	22.0
6-Aug	22.5	22.5	22.5	22.5	22.0	22.0	22.0	22.0	22.5	22.5	22.0	22.0	22.5	24.0	24.0	24.0	23.5	23.0	23.0	24.0	23.5	23.0	23.0	23.0
7-Aug	23.0	22.0	20.0	20.0	21.0	21.0	21.0	22.0	22.5	22.5	22.5	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	22.5	22.0	22.0	22.0
8-Aug	22.0	21.5	21.5	21.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.0	22.0	22.5	22.5
9-Aug	23.0	23.0	23.0	23.5	23.0	23.0	23.5	23.0	24.0	24.0	23.0	23.0	23.0	23.5	23.0	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
10-Aug	24.0	23.5	23.0	23.0	23.0	23.0	23.0	23.0	21.5	21.0	22.0	22.0	23.0	24.0	24.0	24.0	24.0	23.5	24.0	24.0	23.0	22.5	22.0	22.0
11-Aug	21.5	21.0	22.0	22.0	22.5	22.5	23.0	23.0	23.5	23.0	22.5	22.5	22.5	23.5	23.5	23.0	23.5	23.5	22.5	23.0	23.0	23.0	22.5	22.0
12-Aug	22.0	23.5	23.0	23.0	22.0	22.0	22.5	22.0	23.5	23.0	23.0	23.0	23.0	23.5	23.5	23.5	23.5	24.0	24.5	24.0	24.0	23.5	22.0	22.0
13-Aug	22.0	22.0	22.0	22.0	23.5	23.5	23.5	22.5	22.5	22.5	23.0	23.0	23.5	24.0	24.0	24.0	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5
14-Aug	22.0	22.0	23.0	22.0	21.5	21.5	22.0	21.0	22.0	22.0	22.5	22.5	23.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0
15-Aug	22.0	21.0	21.0	22.0	23.0	23.0	23.0	23.5	24.0	24.0	23.0	23.0	24.0	23.0	23.0	23.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0
16-Aug	23.0	22.5	22.0	22.5	23.0	23.0	23.0	23.0	23.0	23.0	23.5	23.5	24.0	24.0	24.0	24.0	24.0	23.0	22.5	23.5	23.0	23.0	23.4	23.0
17-Aug	22.0	21.0	22.0	22.0	21.5	21.5	22.0	22.0	22.5	22.5	22.0	22.0	22.5	13.0	13.0	13.0	13.0	13.0	22.5	24.0	24.0	24.0	24.0	23.5
18-Aug	23.5	23.5	23.5	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.5	23.0	23.0	22.5	22.5	22.5	22.5	22.5	22.5	22.0	22.0	22.0	24.0	24.0
19-Aug	24.0	23.5	23.0	22.0	21.5	21.5	22.0	22.0	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0
20-Aug	24.0	24.0	24.0	23.5	23.0	23.0	23.0	24.0	24.5	24.5	24.5	24.5	23.5	24.0	24.0	24.0	22.0	22.0	22.0	22.5	22.5	22.5	23.0	23.0
21-Aug	23.5	24.0	24.0	24.0	23.5	23.5	23.5	25.5	25.5	25.5	24.5	24.5	24.5	24.5	24.0	23.5	22.5	22.0	22.5	22.0	22.5	21.0	21.0	22.0
22-Aug	21.0	25.0	24.0	23.0	23.0	23.5	23.5	23.0	23.5	23.5	23.0	23.0	22.5	23.0	23.0	23.0	23.0	23.0	22.5	23.0	23.0	22.5	23.0	23.0
23-Aug	21.0	25.0	24.0	23.0	23.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.5	23.0	23.0	23.0	23.0	22.5	23.0	23.0	22.5	22.5	22.5
24-Aug	22.0	22.0	22.5	22.5	23.0	23.0	23.0	23.5	24.0	24.5	23.0	23.5	24.0	23.0	23.0	23.0	21.0	21.0	21.5	21.0	21.0	21.0	20.0	21.0
25-Aug	22.0	23.0	23.0	23.0	23.0	23.0	23.5	24.0	23.0	23.0	23.0	23.0	23.5	22.5	22.5	22.5	22.0	22.0	22.0	22.5	22.5	22.0	22.0	22.0
26-Aug	21.0	20.0	20.0	21.0	22.0	21.5	22.0	24.0	23.7	24.0	22.5	22.5	23.0	22.0	22.0	22.0	21.5	21.0	21.5	24.0	23.5	23.0	23.5	23.0
27-Aug	23.0	23.0	23.0	23.0	22.5	23.5	23.5	21.0	21.5	22.0	22.0	22.0	23.0	23.0	22.0	22.0	21.5	21.5	21.5	22.0	22.0	21.5	22.0	22.0
28-Aug	22.0	21.5	21.5	21.5	21.5	21.5	21.5	22.5	23.0	23.0	23.0	23.0	23.5	23.5	23.5	23.5	23.5	23.5	23.0	23.0	23.0	23.0	23.5	23.5
29-Aug	23.5	23.5	23.5	23.5	24.0	24.0	23.5	23.0	23.5	23.5	23.0	23.0	23.0	23.0	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.0	21.0	21.0
30-Aug	21.5	21.5	21.5	21.5	21.0	18.0	20.5	21.0	22.0	22.0	22.0	23.0	23.5	22.0	22.0	22.0	21.0	21.0	21.0	20.5	20.0	20.5	21.0	21.0
31-Aug	21.0	21.5	21.0	22.0	21.5	20.5	20.0	22.0	22.0	23.0	23.0	23.0	23.0	22.5	22.5	22.5	22.5	22.0	22.0	22.0	23.0	23.0	23.0	23.0

Table A21: Wet bulb temperature abtracted from Khartoum Station (September)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Sep	22.5	22.5	22.5	22.0	22.0	22.0	22.5	23.0	23.5	23.0	23.5	23.5	23.0	23.0	23.5	23.5	23.0	23.0	22.5	23.0	23.0	23.0	23.0	22.5
2-Sep	22.5	23.0	23.0	23.0	23.0	23.0	21.5	20.5	20.5	21.0	21.0	21.5	22.0	22.5	22.5	22.5	22.5	22.0	22.5	23.5	23.5	23.5	23.5	23.5
3-Sep	23.0	23.5	23.5	23.5	23.5	23.5	23.5	22.7	22.5	22.5	23.0	23.0	22.5	23.0	23.0	23.0	22.5	22.0	22.0	23.5	23.0	23.0	23.0	24.0
4-Sep	24.0	24.0	24.0	24.0	24.0	23.0	22.0	24.0	19.5	20.0	20.0	21.0	21.5	21.0	21.0	21.0	21.0	21.0	20.5	21.0	21.0	21.0	20.0	20.5
5-Sep	24.0	24.0	24.0	24.0	24.0	23.0	22.0	24.0	19.5	20.0	20.0	21.0	21.5	21.0	21.0	21.0	21.0	21.0	20.5	21.0	21.0	21.0	20.0	20.5
6-Sep	21.5	23.0	23.0	23.0	23.0	23.0	23.5	23.5	24.0	24.0	24.0	24.5	24.5	24.0	24.0	24.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.5
7-Sep	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.5	23.5	23.0	22.5	23.0	23.0	24.0	24.0	23.5	23.5	23.5	24.0	24.5	24.5	24.0	24.0	24.0
8-Sep	24.0	24.0	23.0	22.0	21.0	22.0	21.5	21.0	22.5	23.0	23.5	24.0	24.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.0	22.0	22.0	23.0
9-Sep	23.0	24.0	24.0	24.0	23.5	23.0	23.0	23.5	22.5	22.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.5	22.0	22.0	22.0
10-Sep	21.0	20.0	21.0	22.0	23.0	23.0	23.0	23.0	24.5	24.5	24.5	24.8	25.0	23.7	23.5	23.0	23.5	23.0	23.0	20.0	20.0	20.0	20.0	20.0
11-Sep	20.5	20.5	20.0	21.0	22.0	22.0	22.0	21.5	24.0	24.0	24.5	24.0	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.0	23.0	23.0	23.0	23.0
12-Sep	23.0	22.5	22.5	22.0	22.0	22.5	22.5	21.0	22.5	22.5	22.5	22.5	22.5	23.0	23.0	23.0	22.5	22.5	22.0	20.0	20.0	21.5	22.0	22.0
13-Sep	22.0	22.5	21.5	22.5	23.0	23.0	23.5	23.5	23.5	23.0	22.0	21.0	21.0	21.0	21.0	21.0	20.0	19.5	19.0	20.0	20.0	20.0	20.0	25.0
14-Sep	25.0	25.0	25.0	25.0	23.0	23.0	23.0	23.0	23.5	23.5	23.0	22.0	23.0	22.5	22.5	22.0	21.5	21.0	20.0	19.5	18.0	18.0	17.0	18.5
15-Sep	20.0	22.0	21.6	21.0	21.5	21.5	22.0	22.0	22.5	22.5	22.5	22.5	23.0	22.5	22.5	22.5	22.5	22.0	21.5	22.0	22.0	21.5	22.5	22.0
16-Sep	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	23.0	23.0	24.0	24.0	24.0	24.0	24.0	24.0	23.5	23.5	23.5	23.5	23.5	23.5	23.0	23.0
17-Sep	23.0	22.0	22.0	22.0	22.0	22.5	22.5	21.5	22.0	22.0	22.5	22.5	23.0	23.0	23.0	23.0	22.0	22.0	22.0	22.0	22.0	21.0	21.0	21.0
18-Sep	21.0	22.0	22.0	22.0	21.5	21.5	22.0	22.5	23.0	23.0	22.0	22.0	22.0	21.0	21.0	21.0	21.0	21.0	21.0	21.5	21.5	21.5	21.0	21.0
19-Sep	22.0	22.5	22.6	22.0	21.0	20.5	21.0	21.0	21.5	22.0	22.0	22.5	23.0	23.0	23.0	23.0	22.0	22.0	22.0	22.5	22.5	22.0	21.0	21.0
20-Sep	21.5	22.0	22.0	22.0	22.3	22.3	22.5	23.0	25.5	25.5	23.0	23.0	23.0	23.5	23.5	23.0	22.5	22.0	21.5	21.5	21.0	21.5	21.5	21.0
21-Sep	21.0	21.0	21.0	21.0	21.0	21.0	21.0	23.0	24.0	24.0	23.5	23.0	23.0	24.5	24.0	24.0	24.0	23.5	23.0	23.0	23.0	22.5	22.0	22.0
22-Sep	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.5	23.0	23.0	23.5	23.5	23.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.0
23-Sep	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.5	23.0	23.0	23.5	23.5	23.0	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.0
24-Sep	21.5	22.0	22.0	22.0	21.5	22.5	22.5	22.5	23.5	23.0	23.0	23.0	23.0	24.0	24.0	24.0	23.5	23.5	23.0	23.5	23.5	23.5	23.0	23.0
25-Sep	22.0	22.0	22.0	22.0	22.0	22.0	22.0	18.5	19.0	19.0	21.0	21.0	22.0	22.5	22.5	22.5	21.5	21.0	21.0	22.0	22.5	21.0	20.5	20.5
26-Sep	20.0	20.0	20.0	20.0	20.0	22.0	19.0	18.0	18.0	19.0	20.0	20.0	20.5	21.0	21.0	21.0	22.0	22.0	22.0	20.0	20.0	20.0	20.0	20.0
27-Sep	20.0	22.0	22.0	22.0	22.5	22.5	22.0	18.0	18.5	18.5	20.0	20.5	20.5	21.0	21.0	21.0	22.0	21.5	22.0	22.5	22.5	21.0	20.0	20.0
28-Sep	20.0	20.0	20.0	20.5	21.0	21.0	21.0	22.0	21.5	24.5	24.5	24.0	24.0	25.0	25.0	25.0	24.5	24.0	23.5	23.0	23.0	23.0	22.0	22.0
29-Sep	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	20.5	21.0	23.0	23.5	23.0	23.5	23.5	23.5	23.0	23.0	22.5	22.5	22.0	21.5	21.0	21.0
30-Sep	21.0	21.0	22.0	22.0	22.0	22.0	22.0	22.0	20.5	21.0	19.5	19.5	19.5	20.0	20.0	20.5	20.5	20.0	20.5	22.5	22.0	22.0	23.0	22.0

Table A22 :Wet bulb temperature abtracted from Khartoum Station (October)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Oct	21.0	21.0	22.0	22.0	22.0	22.0	22.0	22.0	20.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	23.5	23.5	23.5	22.0	22.0	22.0	22.5	22.5
2-Oct	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	23.5	23.5	23.5	23.5	24.0	24.0	24.0	23.5	23.0	23.0	23.0	22.0	22.0	22.0	22.0	22.8
3-Oct	22.0	22.0	22.0	22.0	22.0	22.0	22.5	23.0	22.5	22.5	22.5	22.5	23.0	23.0	23.0	23.0	22.0	21.5	21.5	21.5	21.5	21.5	22.0	22.5
4-Oct	22.5	22.5	22.5	22.5	22.0	22.0	22.0	22.5	23.5	23.5	24.5	24.5	24.0	24.5	24.0	24.0	23.5	23.5	23.5	23.5	23.5	23.5	21.5	21.0
5-Oct	21.0	21.0	21.5	22.0	22.0	22.0	22.0	23.5	24.0	24.0	23.5	23.5	24.0	24.0	23.5	23.5	23.5	22.5	22.0	23.5	23.5	23.5	23.5	23.5
6-Oct	23.5	23.5	23.0	23.0	22.0	22.0	22.5	24.0	23.5	23.5	23.5	23.5	23.0	23.0	23.0	23.0	22.5	22.5	22.5	22.5	23.0	22.0	21.5	21.0
7-Oct	21.0	21.0	21.0	21.0	21.0	21.0	21.0	23.0	22.0	22.0	23.5	23.5	23.5	21.5	21.5	21.5	19.5	19.0	19.0	19.0	19.0	18.0	17.5	17.5
8-Oct	17.0	17.0	17.0	18.0	18.5	18.0	18.5	15.5	17.0	17.0	18.0	18.5	18.5	19.0	19.0	19.0	19.0	19.0	18.5	18.5	18.5	18.0	18.0	18.0
9-Oct	17.0	17.0	17.5	16.5	15.0	16.0	16.0	15.7	17.0	17.5	18.0	18.5	18.0	19.0	20.0	20.0	20.5	20.0	19.5	18.5	18.5	18.0	17.0	16.5
10-Oct	16.0	16.0	16.0	16.0	16.5	16.0	16.0	16.5	18.5	19.0	19.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.0	18.5	18.0	17.0	17.0
11-Oct	17.0	18.5	18.0	18.5	19.0	18.5	17.5	17.0	16.5	17.0	18.5	19.0	19.0	20.0	20.0	20.0	20.0	20.0	20.0	19.0	19.0	19.0	17.5	17.0
12-Oct	17.0	16.0	16.0	16.0	16.0	16.0	16.0	17.0	17.5	18.0	20.4	20.0	20.0	20.0	20.0	20.0	22.0	22.0	21.0	18.5	18.5	18.0	17.0	17.0
13-Oct	17.9	16.5	16.0	16.0	16.0	16.5	16.5	16.5	18.5	19.0	20.0	20.5	21.0	22.0	22.0	21.5	21.5	21.0	21.0	20.5	20.4	20.0	19.0	18.0
14-Oct	19.0	19.0	18.5	18.0	18.0	18.0	18.0	20.0	21.5	22.0	22.0	22.5	23.0	22.0	22.0	22.0	21.5	21.0	21.5	22.0	22.0	22.0	22.0	21.5
15-Oct	21.5	21.5	21.5	21.0	21.0	21.0	22.0	22.5	22.5	23.0	23.0	23.0	23.0	24.0	24.5	23.5	22.0	21.5	21.0	22.5	22.0	21.0	21.0	21.0
16-Oct	21.0	22.5	22.5	22.5	22.5	22.5	22.0	22.0	24.0	24.0	24.0	24.5	24.5	23.5	23.5	22.5	24.0	24.0	24.0	23.0	23.0	23.0	22.0	22.0
17-Oct	22.0	21.5	21.5	21.5	23.0	23.0	23.0	23.0	23.5	24.0	23.8	23.5	23.5	23.0	23.0	23.0	23.5	23.0	22.5	22.0	22.0	22.5	23.5	23.0
18-Oct	22.0	21.0	21.0	21.0	21.5	21.0	21.5	22.0	22.5	22.5	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	21.0	21.0	20.5	20.5	20.0
19-Oct	20.0	19.0	19.0	18.0	17.5	17.5	17.5	20.0	22.5	22.5	24.0	24.5	24.5	24.5	24.5	24.5	24.0	23.5	23.0	23.0	23.0	23.5	21.0	21.0
20-Oct	22.0	23.0	22.5	22.0	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.0	23.0	23.5	23.5	23.5	23.5	23.5	23.0	22.0	22.0	21.5	21.0	21.0
21-Oct	21.0	21.0	21.0	20.5	21.0	21.0	21.5	22.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.5	25.0	25.0	25.5	23.0	23.0	23.0	22.5	22.5
22-Oct	22.5	22.0	22.0	22.0	21.0	21.0	21.0	23.0	23.5	23.5	23.5	23.0	23.0	24.0	24.0	24.0	24.5	24.5	24.5	23.5	23.5	23.0	23.0	23.0
23-Oct	23.0	22.5	22.5	22.5	22.0	22.0	22.0	22.5	23.0	23.0	22.5	22.5	22.0	23.0	23.5	23.5	23.0	23.0	23.0	21.0	20.0	19.5	19.0	19.0
24-Oct	19.0	18.5	18.0	18.0	16.0	16.0	17.0	18.0	20.0	20.0	22.0	22.5	22.5	23.5	23.5	22.5	22.0	22.0	21.5	21.0	20.0	19.5	18.5	18.0
25-Oct	17.5	17.0	17.0	17.0	17.0	16.5	16.5	17.0	19.0	19.0	21.0	21.0	21.0	21.0	21.0	23.5	21.0	20.5	20.0	19.0	19.0	19.0	18.0	18.0
26-Oct	18.0	17.0	17.0	17.0	16.0	16.0	16.5	17.5	21.0	21.0	21.5	21.5	21.5	21.5	22.0	22.0	20.0	20.0	20.0	19.0	19.0	19.0	19.0	19.0
27-Oct	19.0	18.5	18.5	18.5	17.0	17.0	17.0	18.0	19.7	21.0	21.9	22.0	22.0	22.0	22.0	22.0	22.0	22.0	21.0	20.0	20.0	20.0	19.0	19.0
28-Oct	19.0	17.0	17.0	16.0	16.0	16.0	16.5	17.5	19.0	19.0	20.5	21.0	21.5	22.0	22.0	22.0	22.0	22.0	21.5	21.5	21.5	21.5	23.0	23.0
29-Oct	23.0	23.0	23.0	21.0	20.0	21.0	21.0	22.0	22.5	23.0	23.0	23.0	22.5	23.0	23.0	23.0	23.0	23.0	22.5	22.5	22.0	22.0	21.5	21.0
30-Oct	21.0	20.5	20.0	19.0	18.0	19.0	20.0	21.0	23.0	23.0	23.5	24.0	24.0	24.0	24.0	23.0	24.0	23.0	23.0	23.0	22.5	22.0	22.0	22.0
31-Oct	22.0	22.0	21.5	21.0	21.0	21.0	21.5	20.0	20.0	22.0	24.0	24.0	24.0	24.0	24.0	24.0	23.0	23.0	23.0	23.0	22.5	22.0	22.0	22.0

Table A23 :Wet bulb temperature abtracted from Khartoum Station (November)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Nov	20.0	20.0	19.5	19.0	20.0	20.0	20.0	21.0	21.0	22.0	24.0	24.0	24.0	24.0	24.0	24.0	23.0	22.5	22.0	22.0	22.0	22.0	20.5	20.5
2-Nov	20.0	20.0	20.0	19.0	20.0	20.0	20.0	21.0	21.0	22.0	23.0	23.0	23.0	24.0	24.0	23.0	23.0	23.0	22.5	22.5	22.0	22.0	20.5	20.5
3-Nov	20.5	20.0	20.0	20.0	19.0	20.0	20.0	20.0	23.0	23.0	22.5	22.5	23.0	23.0	23.0	23.0	24.0	23.5	23.0	23.5	23.5	23.5	22.0	21.5
4-Nov	21.0	21.0	21.0	20.5	19.0	19.0	19.0	18.0	22.5	23.0	23.0	23.5	24.0	21.5	21.5	21.5	21.0	20.0	19.0	18.5	18.0	18.0	17.0	17.0
5-Nov	17.0	17.0	17.0	16.5	17.0	17.0	17.0	18.0	19.0	20.5	22.0	23.0	21.5	21.5	20.0	20.0	19.5	19.5	19.0	19.0	18.0	18.0	18.5	18.0
6-Nov	18.0	17.0	16.5	16.0	15.0	15.0	15.0	16.0	17.0	17.0	20.0	21.0	21.5	21.0	21.0	21.0	20.0	20.0	19.0	19.0	19.0	18.0	16.5	16.0
7-Nov	15.5	15.5	14.5	14.0	14.0	14.0	14.0	16.0	18.0	19.0	21.0	21.0	21.0	21.5	21.0	20.5	20.0	20.0	20.0	20.0	20.0	19.0	17.8	17.5
8-Nov	17.0	16.5	16.5	16.5	16.5	16.0	16.5	18.0	20.0	20.0	23.0	23.0	22.5	21.5	21.0	21.0	20.0	19.0	19.5	20.0	19.5	19.5	19.0	18.0
9-Nov	17.0	16.0	16.0	16.0	17.0	17.0	18.0	18.0	19.0	20.0	21.0	22.0	22.0	22.0	22.0	21.0	20.0	20.0	20.0	19.5	19.0	19.0	17.0	17.0
10-Nov	17.0	16.0	16.0	16.0	15.0	15.5	16.0	17.0	20.0	20.0	21.0	21.0	20.0	20.5	20.0	19.0	19.0	20.0	19.0	19.0	19.0	18.5	17.0	17.0
11-Nov	17.0	16.5	16.0	15.5	15.5	16.0	16.5	17.5	19.0	20.0	21.0	21.0	21.0	21.0	21.0	20.0	20.0	20.0	19.0	19.5	19.0	19.0	18.5	18.0
12-Nov	18.0	18.0	18.0	17.5	17.0	17.0	17.0	19.0	20.5	21.0	22.0	22.0	22.5	20.5	21.0	21.0	20.5	20.0	19.5	19.0	18.5	18.0	18.0	18.0
13-Nov	17.5	17.0	17.0	16.0	15.5	16.0	16.0	18.0	20.5	20.5	22.0	22.0	22.5	22.0	22.0	21.5	20.0	20.0	19.0	19.0	18.5	18.0	17.0	17.0
14-Nov	16.5	16.0	16.0	15.5	17.5	17.0	17.0	20.0	20.5	20.5	21.0	21.0	21.0	20.0	20.0	19.5	18.5	18.0	17.0	17.0	17.0	16.5	16.0	16.0
15-Nov	13.0	14.0	14.0	14.0	13.0	13.0	13.0	13.5	15.0	16.0	18.0	19.0	18.0	20.0	21.0	17.0	17.5	16.5	16.5	16.0	16.0	16.0	16.0	15.0
16-Nov	15.0	14.0	13.0	13.0	13.0	13.0	13.5	14.5	16.0	17.5	18.5	19.0	19.0	18.0	18.0	18.0	17.0	17.5	16.0	17.0	16.0	16.0	15.5	15.5
17-Nov	13.0	14.5	14.0	14.0	13.0	13.0	14.0	15.0	16.0	16.5	18.0	18.0	18.5	19.0	19.0	19.0	18.5	18.5	18.0	17.5	17.5	16.5	16.0	16.0
18-Nov	16.0	16.0	15.5	15.0	15.0	14.5	14.5	15.0	17.0	20.0	20.0	20.0	20.0	20.0	20.0	19.5	20.0	19.0	19.0	19.0	19.0	18.5	18.0	17.5
19-Nov	17.0	17.0	16.5	16.0	15.5	15.5	16.0	16.0	18.0	20.0	20.5	21.0	21.0	21.0	21.0	21.0	20.0	20.0	20.0	19.0	18.5	18.5	17.0	16.5
20-Nov	16.0	15.5	15.0	15.0	15.0	15.0	15.0	16.5	18.5	19.0	20.0	21.5	21.0	21.0	21.0	19.0	20.0	20.0	20.0	19.0	18.5	18.0	17.5	17.5
21-Nov	17.0	17.0	16.0	16.0	16.0	15.5	16.5	19.0	21.0	22.5	22.5	22.0	22.0	22.0	22.0	22.0	21.0	20.0	20.0	19.0	19.5	18.0	18.0	18.0
22-Nov	18.0	17.0	17.0	16.5	15.0	15.0	15.0	18.5	20.5	21.0	21.0	21.0	21.5	21.5	21.5	20.5	20.0	19.5	19.0	19.0	19.0	18.5	18.5	18.5
23-Nov	18.0	17.0	17.0	16.5	15.0	15.0	15.0	18.5	20.5	21.0	21.0	21.0	21.5	21.5	21.5	20.5	20.0	19.5	19.0	19.0	19.0	18.5	18.5	18.5
24-Nov	18.0	17.5	17.0	16.0	15.0	16.0	16.5	18.0	20.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.0	20.0	19.5	19.0	19.0	19.0	17.5	17.0
25-Nov	16.5	16.5	16.5	16.0	16.0	16.0	16.0	17.0	20.0	18.5	17.5	17.5	18.5	18.0	17.5	17.0	17.0	17.5	17.0	16.0	15.0	15.0	14.5	14.0
26-Nov	14.0	13.0	12.5	12.0	12.0	10.5	13.0	12.0	14.0	16.5	17.0	17.5	17.5	18.0	18.0	18.0	19.0	18.0	17.0	19.5	19.0	19.0	19.0	18.5
27-Nov	18.0	18.0	17.0	16.0	14.0	14.0	14.0	15.5	17.0	18.0	19.0	19.0	19.5	19.5	21.0	20.5	20.0	20.0	19.0	18.5	18.5	18.0	17.5	17.5
28-Nov	17.0	16.5	16.0	15.0	14.0	14.0	14.5	17.0	20.0	20.0	21.0	21.0	21.0	21.0	21.5	21.0	20.5	20.0	20.0	19.0	19.0	19.0	18.5	18.0
29-Nov	17.5	17.0	16.0	16.0	16.0	17.0	17.5	18.0	20.5	21.0	21.5	21.0	21.5	21.5	21.5	21.0	20.0	20.0	20.0	19.5	19.0	19.0	19.0	18.5
30-Nov	18.0	17.5	17.0	16.5	16.0	16.0	16.0	16.0	20.5	21.0	21.0	21.0	21.0	20.0	21.0	21.0	20.0	20.0	20.0	19.5	19.0	19.0	18.0	17.0

Table A24: Wet bulb temperature abtracted from Khartoum Station (December)

DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-Dec	17.0	17.0	17.0	17.0	17.0	17.0	17.0	18.0	20.0	20.0	20.0	20.0	20.5	21.0	20.5	20.0	20.0	20.0	19.0	18.5	18.5	18.0	17.0	17.0
2-Dec	16.5	16.5	16.5	16.0	15.0	15.0	15.5	16.0	17.5	17.0	18.0	18.0	18.0	18.5	18.5	18.5	19.5	18.0	17.5	18.0	17.5	17.5	17.0	16.0
3-Dec	16.0	16.0	16.0	15.5	15.0	15.5	15.0	17.0	18.0	18.5	20.0	20.0	20.5	20.0	20.5	20.5	20.0	20.0	18.5	18.0	17.5	17.5	17.0	17.0
4-Dec	17.0	16.5	16.0	16.5	16.5	16.0	16.0	17.0	18.0	21.0	20.5	21.0	21.0	20.5	20.5	20.0	20.0	20.0	19.0	18.0	18.0	18.0	17.5	17.0
5-Dec	17.0	16.5	16.0	16.0	16.0	16.0	16.0	17.5	19.0	19.5	20.0	20.0	19.0	18.5	18.0	18.0	18.0	18.0	17.0	16.0	16.0	16.0	16.0	15.0
6-Dec	15.0	16.0	16.0	15.0	14.0	14.0	15.0	14.0	16.5	17.0	20.5	21.0	21.0	20.0	20.0	20.0	18.5	18.0	18.0	17.5	17.0	15.5	15.5	15.5
7-Dec	15.0	14.0	14.0	14.0	13.5	13.0	13.5	13.0	15.0	15.5	17.5	18.0	18.5	19.0	19.0	18.5	17.5	17.0	16.5	16.0	15.0	15.0	14.0	13.5
8-Dec	13.0	12.5	12.5	12.0	12.0	14.0	14.5	12.5	13.5	14.5	15.5	16.0	17.5	18.5	19.0	19.0	18.5	18.0	17.0	16.0	16.0	16.0	15.0	14.5
9-Dec	13.5	12.5	12.0	11.5	11.0	11.0	11.0	12.0	13.5	14.0	13.5	18.0	19.5	20.0	20.0	20.0	19.5	20.0	18.0	17.5	17.0	16.5	16.0	15.5
10-Dec	15.5	15.0	14.0	13.0	13.0	13.0	13.5	14.0	15.0	16.5	18.0	19.0	19.5	19.5	19.5	19.0	18.0	18.0	18.0	16.5	16.0	15.5	15.5	15.0
11-Dec	15.0	14.0	14.0	13.0	12.0	12.0	13.0	12.5	14.0	14.5	15.5	17.0	17.5	17.0	17.0	16.5	15.5	15.5	15.0	14.5	14.0	14.0	14.0	13.5
12-Dec	13.0	12.5	12.5	12.5	11.0	11.0	11.0	11.5	12.0	13.0	15.5	16.0	17.0	17.0	17.0	16.5	16.5	16.0	15.5	14.0	13.5	13.0	13.0	13.0
13-Dec	12.5	12.0	12.0	12.0	11.5	11.5	12.5	11.0	12.5	13.5	14.0	14.0	15.0	15.5	15.5	15.0	15.0	16.0	14.0	13.0	13.0	12.0	12.0	11.5
14-Dec	11.5	11.0	11.0	10.5	10.0	10.0	10.0	11.5	12.0	12.5	14.0	15.0	15.5	15.5	15.5	15.0	14.5	14.5	14.0	14.5	14.0	13.5	14.0	14.0
15-Dec	14.0	14.5	14.5	14.0	14.0	12.5	12.0	13.0	15.0	16.0	17.5	19.0	20.0	20.0	19.0	19.0	19.0	18.5	17.0	17.5	17.5	17.5	16.5	16.0
16-Dec	15.5	15.5	15.0	15.0	15.0	15.0	15.0	15.5	16.5	17.0	19.0	19.5	20.0	20.0	19.5	19.0	19.0	18.5	18.0	17.5	17.0	17.0	16.0	16.0
17-Dec	15.5	15.5	15.0	14.5	14.0	14.0	14.5	15.0	15.0	16.0	18.0	19.0	19.5	20.0	20.5	20.0	19.0	18.0	18.0	17.0	17.0	15.5	15.5	15.0
18-Dec	14.5	14.5	14.0	14.0	14.0	14.0	16.0	14.5	15.5	16.5	18.0	19.0	19.0	18.5	19.0	19.0	18.0	18.0	17.0	17.0	16.5	16.0	16.0	15.5
19-Dec	15.5	15.5	15.0	15.0	14.0	14.0	14.0	15.0	16.5	17.0	18.5	19.5	20.0	20.0	20.0	19.5	19.0	18.5	18.0	18.0	17.0	16.0	15.5	15.0
20-Dec	15.5	15.5	15.0	14.5	14.0	14.0	15.0	14.5	15.0	15.5	17.5	18.0	18.5	19.0	18.5	18.5	18.5	18.0	17.5	17.0	16.0	16.0	14.5	14.0
21-Dec	13.0	13.0	13.0	13.0	13.0	13.0	14.0	13.5	15.0	15.0	15.0	15.5	16.0	18.0	18.0	17.0	17.0	16.5	16.0	15.0	15.0	14.5	14.5	14.0
22-Dec	14.0	13.5	13.0	13.0	15.0	14.0	14.0	13.5	14.5	15.0	15.0	15.0	16.0	17.0	17.0	17.0	16.0	15.0	15.5	15.0	14.5	14.0	14.0	13.5
23-Dec	13.0	12.5	12.5	12.0	12.0	13.0	13.5	11.5	12.5	12.5	14.0	14.0	14.5	14.5	14.5	14.5	14.5	14.0	13.5	13.0	13.0	13.0	11.5	11.0
24-Dec	11.0	10.5	10.0	10.0	9.5	9.5	9.5	10.0	17.0	12.5	13.5	14.0	14.0	14.5	14.5	14.0	13.5	13.0	13.0	12.0	12.0	11.5	10.5	10.5
25-Dec	9.5	9.0	9.0	9.0	9.0	9.0	9.0	10.0	11.0	11.5	14.0	14.0	14.0	15.0	15.0	15.0	16.0	15.5	15.0	14.5	14.0	14.0	13.0	13.0
26-Dec	13.0	13.0	12.5	12.0	11.0	11.5	12.5	13.0	14.0	15.0	17.0	17.5	18.0	19.0	19.0	18.3	19.0	19.0	18.0	17.0	17.0	17.0	16.5	16.5
27-Dec	16.0	15.0	15.0	14.0	14.0	14.0	14.0	14.0	15.0	15.5	17.5	17.0	17.0	18.0	18.0	18.0	17.5	16.5	16.0	15.0	14.5	14.0	14.0	13.5
28-Dec	13.0	13.0	13.0	12.5	13.0	12.5	13.5	14.0	15.5	15.5	18.0	18.5	18.5	20.0	19.0	19.0	18.5	18.0	18.0	17.5	17.5	17.0	15.5	15.5
29-Dec	15.0	14.5	14.0	14.0	14.0	14.0	14.0	15.0	18.5	19.0	21.0	19.5	19.5	20.0	20.0	19.5	19.5	19.0	18.0	17.0	17.0	16.0	15.5	15.0
30-Dec	15.0	14.5	14.5	14.5	14.5	14.0	15.0	16.0	18.5	19.0	20.0	20.0	20.5	22.0	21.5	21.0	19.0	18.5	18.0	17.5	17.5	17.0	16.5	16.0
31-Dec	16.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	18.0	18.5	20.0	21.0	21.0	20.5	20.5	20.5	20.0	19.5	18.0	17.0	17.0	16.5	16.0	16.5

Appendix B1

Computer Program

Compute program description

A computer program based on visual basic language was designed to evaluate turbine inlet air cooling options for any site. Figure B-1 shows the computer program Main screen.

1. Operation of the program

To run the program the user is required to enter the following data:-

1- Site weather data.
   a. Parametric pressure.
   b. Dry bulb temperature.
   c. Wet bulb temperature.
2- Gas turbine performance data
   a. ISO output
   b. ISO heat rate
   c. Minimum ambient temperature.
   d. % increase of output per one degree Celsius.
3- The operating period (start and end dates) see figure. B2.
4- The operating hour per day of operation (start and end hour)
5- Wetted media evaporative cooling options parameters.
   a. Evaporative cooling effectiveness.
   b. Blow down rate
   c. Minimum outlet temperature from the system.
   d. Installation cost of the system ($/kW)
6- Fogging option parameters.
   a. Evaporative cooling effectiveness.
   b. Minimum outlet temperature from the system.
   c. Installation cost of the system ($/kW)
7- Refrigrative cooling
   a. Chiller load (Ton of refrigeration)
   b. Chiller parasitic load (kW/ Ton of refrigeration)

c. Minimum outlet temperature from the coils.

b. Installation cost of the system ($/kW)

2. Program output

The following are the output data of the program.

1- Site output corrected to ISO rating.

2- Heat rate corrected to ISO heat rate.

3- Annual inlet cooling degree hour for the site.

4- Annual extra MWh generated at the site from the cooling option

5- Annual ton of refrigeration and parasitic loads of the refrigrative inlet cooling.

6- Technical evaluation of the cooling options as shown in figure A3.

7- Economical evaluation of the cooling options as shown in figure A4.

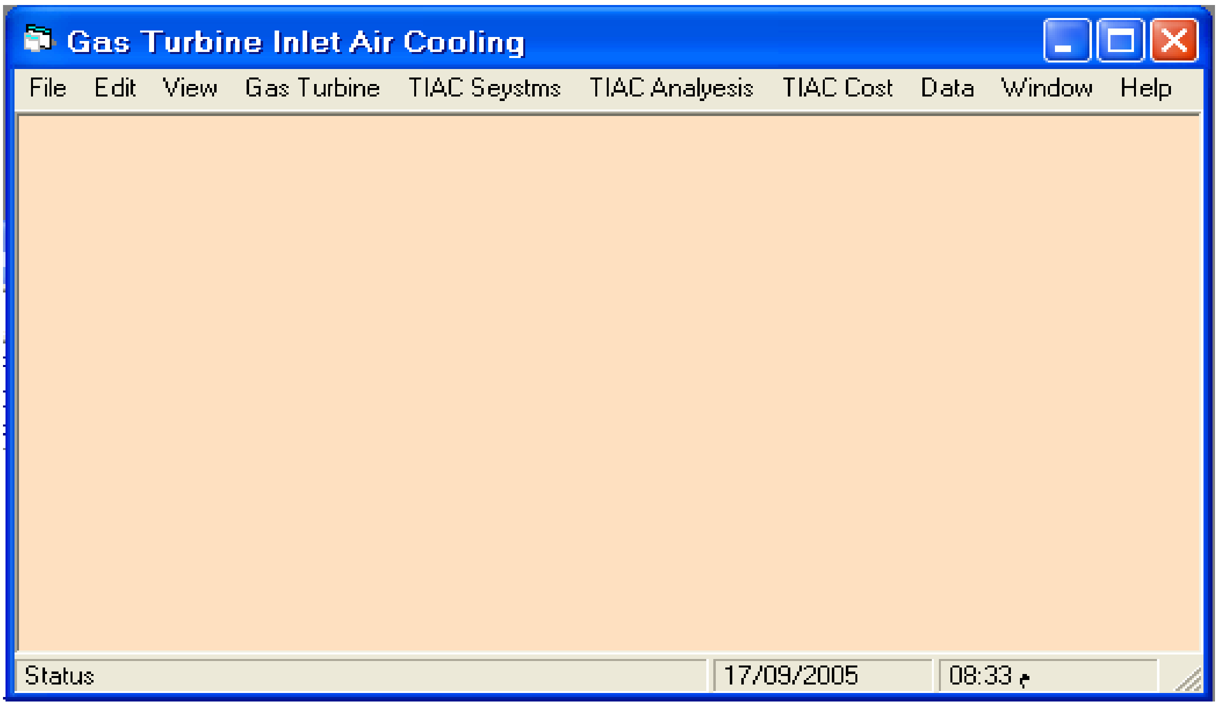


Fig. B-1 The Computer program Main screen

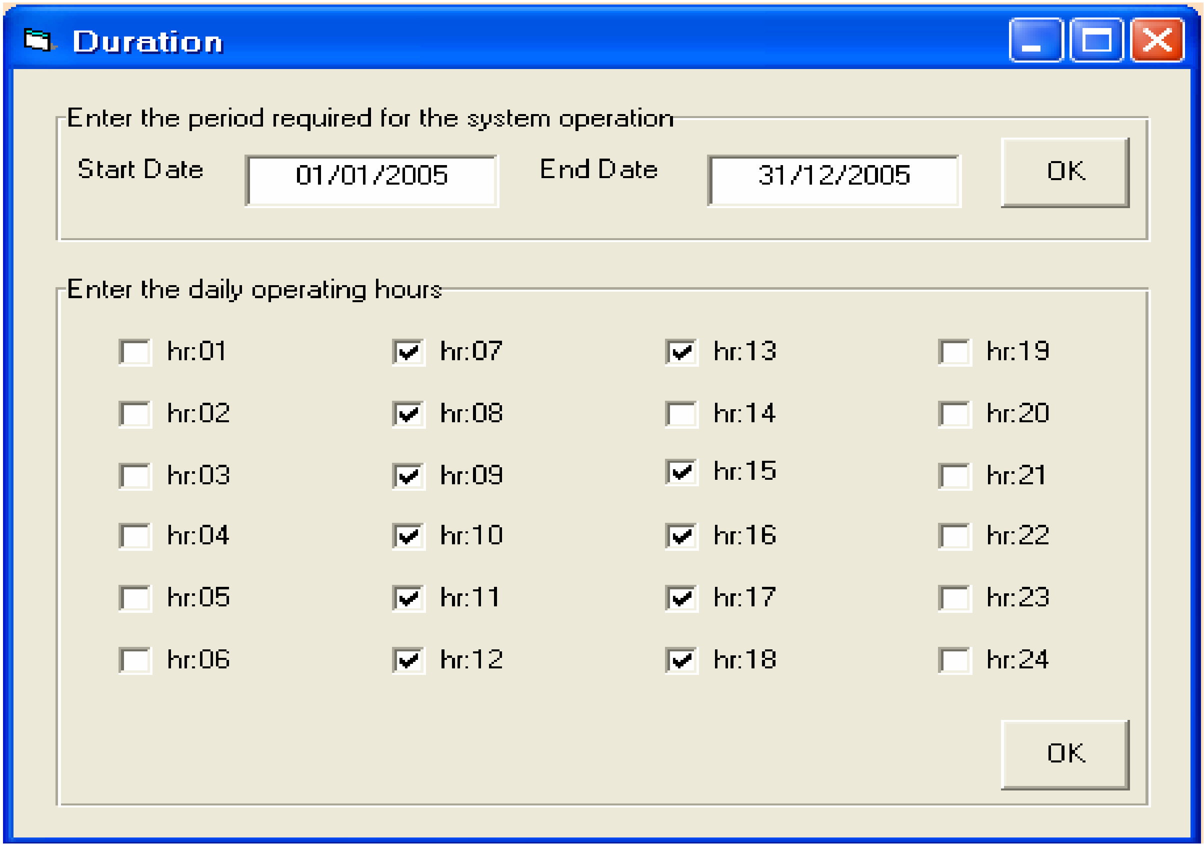


Fig. B-2 Required period Screen

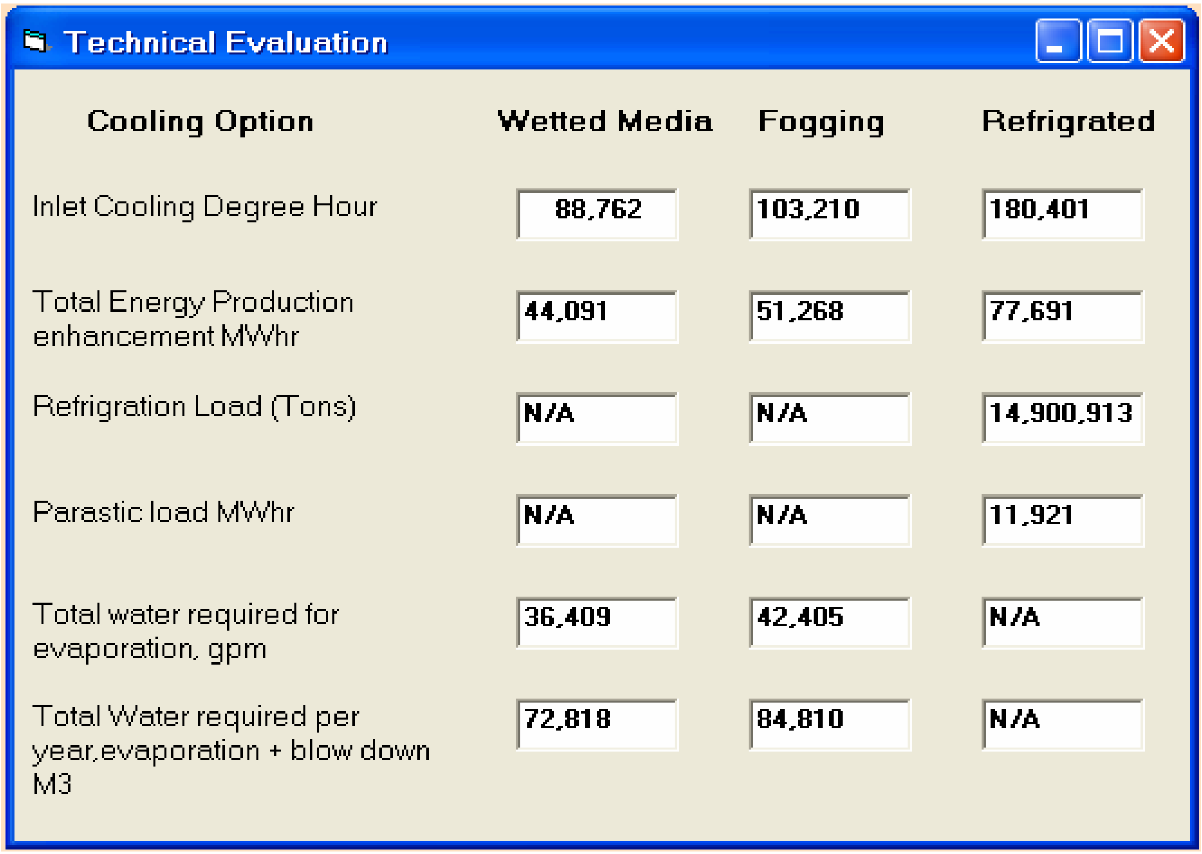
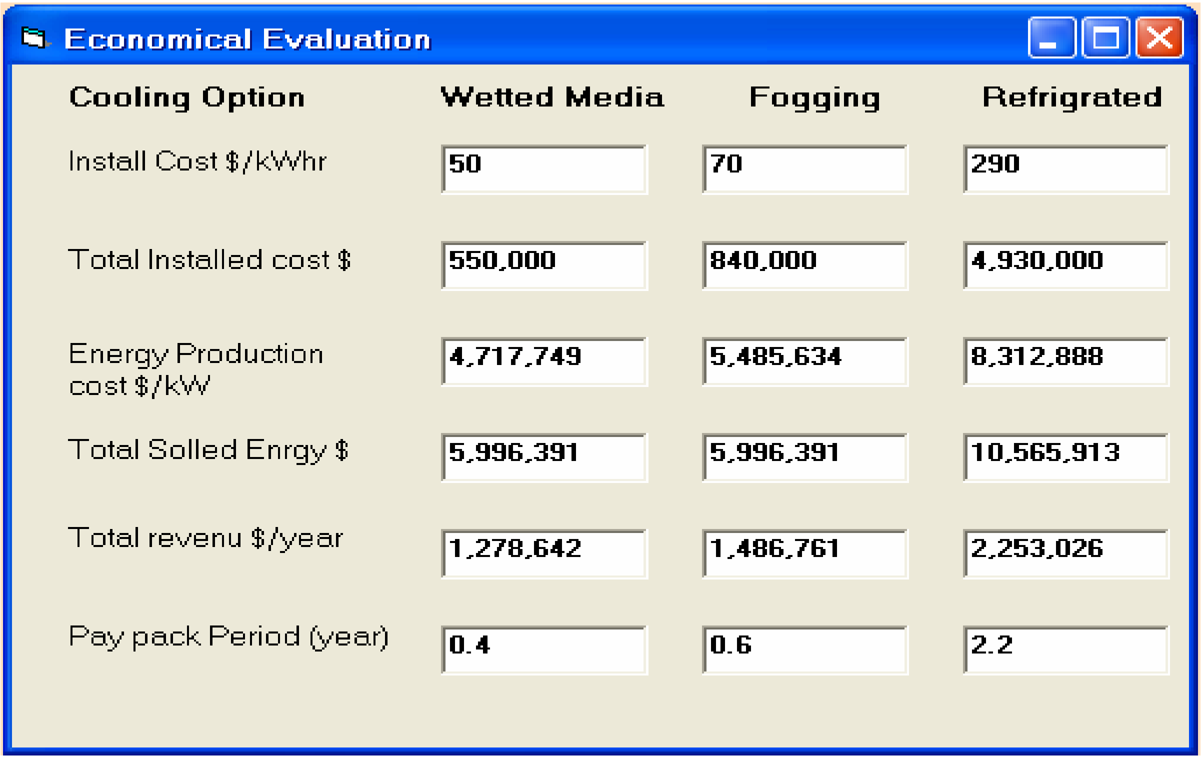


Fig. B-3 Technical Evaluation of TIAC systems


Economical Evaluation

Cooling Option	Wetted Media	Fogging	Refrigrated
Install Cost $/kWhr	50	70	290
Total Installed cost $	550,000	840,000	4,930,000
Energy Production cost $/kW	4,717,749	5,485,634	8,312,888
Total Solled Enrgy $	5,996,391	5,996,391	10,565,913
Total revenu $/year	1,278,642	1,486,761	2,253,026
Pay pack Period (year)	0.4	0.6	2.2

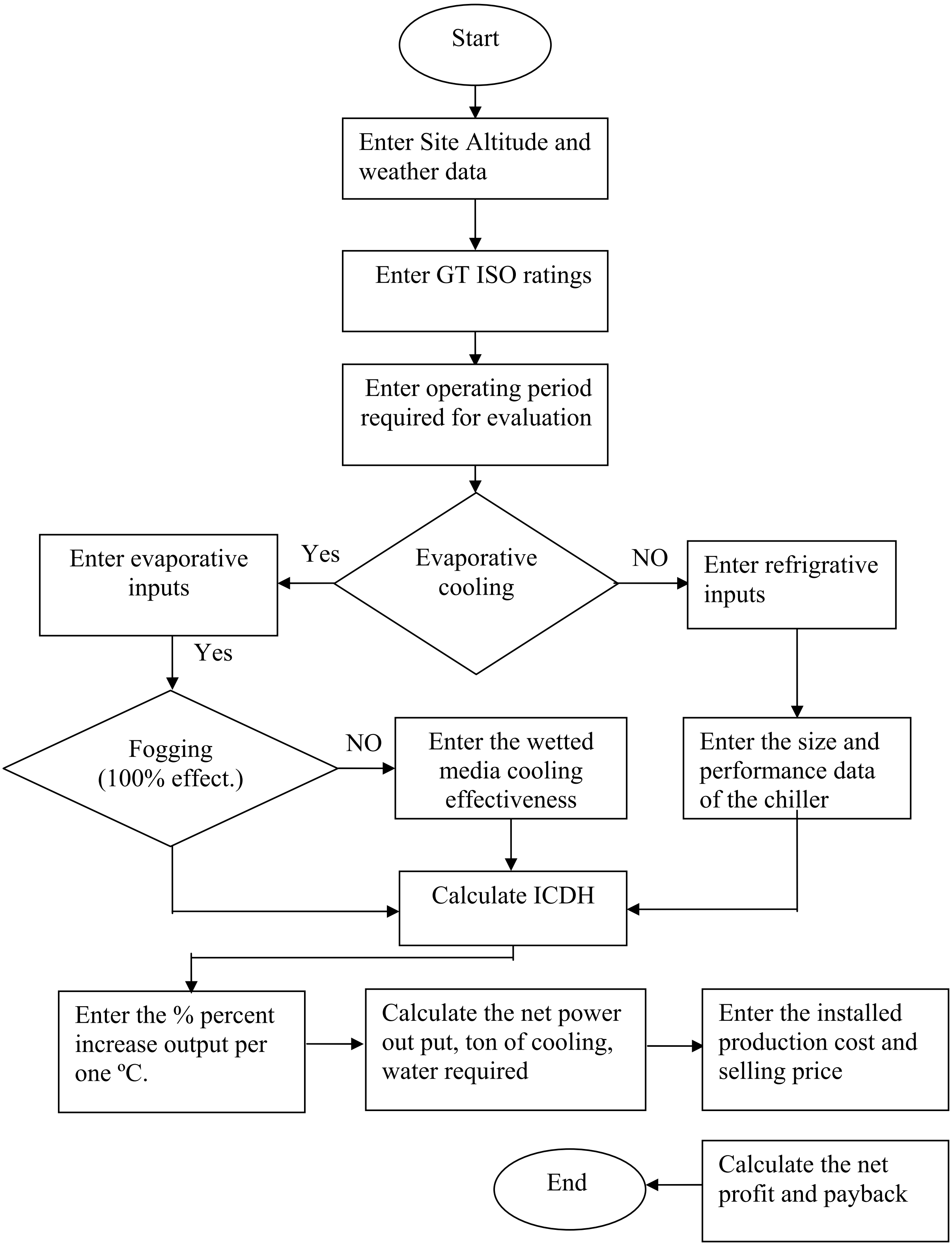
Fig. B-4 Economical Evaluation of TIAC systems

Appendix B2

Computer program flow chart

Compute program flow chart

The following diagram shows flow chart of the computer program



Appendix B3

Calculation Results

Table B-1a: Available ICDH of wetted media system with 85% effectivness

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	144	122	113	99	89	90	109	154	196	232	272	306
Feb	151	132	120	107	95	89	104	130	186	224	260	294
Mar	323	302	290	268	245	248	269	300	361	393	429	453
Apr	344	313	307	300	283	288	314	350	400	424	463	488
May	310	292	284	273	279	286	301	332	373	398	440	467
Jun	323	314	300	282	268	266	283	307	348	372	415	435
Jul	261	238	230	215	187	187	199	209	246	279	331	357
Aug	201	167	160	158	134	140	148	160	190	227	287	312
Sep	223	195	192	178	166	168	189	210	258	277	333	360
Oct	271	256	247	236	228	232	257	283	320	344	379	398
Nov	254	244	240	235	228	221	231	254	258	279	322	344
Dec	214	202	197	180	160	158	168	183	218	251	293	311
Total	**3,019**	**2,776**	**2,680**	**2,531**	**2,361**	**2,373**	**2,572**	**2,871**	**3,353**	**3,701**	**4,223**	**4,525**

Table B-2a: Ueseful ICDH of wetted media system with 85% effectivness

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	210	198	195	183	177	177	191	219	231	258	277	309
Feb	209	199	192	184	175	168	182	201	231	259	275	303
Mar	330	315	307	296	281	282	293	315	364	395	430	453
Apr	345	318	315	308	295	297	318	351	400	424	463	488
May	310	292	284	273	280	286	301	332	373	398	440	467
Jun	323	314	300	282	268	266	283	307	348	372	415	435
Jul	261	238	230	215	187	187	199	209	246	279	331	357
Aug	201	167	160	158	134	140	148	160	190	227	287	312
Sep	223	195	192	178	166	168	189	210	258	277	333	360
Oct	271	256	247	236	228	232	257	283	320	344	379	398
Nov	254	244	240	236	228	223	231	254	258	279	322	344
Dec	221	212	209	196	181	178	184	196	222	253	293	311
Total	**3,157**	**2,948**	**2,871**	**2,744**	**2,599**	**2,605**	**2,777**	**3,037**	**3,439**	**3,765**	**4,243**	**4,538**

Table B-1b: Available ICDH of wetted media system with 85% effectivness

Month/Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	319	338	341	327	318	296	269	239	216	197	174	156	5115
Feb	322	340	347	341	328	305	291	252	230	215	192	172	5226
Mar	465	491	497	495	475	462	444	419	393	381	360	346	9108
Apr	488	512	520	514	500	491	468	427	415	393	371	348	9720
May	476	492	496	488	477	458	429	390	374	365	341	321	9143
Jun	455	476	480	474	477	459	436	399	381	364	353	338	9007
Jul	383	416	424	423	413	394	375	354	338	318	299	281	7357
Aug	337	381	384	379	379	359	333	293	271	253	232	217	6102
Sep	379	403	409	405	407	386	361	316	300	287	264	250	6917
Oct	419	432	431	421	405	375	365	347	332	318	303	287	7887
Nov	365	382	387	385	371	350	336	300	282	273	271	259	7071
Dec	343	357	364	355	346	329	313	292	277	261	244	233	6251
Total	**4,750**	**5,021**	**5,080**	**5,009**	**4,896**	**4,665**	**4,421**	**4,027**	**3,809**	**3,624**	**3,405**	**3,208**	**88,902**

Table B-2b: Ueseful ICDH of wetted media system with 85% effectivness

Month/Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	322	340	344	331	322	303	280	262	247	238	228	221	6061
Feb	327	344	350	345	333	313	300	268	251	243	235	220	6107
Mar	465	491	497	495	475	462	444	419	393	381	363	352	9298
Apr	488	512	520	514	500	491	468	427	415	393	371	348	9768
May	476	492	496	488	477	458	429	390	374	365	341	321	9143
Jun	455	476	480	474	477	459	436	399	381	364	353	338	9007
Jul	383	416	424	423	413	394	375	354	338	318	299	281	7357
Aug	337	381	384	379	379	359	333	293	271	253	232	217	6102
Sep	379	403	409	405	407	386	361	316	300	287	264	250	6917
Oct	419	432	431	421	405	375	365	347	332	318	303	287	7887
Nov	365	382	387	385	371	350	336	300	282	273	271	259	7074
Dec	343	357	364	355	346	329	313	293	277	262	248	238	6383
Total	**4,759**	**5,027**	**5,087**	**5,016**	**4,907**	**4,679**	**4,441**	**4,068**	**3,861**	**3,696**	**3,509**	**3,331**	**91,103**

Table B-3a: Available ICDH for Fogging system with 100% effectiveness

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	247	233	229	216	208	208	225	257	271	304	326	364
Feb	246	234	226	216	206	198	214	237	271	305	323	357
Mar	388	371	362	348	331	332	345	370	428	464	506	533
Apr	406	374	370	362	347	349	374	412	470	499	544	575
May	365	344	335	321	329	337	354	391	438	468	517	550
Jun	380	369	353	332	315	313	333	362	410	438	489	512
Jul	307	280	271	253	221	221	235	246	289	328	389	420
Aug	237	197	188	186	158	165	175	188	224	267	338	367
Sep	263	229	226	209	195	198	223	247	304	326	391	424
Oct	319	301	291	278	268	274	302	333	377	405	446	468
Nov	299	288	283	278	268	262	272	299	303	329	379	405
Dec	260	249	246	230	213	210	217	231	261	298	345	366
Total	**3,715**	**3,469**	**3,378**	**3,228**	**3,057**	**3,065**	**3,267**	**3,573**	**4,046**	**4,429**	**4,992**	**5,339**

Table B-4a: Ueseful ICDH of Fogging system with 100% effectivness

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	158	136	125	110	99	99	117	164	211	254	306	350
Feb	162	140	127	112	99	93	109	135	199	249	293	333
Mar	357	328	309	282	251	252	280	323	410	452	499	529
Apr	396	355	347	337	317	323	354	404	468	498	544	575
May	365	342	332	316	323	332	352	391	438	468	517	550
Jun	380	369	353	332	315	313	333	362	410	438	489	512
Jul	307	280	271	253	221	221	235	246	289	328	389	420
Aug	237	197	188	186	158	165	175	188	224	267	338	367
Sep	263	229	226	209	195	198	223	247	304	326	391	424
Oct	319	301	291	278	268	274	302	333	377	405	446	468
Nov	297	287	280	275	263	256	269	297	303	329	379	405
Dec	242	226	221	200	178	176	190	204	250	290	344	366
Total	**3,481**	**3,189**	**3,069**	**2,888**	**2,685**	**2,700**	**2,936**	**3,292**	**3,883**	**4,302**	**4,935**	**5,297**

Table B-3b: Available ICDH for Fogging system with 100% effectiveness

Month/Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	378	401	405	389	379	356	330	308	290	280	269	260	7131
Feb	385	404	412	406	392	368	353	316	295	286	276	259	7185
Mar	547	578	584	582	559	544	522	493	463	449	427	414	10939
Apr	575	603	611	605	588	577	551	503	488	463	436	410	11491
May	560	579	583	574	562	539	505	459	440	429	402	378	10757
Jun	535	560	565	558	562	540	514	469	449	428	416	398	10596
Jul	451	490	499	498	486	464	442	416	398	374	352	330	8655
Aug	396	448	452	446	446	423	392	345	319	297	273	255	7178
Sep	446	474	482	477	479	455	425	372	354	338	311	294	8138
Oct	492	509	508	495	476	441	430	408	391	374	357	338	9278
Nov	429	450	456	453	437	412	396	353	332	321	319	305	8322
Dec	404	420	429	418	408	388	369	345	326	309	292	280	7510
Total	**5,599**	**5,914**	**5,984**	**5,901**	**5,773**	**5,505**	**5,225**	**4,785**	**4,542**	**4,348**	**4,129**	**3,919**	**107,180**

Table B-4b: Ueseful ICDH of Fogging system with 100% effectivness

Month/Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	368	392	393	378	363	334	300	261	234	214	189	171	5723
Feb	368	394	402	396	380	353	333	284	259	239	210	187	5851
Mar	545	578	584	580	559	544	522	487	456	439	406	386	10357
Apr	575	603	611	605	588	577	551	503	488	463	432	405	11318
May	560	579	583	574	562	539	505	459	440	429	402	378	10734
Jun	535	560	565	558	562	540	514	469	449	428	416	398	10596
Jul	451	490	499	498	486	464	442	416	398	374	352	330	8655
Aug	396	447	451	445	445	422	392	345	319	297	273	255	7173
Sep	446	474	482	477	479	455	425	372	354	338	311	294	8138
Oct	492	509	508	495	476	441	430	408	391	374	357	338	9278
Nov	429	450	456	453	437	412	396	353	332	321	319	305	8297
Dec	404	420	429	418	407	387	367	341	322	302	282	267	7229
Total	**5,570**	**5,893**	**5,961**	**5,876**	**5,743**	**5,465**	**5,173**	**4,697**	**4,439**	**4,217**	**3,946**	**3,713**	**103,349**

Table B-5a: Inlet Cooling Degree Hour (ICDH) of Refrigrative cooling

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	297	273	253	230	207	208	232	289	355	413	493	535
Feb	268	244	226	202	183	177	198	232	319	373	444	492
Mar	487	457	434	406	375	376	404	452	559	613	696	732
Apr	579	540	521	504	478	486	525	598	690	742	807	847
May	633	598	584	562	566	577	604	666	745	786	849	886
Jun	651	636	617	589	571	582	602	653	715	754	811	846
Jul	658	632	617	596	574	574	591	623	684	727	785	818
Aug	612	585	573	569	541	546	561	581	627	670	734	766
Sep	623	598	593	577	562	567	587	611	669	694	766	801
Oct	637	612	599	580	562	569	603	653	725	765	824	852
Nov	513	492	477	459	440	435	454	517	579	627	703	736
Dec	397	376	366	341	315	312	331	352	431	482	571	609
Total	**6,353**	**6,042**	**5,858**	**5,613**	**5,372**	**5,406**	**5,691**	**6,225**	**7,096**	**7,645**	**8,481**	**8,918**

Table B-5b: Inlet Cooling Degree Hour (ICDH) of Refrigrative cooling

Month/Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	560	596	596	579	555	517	475	425	394	368	337	312	9499
Feb	538	570	583	574	554	516	490	428	399	375	332	303	9016
Mar	762	811	820	808	776	750	715	653	614	586	542	521	14348
Apr	859	891	898	887	859	830	792	736	707	671	634	601	16678
May	904	924	931	920	900	867	822	770	745	720	684	655	17894
Jun	869	903	909	902	895	867	833	788	761	731	705	680	17868
Jul	848	883	890	885	872	847	818	787	761	730	708	685	17587
Aug	802	842	845	838	827	800	776	738	709	680	657	637	16512
Sep	826	858	865	858	853	823	787	737	715	694	660	650	16968
Oct	877	898	899	884	857	816	798	759	737	712	681	659	17557
Nov	761	777	784	765	736	704	673	626	597	577	553	530	14508
Dec	660	687	693	674	652	621	580	537	509	479	447	425	11840
Total	**9,265**	**9,637**	**9,710**	**9,571**	**9,335**	**8,956**	**8,558**	**7,982**	**7,646**	**7,322**	**6,939**	**6,656**	**180,275**

Table B-6: ANet MW-hr can be generated for TIAC options

Month	Uesful Inlet cooling degree hours (ICDH)			Refrigrative MW-hr Consumed				Net MW-hr can be generated		
	Refrig	Fog	wetted	ICDH	MW-hr	Cooling -T	Chiller load	Refrigrative	Fogging	wetted media
Jan	9,499	5,723	5,115	9,499	4,719	785,189	628	4,091	2,839	2,538
Feb	9,016	5,851	5,226	9,016	4,478	745,208	596	3,882	2,903	2,593
Mar	14,348	10,357	9,108	14,348	7,127	1,185,944	949	6,178	5,138	4,519
Apr	16,678	11,318	9,720	16,678	8,285	1,378,554	1,103	7,182	5,615	4,822
May	17,894	10,734	9,143	17,894	8,888	1,479,037	1,183	7,705	5,326	4,536
Jun	17,868	10,596	9,007	17,868	8,876	1,476,896	1,182	7,694	5,257	4,469
Jul	17,587	8,655	7,357	17,587	8,736	1,453,719	1,163	7,573	4,294	3,650
Aug	16,512	7,173	6,102	16,512	8,202	1,364,830	1,092	7,110	3,559	3,027
Sep	16,968	8,138	6,917	16,968	8,429	1,402,527	1,122	7,307	4,037	3,432
Oct	17,557	9,278	7,887	17,557	8,721	1,451,170	1,161	7,560	4,603	3,913
Nov	14,508	8,297	7,071	14,508	7,206	1,199,159	959	6,247	4,117	3,508
Dec	11,840	7,229	6,251	11,840	5,881	978,680	783	5,099	3,587	3,101
Total	180,275	103,349	88,902	180,275	89,548	14,900,913	11,921	77,628	51,275	44,107

Table B-7: Uesful and Available Inlet cooling degree hours (ICDH)

Month	Uesful Inlet cooling degree hours (ICDH)			Available Inlet cooling degree hours (ICDH)		
	Refrigrative	Fogging	wetted MD.	Refrigrative	Fogging	wetted MD.
Jan	9,499	5,723	5,115	9,499	7,131	6,061
Feb	9,016	5,851	5,226	9,016	7,185	6,107
Mar	14,348	10,357	9,108	14,348	10,939	9,298
Apr	16,678	11,318	9,720	16,678	11,491	9,768
May	17,894	10,734	9,143	17,894	10,757	9,143
Jun	17,868	10,596	9,007	17,868	10,596	9,007
Jul	17,587	8,655	7,357	17,587	8,655	7,357
Aug	16,512	7,173	6,102	16,512	7,178	6,102
Sep	16,968	8,138	6,917	16,968	8,138	6,917
Oct	17,557	9,278	7,887	17,557	9,278	7,887
Nov	14,508	8,297	7,071	14,508	8,322	7,074
Dec	11,840	7,229	6,251	11,840	7,510	6,383
Total/Avrg	180,275	103,349	88,902	180,275	107,180	91,103

Table: B-8a Water requirement (M3) for wetted media evaporative cooling 85% effectiveness.

Month / Hr	1	2	3	4	5	6	7	8	9	10	11	12
Jan	109	93	86	75	66	67	83	120	154	183	215	242
Feb	123	107	97	86	77	72	84	105	151	182	212	239
Mar	261	244	234	217	198	200	217	243	293	319	349	368
Apr	280	255	250	244	230	234	255	285	326	346	378	399
May	254	239	233	223	228	234	246	272	306	327	361	383
Jun	265	257	246	231	219	218	232	252	286	305	341	357
Jul	216	197	190	178	155	155	165	173	204	232	274	296
Aug	167	139	133	132	112	116	124	133	159	189	238	259
Sep	185	162	159	148	138	140	157	174	214	228	275	298
Oct	224	211	204	195	188	191	211	233	264	284	313	329
Nov	208	200	197	192	186	180	189	208	212	230	265	284
Dec	175	165	161	147	130	129	137	149	178	206	240	255
Total	**2,466**	**2,270**	**2,190**	**2,069**	**1,927**	**1,939**	**2,102**	**2,348**	**2,747**	**3,032**	**3,461**	**3,709**

Blow down rate =Evaporation rate

Table: B-8b Water requirement (M3) for wetted media evaporative cooling 85% effectivness

Month / Hr	13	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	252	265	267	256	249	232	212	187	172	153	135	122	3,996
Feb	262	277	282	278	267	249	237	205	187	175	156	140	4,249
Mar	378	400	404	402	387	376	361	340	319	309	292	281	7,395
Apr	399	419	424	420	408	400	382	349	338	321	302	284	7,927
May	391	403	407	401	392	376	352	320	307	299	280	263	7,496
Jun	373	391	394	390	392	377	358	328	313	299	290	277	7,394
Jul	317	344	350	350	341	326	310	292	279	263	247	232	6,089
Aug	280	315	318	314	313	297	276	243	225	210	193	180	5,062
Sep	314	333	338	335	336	319	298	261	249	238	219	207	5,727
Oct	346	357	356	348	334	309	301	287	274	262	250	237	6,509
Nov	301	315	319	316	305	288	276	247	232	224	222	212	5,808
Dec	281	293	298	291	284	270	256	239	226	213	199	190	5,110
Total	**3,894**	**4,111**	**4,160**	**4,100**	**4,007**	**3,817**	**3,619**	**3,297**	**3,121**	**2,965**	**2,785**	**2,624**	**72,760**

Blow down ra Blow down rate =Evaporation rate

Table B-9a: Water requirement (M3) for Fogging cooling with 100% effectivness

Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12	13
Jan	64	55	51	45	40	40	48	66	86	104	125	143	151
Feb	66	57	52	45	40	37	44	55	81	101	119	136	150
Mar	145	133	125	114	102	102	113	131	166	184	203	215	222
Apr	161	145	142	137	129	132	144	165	191	204	223	235	235
May	150	140	136	130	132	136	144	160	180	192	213	226	230
Jun	156	152	145	136	129	129	137	149	168	180	201	210	220
Jul	127	116	112	105	92	92	97	102	120	136	161	174	187
Aug	98	82	78	77	66	69	73	78	93	111	140	153	165
Sep	109	95	94	87	81	83	93	103	126	134	162	176	185
Oct	132	124	120	115	110	113	125	138	156	167	184	194	204
Nov	122	117	115	112	108	105	110	122	125	136	156	167	177
Dec	99	92	90	82	73	72	77	83	102	118	141	150	166
Total	**1,429**	**1,309**	**1,259**	**1,185**	**1,101**	**1,108**	**1,204**	**1,351**	**1,596**	**1,768**	**2,030**	**2,179**	**2,291**

Table B-9b: Water requirement (M3) for Fogging cooling with 100% effectivness

Month/Hr	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	160	161	154	148	136	122	106	95	87	77	69	2,334
Feb	161	164	162	155	144	136	116	105	97	85	76	2,382
Mar	236	238	236	228	221	212	198	186	178	165	157	4,211
Apr	247	250	248	241	236	225	206	199	189	176	165	4,624
May	238	240	236	231	221	207	189	181	176	165	155	4,408
Jun	231	233	230	231	222	211	193	185	176	171	163	4,357
Jul	203	206	206	201	192	183	172	164	155	146	137	3,587
Aug	185	187	184	184	174	162	143	132	123	114	106	2,979
Sep	196	199	197	198	188	176	154	147	140	129	122	3,373
Oct	210	210	205	197	182	178	169	161	154	147	140	3,834
Nov	185	188	186	180	170	163	145	137	132	131	125	3,412
Dec	172	176	172	167	158	150	139	131	123	115	109	2,958
Total	**2,424**	**2,452**	**2,416**	**2,360**	**2,246**	**2,125**	**1,930**	**1,824**	**1,732**	**1,620**	**1,524**	**42,459**

Table B-10a: Refrigrative inlet cooling load (Ton)

Month / Hr	1	2	3	4	5	6	7	8	9	10	11	12	13
Jan	24,541	22,565	20,912	19,011	17,110	17,176	19,201	23,896	29,327	34,137	40,750	44,246	46,296
Feb	22,152	20,168	18,680	16,655	15,126	14,589	16,325	19,168	26,351	30,831	36,675	40,667	44,469
Mar	40,272	37,799	35,873	33,559	31,021	31,079	33,410	37,369	46,172	50,685	57,488	60,505	62,960
Apr	47,842	44,602	43,086	41,659	39,469	40,130	43,362	49,396	57,017	61,348	66,704	69,969	70,977
May	52,280	49,429	48,230	46,412	46,742	47,693	49,941	55,053	61,563	64,952	70,134	73,234	74,722
Jun	53,812	52,570	51,024	48,685	47,222	48,106	49,784	53,934	59,058	62,282	67,035	69,911	71,804
Jul	54,347	52,231	50,958	49,263	47,404	47,404	48,850	51,454	56,573	60,091	64,861	67,588	70,052
Aug	50,597	48,354	47,321	46,990	44,717	45,131	46,370	48,007	51,784	55,380	60,687	63,332	66,315
Sep	51,495	49,387	48,999	47,652	46,412	46,825	48,495	50,503	55,281	57,364	63,290	66,200	68,250
Oct	52,628	50,578	49,511	47,941	46,470	47,032	49,842	54,000	59,959	63,199	68,134	70,415	72,482
Nov	42,395	40,667	39,386	37,939	36,328	35,914	37,485	42,692	47,825	51,784	58,066	60,794	62,935
Dec	32,773	31,038	30,211	28,145	26,037	25,748	27,359	29,054	35,584	39,841	47,197	50,297	54,553
Total	**525,133**	**499,387**	**484,192**	**463,911**	**444,057**	**446,826**	**470,424**	**514,525**	**586,493**	**631,894**	**701,020**	**737,157**	**765,814**

Table B-10b: Refrigrative inlet cooling load (Ton)

Month / Hr	14	15	16	17	18	19	20	21	22	23	24	Total
Jan	49,263	49,255	47,817	45,891	42,767	39,295	35,113	32,567	30,376	27,864	25,814	785,189
Feb	47,123	48,156	47,461	45,792	42,618	40,494	35,352	32,939	31,013	27,401	25,004	745,208
Mar	67,010	67,803	66,745	64,175	61,951	59,075	53,934	50,784	48,437	44,816	43,023	1,185,944
Apr	73,606	74,209	73,350	70,969	68,613	65,431	60,860	58,422	55,487	52,371	49,677	1,378,554
May	76,375	76,929	76,028	74,366	71,630	67,902	63,646	61,588	59,513	56,512	54,165	1,479,037
Jun	74,639	75,135	74,515	73,978	71,688	68,853	65,092	62,902	60,406	58,298	56,165	1,476,896
Jul	72,953	73,564	73,110	72,035	69,969	67,613	65,051	62,860	60,331	58,537	56,620	1,453,719
Aug	69,556	69,804	69,225	68,374	66,125	64,100	60,959	58,562	56,215	54,272	52,652	1,364,830
Sep	70,878	71,498	70,878	70,506	68,026	65,051	60,877	59,100	57,322	54,553	53,686	1,402,527
Oct	74,226	74,267	73,102	70,870	67,415	65,960	62,695	60,877	58,852	56,289	54,429	1,451,170
Nov	64,183	64,762	63,191	60,794	58,149	55,628	51,768	49,305	47,652	45,709	43,808	1,199,159
Dec	56,744	57,240	55,669	53,851	51,288	47,966	44,387	42,072	39,593	36,948	35,088	978,680
Total	**796,554**	**802,621**	**791,091**	**771,600**	**740,240**	**707,368**	**659,733**	**631,977**	**605,196**	**573,571**	**550,130**	**14,900,913**