TO DEVELOP A METHODOLOGY TO IMPROVE AIR-CONDITIONING OF AN OPERATIONAL DATA CENTRE FOR ENERGY EFFICIENCY

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ABSTRACT

Energy Efficiency has become an absolute essential not only because of depleting energy reserves but also due to the tightening economic conditions all around the world. In Pakistan a country gripped by energy crisis, this concept although very critical, is hardly implied – the main reason being the lack of awareness of the methods and techniques involved. This study makes an attempt to reduce this awareness gap. For that purpose the author collaborated with The National University of Sciences & Technology (NUST), Main Campus in H-12 and took on the task of implementing the energy efficiency concept on two of its main laboratories in the School of Electrical Engineering and Computer Science (SEECS) and Research Center for Modeling and Simulation (RCMS). In this regard, the objectives are twofold. The first step is to study the present layout and analyze the various inherent deficiencies. Based on that study, few major points are highlighted which include the inadequate redundancies of the system, improper zoning and the absence of humidity and temperature sensors. To counter these problems, the author has made detailed recommendations. The energy efficiency achieved through these measures although significant, is not drastic. To further enhance and improve the energy efficiency the author introduced the concept of free cooling. In this regard, the bin data spanning over the course of the last 16 years was collected from the metrological department and then keeping dry bulb tempertaure and humidity as base parametres a detailed analysis was carried out with the help of ASHRAE psychrometric, ELITE CHVAC and AUTOCAD. An inside tempertaure range of 18 to 22℃ was defined for the sake of this study and with the help of ASHRAE recommended envelopes, it was shown that this range can be applied safely till an outisde tempertaure as much as 27℃. This result of free cooling comes in the form of a radical increase in the Coeffieicnt of Performance (COP) of the cooling equipment.

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LIST OF ABBREVIATIONS

SEECS	School of Electrical Engineering and Computer Science
RCMS	Research Center for Modeling and Simulation
TR	Tons of Refrigeration
CRAC Unit	Computer Room Air-Conditioning Unit
CFM	Cubic Feet per Mint
Btu	British thermal unit
IT	Information Technology
UPS	Uninterrupted Power Supply
FDS	Fire Detection and Suppression
Kw	Kilowatt
COP	Coeffieicnt of Performance
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers

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1 INTRODUCTION

1.1 Energy Consumption in Buildings

Energy conservation has become one of the most important issues in countries all around the world, especially the third world countries, where either the energy sources are scarce or have not been tapped effectively. Contrary to many general perceptions, most of the energy wastage occurs in domestic buildings. A breakdown of the energy consumption in United States [1] has been shown in Figure 1-1. Here the pie chart clearly shows that domestic buildings account for a total of 46 percent energy consumption, while the industrial sector consumes nearly half of it [2]. A major chunk of the domestic energy wastage arises from heating and cooling issues [3].

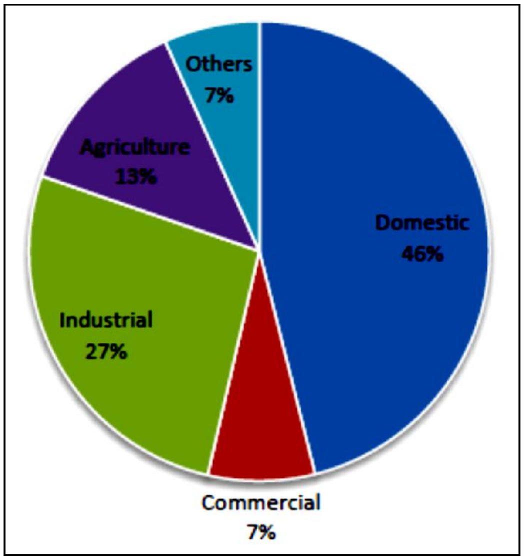


Figure 1-1 - Sector wise energy consumption

Holistically speaking, buildings consume about 53 percent of the total energy supply in United States. Same is the situation in other countries, if not worse, and as such there is a strong need of developing some techniques through which the limited energy resources can be efficiently utilized, while saving a lot of cost.

1.2 Energy Crisis in Pakistan

Pakistan, like most South Asian countries, ranks very high among countries where there is wide scale inefficient use of energy. The result is evident in the form of massive energy shortfalls, according to one estimate 4000 MW [4]. This has led not only in massive down fall of the industrial sector which has either moved its base, or has switched from electric energy to other alternates like compressed natural gas and liquefied natural gas. According to a report published in 2006 the intensity of Total Primary energy supply is about twice that of the global average [5]. This inefficient use of energy persists when it comes to domestic consumption and is in fact alarming. This trend is shown in Figure 1-2 [6].

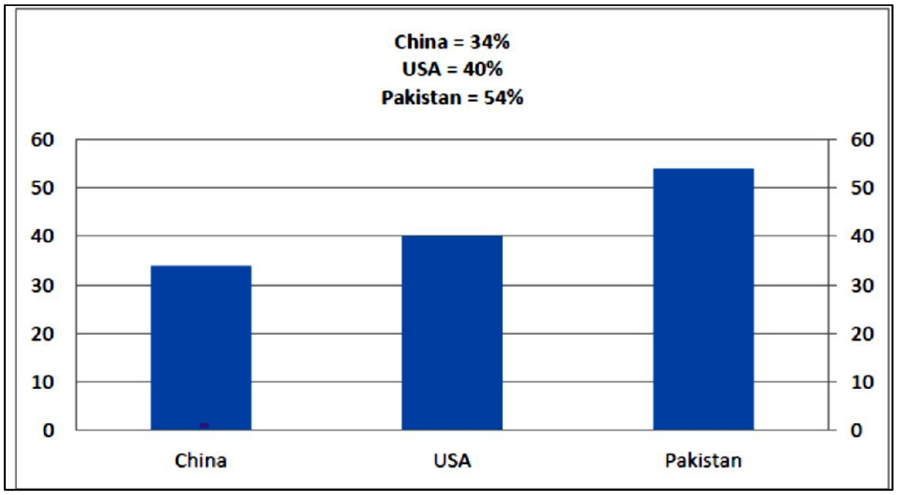


Figure 1-2 - Inefficient Energy Consumption in buildings – a comparison

1.3 Data Centers

A data center can generally be defined as a dedicated space which houses high performance computers, storage servers, communication racks, and a host of other information technology (IT) equipment. These centers form the base from where digital data can be managed, processed and exchanged [7, 8]. The main components of a typical data center have been shown in Figure 1-4 while the auxiliary components have been shown in Figure 1-4.

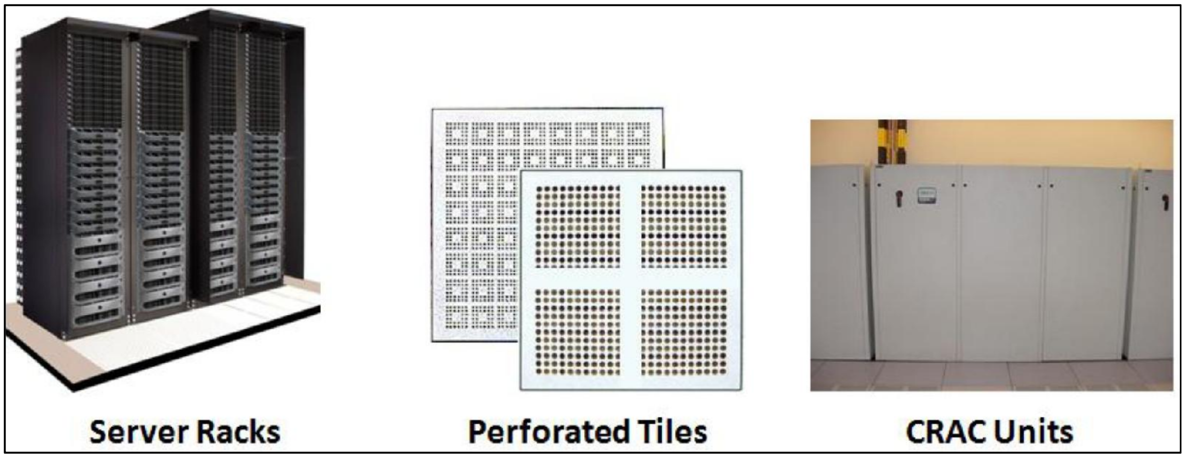


Figure 1-3 - Main components of a data center

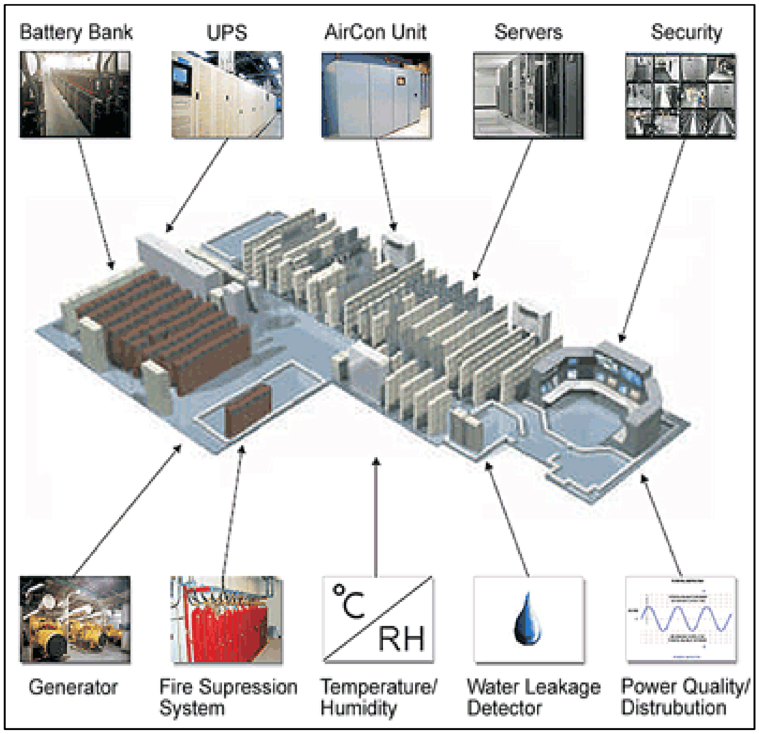
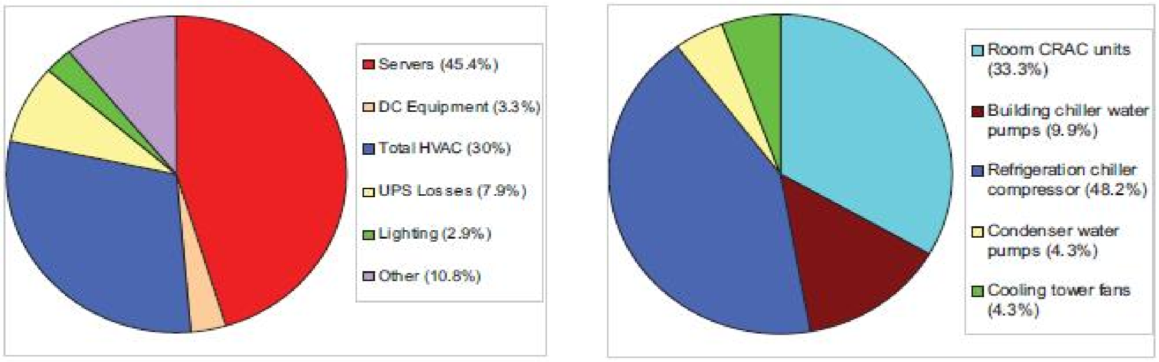


Figure 1-4 - Components of a typical data center

Although highly effective in data management, major downside of these data centers is the large amount of energy consumption both in domestic and industrial use [9, 10]. In Figure 1-5(a) [11], the breakdown of energy consumption in data centers is shown. Out of the total consumption, cooling uses one third of energy. Two primary contributors are refrigeration Chillers and CRAC units as shown in Figure 1-5(b).



(a) (b)

Figure 1-5 - Review of Energy Consumption in Data Centers

A typical data server consumes about 30 KW of power and with the ominous introduction of ultra-dense computing architectures in the next few years; this power consumption is projected to increase to as much as 70 KW [12]. The number of racks in a building can vary depending upon the nature of operational use, but there can be hundreds and in some cases even thousands of racks in a building, all of which amounts to an extremely high rate of energy consumption.

According to a report published in 2007 [13], buildings, housing data centers can be as much as 40 percent more energy intensive as compared to normal buildings. Between 2005 and 2010, the energy consumption by data centers increased by 36 percent in the Unites States, which made nearly two percent of the total energy consumption in the country [14]. A major chunk of energy consumed by the data centers is accounted by the cooling systems, mainly computer room air conditioning units (CRACs). In fact, nearly 40 percent of the power consumption is due to the operation of CRACs [15, 16]. The main objective of researchers is therefore to introduce ways through which this huge energy consumption can be reduced to a significant extent.

In a traditional cooling system large amount of energy is consumed through losses in piping system, pumps and fans while it is also dissipated by the mixing of hot and cold air streams. These hurdles can however be overcome by using frequency conversion fans [17], ceiling coolers [18, 19], rack backdoor coolers [15], using properly designed and optimized perforated tiles [20, 21, 22, 23], proper relative positioning of the racks [24, 25] and optimizing the mode of supply and return air [26, 27]. However, to avoid the high energy consumption of the cold source free cooling represents an ideal choice. In this approach, ambient air is used to cool data center equipment. The potential for this cooling depends on the atmospheric parameters, such as dry-bulb temperature and humidity. In more holistic terms, this potential depends on the capability of ventilation [28]. It is pertinent to note that free cooling does not involve mechanical cooling equipment; in fact, it complements these equipment and increases the energy efficiency.

There are a number of studies in literature which indicate that considerable energy savings can be made by using this technique. Bulut et al. and Zhang et al. [29, 30] organized the bin weather data for different cities of Turkey and China respectively. This bin data can be used to extract free cooling potential of the atmosphere. Bulut et al. then used this bin data concept to study the free-cooling potential in domestic environment [31]. This bin data model quickly became the most commonly used concept to investigate the free-cooling potential of any given environment. Papakostas et al. [32] further worked on this concept and developed the data for 38 Greek cities. Ghiaus et al. [28] studied the potential for free cooling in domestic environment using a method centered on the indoor-outdoor temperature differences. Dovrtel et al. [33] studied the free-cooling method with variable flow rate control, which incorporated weather forecasts into a control system. Budaiwi et al. [34] investigated the energy performance of an economizer cycle under three different climatic conditions and delivered significant results with regard to energy-saving potential.

These studies showed that for the purpose of energy efficiency, free cooling method should only be employed when the outdoor air temperature is sufficiently low to use as the cooling medium [35]. This is exactly the theme which has been followed in the study, where we have reduced ourselves to three specific months. The concept of free cooling technology dictates that the mechanical cooling systems installed within a data center/building are subtracted while the ventilation capacity is tampered with using various variables [28].

There are many control methods through which energy savings through free cooling can be achieved. Wacker et al. [36] explored the energy savings and thermal comfort effect of free cooling technology applied to a rooftop air conditioning system in Asheville, NC, U.S.A. His results showed a remarkable difference between the energy savings when the differential enthalpy control and dry-bulb temperature control methods were used, with the efficiency being higher in the latter case. However as far as the thermal comfort conditions are concerned, the differential enthalpy control method has greater efficiency. Ye et al [37] investigated the energy saving ratio of air-side free cooling in office buildings within six different climatic zones in China. He used temperature and enthalpy controls and deduced that more energy saving can be achieved in regions with greater humidity levels, even if they are hotter than those regions with low humidity percentages. He also connected the enthalpy control free cooling method with humidity, the energy efficiency being greater in the hot-humid climate zone and lower in the dry climate zone.

Yiu et al. [38] further worked on enthalpy control for energy efficiency and made his case studies in urban, suburban, and rural areas which adopted air-side free cooling. He found that the energy savings were higher in suburban areas, and also used the ASHRAE defined A2 and A3 envelopes.

Harvey et al. [39] used the atmospheric dry-bulb temperature and dew point temperature as his free cooling efficiency parameter and calculated the total number of hours in a year when the outdoor dry-bulb temperature and dew point temperature were lower or equal to Classes A2 and A3 in North America, Europe, and Japan.

1.4 AIM OF STUDY

The aim of this study is to propose a methodology to optimize energy consumption in the SEECS and RCMS labs, by removing its sole dependence from mechanical cooling equipment. We have used the bin data concept for free cooling. This data, spanning over the course of last 16 years, is collected from the Metrological Department of Pakistan. Free cooling is achieved keeping dry bulb tempertaure and humidity as base parameters with detailed analysis performed with the help of ASHRAE psychrometric charts and softwares, such as ELITE, CHVAC, and AUTOCAD. An inside tempertaure range of 18 to 27℃ is defined and with the help of ASHRAE recommended envelopes, it is shown that this range can be applied safely till an outisde tempertaure of as much as 27℃. In general, free cooling concept incorporates the usage of air side economizers. However, in this study, an effort has been made to achieve free cooling solely dependent on the outisde ambient tempertaure. It is for this reason, the ideal months for complete free cooling have been highlighted.

1.5 Objectives

The objectives of the research conducted here can be enumerated as follows:

a. To perform energy budget of both data centers.
b. To investigate and improve the HVAC design for energy efficiency
c. To investigate the free cooling potential

1.6 Methodology

The methodology used in this thesis is shown in Figure 1-6.

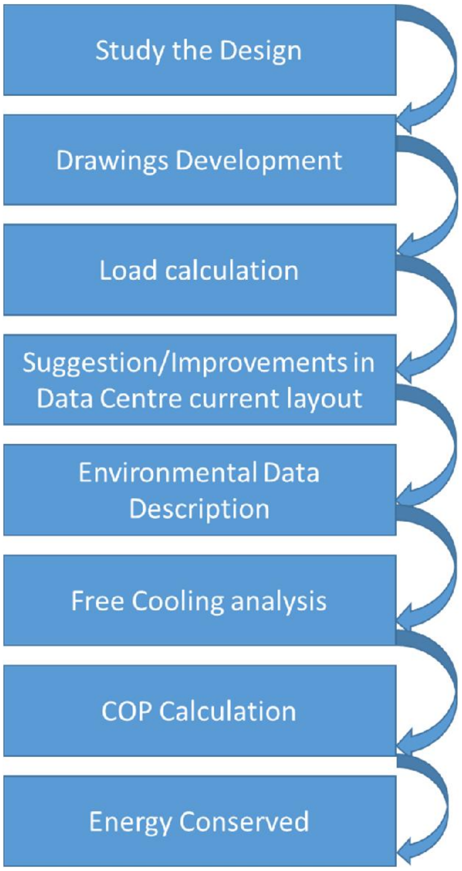


Figure 1-6 – Methodology

2 DATA CENTRE ANALYSIS

2.1 Data Centre Overview

In this study two operational data centres are under focus, namely SEECS and RCMS, both located the National University of Sciences and Technology (NUST) in Sector H-12. The first objective was to carry out a detailed study of these data centres with respect to energy efficiency. This comprehensive study included all the aspects of the data centre ranging from its rack capacities to associative electrical system and the air-conditioning system already in place. To execute this study the first pre-requisite is a thorough understanding of all the components of the data centre. The detailed description of these components have already been discussed in Chapter one; here, we will be more focused about the system ratings and tier of the system (redundancy level).

2.2 SEECS

For clarification, we will first discuss the SEECS data centre in detail followed by the RCMS data centre.

2.2.1 Component Description

Following are the components installed inside the SEECS data centre.

a. **Server Racks**

   There are a total of 14 server racks inside the SEECS data centre. Currently, the maximum rack capacities being used are 4.5 KW per rack and they have a future desire to increase the capacity up to 6 KW per rack.

b. **Communication Racks**

   There are a total of four communication rack inside the data centre. Normally, these racks have a low capacity and in consideration with that, they are presently operating at 3 KW per rack and the maximum load to which it can be extended is 4 KW.

c. **CRAC Units**

Currently there are two CRAC units installed in the centre with a capacity of 20.64 TR each. They have two compressors each, having capacities of 10.32 TR.

d. **UPS**

There are three UPS's installed in the data centre each having capacities of 80 KVA.

e. **GEN-SET**

There is a single generator with a capacity of 250 KVA.

2.2.2 TIER OF SYSTEM

The current system has been designed on tier 2. The detailed schematic of a standard tier 2 system is shown in Figure 2-1. As defined in Chapter one, in tier 2 system, we have a redundancy criteria of n+1. This redundancy is often taken in the critical components of power supply, which in this case are the UPS's and Gen-Set. Taking the current line diagram into account, the system has a total requirement of let's say 'X' KVA. We divided that total capacity into three and installed three generator sets for that. However, to cater for the redundancy, we installed yet another generator. Thus in case of any failure in the gen-sets, we have a redundancy of one as shown in Figure 2-2.

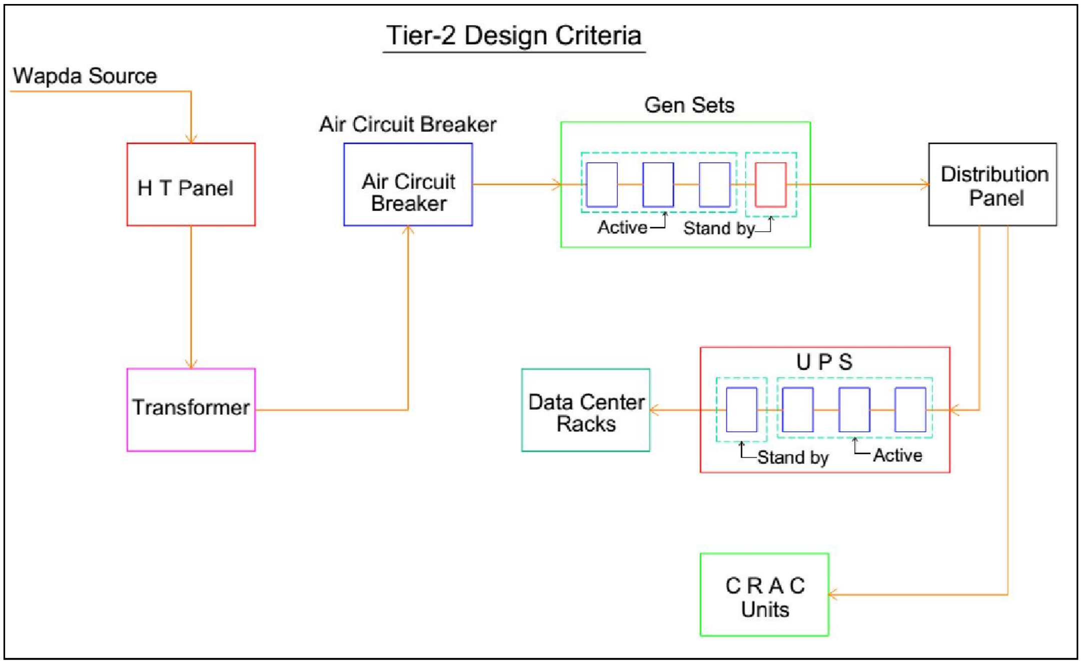


Figure 2-1 - Tier 2 Design Schematic

In the SEECS data centre though, only a single gen-set has been installed and the redundancy of the system is zero. Thus in case of failure of that only generator, the entire system will be shut down, which is highly detrimental to the basic operational philosophy of the data centre.

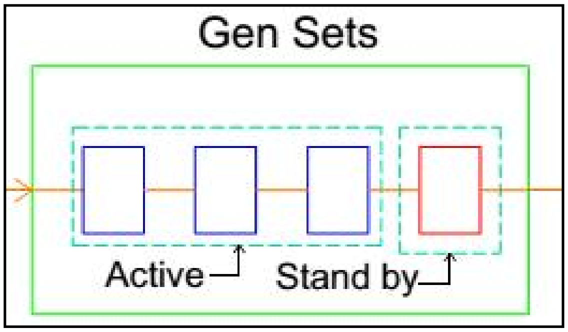
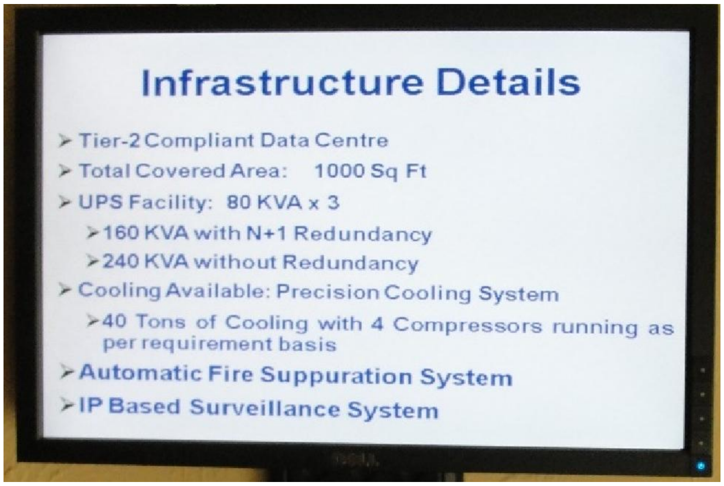


Figure 2-2 - Schematic of Gen-Set in Tier - 2 Systems

The second major drawback is that there is one alternate power source, which cumulatively encompasses the whole capacity of the data centre. This is also a malpractice, as the alternate source should be broken down into as many units as possible, or at least two in this case. Thus the tier 2 criteria cannot be fulfilled based only on the gen-set system.

Similarly, as far as the UPS's are concerned, the same n+1 criteria for redundancy is followed. In our case, there are two active and one redundant UPS for the system. Thus the tier 2 criteria is fulfilled. As can be seen from the line diagram, there are multiple panels and switches etc. where redundancy can also be applied. However, we are intentionally foregoing those details, because they are under focus.



Infrastructure Details

- Tier-2 Compliant Data Centre
- Total Covered Area: 1000 Sq Ft
- UPS Facility: 80 KVA x 3
  - 160 KVA with N+1 Redundancy
  - 240 KVA without Redundancy
- Cooling Available: Precision Cooling System
  - 40 Tons of Cooling with 4 Compressors running as per requirement basis
- Automatic Fire Suppuration System
- IP Based Surveillance System

Figure 2-3 - SEECS Data Centre Display Information

It is pertinent to mention here that UPS's can only operate the racks inside the data centre. They however cannot operate the CRAC system installed inside. It is therefore impossible to impose the tier 2 criteria on the SEECS data centre, see Figure 2-3.

2.2.3 Drawings

The next step was to take the measurements of the entire data centre including the equipment and components inside. Based on these measurement, the detailed schematics of the data centre were developed by using Autocad 2011 are shown in Figure 2-4, Figure 2-5 and Figure 2-6.

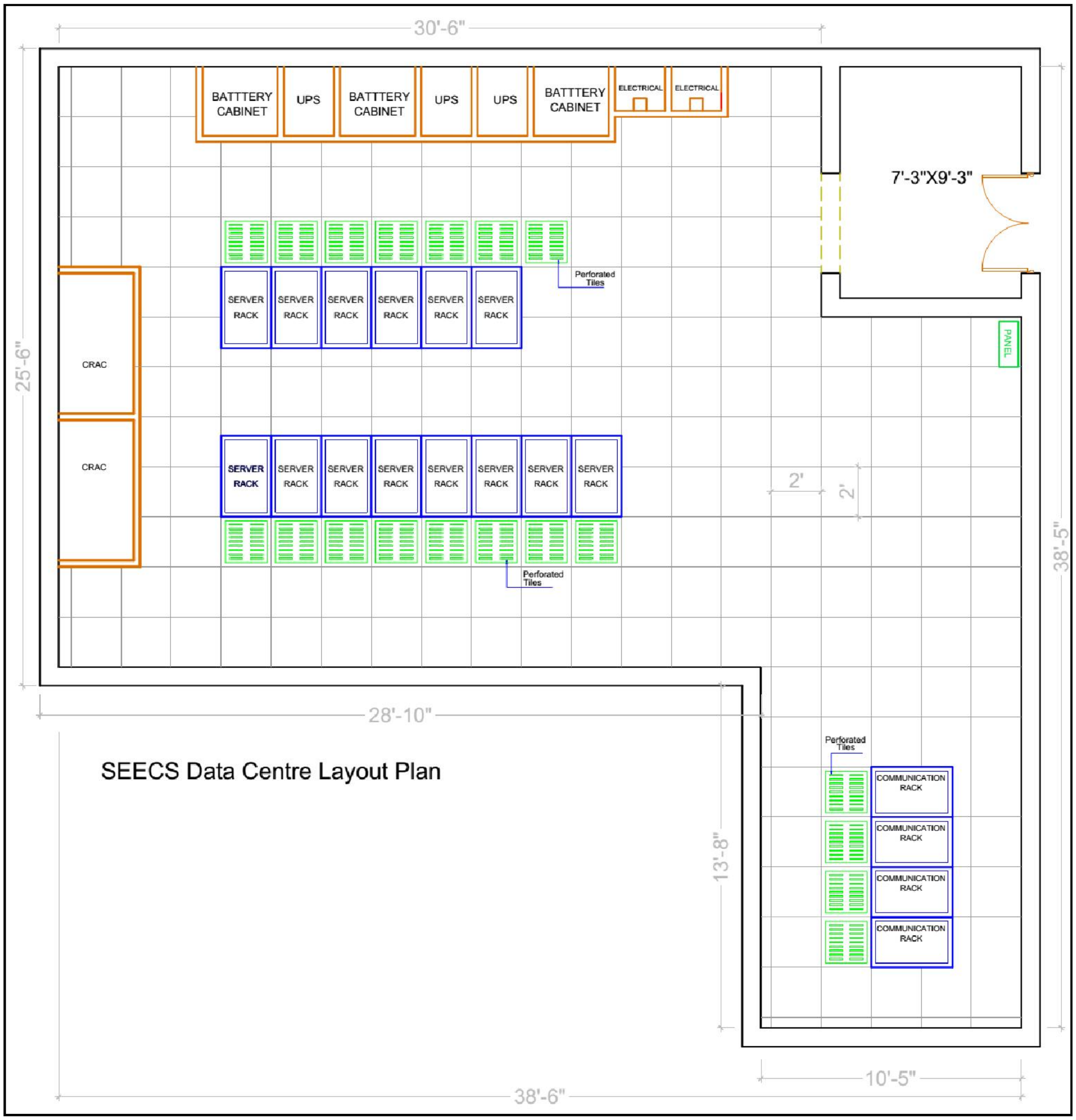


Figure 2-4 - SEECS Data Centre Layout Plan

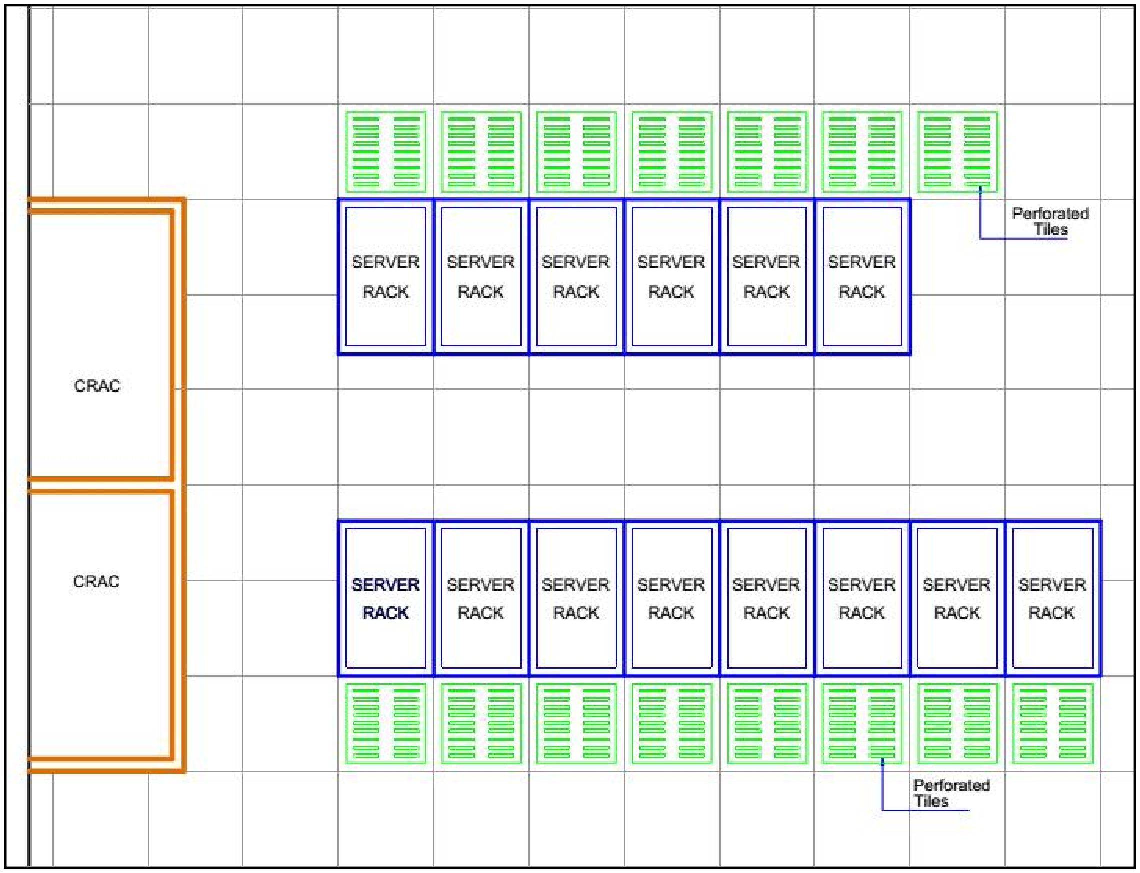


Figure 2-5 - SEECS Data Centre Blowup of CRAC Units and Data Racks

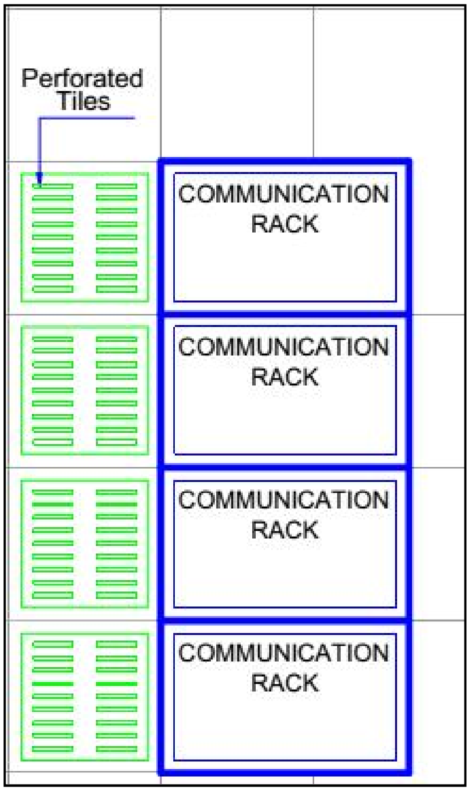


Figure 2-6 - SEECS Data Centre Blow up of Communication Racks

2.2.4 Cooling Load Calculations

The first step is to calculate the load of empty room, which will remains constant, and we can then apply varying conditions. These load calculations have been shown in Annexure 'A'. These calculations have been carried out with the help of ELITE CHVAC Version 7. According to these calculations, the total cooling required is 2.32 TR. The load consumption for the data centre, as indicated by the panel installed inside it, indicate that a 60 - 70 KVA is the normal operating range. The maximum load is 90 KVA. It means that the data centre has not reached a high density so far. Keeping this in mind, we have divided the load calculations at four different densities, which have been shown in Table 2-1, Table 2-2, Table 2-3 and Table 2-4. First, we are considering the higher load density for the racks, i.e. 6 KW for the data racks and KW for the communication racks. The load summary for this rack density has been given in Table 2-1.

Server Rack Load (Kw)	**No. Of Server Racks**	**Total Server Racks Load (Kw)**	**Total Server Racks Load (TR)**	**Total Server Racks Load (Btu/hr)**
6	14	84.00	23.88	286,619.90
Communication Rack Load (Kw)	**No. Of Communication Racks**	**Total Communication Racks Load (Kw)**	**Total Communication Racks Load (TR)**	**Total Communication Racks Load (Btu/hr)**
4	4	16.00	4.55	54,594.27
TOTAL		**100.00**	**28.43**	**341,214.16**
UPS + Battery Bank Load (Kw)	**No. of UPS + Battery Banks**	**Total UPS + Battery Banks Load (Kw)**	**Total UPS + Battery Banks Load (TR)**	**Total UPS + Battery Banks Load (Btu/hr)**
5.05	3	15.16	4.31	51,732.00
Space Load	**No. of Spaces**	**Total Space Load (Kw)**	**Total Space Load (TR)**	**Total Space Load (Btu/hr)**
8.17	1	8.17	2.32	27,876.00
GRAND TOTAL				**420,822.16**

Table 2-1 - SEECS Data Centre Equipment Load Summary (At High Density)

The total load in this condition is 123 KW or 35.07 TR. It is important to note that only one CRAC unit is operated in the data center with 20 TR, which means that the load is 20 TR or below. However as mentioned that the normal operating range lies from 60-70 KVA with highest random value reaching as much as 90 KVA, so we need to cater for lower densities as well which have been done as well.

Now we consider that the higher density which we have calculated is not viable and divide the density by two. The calculations have been shown in Table 2-2.

Server Rack Load (Kw)	**No. Of Server Racks**	**Total Server Racks Load (Kw)**	**Total Server Racks Load (TR)**	**Total Server Racks Load (Btu/hr)**
3	14	42.00	11.94	143,309.95
Communication Rack Load (Kw)	**No. Of Communication Racks**	**Total Communication Racks Load (Kw)**	**Total Communication Racks Load (TR)**	**Total Communication Racks Load (Btu/hr)**
2	4	8.00	2.27	27,297.13
TOTAL		**50.00**	**14.22**	**170,607.08**
UPS + Battery Bank Load (Kw)	**No. of UPS + Battery Banks**	**Total UPS + Battery Banks Load (Kw)**	**Total UPS + Battery Banks Load (TR)**	**Total UPS + Battery Banks Load (Btu/hr)**
5.05	3	5.16	4.31	51,732.00
Space Load	**No. of Spaces**	**Total Space Load (Kw)**	**Total Space Load (TR)**	**Total Space Load (Btu/hr)**
8.17	1	8.17	2.32	27,876.00
GRAND TOTAL		**73.33**	**20.85**	**250,215.08**

Table 2-2 - SEECS Data Centre Equipment Load Summary (At High Density/2)

The 20.85 TR is still higher than the load which is required in the data center. Thus we take into account two more densities, as shown in Table 2-3 and Table 2-4, respectively.

Server Rack Load (Kw)	No. Of Server Racks	Total Server Racks Load (Kw)	Total Server Racks Load (TR)	Total Server Racks Load (Btu/hr)
4.5	14	63.00	17.91	214,964.92
Communication Rack Load (Kw)	**No. Of Communication Racks**	**Total Communication Racks Load (Kw)**	**Total Communication Racks Load (TR)**	**Total Communication Racks Load (Btu/hr)**
3	4	12.00	3.41	40,945.70
TOTAL		**75.00**	**21.33**	**255,910.62**
UPS + Battery Bank Load (Kw)	**No. of UPS + Battery Banks**	**Total UPS + Battery Banks Load (Kw)**	**Total UPS + Battery Banks Load (TR)**	**Total UPS + Battery Banks Load (Btu/hr)**
5.05	3	15.16	4.31	51,732.00
Space Load	**No. of Spaces**	**Total Space Load (Kw)**	**Total Space Load (TR)**	**Total Space Load (Btu/hr)**
8.17	1	8.17	2.32	27,876.00
GRAND TOTAL		**98.33**	**27.96**	**335,518.62**

Table 2-3 - SEECS Data Centre Equipment Load Summary (At Low Density)

Currently the CRAC unit installed in the SEECS lab is a STULZ, cyber air 2, ALD 702 with R407C (having two compressors). The detailed specifications of this unit have been shown in Table 2-5.

Server Rack Load (Kw)	No. Of Server Racks	Total Server Racks Load (Kw)	Total Server Racks Load (TR)	Total Server Racks Load (Btu/hr)
2.25	14	31.50	8.96	107,482.46
Communication Rack Load (Kw)	**No. Of Communication Racks**	**Total Communication Racks Load (Kw)**	**Total Communication Racks Load (TR)**	**Total Communication Racks Load (Btu/hr)**
1.5	4	6.00	1.71	20,472.85
TOTAL		**37.50**	**10.66**	**127,955.31**
UPS + Battery Bank Load (Kw)	**No. of UPS + Battery Banks**	**Total UPS + Battery Banks Load (Kw)**	**Total UPS + Battery Banks Load (TR)**	**Total UPS + Battery Banks Load (Btu/hr)**
5.05	3	15.16	4.31	51,732.00
Space Load	**No. of Spaces**	**Total Space Load (Kw)**	**Total Space Load (TR)**	**Total Space Load (Btu/hr)**
8.17	1	8.17	2.32	27,876.00
GRAND TOTAL		**60.83**	**17.30**	**207,563.31**

Table 2-4 - SEECS Data Centre Equipment Load Summary (At Low Density/2)

Description	Cooling Capacity (Watt)	Cooling Capacity Btu/h)	Unit Quantity (No)	Total Cooling Capacity (Watt)	Total Cooling Capacity (Btu/h)	Total Cooling Capacity of 2 Units (TR)
Stulz, cyber air 2, ALD 702 with R407C (Two Compressors)	72,600.00	247,721.41	2.00	145,200.00	495,442.83	**41.28**

Table 2-5 - SEECS Data Centre CRAC Unit Specifications

In the above four cases, the load was calculated manually. However, in order to garner more accurate results, the whole process was also run on ELITE CHVAC, which is the state of the art air-conditioning load calculation software.

The summary of the load calculation through both methods has been given in Table 2-6.

Description	Load Calculated manually (Btu/hr)	Load Calculated with Elite CHVAC (Btu/hr)	Error (%)
At High Density	420,822.16	439,585.00	4.46
At High Density/2	250,215.08	260,831.00	4.24
At Low Density	335,518.62	350,207.00	4.38
At Low Density/2	207,563.31	216,143.00	4.13

Table 2-6 - SEECS Data Centre Equipment Load Comparison

The difference between the numerical and manually calculated values is because of fan heat gains, supply duct heat gains and return duct heats gains which we had neglected in our manual load calculation here.

2.3 RCMS

2.3.1 Component Description

Following are the components installed inside the RCMS data centre.

a. **Server Racks**

There are a total of 3 server racks inside the RCMS data centre. One Rack Capacity is 34.66 KW and the other two have a combine capacity of 7 KW.

b. **Communication Racks**

There are no dedicated communication rack in RCMS Data Centre.

c. **CRAC Units**

Currently there is only one CRAC units installed in the centre with a capacity of 11.4 TR. This Unit have a single compressor, having capacities of 11.4 TR.

d. **UPS**

There are two no of UPS's installed in the data centre each having capacities of 40 KVA with a power factor of 0.7.

e. **GEN-SET**

There is no dedicated generator for this data centre.

2.3.2 TIER OF SYSTEM

There is no defined tier in the RCMS lab, but the closest approximation which can be made is with the tier 1. This is because there is no redundancy for CRAC unit and UPS units. Secondly, as far as the gen-set is concerned, it is not even wholly dedicated to the lab. Last and most importantly, the CRAC unit installed in this lab has a single compressor. In case of failure, there is no back up for the unit.

2.3.3 Drawings

The next step was to create and analyze the drawings of RCMS lab and as was done in the SEECS lab case, these drawings were created in AUTOCAD are shown in Figure 2-7and Figure 2-8.

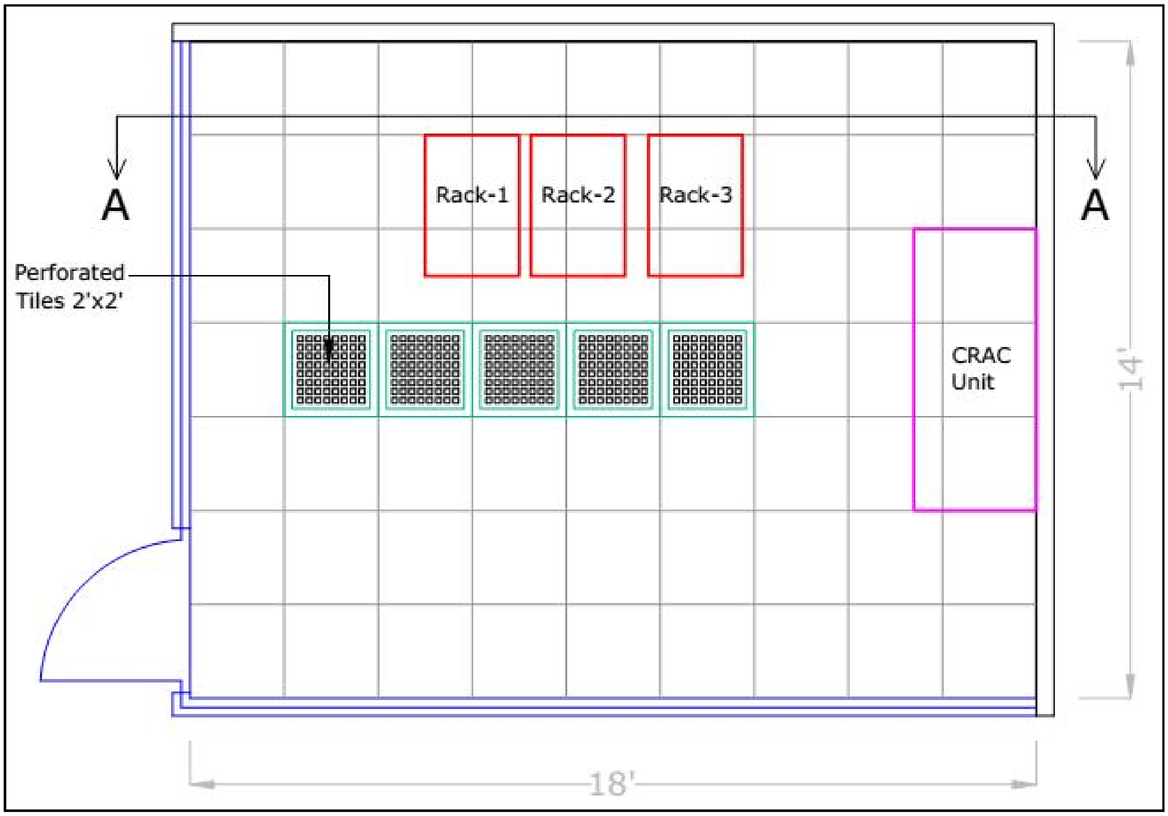


Figure 2-7 - RCMS Data Centre Layout Plan

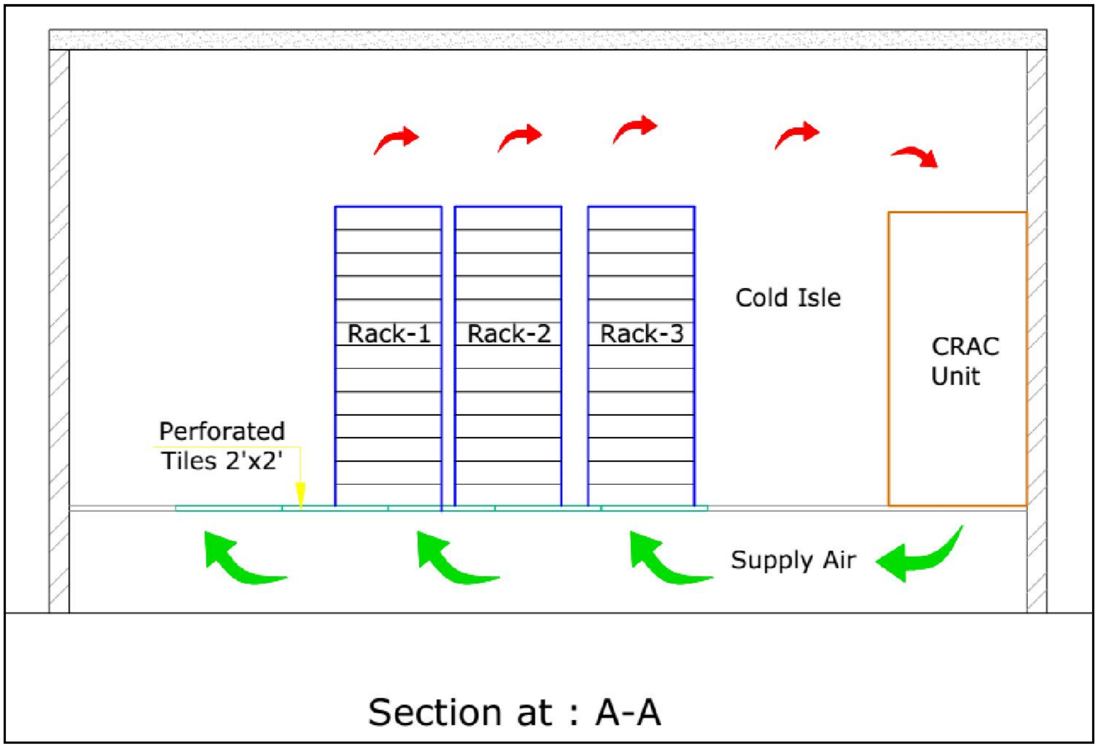


Figure 2-8 - RCMS Data Centre Section Plan at A-A

2.3.4 Cooling Load Calculations

As was done in the SEECS lab case, the cooling load calculations were made and the results can be seen in Table 2-7.

S. No.	Description	Power (Watt)	Power (Btu/h)	Quantity	Total Power (Watt)	Total Power (Btu/h)	TR
1A	NIVIDIA Tesla S1070 IU System-S1070-500	700	2,388.50	32	22,400.00	76,431.95	6.37
1B	HP Prolient DL 160se G6	330	1,126.01	32	10,560.00	36,032.21	3.00
1C	Head Node HP Prolient DL 380 G6	350	1,194.25	2	700.00	2,388.50	0.20
1D	Other components	1000	3,412.14	1	1,000.00	3,412.14	0.28
					34,660.00	**118264.80**	**9.86**
2	2 x Racks	7000	23,884.98	1	7,000.00	23,884.98	1.99
	Total Load of Racks				**41,660.00**	**142,149.78**	**11.85**
3	Room Load	2506.64	8,553	1	2,506.64	8,553.00	0.71
	Total Load (Room + Racks)				**44,166.64**	**150,702.78**	**12.56**

Table 2-7 - RCMS Data Centre Equipment Load Summary

The calculations which were made in ELITE CHVAC can be seen in Annexure 'A'. The current capacity of the RCMS lab was an unknown variable in this case and to cater for that we analyzed the current-power consumption of the racks, which was being drawn from the UPS. A breakdown of this consumption has been shown in Table 2-8.

S. No	Description	KVA	Power Factor	KW
1	UPS Capacity	80.00	0.7	56.00
2	Data Centre Load	59.51	0.7	41.66
3	UPS Current Maximum Running Capacity (44%), neglected the lighting, fire detection and other ELV system etc. load	35.2	0.7	24.64

Table 2-8 - RCMS Data Centre Current system load

From this figure it is clear that the RCMS Data Centre is currently running at maximum of 59.15 % of its total Capacity i.e. 24.64 KW of its 41.66 KW. The detailed specifications of the CRAC unit installed in the RCMS lab are shown in Table 2-9. The current cooling capacity required has also been shown in Table 2-9.

Description	Cooling Capacity (Watt)	Cooling Capacity Btu/h)	Unit Quantity (No)	Total Cooling Capacity (Watt)	Total Cooling Capacity (Btu/h)	Cooling Capacity (TR)
Stulz, cyber air 2, ASD 401 with R407C (single Compressor)	40,100.00	136,826.84	1	40,100.00	136,826.84	**11.40**

Table 2-9 - RCMS Data Centre CRAC Unit installed and current cooling capacity

The comparison between the numerical (ELITE CHVAC) and manual cooling loads has been given in Table 2-10.

Description	Load Calculated manually (Btu/hr)	Load Calculated with Elite CHVAC (Btu/hr)	Error (%)
Total Load (Racks + Room)	150,702.78	157,276.00	4.36

Table 2-10 - RCMS Data Centre Equipment Load Comparison

2.4 Suggestions/Recommendations

After studying the cases, both supply and return air are being sucked from the same environment i.e. there is no separation between the cycles. What this means is that short cycling occurs (some part of the supply air which was supposed to enter the equipment bypasses it and exits as return air). The main disadvantage due to this results in the form of energy loss. Additionally, when the cold bypass air reaches directly to the return unit sensor, a false signal is generated to the control, and can result in system shutdown. The proper way to encounter this problem will be to create a closed zone surrounding the racks, so that when the air is sucked back through the CRAC unit, the cold air which is yet to pass through the racks is not part of that suction. There are two ways to it, either you create a hot isle and the remaining room will be a cold isle and vice versa. These recommended layouts have been shown below in Figure 2-9, Figure 2-10, Figure 2-11 and Figure 2-12.

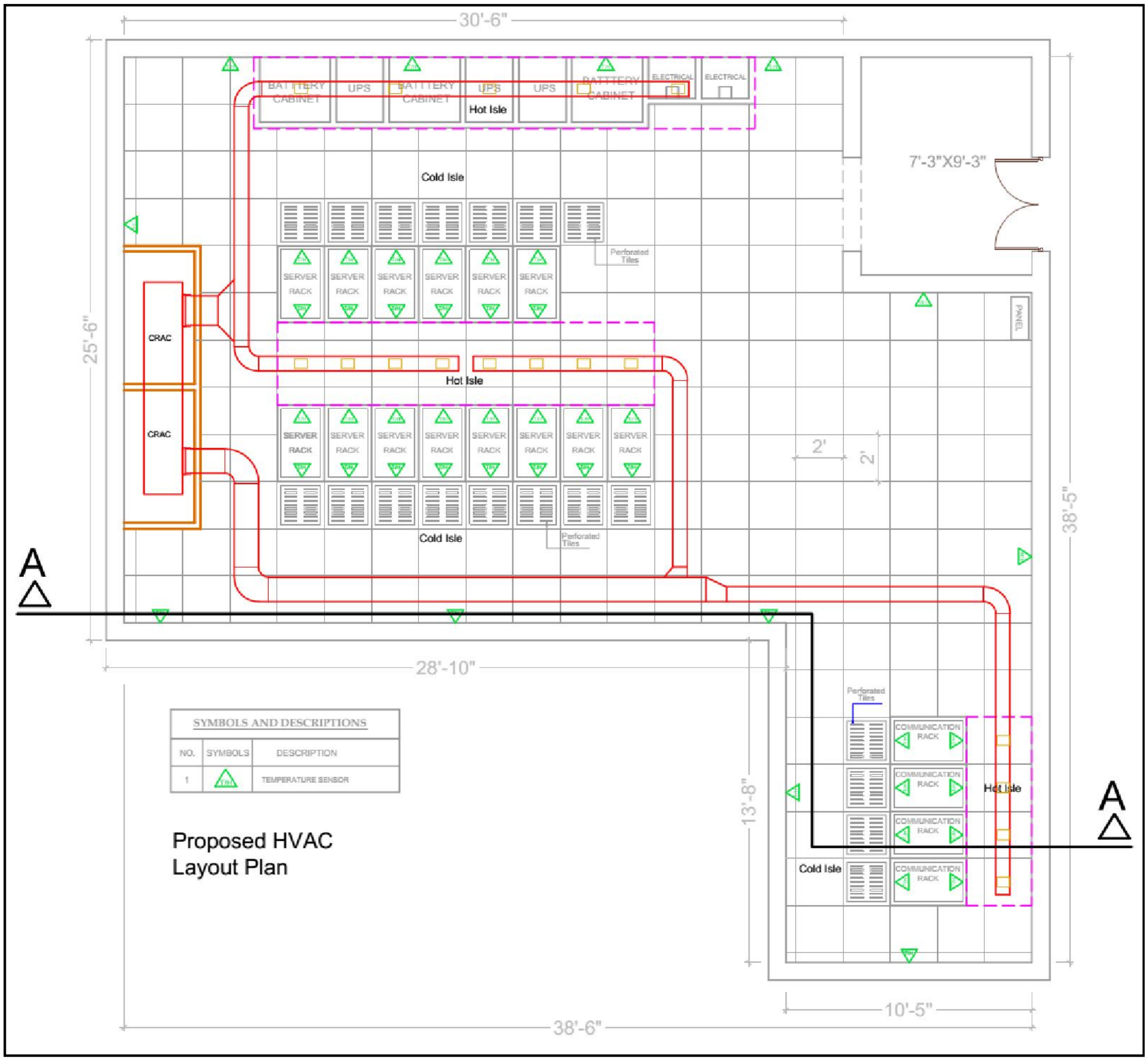


Figure 2-9 - SEECS Data Centre Proposed HVAC Layout Plan

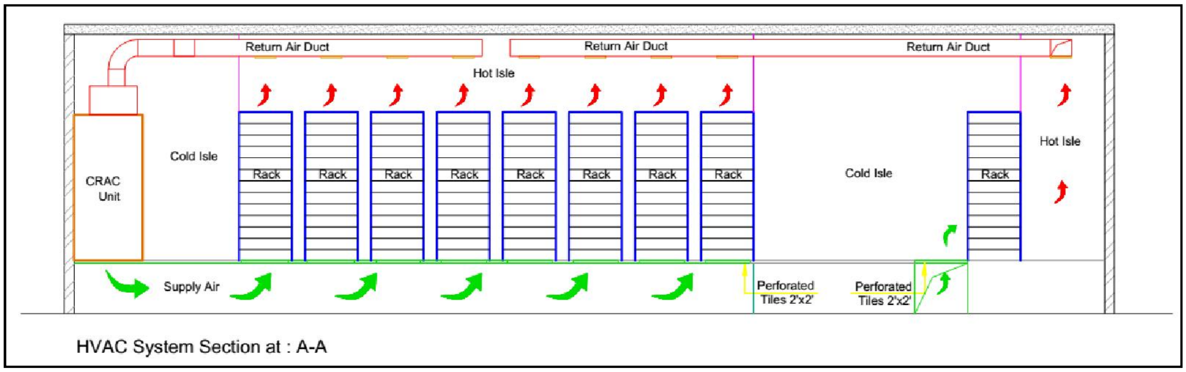


Figure 2-10 - SEECS Data Centre Proposed HVAC Layout Plan Section at A-A

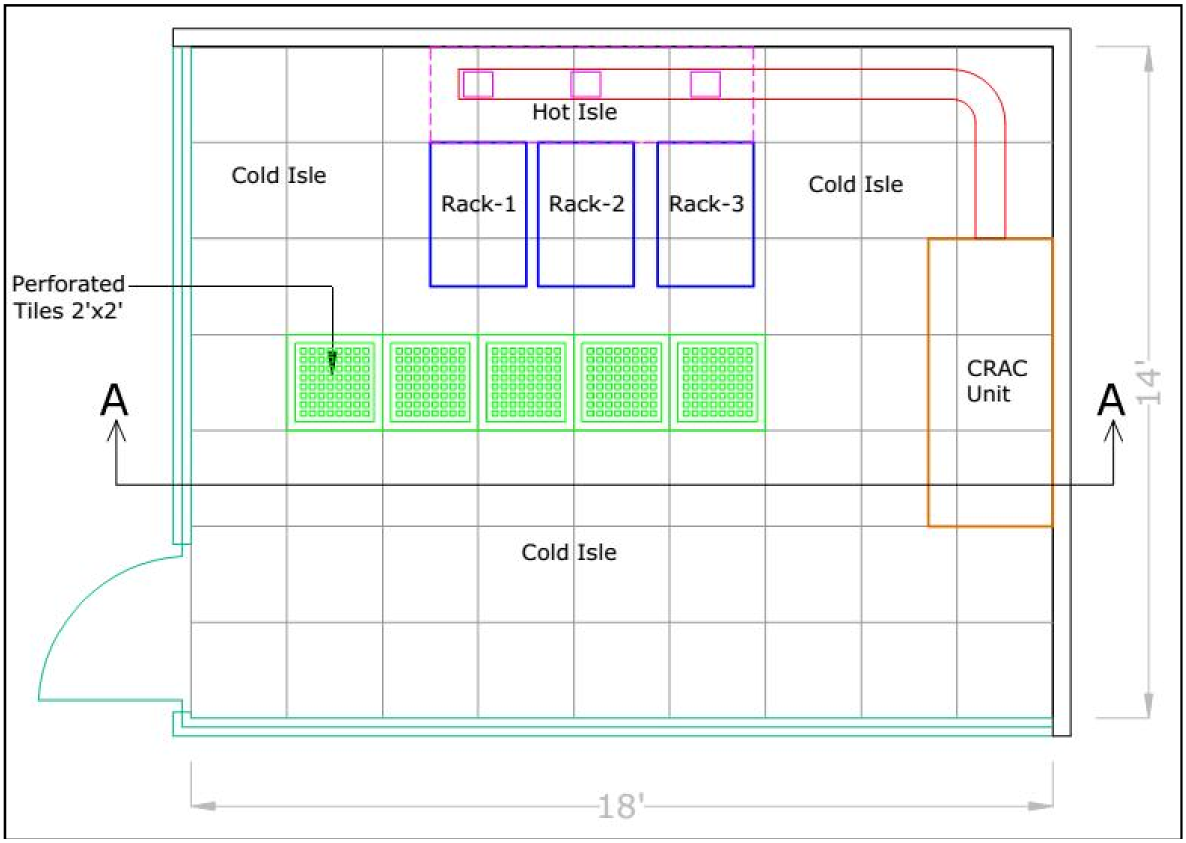


Figure 2-11 - RCMS Data Centre Proposed HVAC Layout Plan

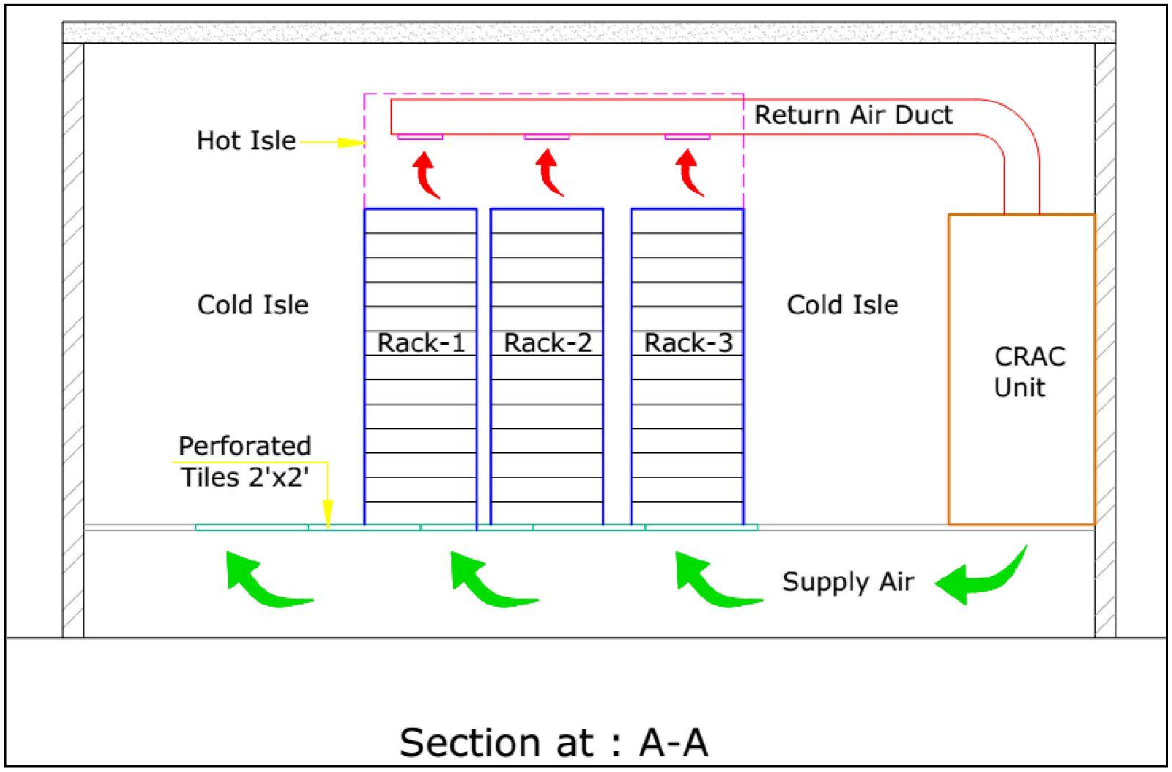


Figure 2-12 - RCMS Data Centre Proposed HVAC Layout Plan Section at A-A

Additionally, temperature and humidity sensors must be placed as shown in Figure 2-13 and Figure 2-14 to moniter the temperature/humidity variations round the clock (there should be a proper log). This can identify the hot zones and temperature/humidity variations in the data centre round the clock for the whole year. According to Ashrae data com series [12], the temperature/humidity sensors should be installed under floor, at rack input/output and CRAC Unit Return.

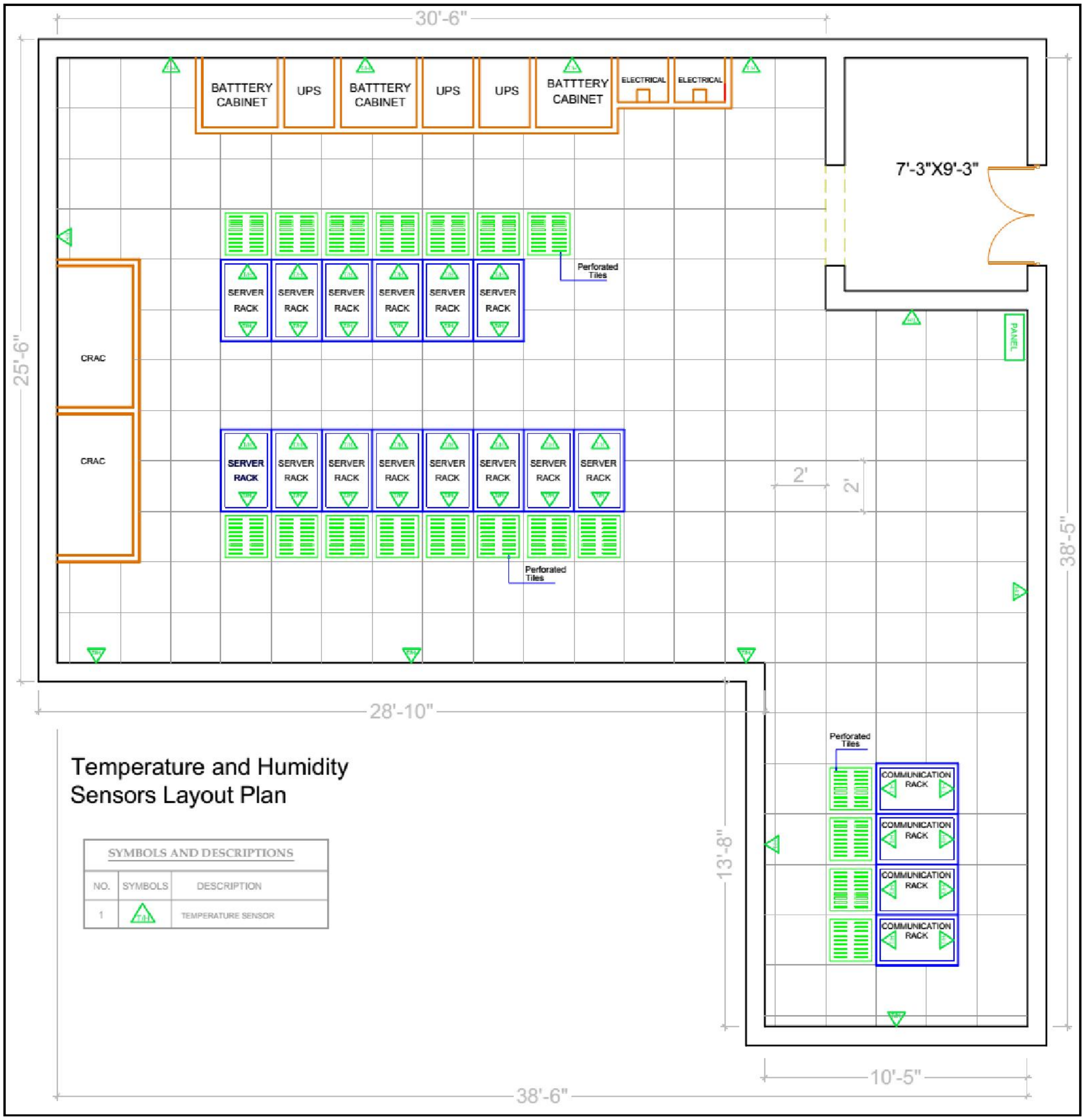


Figure 2-13 - SEECS Data Centre Temperature and Humidity Layout Plan

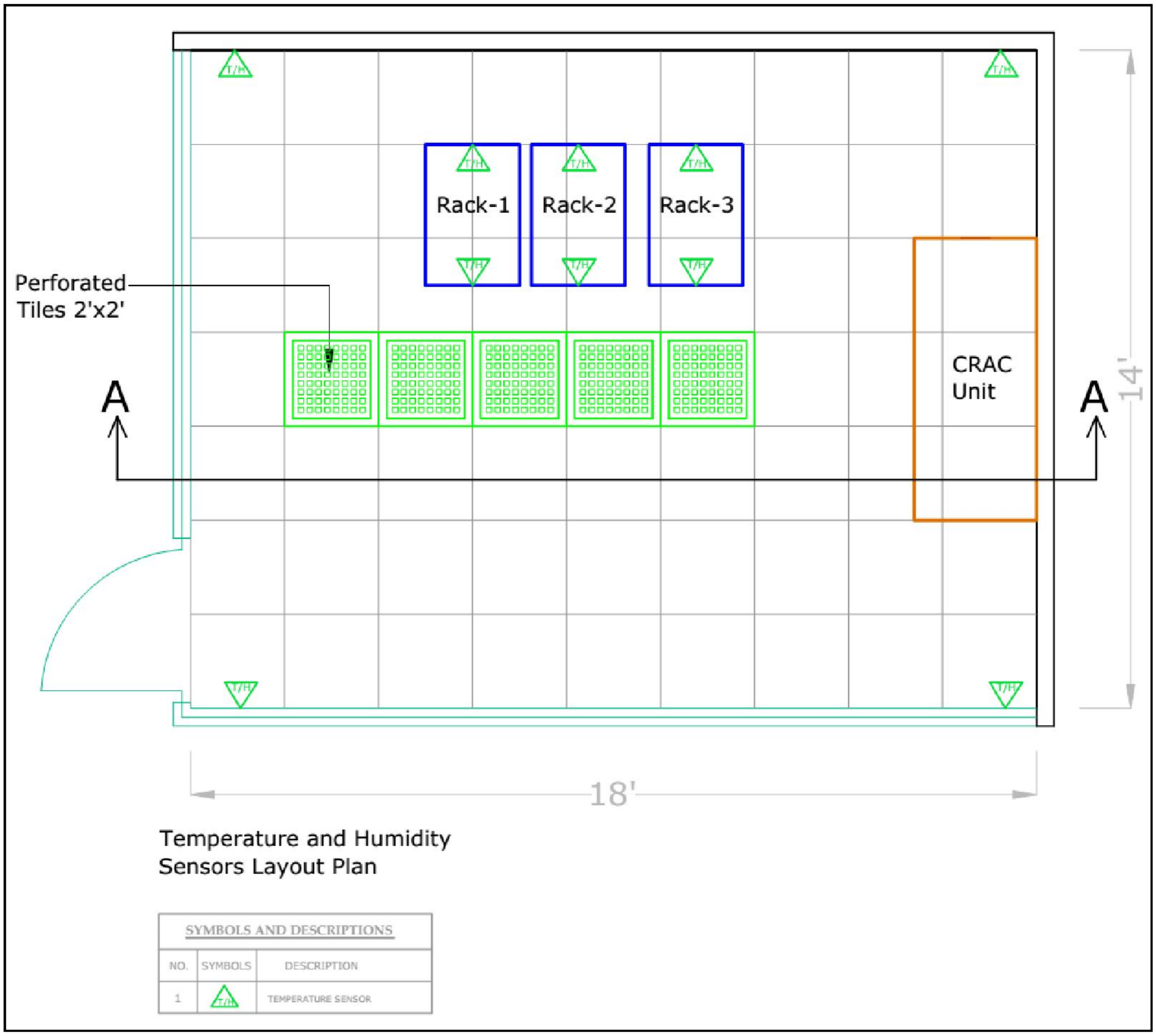


Figure 2-14 - RCMS Data Centre Temperature and Humidity Layout Plan

3 DATA DESCRIPTION

In this chapter, the data that was extracted in raw form from the metrological department and was compiled in accordance to the specific requirements of this study. This chapter will focus on how the data was perceived and then re-arranged into input parameters for free cooling calculations of the labs under focus. Here, it is pertinent to mention that the environmental data (commonly known as bin data) which has been used in this study is generally very readily available. However, Pakistan being an under-developed country, the access to this data became a very tedious job and even after it was received from the MET department, its proper organization proved to be an extremely hectic job. Add to it the fact that there are no precedents focusing on free cooling available locally, and the task became all the more difficult.

The bin data was ultimately arranged in MS EXCEL, and has been attached as Annexure ‘B’. The significance of the bin data, which was so judiciously formulated, is that it gives us an elaborate idea of the amount of free cooling potential which can be extracted from the environment. Or, in other words, it tells us about the energy we can save in our labs just be corrected designing of the parameters involved in free cooling. It is also important to note, that the bin data compiled in this study, can not only be used with the labs, but for comfort cooling as well.

Normally the bin data available internationally has per hour distribution of various parameters like dry bulb temperature, wet bulb temperature, humidity, plate evaporation etc. but we were only afforded this data for three specific timings 3, 9 and 12 GMT (0800, 1400 and 1700 hrs. PST). The data at these timings is available for a total of 16 years, starting from 1996 to 2011, which will give us a detailed insight over the temperature patterns.

Before we start explaining the distribution of this data, the important thing to understand that for psychrometric analysis, which defines the air properties, we require two variables. These variables are normally dry bulb temperature and a choice between humidity and wet bulb temperature. Therefore, for the purpose of this study we have only organized these three variables, in a daily, monthly, yearly and 16 yearly form. As to how this data was organized will now be explained. We first take a look at Table 3-1 which shows the dry-bulb and wet-bulb temperature data for January 2008. To understand this data and make it significant for our free cooling calculations, we have developed a strategy which has been displayed in Table 3-2. In this table at 3 GMT, the values in the second row represent the temperature range in degree Centigrade from -4 to 48 which been broken down into 2 degree intervals, with each interval represented by a separate column. Below the second row, a series of entries, which are either zero or one can be seen. The entries marked as one represent the occurrence of a specific temperature interval at 3 GMT on a particular day. For example, as per table 4.1, on 10th of January, the dry bulb temperature is 9.4 °C at 3 GMT. Now, in Table 3-2, it will be represented as one below the interval 8-10 and parallel to the day 10 row. The details for the three reference timings can be seen in Annexure 'B'.

The next step was to accumulate this monthly data into a yearly form, which can then further be integrated into a 16 yearly data. In Table 3-3, the data for 2008 has been shown. As was done in the monthly distribution, the second row represents the temperature intervals. Here, column one represents the month, under which the three reference timings has been encompassed in column 2. For each month, the total number of occurrence of a specific temperature range has been mentioned parallel to the timings. In the end row the total occurrences for a specific range have been accumulated column wise.

The whole process was undertaken for 16 years and the data was then compiled in the form of a singular Table 3-4. This table follow the same format as was established in per year calculations, the only difference being the duration change from one year to sixteen years. In Table 3-5, the yearly values at each specific time have been segregated to present an alternate overview of the temperature patterns.

Similarly the wet bulb temperature distribution has been explained in an identical manner (please see Annexure 'B'). The third parameter, relative humidity, was also segregated in more or less the same way. This can be explained with the help of Table 3-6 and Table 3-7 respectively. In the table 4.6, the humidity percentages have been sorted out with respect to the reference timings i.e. 3, 9 and 12 GMT. In the Table 3-7, the number of occurrences at 3 GMT have been measured by introducing a relative humidity range of 5 percent, as compared to the 2°C in the wet and dry bulb temperatures. In the following tables Table 3-8, Table 3-9 and Table 3-10, the relative humidity calculations have been shown in yearly (2008 only), 16 yearly and time based formats.

Day	**3 GMT (0800 PST)**		**9 GMT (1400 PST)**		**12 GMT (1700 PST)**	
	Air Temperature (°C)					
	Dry Bulb	**Wet Bulb**	**Dry Bulb**	**Wet Bulb**	**Dry Bulb**	**Wet Bulb**
1	2.4	1.3	18.9	9.2	15.0	7.0
2	0.0	-0.5	18.7	9.1	14.4	7.7
3	0.6	0.0	15.1	8.7	13.4	9.4
4	2.8	2.0	14.9	8.5	13.5	9.5
5	8.3	6.5	12.8	10.0	13.2	10.7
6	9.4	9.0	10.1	9.4	11.0	10.3
7	8.9	8.0	11.3	10.7	12.2	11.5
8	10.6	10.0	12.8	12.5	12.2	11.7
9	10.8	10.6	12.8	12.5	12.8	12.3
10	9.4	9.0	7.8	7.4	8.2	7.2
11	3.9	3.5	14.3	10.2	11.6	8.6
12	5.0	4.5	14.7	9.3	12.9	8.6
13	3.9	3.5	15.6	9.5	13.4	8.6
14	4.4	4.0	17.2	12.6	13.1	8.2
15	5.0	4.5	17.2	11.0	14.7	11.6
16	11.1	8.5	13.3	12.0	12.2	11.5
17	10.7	10.4	10.6	10.5	9.4	9.2
18	5.6	5.0	13.3	7.8	11.9	7.3
19	5.0	4.5	13.6	6.3	11.5	6.5
20	5.6	5.0	13.5	5.8	11.1	4.5
21	0.9	-0.6	12.8	6.5	10.7	5.5
22	1.7	0.7	10.6	7.0	10.4	4.8
23	1.1	0.5	12.2	6.5	10.6	5.0
24	1.7	0.5	13.5	7.0	10.5	5.0
25	1.7	0.7	12.7	7.0	11.3	6.7
26	1.7	0.4	12.8	6.4	10.9	5.9
27	1.7	0.7	15.0	8.0	12.8	7.0
28	6.9	4.5	15.6	8.0	14.9	9.7
29	2.2	1.2	15.0	8.0	13.1	6.8
30	1.7	0.4	15.6	8.0	13.4	7.7
31	1.1	1.0	17.2	8.2	14.6	7.8

Table 3-1 - Dry Bulb and Wet Bulb Temperature for January 2008

The final data which needed to be accumulated before we could start with our free cooling calculations focused around mean and extreme temperatures experienced in the last 16 years.

This was done using the dry bulb temperatures at 3 GMT and 12 GMT. It is important to note here that temperatures at 3 GMT will not be minimum by any account, as night temperatures are often lower. However, our major and valid constraint in this regard was the scarcity of the data available from the Pakistan Metrological Department, which only calculates the temperature readings at the three reference timings which we have used in this study, and considers the minimum temperature as One (1) which occurs at 3 GMT and maximum temperature which occurs at 12 GMT. It is for this very reason that we have followed this nomenclature in our free cooling analysis (not calculations). These values have been attained to observe the temperature patterns. The mean temperature values for January 2008 have been shown in this chapter, all the data has been formulated in an easily usable format. The next step will be the implementation of this data in the two research laboratories and attain the results. This, and the result discussions are included in the next chapter.

Day	Dry Bulb at 3 GMT (0800 PST)																								
	-4/-2	-2/0	0/2	2/4	4/6	6/8	8/10	10/12	12/14	14/16	16/18	18/20	20/22	22/24	24/26	26/28	28/30	30/32	32/34	34/36	36/38	38/40	40/42	42/44	44/46	46/48
1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	11	5	6	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31

Table 3-2 - Dry Bulb Temperature Bin Values at 3 GMT for January 2008

	Time	Dry Bulb Temperature Bin (C)																									
		-4/-2	-2/0	0/2	2/4	4/6	6/8	8/10	10/12	12/14	14/16	16/18	18/20	20/22	22/24	24/26	26/28	28/30	30/32	32/34	34/36	36/38	38/40	40/42	42/44	44/46	46/48
January	3 GMT	0	0	11	5	6	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	1	0	4	12	9	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	2	11	13	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	11	5	6	2	6	19	25	14	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	3 GMT	0	0	0	6	3	6	4	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	2	2	1	2	3	3	3	2	8	0	1	2	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	1	0	0	3	2	5	2	2	3	4	4	2	1	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	7	3	8	9	12	7	6	5	6	6	12	2	2	2	0	0	0	0	0	0	0	0	0
March	3 GMT	0	0	0	0	0	0	0	1	2	13	10	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	11	13	3	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	13	1	11	5	1	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	1	2	13	10	4	1	15	3	22	18	4	0	0	0	0	0	0	0	0
April	3 GMT	0	0	0	0	0	0	0	0	0	3	5	7	3	3	2	7	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	1	0	1	2	7	0	2	4	3	8	0	2	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	2	1	4	5	0	7	3	1	6	0	1	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	4	7	9	9	15	2	16	7	4	14	0	3	0	0	0	0	0
May	3 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	14	8	4	1	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	13	4	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	15	7	5	1	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	14	8	7	19	17	18	5	0	0	0	0
June	3 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	5	9	7	4	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	4	4	9	5	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5	4	7	9	1	0	0	0	0

	Total	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	14	17	12	11	18	6	0	0	0	0
July	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	6	7	10	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	6	6	12	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	6	3	15	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	12	12	18	9	21	12	0	0	0	0	0
August	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	12	14	2	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	7	9	7	3	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	4	10	10	2	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	15	19	19	19	9	3	0	0	0	0	0
September	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	1	0	17	3	6	3	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	2	4	11	9	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	3	6	15	2	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	2	3	19	3	8	8	10	26	11	0	0	0	0	0	0
October	**3 GMT**	0	0	0	0	0	0	0	0	0	3	6	8	6	6	0	2	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	10	7	7	1	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	10	7	5	7	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	3	6	8	6	9	0	17	17	12	14	1	0	0	0	0	0	0
November	**3 GMT**	0	0	0	0	0	0	0	9	7	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	6	2	5	5	6	6	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	3	13	1	2	3	5	3	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	9	7	13	4	19	3	7	8	11	9	0	0	0	0	0	0	0	0	0
December	**3 GMT**	0	0	0	0	0	1	14	13	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	2	1	2	4	11	1	9	1	0	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	2	1	6	13	7	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	1	14	17	5	8	17	18	1	11	1	0	0	0	0	0	0	0	0	0	0	0

Table 3-3 - Dry Bulb Temperature Bin Values for 2008

	Time	Dry Bulb Temperature Bin (C)																									
		-4/-2	**-2/0**	**0/2**	**2/4**	**4/6**	**6/8**	**8/10**	**10/12**	**12/14**	**14/16**	**16/18**	**18/20**	**20/22**	**22/24**	**24/26**	**26/28**	**28/30**	**30/32**	**32/34**	**34/36**	**36/38**	**38/40**	**40/42**	**42/44**	**44/46**	**46/48**
January	**3 GMT**	1	3	43	119	123	101	68	28	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	8	17	25	47	96	146	100	38	12	6	0	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	8	25	57	120	133	89	50	10	2	1	0	0	0	0	0	0	0	0	0	0	0
	Total	1	3	43	119	123	117	110	110	176	230	235	150	48	14	7	0	0	0	0	0	0	0	0	0	0	0
February	**3 GMT**	0	0	0	20	47	90	111	108	62	11	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	2	10	19	35	31	68	103	91	64	20	7	2	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	1	0	2	15	31	37	67	107	91	62	24	12	3	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	21	47	94	136	158	134	109	177	195	153	88	32	10	2	0	0	0	0	0	0	0	0	0
March	**3 GMT**	0	0	0	0	1	3	19	61	99	124	83	48	22	5	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	1	0	3	9	17	14	36	47	91	80	71	53	30	12	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	1	0	1	4	9	20	36	60	77	84	59	59	33	19	3	0	0	0	0	0	0	0
	Total	0	0	0	0	2	4	20	68	117	161	133	144	146	180	139	130	86	49	15	0	0	0	0	0	0	0
April	**3 GMT**	0	0	0	0	0	0	0	2	4	21	49	85	86	83	85	47	17	1	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	1	0	0	0	0	2	5	1	7	11	37	29	53	79	65	86	67	25	12	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	3	3	8	8	18	38	41	79	72	53	95	41	18	3	0	0	0	0
	Total	0	0	0	1	0	0	0	2	9	29	58	100	115	158	155	179	168	119	181	108	43	15	0	0	0	0
May	**3 GMT**	0	0	0	0	0	0	0	0	0	2	7	6	25	37	69	118	132	71	25	2	1	0	0	0	0	0
	9 GMT	0	0	0	0	1	0	0	0	0	2	2	1	3	6	12	10	19	39	84	95	105	86	26	4	0	0
	12 GMT	0	0	0	0	0	0	0	0	2	0	2	2	5	11	10	22	35	34	110	92	95	61	15	0	0	0
	Total	0	0	0	0	1	0	0	0	2	4	11	9	33	54	91	150	186	144	219	189	201	147	41	4	0	0
June	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	6	16	37	80	112	128	81	16	4	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	18	34	61	82	109	100	48	16	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	6	29	36	68	79	103	80	28	8	1	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	8	21	47	93	159	198	210	177	216	180	76	24	1	0
July	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	6	42	76	97	145	83	41	6	0	0	0	0	0	0
	9 GMT	0	0	0	0	1	0	0	0	0	0	0	0	0	5	16	29	37	53	117	114	80	33	11	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	27	49	76	113	114	65	28	11	0	0	0

	Total	0	0	0	0	1	0	0	0	0	0	0	0	6	49	103	153	231	212	271	234	145	61	22	0	0	0
August	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	2	15	56	76	152	155	37	1	1	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	2	8	15	30	70	88	170	95	16	2	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	1	7	10	30	90	125	160	65	8	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	2	18	71	101	212	315	250	331	161	24	2	0	0	0	0
September	**3 GMT**	0	0	0	0	0	0	0	0	0	0	1	13	53	115	112	123	61	2	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	1	1	3	7	9	24	65	100	200	65	5	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	5	7	15	46	98	149	127	30	3	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	2	14	61	129	136	193	224	251	327	95	8	0	0	0	0	0
October	**3 GMT**	0	0	0	0	0	0	3	11	24	63	105	118	82	68	16	5	1	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	2	0	0	0	0	0	0	3	4	8	12	27	78	163	124	65	7	1	1	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	2	3	9	18	48	92	140	99	55	30	0	0	0	0	0	0	0
	Total	0	0	0	2	0	0	3	11	24	65	111	131	108	128	135	223	263	179	95	7	1	1	0	0	0	0
November	**3 GMT**	0	0	0	0	2	33	70	101	115	103	50	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	2	1	2	9	27	55	108	117	126	32	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	1	6	14	56	139	103	90	48	19	4	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	2	33	70	104	122	119	115	170	158	199	165	145	36	0	0	0	0	0	0	0	0	0
December	**3 GMT**	0	0	15	63	119	123	118	40	12	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	9	19	35	87	149	125	60	11	1	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	6	22	76	126	178	73	13	2	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	15	63	119	123	124	71	107	167	265	222	138	62	11	1	0	0	0	0	0	0	0	0	0	0

Table 3-4 - 16 years total Monthly Dry Temperature bin values for Islamabad/Rawalpindi

Time	**Dry Bulb Temperature Bin (C)**																									
	-4/-2	**-2/0**	**0/2**	**2/4**	**4/6**	**6/8**	**8/10**	**10/12**	**12/14**	**14/16**	**16/18**	**18/20**	**20/22**	**22/24**	**24/26**	**26/28**	**28/30**	**30/32**	**32/34**	**34/36**	**36/38**	**38/40**	**40/42**	**42/44**	**44/46**	**46/48**
3 GMT	1	3	58	202	292	350	389	351	325	331	297	277	295	423	471	622	623	322	148	25	5	0	0	0	0	0
9 GMT	0	0	0	3	2	11	27	58	113	188	331	428	383	412	345	436	538	533	795	525	341	234	85	20	0	0
12 GMT	0	0	0	1	1	10	47	115	253	365	479	432	314	318	306	431	509	547	706	421	292	172	54	8	1	0
Total	1	3	58	206	295	371	463	524	691	884	1107	1137	992	1153	1122	1489	1670	1402	1649	971	638	406	139	28	1	0

Table 3-5 - 16 years total Dry Temperature bin values for Islamabad/Rawalpindi

Day	3 GMT (0800 PST)	9 GMT (1400 PST)	12 GMT 1700 PST)
	Relative Humidity %	**Relative Humidity %**	**Relative Humidity %**
1	84	23	27
2	91	24	35
3	91	39	59
4	88	39	59
5	78	73	76
6	94	91	91
7	87	94	91
8	94	97	94
9	97	97	97
10	94	93	87
11	92	60	70
12	93	47	57
13	92	44	53
14	89	53	49
15	93	45	72
16	74	87	91
17	97	99	97
18	93	46	52
19	93	30	47
20	93	25	31
21	96	35	41
22	83	63	38
23	91	40	38
24	79	36	38
25	83	41	52
26	79	34	46
27	83	35	42
28	67	39	50
29	83	35	37
30	79	32	43
31	91	24	35

Table 3-6 - Relative Humidity % for January 2008

Day	Relative Humidity % at 3 GMT (0800 PST)																			
	0/5	5/10	10/15	15/20	20/25	25/30	30/35	35/40	40/45	45/50	50/55	55/60	60/65	65/70	70/75	75/80	80/85	85/90	90/95	95/ 100
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

28	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	5	3	14	3	31

Table 3-7 Relative Humidity % Bin Values at 3 GMT for January 2008

	Time	Relative Humidity %																			
		0/5	5/10	10/15	15/20	20/25	25/30	30/35	35/40	40/45	45/50	50/55	55/60	60/65	65/70	70/75	75/80	80/85	85/90	90/95	95/100
January	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	5	3	14	3
	9 GMT	0	0	0	0	3	1	3	7	3	3	1	0	2	0	1	0	0	1	3	3
	12 GMT	0	0	0	0	0	1	1	6	3	3	4	3	0	0	2	1	0	1	4	2
	Total	0	0	0	0	3	2	4	13	6	6	5	3	2	1	4	5	5	5	21	8
February	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	12	1	3	10	1
	9 GMT	0	0	0	0	1	2	1	7	2	0	4	3	0	2	0	0	1	3	3	0
	12 GMT	0	0	0	0	2	0	3	5	7	1	2	0	0	0	2	0	1	2	3	1
	Total	0	0	0	0	3	2	4	12	9	1	6	4	0	2	3	12	3	8	16	2
March	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	1	8	6	9	4	3	0	0	0
	9 GMT	0	0	0	0	2	3	6	8	9	1	2	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	3	4	3	6	5	6	3	0	1	0	0	0	0	0	0
	Total	0	0	0	0	2	6	10	11	15	6	8	4	8	7	9	4	3	0	0	0
April	**3 GMT**	0	0	0	0	0	0	1	1	0	4	3	3	4	1	2	1	6	0	3	1
	9 GMT	0	0	0	0	2	2	5	5	3	1	2	3	1	2	0	3	0	0	1	0
	12 GMT	0	0	0	0	1	0	6	5	4	0	3	0	0	4	0	5	2	0	0	0
	Total	0	0	0	0	3	2	12	11	7	5	8	6	5	7	2	9	8	0	4	1
May	**3 GMT**	0	0	0	0	0	1	0	3	3	13	8	1	2	0	0	0	0	0	0	0
	9 GMT	0	0	0	3	4	12	3	5	2	2	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	8	5	10	3	2	2	0	0	0	0	0	1	0	0	0	0
	Total	0	0	0	3	12	18	13	11	7	17	8	1	2	0	0	1	0	0	0	0
June	**3 GMT**	0	0	0	0	0	0	0	1	2	0	2	2	2	4	4	5	2	3	1	2

	9 GMT	0	0	0	0	0	1	1	0	6	6	0	8	3	2	3	0	0	0	0	0
	12 GMT	0	0	0	0	0	1	0	2	8	5	0	4	4	2	4	0	0	0	0	0
	Total	0	0	0	0	0	2	1	3	16	11	2	14	9	8	11	5	2	3	1	2
July	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	1	3	8	5	3	1	5	5
	9 GMT	0	0	0	0	0	0	0	1	3	5	6	3	7	3	1	1	0	0	0	1
	12 GMT	0	0	0	0	0	0	0	0	3	4	8	5	2	2	4	1	1	0	1	0
	Total	0	0	0	0	0	0	0	1	6	9	14	8	10	8	13	7	4	1	6	6
August	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	12	5	3	2	1
	9 GMT	0	0	0	0	0	0	0	0	1	1	6	5	4	7	3	0	1	2	1	0
	12 GMT	0	0	0	0	0	0	0	0	2	0	3	3	7	6	4	2	0	0	1	3
	Total	0	0	0	0	0	0	0	0	3	1	9	8	11	17	11	14	6	5	4	4
September	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	2	3	13	1	2	9	0	0	0
	9 GMT	0	0	0	0	0	0	3	6	3	6	5	1	2	1	0	0	1	1	0	1
	12 GMT	0	0	0	0	0	0	0	2	10	7	3	2	1	1	0	1	2	0	0	1
	Total	0	0	0	0	0	0	3	8	13	13	8	5	6	15	1	3	12	1	0	2
October	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	1	6	14	3	5	2	0	0
	9 GMT	0	0	0	0	0	0	3	10	10	4	3	0	1	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	1	7	16	0	3	4	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	4	17	26	4	6	4	2	6	14	3	5	2	0	0
November	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	3	12	9	3	2	1	0
	9 GMT	0	0	0	0	0	3	2	5	7	4	3	2	1	0	3	0	0	0	0	0
	12 GMT	0	0	0	0	0	2	6	2	0	2	8	4	0	0	5	0	0	1	0	0
	Total	0	0	0	0	0	5	8	7	7	6	11	6	1	3	20	9	3	3	1	0
December	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	13	6	6	5	0
	9 GMT	0	0	0	0	0	0	2	0	4	4	10	4	1	1	0	0	2	3	0	0
	12 GMT	0	0	0	0	0	0	2	0	0	5	5	14	0	1	0	0	1	0	3	0
	Total	0	0	0	0	0	0	4	0	4	9	15	18	1	2	1	13	9	9	8	0

Table 3-8 - Relative Humidity % bin values for 2008

	Time	**Relative Humidity %**																			
		0/5	**5/10**	**10/15**	**15/20**	**20/25**	**25/30**	**30/35**	**35/40**	**40/45**	**45/50**	**50/55**	**55/60**	**60/65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**90/95**	**95/100**
January	**3 GMT**	0	0	0	0	0	0	0	1	0	0	3	2	1	17	16	50	110	98	139	28
	9 GMT	0	0	1	5	25	33	47	45	60	63	42	36	21	16	8	16	11	11	14	11
	12 GMT	0	0	1	4	10	12	18	32	43	48	52	37	50	24	26	24	28	15	31	10
	Total	0	0	2	9	35	45	65	78	103	111	97	75	72	57	50	90	149	124	184	49
February	**3 GMT**	0	0	0	0	0	1	0	1	0	0	2	10	13	15	20	70	95	126	81	18
	9 GMT	0	2	1	14	22	35	53	51	49	45	40	31	17	18	3	12	20	12	22	5
	12 GMT	0	0	5	7	16	22	39	23	56	59	48	30	33	17	17	14	25	14	21	6
	Total	0	2	6	21	38	58	92	75	105	104	90	71	63	50	40	96	140	152	124	29
March	**3 GMT**	0	0	0	0	0	0	1	1	11	25	23	39	40	44	58	72	84	43	17	7
	9 GMT	0	1	2	25	22	53	78	73	59	33	31	25	10	9	7	10	10	4	9	3
	12 GMT	0	0	4	15	24	38	67	57	48	55	42	26	21	15	10	8	17	10	5	3
	Total	0	1	6	40	46	91	146	131	118	113	96	90	71	68	75	90	111	57	31	13
April	**3 GMT**	0	0	0	0	5	13	16	28	40	64	53	68	63	38	26	24	23	7	10	2
	9 GMT	0	3	24	44	84	94	66	45	32	23	16	15	8	8	6	3	1	1	5	2
	12 GMT	0	4	24	49	63	80	58	60	39	27	18	9	7	13	8	5	7	4	4	1
	Total	0	7	48	93	152	187	140	133	111	114	87	92	78	59	40	32	31	12	19	5
May	**3 GMT**	0	0	0	1	2	23	55	72	98	68	60	49	25	13	5	7	7	5	5	1
	9 GMT	0	5	28	77	104	105	63	51	20	14	10	2	5	3	2	2	2	1	2	0
	12 GMT	0	6	34	75	96	97	56	54	23	19	6	10	3	4	2	3	3	2	2	1
	Total	0	11	62	153	202	225	174	177	141	101	76	61	33	20	9	12	12	8	9	2
June	**3 GMT**	0	1	0	0	4	15	33	69	61	65	52	45	36	29	22	14	17	8	5	4
	9 GMT	0	0	15	51	72	68	50	55	61	31	27	23	7	11	7	0	0	0	2	0
	12 GMT	0	1	27	46	55	66	48	69	53	37	19	22	12	10	5	5	1	2	2	0
	Total	0	2	42	97	131	149	131	193	175	133	98	90	55	50	34	19	18	10	9	4
July	**3 GMT**	1	0	0	0	0	2	1	1	6	19	35	42	48	68	50	59	53	36	34	40
	9 GMT	1	0	0	0	2	16	25	39	49	67	75	59	51	42	14	18	9	15	5	9
	12 GMT	1	0	0	0	2	9	30	47	54	64	62	63	51	46	18	13	19	9	5	3

	Total	3	0	0	0	4	27	56	87	109	150	172	164	150	156	82	90	81	60	44	52
August	**3 GMT**	0	0	0	0	0	0	0	0	0	1	1	5	21	44	79	103	100	46	49	46
	9 GMT	0	0	0	0	0	1	0	4	17	33	75	104	79	62	36	33	25	9	11	7
	12 GMT	0	0	0	0	0	0	1	3	14	43	62	91	97	70	32	43	19	8	4	9
	Total	0	0	0	0	0	1	1	7	31	77	138	200	197	176	147	179	144	63	64	62
September	**3 GMT**	0	0	0	0	0	0	0	0	0	1	7	14	37	59	91	108	88	36	28	11
	9 GMT	0	0	0	0	0	3	18	31	61	103	89	60	47	25	13	13	9	4	2	2
	12 GMT	0	0	0	0	0	0	10	26	50	102	79	67	55	38	21	15	10	2	1	4
	Total	0	0	0	0	0	3	28	57	111	206	175	141	139	122	125	136	107	42	31	17
October	**3 GMT**	0	0	0	0	0	0	0	0	0	4	9	27	51	77	81	109	87	40	10	1
	9 GMT	0	0	0	6	35	57	86	92	77	45	29	23	24	9	6	1	3	0	2	1
	12 GMT	0	0	0	1	7	30	46	89	84	70	48	36	21	27	19	9	2	5	1	1
	Total	0	0	0	7	42	87	132	181	161	119	86	86	96	113	106	119	92	45	13	3
November	**3 GMT**	0	0	0	0	0	0	1	1	2	5	5	9	14	26	72	89	146	81	29	0
	9 GMT	0	0	0	19	42	56	80	85	64	47	30	22	13	9	6	2	3	0	2	0
	12 GMT	0	0	0	1	7	20	37	38	57	81	75	44	46	28	20	16	6	2	2	0
	Total	0	0	0	20	49	76	118	124	123	133	110	75	73	63	98	107	155	83	33	0
December	**3 GMT**	0	0	0	0	0	0	0	0	0	1	3	4	16	20	30	88	103	125	91	14
	9 GMT	0	0	1	19	52	43	59	51	67	58	38	30	27	13	6	9	11	7	3	2
	12 GMT	0	0	0	1	17	31	34	34	44	46	59	73	31	28	34	23	22	4	13	2
	Total	0	0	1	20	69	74	93	85	111	105	100	107	74	61	70	120	136	136	107	18

Table 3-9 - 16 years total Monthly Relative Humidity % bin values for Islamabad/Rawalpindi

Time	**Relative Humidity %**																			
	0/5	**5/10**	**10/15**	**15/20**	**20/25**	**25/30**	**30/35**	**35/40**	**40/45**	**45/50**	**50/55**	**55/60**	**60/65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**90/95**	**95/100**
3 GMT	1	1	0	1	11	54	107	174	218	253	253	314	365	450	550	793	913	651	498	172
9 GMT	1	11	72	260	460	564	625	622	616	562	502	430	309	225	114	119	104	64	79	42
12 GMT	1	11	95	199	297	405	444	532	565	651	570	508	427	320	212	178	159	77	91	40
Total	3	23	167	460	768	1023	1176	1328	1399	1466	1325	1252	1101	995	876	1090	1176	792	668	254

Table 3-10 - 16 years total Relative Humidity % bin values for Islamabad/Rawalpindi

Day	3 GMT (0800 PST)	9 GMT (1400 PST)	12 GMT (1700 PST)
	Air Temperature (°C)		
	Min	Max	MEAN AIR TEMP. (ºC)
1	1.0	20.0	10.5
2	-0.2	19.4	9.6
3	0.0	15.7	7.9
4	1.5	15.7	8.6
5	6.4	16.2	11.3
6	9.0	11.6	10.3
7	8.0	12.5	10.3
8	10.0	12.8	11.4
9	10.3	13.2	11.8
10	9.0	13.0	11.0
11	3.5	15.3	9.4
12	4.0	16.2	10.1
13	3.4	16.4	9.9
14	4.0	18.3	11.2
15	4.0	20.0	12.0
16	7.0	13.5	10.3
17	9.6	13.9	11.8
18	5.0	13.8	9.4
19	4.0	14.1	9.1
20	4.8	13.8	9.3
21	-0.8	13.8	6.5
22	0.5	13.5	7.0
23	0.0	13.0	6.5
24	0.0	14.0	7.0
25	0.0	13.8	6.9
26	-1.0	14.1	6.6
27	0.0	16.6	8.3
28	2.0	16.5	9.3
29	0.2	15.7	8.0
30	0.0	16.7	8.4
31	0.5	17.6	9.1

Table 3-11 - Dry Bulb Temperature minimum, maximum and mean temperature values for January 2008

4 RESULTS AND DISCUSSIONS

4.1 RESULTS AND DISCUSSIONS

After compiling and analyzing all the collected data, the next step was to derive a fixed trend and for that variation of extreme and mean temperatures throughout the year was compiled in the form a graph which has been shown in Figure 4-1.

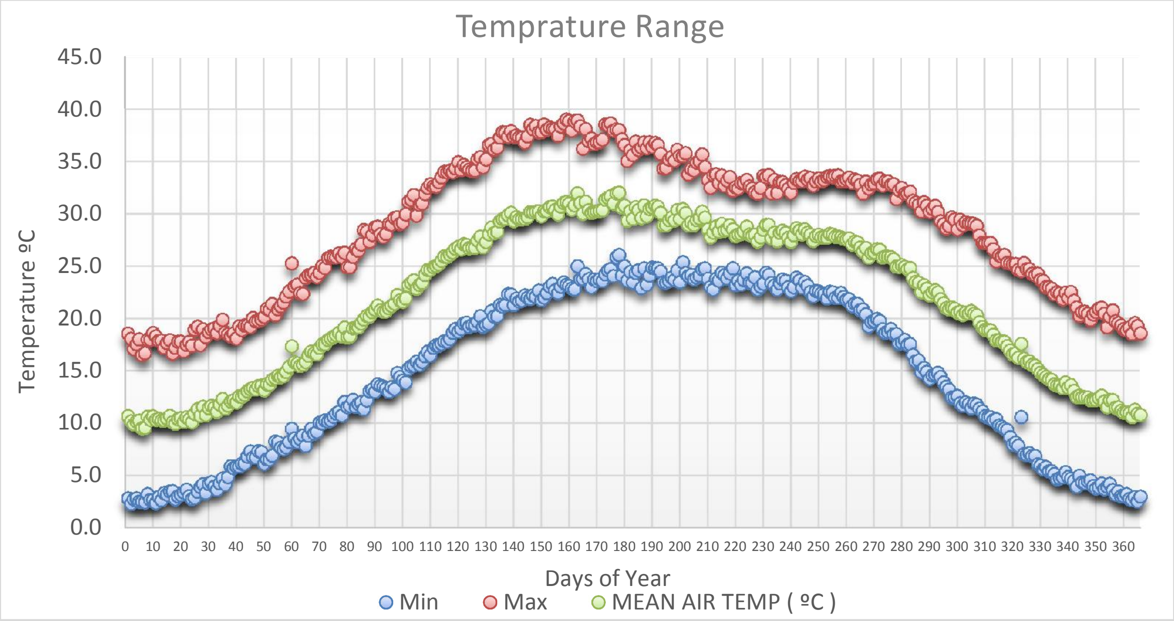


Figure 4-1 - The Variation of Mean and Extreme Temperature throughout the year (average of 16 years)

In this graph, the number of days in a complete year has been incorporated along the x-axis while along the y-axis; there is variation in temperature in degree Celsius. There are basically three temperature ranges defined in the graph. The curve in blue represents the minimum temperature (T_{min}); while the curve in middle (green) represents the mean temperature (T_{mean}) recorded over sixteen years. Similarly, the upper most curve in red, represents the maximum temperature (T_{max}).

As we can see in the graph, the minimum temperature range in the month of January is from 2.3 to 4.4 degree Celsius. During the same month, the range of maximum temperature, which is represented by the red curve, varies from 16.5 to 19.2 degree Celsius. Similarly, for mean value of Temperature in January, the range is defined from 9.5 to 11.7 degree Celsius.

Similarly, the ranges of minimum, maximum and mean temperatures from the month of February till December have been shown in Table 4-1.

Month	**Min Temp Range**		**Max Temp Range**		**Mean Temp Range**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
January	*2.3*	*4.4*	*16.5*	*19.2*	*9.5*	*11.7*
February	3.6	9.5	18.1	25.3	11.1	17.4
March	8.2	13.7	22.3	28.8	15.5	21.2
April	13.0	19.0	27.8	34.9	20.6	26.8
May	19.2	22.7	34.1	38.5	26.7	30.3
June	*22.4*	*26.1*	*35.0*	*39.0*	*29.3*	*32.0*
July	22.8	24.8	33.3	36.9	27.8	30.8
August	22.6	24.8	31.9	33.7	27.3	28.9
September	18.6	23.5	31.9	33.7	25.8	28.5
October	11.4	19.0	29.0	33.1	20.3	25.9
November	5.1	11.9	22.3	29.0	13.7	20.4
December	2.5	5.3	18.5	22.5	10.6	13.9

Table 4-1 - Temperature ranges for minimum, maximum and mean temperature for a year (average of 16 years)

In this set of data values, an interesting case in that of June. Here, the maximum values within each respective range are higher as compared to other month as we can see from the table above. The reason behind it is the low humidity and high dry bulbs temperatures during this month, which has traditionally been considered the hottest month in Pakistan.

After defining the minimum, maximum and mean temperature ranges per month for duration of 16 years, we can safely say that we have a basic understanding of variation in the temperature surrounding our control system which in this case are the SEECS (Lab A) and RCMS (Lab B). The next step in this study is to cater for the dry bulb temperature and the humidity in the environment, which will eventually lead us in establishing a criterion for free cooling within the labs in focus.

There are a few steps to that, the first one of which is related to the determination of the supply air temperature for the IT equipment defined by ASHRAE [12]. This can be understood by Figure 4-2 below.

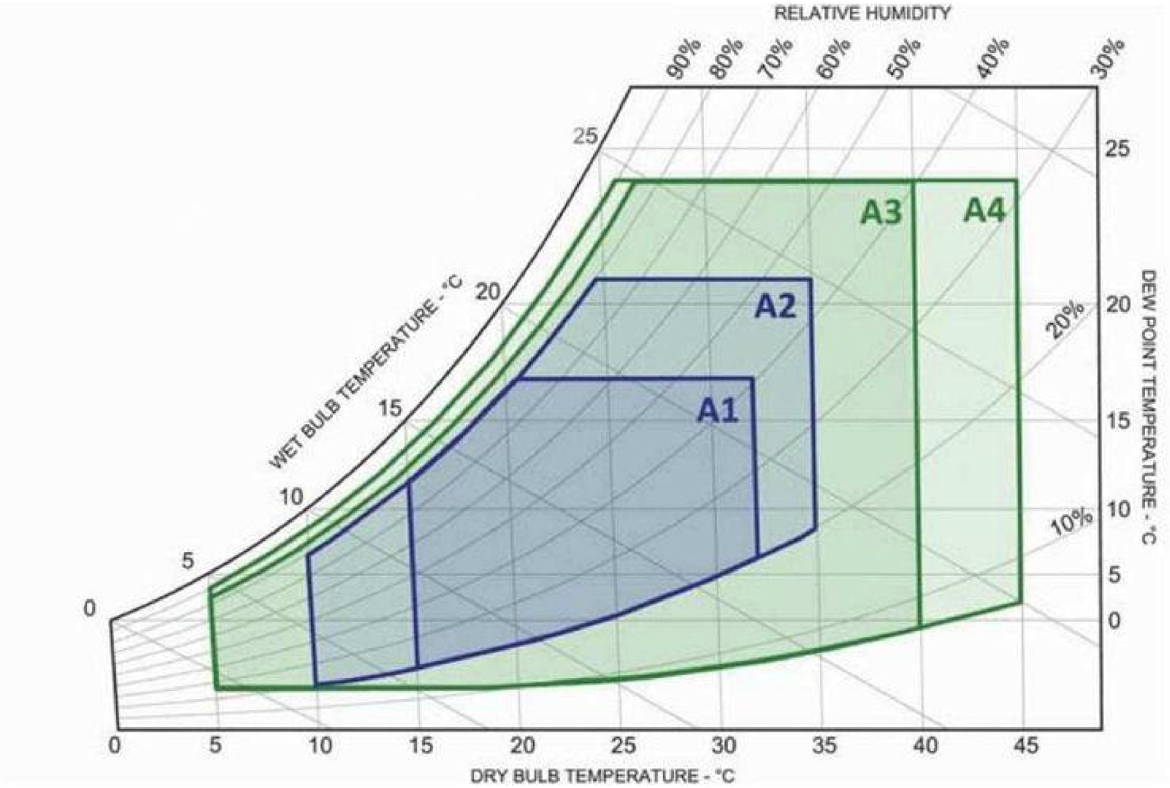


Figure 4-2 - Environmental Classes for Data Centers [12]

In this figure, four classes of IT equipment have been defined A1, A2, A3, and A4 respectively. These classes have been segregated on the basis of energy consumption intensity. Although there are six classes [12] of IT equipment which can be defined based on this criteria, the above mentioned classes have been selected because in them, the intensity of energy absorption is maximum. This gives us the worst case scenario, and calculations according to this can be considered applicable to all situations, especially considering the future changes which may be carried in Lab A and Lab B.

With the help of Figure 4-2 and the data at hand, we can define the recommended and allowable inlet air conditions for the four classes of IT equipment (narrated above). This can be seen in Table 4-2. These values have been extracted from Figure 4-2 above.

Class	**Low Temp Limit (°C)**	**High Temp Limit (°C)**	**Low Moisture Limit (RH %)**	**High Moisture Limit (RH %)**
Class A1 Allowable Range	15	32	20	80
Class A2 Allowable Range	10	35	20	80
Class A3 Allowable Range	5	40	8	85
Class A4 Allowable Range	5	45	8	90
A1 to A4 Recommended	18	27	5.5 °C DP to 60% RH & 15 °C DP	

Table 4-2 - Equipment Environment Specifications for Air Cooling [12]

Before we start explaining the classes and how they have been incorporated in our design calculation, it is pertinent to mention the laboratories under consideration have a low density rack configuration. Greater the density of the racks inside the room, narrower the allowable temperature and humidity ranges will become.

The next step was to integrate the equipment class with the temperature data which has been collected over the course of last sixteen years. This was done with the aid of the psychrometric chart as shown in Figure 4-2. The first step in this was to define a room condition, which in this case has been allocated at a dry bulb temperature of 20±2 degree Celsius (DBT) and 45±5 percent relative humidity (RH%). The next step was to draw that point on the psychrometric chart. The room sensible heat ratio line for the lab was then drawn which has been represented by the black line on the chart.

It is pertinent to mention that the air conditioning units used for comfort cooling are used for sensible as well as the moisture removal from the space to be conditioned. The percentage of moisture which these devices can remove range from 35 to 45 percent approximately of the total cooling load. The precision cooling equipment, such as the ones used in the laboratories under consideration, are however designed more to remove the sensible heat rather than moisture. The moisture removal capacity of these units is as low as five percent. It is for this reason that the sensible heat ratio line which has been drawn on the psychometrics chart is at 95 percent sensible heat i.e. the slope of sensible heat ratio line is 0.95.

Based on the environmental data we have collected for this particular study, the next step was to calculate the free cooling potential at different environmental conditions. We already know that the temperature values vary significantly through day and night, and even months. This, as compared to the precision cooling equipment where we have a fixed supply air temperature, poses a stark contrast. To cater for this contrast, we need to relate the varying temperature with another controllable parameter, which can be maneuvered around so that our free cooling potential remains constant. This controllable parameter was the supply air flow rate which vary with the change in supply air to room condition temperature difference in our case, which has been related to the environmental temperature through the formulae;

Supply air flow rate (cfm) calculation [40].

$$\mathbf{Q = [H_S / 1.08 \times (T_R - T_S)]}$$

Where, Q = air flow in cubic feet per minute (CFM), H_S = total room sensible heat gain (BTU per hr), T_R = Room dry bulb temperature (°F), T_S = Supply air or leaving air temperature from the cooling coil (ºF), 1.08 = conversion constant = 0.244 X (60/13.5), 0.244 = specific heat of moist air (Btu/lb of dry air), 13.5 = specific volume of moist air (cu-ft. per lb of dry air (@70° F, 50% RH) and 60 is conversion from hour to minute.

The values which we achieved through this formula have been represented in the form of Table 4-3, Table 4-4 and Table 4-5.

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	392,946.00	1.08	64.40	18.00	44.40	6.89	18,192	20.00
2	392,946.00	1.08	64.40	18.00	45.40	7.44	19,149	19.00
3	392,946.00	1.08	64.40	18.00	46.40	8.00	20,213	18.00
4	392,946.00	1.08	64.40	18.00	47.40	8.56	21,402	17.00
5	392,946.00	1.08	64.40	18.00	48.40	9.11	22,740	16.00
6	392,946.00	1.08	64.40	18.00	49.40	9.67	24,256	15.00
7	392,946.00	1.08	64.40	18.00	50.40	10.22	25,988	14.00
8	392,946.00	1.08	64.40	18.00	51.40	10.78	27,988	13.00
9	392,946.00	1.08	64.40	18.00	52.40	11.33	30,320	12.00
10	392,946.00	1.08	64.40	18.00	53.40	11.89	33,076	11.00
11	392,946.00	1.08	64.40	18.00	54.40	12.44	36,384	10.00

Table 4-3 - SEECS Data Centre supply air temperature values for room condition (18 C DB, 40% RH)

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	392,946.00	1.08	68.00	20.00	48.00	8.89	18,192	20.00
2	392,946.00	1.08	68.00	20.00	49.00	9.44	19,149	19.00
3	392,946.00	1.08	68.00	20.00	50.00	10.00	20,213	18.00
4	392,946.00	1.08	68.00	20.00	51.00	10.56	21,402	17.00
5	392,946.00	1.08	68.00	20.00	52.00	11.11	22,740	16.00
6	392,946.00	1.08	68.00	20.00	53.00	11.67	24,256	15.00
7	392,946.00	1.08	68.00	20.00	54.00	12.22	25,988	14.00
8	392,946.00	1.08	68.00	20.00	55.00	12.78	27,988	13.00
9	392,946.00	1.08	68.00	20.00	56.00	13.33	30,320	12.00
10	392,946.00	1.08	68.00	20.00	57.00	13.89	33,076	11.00
11	392,946.00	1.08	68.00	20.00	58.00	14.44	36,384	10.00

Table 4-4 - SEECS Data Centre supply air temperature values for room condition (20 C DB, 40% RH)

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	392,946.00	1.08	71.60	22.00	51.60	10.89	18,192	20.00
2	392,946.00	1.08	71.60	22.00	52.60	11.44	19,149	19.00
3	392,946.00	1.08	71.60	22.00	53.60	12.00	20,213	18.00
4	392,946.00	1.08	71.60	22.00	54.60	12.56	21,402	17.00
5	392,946.00	1.08	71.60	22.00	55.60	13.11	22,740	16.00
6	392,946.00	1.08	71.60	22.00	56.60	13.67	24,256	15.00
7	392,946.00	1.08	71.60	22.00	57.60	14.22	25,988	14.00
8	392,946.00	1.08	71.60	22.00	58.60	14.78	27,988	13.00
9	392,946.00	1.08	71.60	22.00	59.60	15.33	30,320	12.00
10	392,946.00	1.08	71.60	22.00	60.60	15.89	33,076	11.00
11	392,946.00	1.08	71.60	22.00	61.60	16.44	36,384	10.00

Table 4-5 - SEECS Data Centre supply air temperature values for room condition (22 C DB, 40% RH)

In the tables, Delta T in Fahrenheit represents the differential temperature which is to be maintained between supply air and room temperature. As we keep on decreasing the value of this temperature differential, the value of the flow rate which is to be injected inside the laboratory increases. Here in all the three cases we are limiting the supply air up to 59 F (15 C), i.e. when outside DB temperature is 59 F (15 C) or below we will use it for our free cooling.

It is important to mention here that we are still under the recommended envelope which has been shown in Figure 4-2 and Table 4-2 above. That envelope allows a temperature range from 18-27 degree Celsius while we are operating from 18 to 22 degree Celsius in the three cases shown in the tabular form above. A designer can extend this study to 27 degree Celsius, but then there arise a number of other factors like abrupt temperature changes, high humidity at higher temperatures and human factor, all of which result in decreased equipment reliability. Operating at high temperature continuous monitoring is required. However, if the data center is at a lower heat density, these factors can be controlled easily at higher temperatures (i.e. till 27 degree Celsius).

These three conditions were then drawn on the psychometrics chart and we can see from the Figure 4-3, Figure 4-4, Figure 4-5 and Figure 4-6 below that all the three conditions are within the recommended range.

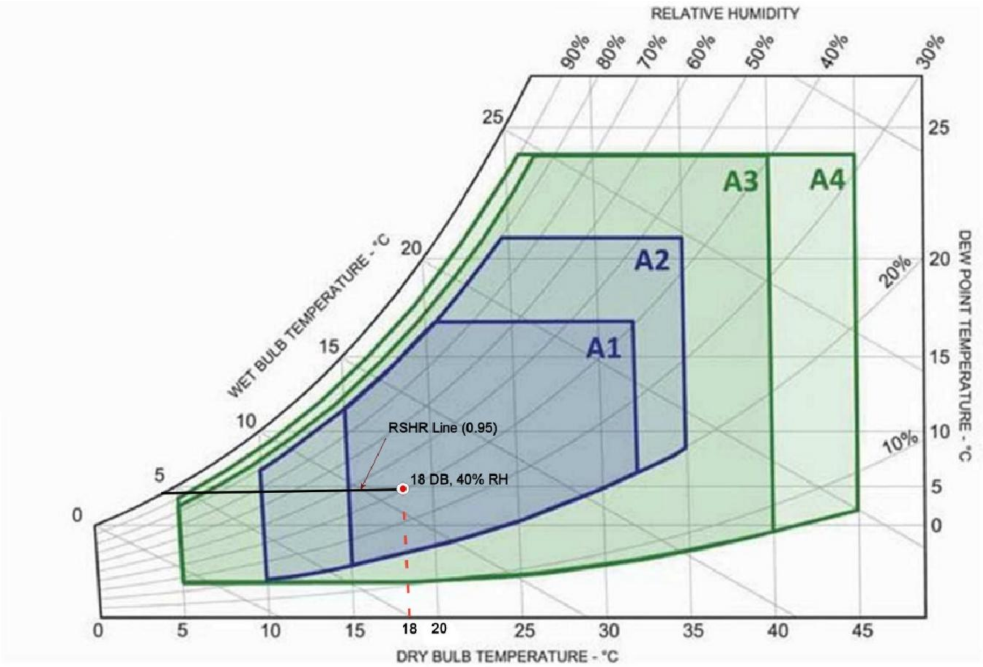


Figure 4-3 - Room conditions (18 C DB, 40% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

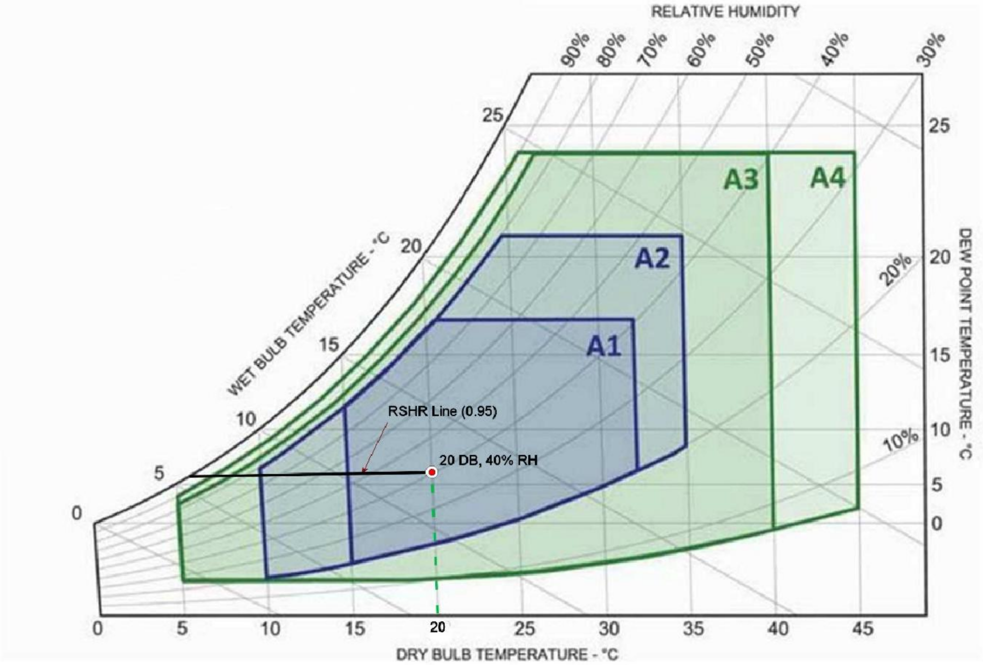


Figure 4-4 - Room conditions (20 C DB, 40% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

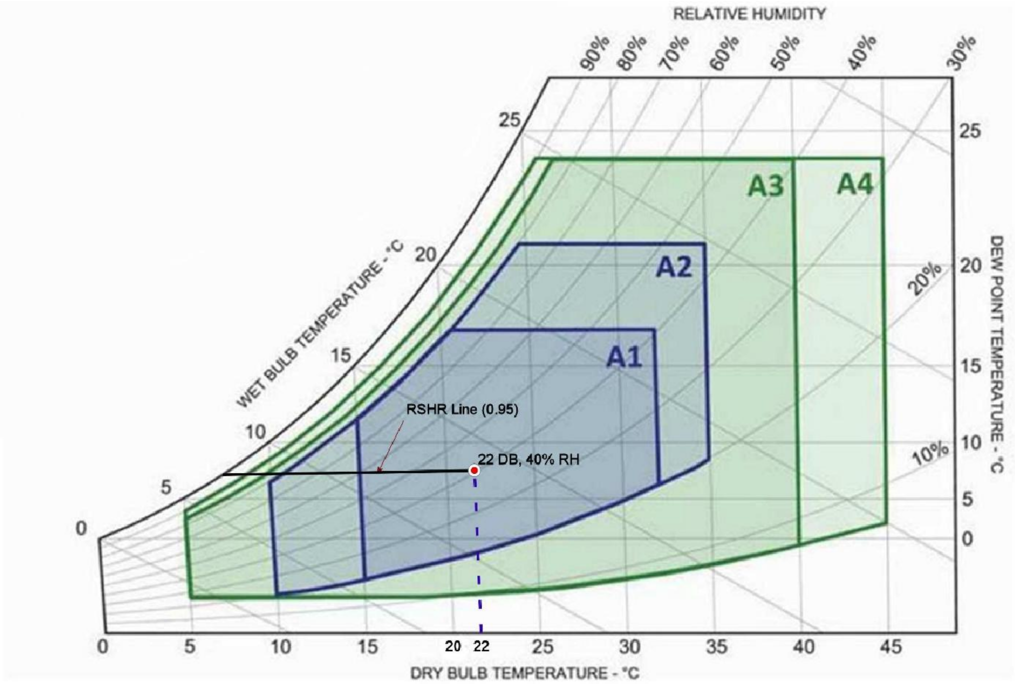


Figure 4-5 - Room conditions (22 C DB, 40% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

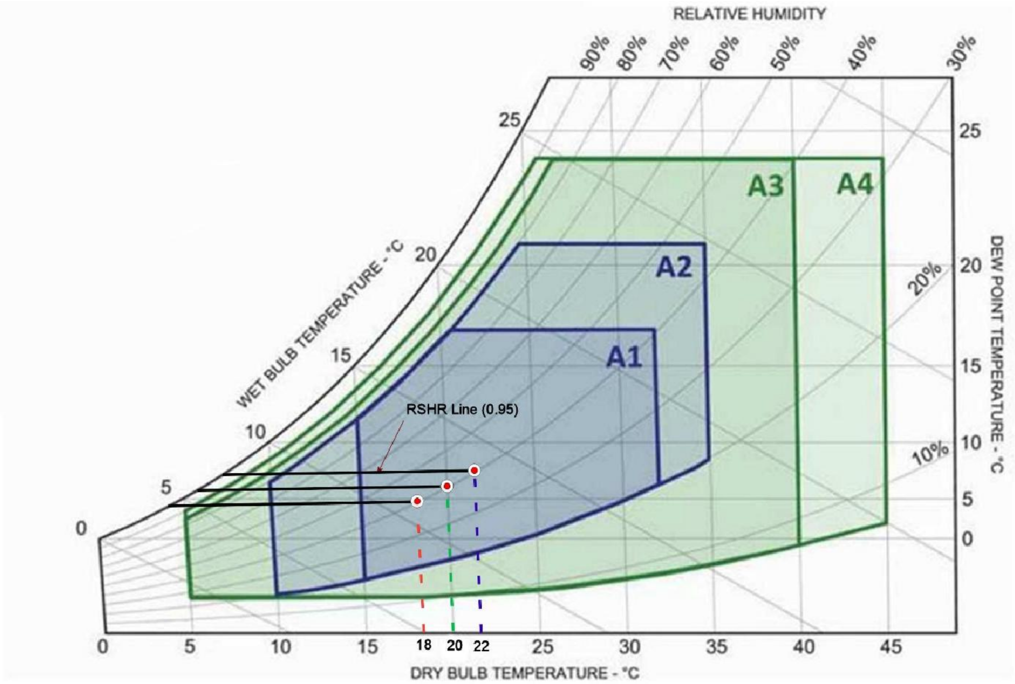


Figure 4-6 - All Three Room conditions (18 C, 20 C and 22 C DB, 40% RH) plotted on psychrometric chart, marked with ASHRAE Environmental Classes for Data Centers

In these results, the role of humidity is also significant and has been duly considered in this study. In the three cases above, we simply took humidity at 40 percent and then analyzed our required conditions. However, even if outside humidity drops, still the three cases which have been defined remain within the recommended range, something which has been shown by the Figure 4-7, Figure 4-8, Figure 4-9 and Figure 4-10 below.

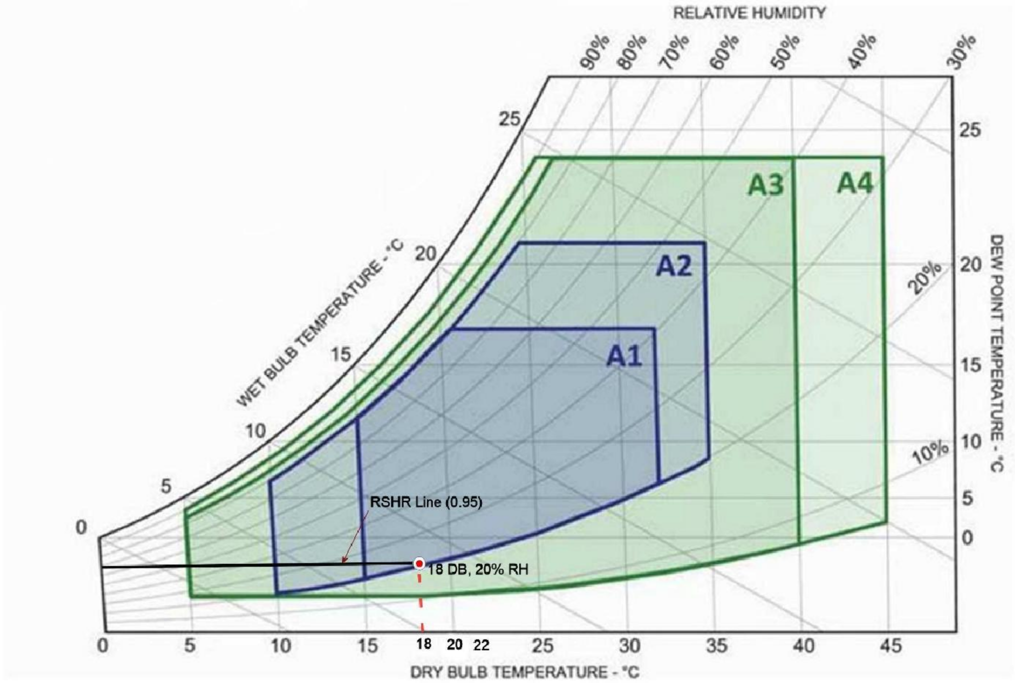


Figure 4-7 - Room conditions (18 C DB, 20% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

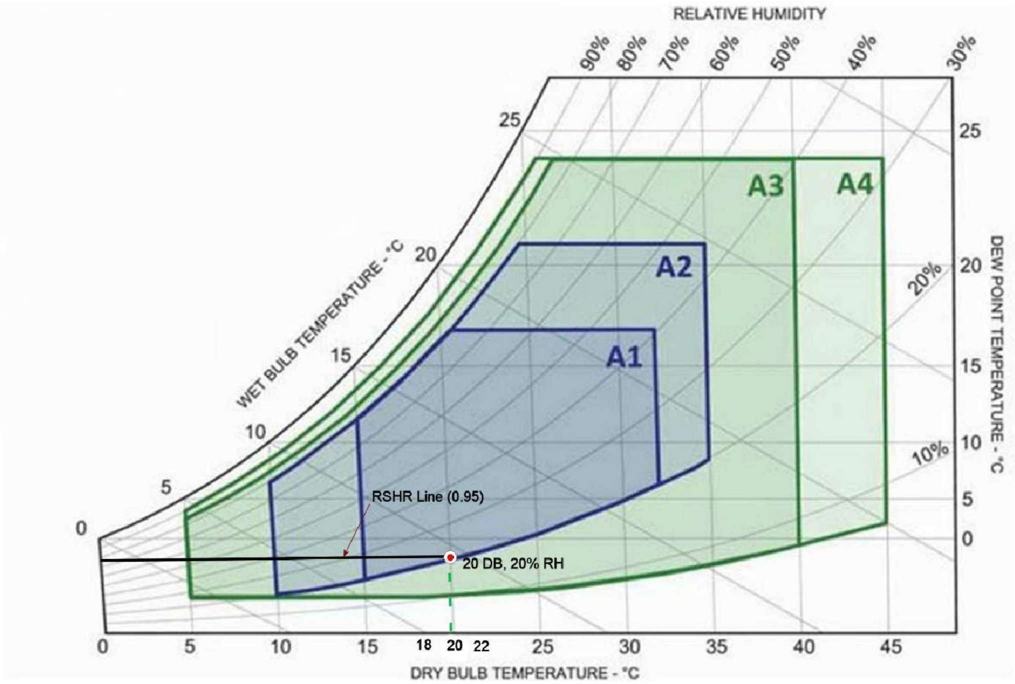


Figure 4-8 - Room conditions (20 C DB, 20% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

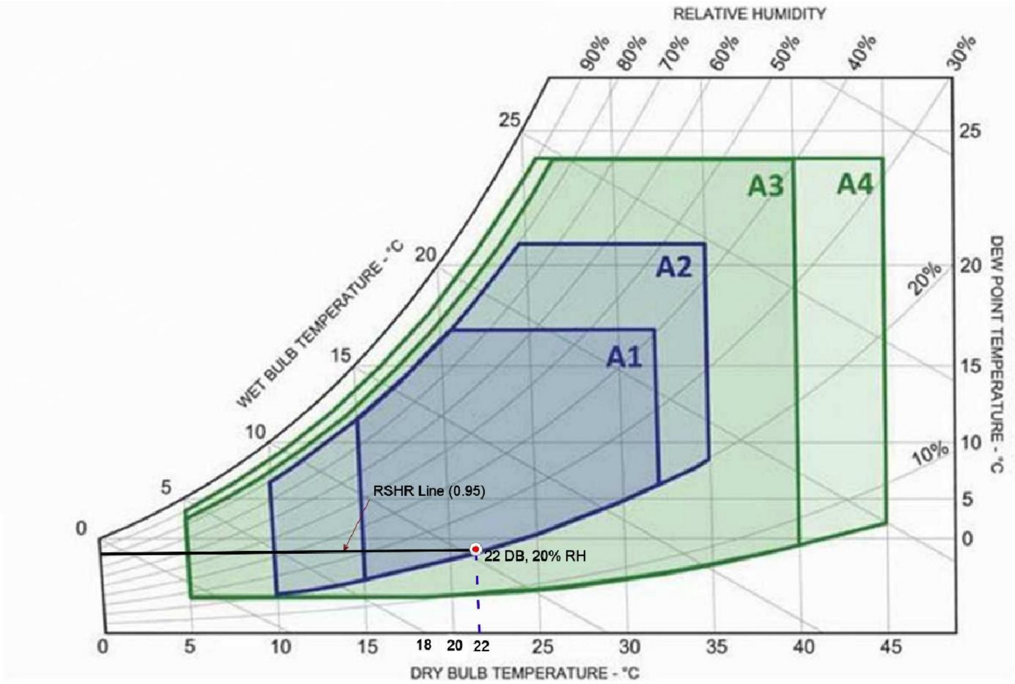


Figure 4-9 - Room conditions (22 C DB, 20% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

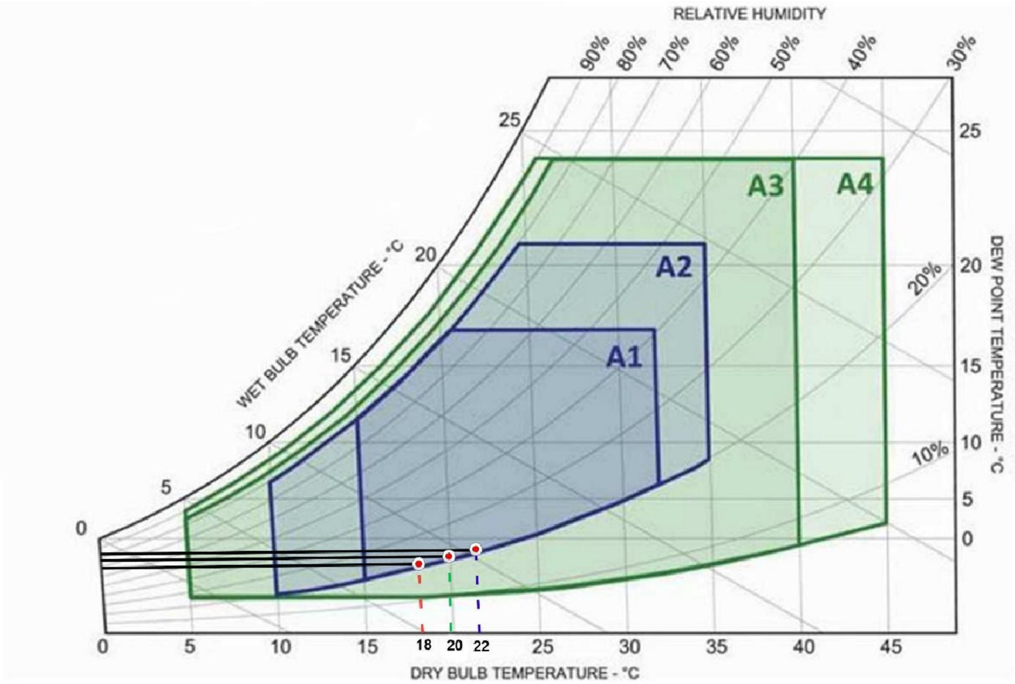


Figure 4-10 - All Three Room conditions (18 C, 20 C and 22 C DB, 20% RH) plotted on psychometrics chart, marked with ASHRAE Environmental Classes for Data Centers

After elaborating the temperature and humidity conditions which are to be followed for free cooling in the laboratories under consideration, the next step, i.e. the determination of month-wise free cooling potential, became simpler. This process will be carried out with the help of Table 4-6 shown below. In this table, which has been explained in detail in the previous chapter, we can see that a lot of values under 15 Degree Celsius occur in the months of January, February, March and October, November December – all months which are normally associated with the winter season in Islamabad.

In January, we are getting a lot of desire bin values at both night and day, while as we move on to February, these occurrences are more dominant at night. In March, the trend of desired bin values occurring at night time continues.

	Time	Dry Bulb Temperature Bin (C)																									
		-4/-2	**-2/0**	**0/2**	**2/4**	**4/6**	**6/8**	**8/10**	**10/12**	**12/14**	**14/16**	**16/18**	**18/20**	**20/22**	**22/24**	**24/26**	**26/28**	**28/30**	**30/32**	**32/34**	**34/36**	**36/38**	**38/40**	**40/42**	**42/44**	**44/46**	**46/48**
January	**3 GMT**	1	3	43	119	123	101	68	28	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	8	17	25	47	96	146	100	38	12	6	0	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	8	25	57	120	133	89	50	10	2	1	0	0	0	0	0	0	0	0	0	0	0
	Total	1	3	43	119	123	117	110	110	176	230	235	150	48	14	7	0	0	0	0	0	0	0	0	0	0	0
February	**3 GMT**	0	0	0	20	47	90	111	108	62	11	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	2	10	19	35	31	68	103	91	64	20	7	2	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	1	0	2	15	31	37	67	107	91	62	24	12	3	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	21	47	94	136	158	134	109	177	195	153	88	32	10	2	0	0	0	0	0	0	0	0	0
March	**3 GMT**	0	0	0	0	1	3	19	61	99	124	83	48	22	5	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	1	0	3	9	17	14	36	47	91	80	71	53	30	12	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	1	0	1	4	9	20	36	60	77	84	59	59	33	19	3	0	0	0	0	0	0	0
	Total	0	0	0	0	2	4	20	68	117	161	133	144	146	180	139	130	86	49	15	0	0	0	0	0	0	0
April	**3 GMT**	0	0	0	0	0	0	0	2	4	21	49	85	86	83	85	47	17	1	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	1	0	0	0	0	2	5	1	7	11	37	29	53	79	65	86	67	25	12	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	3	3	8	8	18	38	41	79	72	53	95	41	18	3	0	0	0	0
	Total	0	0	0	1	0	0	0	2	9	29	58	100	115	158	155	179	168	119	181	108	43	15	0	0	0	0
May	**3 GMT**	0	0	0	0	0	0	0	0	0	2	7	6	25	37	69	118	132	71	25	2	1	0	0	0	0	0
	9 GMT	0	0	0	0	1	0	0	0	0	2	2	1	3	6	12	10	19	39	84	95	105	86	26	4	0	0
	12 GMT	0	0	0	0	0	0	0	0	2	0	2	2	5	11	10	22	35	34	110	92	95	61	15	0	0	0
	Total	0	0	0	0	1	0	0	0	2	4	11	9	33	54	91	150	186	144	219	189	201	147	41	4	0	0
June	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	6	16	37	80	112	128	81	16	4	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	18	34	61	82	109	100	48	16	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	6	29	36	68	79	103	80	28	8	1	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	8	21	47	93	159	198	210	177	216	180	76	24	1	0
July	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	0	6	42	76	97	145	83	41	6	0	0	0	0	0	0
	9 GMT	0	0	0	0	1	0	0	0	0	0	0	0	0	5	16	29	37	53	117	114	80	33	11	0	0	0

	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	27	49	76	113	114	65	28	11	0	0	0
	Total	0	0	0	0	1	0	0	0	0	0	0	0	6	49	103	153	231	212	271	234	145	61	22	0	0	0
August	**3 GMT**	0	0	0	0	0	0	0	0	0	0	0	2	15	56	76	152	155	37	1	1	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	0	0	2	8	15	30	70	88	170	95	16	2	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	1	7	10	30	90	125	160	65	8	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	2	18	71	101	212	315	250	331	161	24	2	0	0	0	0
September	**3 GMT**	0	0	0	0	0	0	0	0	0	0	1	13	53	115	112	123	61	2	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	0	0	0	1	1	3	7	9	24	65	100	200	65	5	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	0	0	0	5	7	15	46	98	149	127	30	3	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	2	14	61	129	136	193	224	251	327	95	8	0	0	0	0	0
October	**3 GMT**	0	0	0	0	0	0	3	11	24	63	105	118	82	68	16	5	1	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	2	0	0	0	0	0	0	3	4	8	12	27	78	163	124	65	7	1	1	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	0	0	2	3	9	18	48	92	140	99	55	30	0	0	0	0	0	0	0
	Total	0	0	0	2	0	0	3	11	24	65	111	131	108	128	135	223	263	179	95	7	1	1	0	0	0	0
November	**3 GMT**	0	0	0	0	2	33	70	101	115	103	50	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	2	1	2	9	27	55	108	117	126	32	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	0	1	6	14	56	139	103	90	48	19	4	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	2	33	70	104	122	119	115	170	158	199	165	145	36	0	0	0	0	0	0	0	0	0
December	**3 GMT**	0	0	15	63	119	123	118	40	12	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9 GMT	0	0	0	0	0	0	0	9	19	35	87	149	125	60	11	1	0	0	0	0	0	0	0	0	0	0
	12 GMT	0	0	0	0	0	0	6	22	76	126	178	73	13	2	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	15	63	119	123	124	71	107	167	265	222	138	62	11	1	0	0	0	0	0	0	0	0	0	0

Table 4-6 - 16 years total Monthly Dry Temperature bin values for Islamabad/Rawalpindi

Time	**Dry Bulb Temperature Bin (C)**																									
	-4/-2	**-2/0**	**0/2**	**2/4**	**4/6**	**6/8**	**8/10**	**10/12**	**12/14**	**14/16**	**16/18**	**18/20**	**20/22**	**22/24**	**24/26**	**26/28**	**28/30**	**30/32**	**32/34**	**34/36**	**36/38**	**38/40**	**40/42**	**42/44**	**44/46**	**46/48**
3 GMT	1	3	58	202	292	350	389	351	325	331	297	277	295	423	471	622	623	322	148	25	5	0	0	0	0	0
9 GMT	0	0	0	3	2	11	27	58	113	188	331	428	383	412	345	436	538	533	795	525	341	234	85	20	0	0
12 GMT	0	0	0	1	1	10	47	115	253	365	479	432	314	318	306	431	509	547	706	421	292	172	54	8	1	0
Total	1	3	58	206	295	371	463	524	691	884	1107	1137	992	1153	1122	1489	1670	1402	1649	971	638	406	139	28	1	0

Table 4-7 - 16 years total Dry Temperature values for Islamabad/Rawalpindi

Similarly, when we move to October, we start getting the desired bin values at night time and as we move on to December, we getting these values both at day and nights. In all the month, the highest number of bin values occur in January, which means that it is the most productive month as far as attaining the maximum free cooling potential is concerned.

In Table 4-7, we have shown the bin values occurrences throughout the 12 months for the last sixteen years. In this table, we can see the maximum bin occurrences are indicated at night time.

In Table 4-8 for the moths we discussed above the humidity values have been highlighted for the same months that ranges from 20% RH to 80% RH, which is the allowable range for the equipment which have been specified from ASHRAE as shown in table 5.2 above. Similarly, in Table 4-9 the humidity values occurrences throughout the year for the last 16 years have been shown.

Thus far, we have established the free cooling potential available in the environmental conditions of Islamabad. The next step is to show whether the process we have developed actually results in energy efficiency or not. For that purpose, some detailed calculations were carried out.

The first step in these calculation was to configure the total electric load consumed by the CRAC units. This was done by using the manufacturer's catalog of that specific unit. These results have been shown in Table 4-10.

The next step was the selection of fans, which were to be used as an alternate to CRAC units. As per Table 4-3 above, the amount of heat that has to be removed from the SEECS lab is 392,946.00 Btu/hr. According to the same table the amount of air (cfm) is 21,219 at a temperature differential of 20°F and 42,438 at a differential of 10°F. Keeping in view these cfm minimum and maximum cfm values we selected a fan unit of 5500 cfm each, their total number being 8. The supply air fan configuration is shown in Table 4-11.

	Time	**Relative Humidity %**																			
		0/5	**5/10**	**10/15**	**15/20**	**20/25**	**25/30**	**30/35**	**35/40**	**40/45**	**45/50**	**50/55**	**55/60**	**60/65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**90/95**	**95/100**
January	**3 GMT**	0	0	0	0	0	0	0	1	0	0	3	2	1	17	16	50	110	98	139	28
	9 GMT	0	0	1	5	25	33	47	45	60	63	42	36	21	16	8	16	11	11	14	11
	12 GMT	0	0	1	4	10	12	18	32	43	48	52	37	50	24	26	24	28	15	31	10
	Total	0	0	2	9	35	45	65	78	103	111	97	75	72	57	50	90	149	124	184	49
February	**3 GMT**	0	0	0	0	0	1	0	1	0	0	2	10	13	15	20	70	95	126	81	18
	9 GMT	0	2	1	14	22	35	53	51	49	45	40	31	17	18	3	12	20	12	22	5
	12 GMT	0	0	5	7	16	22	39	23	56	59	48	30	33	17	17	14	25	14	21	6
	Total	0	2	6	21	38	58	92	75	105	104	90	71	63	50	40	96	140	152	124	29
March	**3 GMT**	0	0	0	0	0	0	1	1	11	25	23	39	40	44	58	72	84	43	17	7
	9 GMT	0	1	2	25	22	53	78	73	59	33	31	25	10	9	7	10	10	4	9	3
	12 GMT	0	0	4	15	24	38	67	57	48	55	42	26	21	15	10	8	17	10	5	3
	Total	0	1	6	40	46	91	146	131	118	113	96	90	71	68	75	90	111	57	31	13
April	**3 GMT**	0	0	0	0	5	13	16	28	40	64	53	68	63	38	26	24	23	7	10	2
	9 GMT	0	3	24	44	84	94	66	45	32	23	16	15	8	8	6	3	1	1	5	2
	12 GMT	0	4	24	49	63	80	58	60	39	27	18	9	7	13	8	5	7	4	4	1
	Total	0	7	48	93	152	187	140	133	111	114	87	92	78	59	40	32	31	12	19	5
May	**3 GMT**	0	0	0	1	2	23	55	72	98	68	60	49	25	13	5	7	7	5	5	1
	9 GMT	0	5	28	77	104	105	63	51	20	14	10	2	5	3	2	2	2	1	2	0
	12 GMT	0	6	34	75	96	97	56	54	23	19	6	10	3	4	2	3	3	2	2	1
	Total	0	11	62	153	202	225	174	177	141	101	76	61	33	20	9	12	12	8	9	2
June	**3 GMT**	0	1	0	0	4	15	33	69	61	65	52	45	36	29	22	14	17	8	5	4
	9 GMT	0	0	15	51	72	68	50	55	61	31	27	23	7	11	7	0	0	0	2	0
	12 GMT	0	1	27	46	55	66	48	69	53	37	19	22	12	10	5	5	1	2	2	0
	Total	0	2	42	97	131	149	131	193	175	133	98	90	55	50	34	19	18	10	9	4

July	**3 GMT**	1	0	0	0	0	2	1	1	6	19	35	42	48	68	50	59	53	36	34	40
	9 GMT	1	0	0	0	2	16	25	39	49	67	75	59	51	42	14	18	9	15	5	9
	12 GMT	1	0	0	0	2	9	30	47	54	64	62	63	51	46	18	13	19	9	5	3
	Total	3	0	0	0	4	27	56	87	109	150	172	164	150	156	82	90	81	60	44	52
August	**3 GMT**	0	0	0	0	0	0	0	0	0	1	1	5	21	44	79	103	100	46	49	46
	9 GMT	0	0	0	0	0	1	0	4	17	33	75	104	79	62	36	33	25	9	11	7
	12 GMT	0	0	0	0	0	0	1	3	14	43	62	91	97	70	32	43	19	8	4	9
	Total	0	0	0	0	0	1	1	7	31	77	138	200	197	176	147	179	144	63	64	62
September	**3 GMT**	0	0	0	0	0	0	0	0	0	1	7	14	37	59	91	108	88	36	28	11
	9 GMT	0	0	0	0	0	3	18	31	61	103	89	60	47	25	13	13	9	4	2	2
	12 GMT	0	0	0	0	0	0	10	26	50	102	79	67	55	38	21	15	10	2	1	4
	Total	0	0	0	0	0	3	28	57	111	206	175	141	139	122	125	136	107	42	31	17
October	**3 GMT**	0	0	0	0	0	0	0	0	0	4	9	27	51	77	81	109	87	40	10	1
	9 GMT	0	0	0	6	35	57	86	92	77	45	29	23	24	9	6	1	3	0	2	1
	12 GMT	0	0	0	1	7	30	46	89	84	70	48	36	21	27	19	9	2	5	1	1
	Total	0	0	0	7	42	87	132	181	161	119	86	86	96	113	106	119	92	45	13	3
November	**3 GMT**	0	0	0	0	0	0	1	1	2	5	5	9	14	26	72	89	146	81	29	0
	9 GMT	0	0	0	19	42	56	80	85	64	47	30	22	13	9	6	2	3	0	2	0
	12 GMT	0	0	0	1	7	20	37	38	57	81	75	44	46	28	20	16	6	2	2	0
	Total	0	0	0	20	49	76	118	124	123	133	110	75	73	63	98	107	155	83	33	0
December	**3 GMT**	0	0	0	0	0	0	0	0	0	1	3	4	16	20	30	88	103	125	91	14
	9 GMT	0	0	1	19	52	43	59	51	67	58	38	30	27	13	6	9	11	7	3	2
	12 GMT	0	0	0	1	17	31	34	34	44	46	59	73	31	28	34	23	22	4	13	2
	Total	0	0	1	20	69	74	93	85	111	105	100	107	74	61	70	120	136	136	107	18

Table 4-8 - 16 Years Total Monthly Humidity Ratio % values for Islamabad/Rawalpindi

Time	**Relative Humidity %**																			
	0/5	**5/10**	**10/15**	**15/20**	**20/25**	**25/30**	**30/35**	**35/40**	**40/45**	**45/50**	**50/55**	**55/60**	**60/65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**90/95**	**95/100**
3 GMT	1	1	0	1	11	54	107	174	218	253	253	314	365	450	550	793	913	651	498	172
9 GMT	1	11	72	260	460	564	625	622	616	562	502	430	309	225	114	119	104	64	79	42
12 GMT	1	11	95	199	297	405	444	532	565	651	570	508	427	320	212	178	159	77	91	40
Total	3	23	167	460	768	1023	1176	1328	1399	1466	1325	1252	1101	995	876	1090	1176	792	668	254

Table 4-9 - 16 Years Total Humidity Ratio % values for Islamabad/Rawalpindi

Compressor power (KW)	**Total Compressor Power of two Compressors (KW)**	**Fan Power (KW)**	**Total Fan Power of Two Fans (KW)**	**Total Power for one CRAC unit (KW)**	**Total Power of two CRAC Units (KW)**
15	30	5	10	40	80

Table 4-10 - Electric Load Summary of SEECS Data Centre CRAC Units

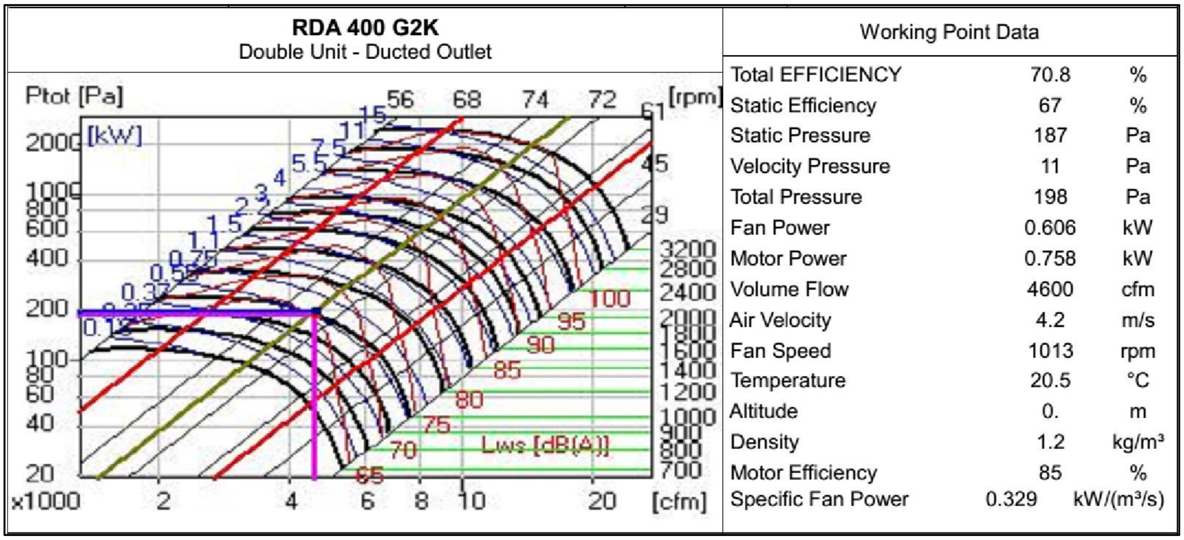
S. No.	**Fan (cfm)**	**No. of fans**	**Total cfm**	**KW**
1	4600	1	4,600	0.76
2	4600	2	9,200	1.52
3	4600	3	13,800	2.27
4	*4600*	*4*	*18,400*	*3.03*
5	4600	5	23,000	3.79
6	4600	6	27,600	4.55
7	4600	7	32,200	5.31
8	*4600*	*8*	*36,800*	*6.06*

Table 4-11 - SEECS Data Centre Supply Air Fan Configurations

It is important to note here that smaller fan units have been selected here to minimize the energy wastage in case there is a lower demand of supply air inside the lab. For example, we selected two large fan units of 18,400 cfm, then in case the required cfm in the lab was 20,000 cfm, we would have to switch both the fan units and a large amount of energy would be dissipated. At the other end of the spectrum, we kept the number of fans to the minimum possible in an attempt to save the capital required.

After the selection of the fan, the next step was to calculate the power consumption of the fan. The fan selection depends upon cfm and the static pressure. The power of the fan depends primarily on these two parameters. While determining the power consumption for CRAC unit fan, we took a nominal static pressure, which was 0.124 inches of water (31 Pa). The static pressure while selecting the fan however is being taken at 0.795 inches of water (198 Pa). The nominal pressure drop was not taken in case of fans because filtration is required in this case and there will also a pressure drop across them, which will tend to increase the fan power.

After the fan static and cfm has been established the fan selection was done by NICOTRA [41] Fan Selection Software as shown in Figure 4-11.



Working Point Data

Total EFFICIENCY	70.8	%
Static Efficiency	67	%
Static Pressure	187	Pa
Velocity Pressure	11	Pa
Total Pressure	198	Pa
Fan Power	0.606	kW
Motor Power	0.758	kW
Volume Flow	4600	cfm
Air Velocity	4.2	m/s
Fan Speed	1013	rpm
Temperature	20.5	°C
Altitude	0.	m
Density	1.2	kg/m³
Motor Efficiency	85	%
Specific Fan Power	0.329	kW/(m³/s)

Figure 4-11 - SEECS Data Centre Fan Selection Using NICOTRA

The value of power consumed by the fan is 0.758 KW. Now to remove 392,946.00 Btu/hr from SEECS lab, the Coefficient of Performance (COP) for both the CRAC units and the fan was calculated, the results of which have been shown in Table 4-12 below.

S. No.	Description	Input (KW)	Output (KW)	COP
1	To remove 392,946.16 Btu/hr or 32.75 TR (115.16 KW) by Stulz Unit	80	115.16	**1.44**
2	Fresh Air Fans (when delta T is 20 F) required cfm is 21,219, so we need 4 Fans	3.03	115.16	**37.98**
3	Fresh Air Fans (when delta T is 10 F) required cfm is 42,438, so we need 8 Fans	6.06	115.16	**18.99**

Table 4-12 - SEECS Data Centre COP Calculation of Fans and CRAC unit

From this table, it is clear that the COP of fan is much higher than that of the CRAC unit. The above calculations have been carried out for the SEECS lab. For the RCMS lab, the same procedure has been carried out and has been represented in a series of figures shown below.

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	142,149.78	1.08	64.40	18.00	44.40	6.89	6,581	20.00
2	142,149.78	1.08	64.40	18.00	45.40	7.44	6,927	19.00
3	142,149.78	1.08	64.40	18.00	46.40	8.00	7,312	18.00
4	142,149.78	1.08	64.40	18.00	47.40	8.56	7,742	17.00
5	142,149.78	1.08	64.40	18.00	48.40	9.11	8,226	16.00
6	142,149.78	1.08	64.40	18.00	49.40	9.67	8,775	15.00
7	142,149.78	1.08	64.40	18.00	50.40	10.22	9,401	14.00
8	142,149.78	1.08	64.40	18.00	51.40	10.78	10,125	13.00
9	142,149.78	1.08	64.40	18.00	52.40	11.33	10,968	12.00
10	142,149.78	1.08	64.40	18.00	53.40	11.89	11,965	11.00
11	142,149.78	1.08	64.40	18.00	54.40	12.44	13,162	10.00

Table 4-13 - RCMS Data Centre supply air temperature values for room condition (18 C DB, 40% RH)

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	142,149.78	1.08	68.00	20.00	48.00	8.89	6,581	20.00
2	142,149.78	1.08	68.00	20.00	49.00	9.44	6,927	19.00
3	142,149.78	1.08	68.00	20.00	50.00	10.00	7,312	18.00
4	142,149.78	1.08	68.00	20.00	51.00	10.56	7,742	17.00
5	142,149.78	1.08	68.00	20.00	52.00	11.11	8,226	16.00
6	142,149.78	1.08	68.00	20.00	53.00	11.67	8,775	15.00
7	142,149.78	1.08	68.00	20.00	54.00	12.22	9,401	14.00
8	142,149.78	1.08	68.00	20.00	55.00	12.78	10,125	13.00
9	142,149.78	1.08	68.00	20.00	56.00	13.33	10,968	12.00
10	142,149.78	1.08	68.00	20.00	57.00	13.89	11,965	11.00
11	142,149.78	1.08	68.00	20.00	58.00	14.44	13,162	10.00

Table 4-14 - RCMS Data Centre supply air temperature values for room condition (20 C DB, 40% RH)

			T_R		T_S			
S. No	**H_S**	**Conversion Constant**	°F	°C	°F	°C	**Q (cfm)**	**Delta T (°F)**
1	142,149.78	1.08	71.60	22.00	51.60	10.89	6,581	20.00
2	142,149.78	1.08	71.60	22.00	52.60	11.44	6,927	19.00
3	142,149.78	1.08	71.60	22.00	53.60	12.00	7,312	18.00
4	142,149.78	1.08	71.60	22.00	54.60	12.56	7,742	17.00
5	142,149.78	1.08	71.60	22.00	55.60	13.11	8,226	16.00
6	142,149.78	1.08	71.60	22.00	56.60	13.67	8,775	15.00
7	142,149.78	1.08	71.60	22.00	57.60	14.22	9,401	14.00
8	142,149.78	1.08	71.60	22.00	58.60	14.78	10,125	13.00
9	142,149.78	1.08	71.60	22.00	59.60	15.33	10,968	12.00
10	142,149.78	1.08	71.60	22.00	60.60	15.89	11,965	11.00
11	142,149.78	1.08	71.60	22.00	61.60	16.44	13,162	10.00

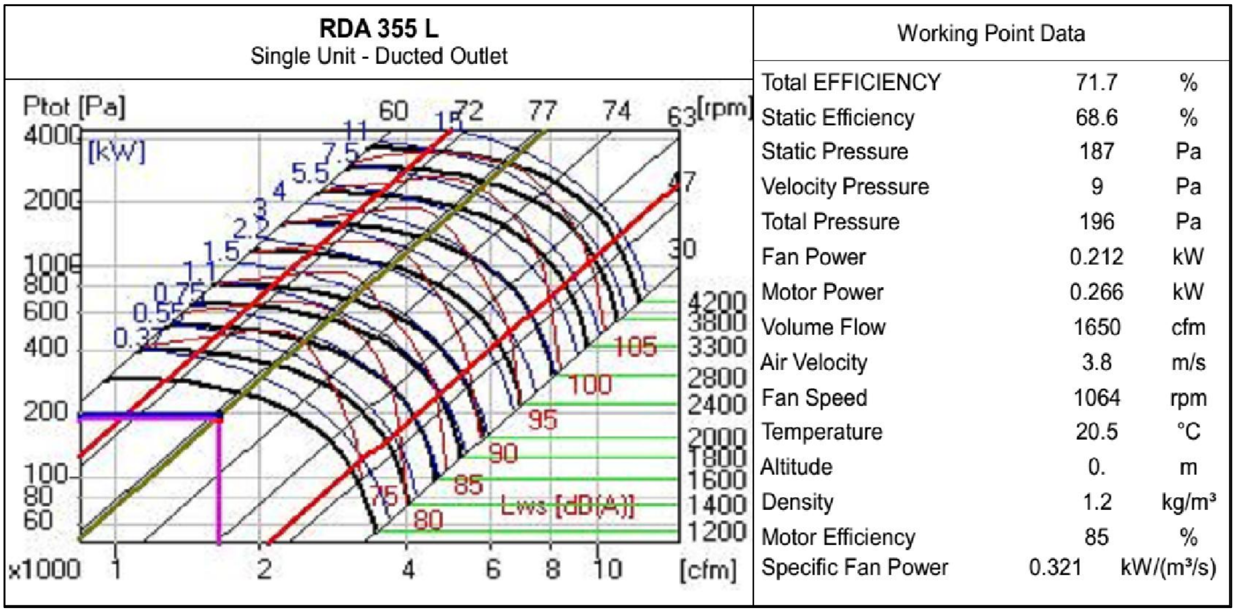
Table 4-15 - RCMS Data Centre supply air temperature values for room condition (22 C DB, 40% RH)

Compressor power (Kw)	**No. of Compressors**	**Total Compressor Power**	**Fan Power**	**No. of Fans**	**Total Fan Power**	**Total Power of CRAC Unit (KW)**
8.4	1	8.4	2.95	1	2.95	11.35

Table 4-16 - Electric Load Summary of RCMS Data Centre CRAC Units

S. No	**Fan (cfm)**	**No. of fans**	**Total cfm**	**KW**
1	1650	1	1,650	0.266
2	1650	2	3,300	0.532
3	1650	3	4,950	0.798
4	*1650*	*4*	*6,600*	*1.064*
5	1650	5	8,250	1.33
6	1650	6	9,900	1.596
7	1650	7	1,550	1.862
8	*1650*	*8*	*13,200*	*2.128*

Table 4-17 - SEECS Data Centre Supply Air Fan Configurations



Working Point Data		
Total EFFICIENCY	71.7	%
Static Efficiency	68.6	%
Static Pressure	187	Pa
Velocity Pressure	9	Pa
Total Pressure	196	Pa
Fan Power	0.212	kW
Motor Power	0.266	kW
Volume Flow	1650	cfm
Air Velocity	3.8	m/s
Fan Speed	1064	rpm
Temperature	20.5	°C
Altitude	0.	m
Density	1.2	kg/m³
Motor Efficiency	85	%
Specific Fan Power	0.321	kW/(m³/s)

Figure 4-12 - RCMS Data Centre Fan Selection Using NICOTRA

S. No.	Description	Input (KW)	Output (KW)	COP
1	To remove 142,148.78 Btu/hr or 11.85 TR (41.66 KW) by Stulz Unit	11.35	41.66	**3.67**
2	Fresh Air Fans (when delta T is 20 F) required cfm is 7,676, so we need 4 Fans	1.064	41.66	39.15
3	Fresh Air Fans (when delta T is 10 F) required cfm is 15,352, so we need 8 Fans	2.128	41.66	19.58

Table 4-18 - RCMS Data Centre COP Calculation of Fans and CRAC unit

5 CONCLUSION

The detailed study of the SEECS and RCMS labs were carried out and a number of issues were pointed out in various categories. Starting from its design, the redundancies of the system were not completely achieved in both the labs, which can result in total shutdown in case of an extended power failure. Secondly, in terms of energy efficiency, the hot isle and cold isle zoning was not properly done, which results in short-cycling and subsequently energy loss. Moreover, temperature and humidity sensors, required for detecting hotspots are not installed in both the labs.

These issues have been addressed in the study and recommendations have been made to help increase the energy efficiency, including the placement layout of the sensors and the zoning scheme. However, if we are to achieve a drastic increase in energy efficiency, free cooling has to be introduced. This has been done so by manipulating the bin data and using the air conditioning design principles. In this regard, dry bulb temperature and humidity were chosen as base parameters and the cooling requirements were achieved while remaining inside the recommended ASHRAE temperature and humidity ranges. The temperature range selected for this study was from 18 to 22°C. This was done so define a design criteria, which can be implemented on any range of temperature, although continuous monitoring is required for higher temperatures – for our range the highest temperature can be as much as 27°C according to the recommended ASHRAE Envelope.

The COP improvement in case of free cooling is evident from the Table 4-12, Table 4-18. Also, under the proposed free cooling configuration, the amount of input power required can be reduced drastically, which would result in significant energy savings. Energy conservation and cost analysis was done based on this and has been highlighted in Table 5-1 and Table 5-2. It can be seen that by using free cooling nearly 3.3 million Pakistani Rupees can be saved in electricity bills during the months of December, January and February. It is pertinent to mention that this energy saving potential has been achieved for a very small data centre with limited IT equipment. There is room for much more energy saving if the data centre under focus is larger, and if partial free cooling is also considered.

Description	Mechanical Cooling (KWh)	Free Cooling (KWh)	Energy Conserved (KWh)	Energy Conserved per day (KWh)	Energy Conserved per month (KWh)	Energy Conserved for 3 months (KWh)
SEECS	80	3.03	76.97	1,847	55,418	166,255
RCMS	11.35	1.064	10.286	247	7,406	22,218

Table 5-1- Energy Conservation achieved with free cooling

Description	Price for Commercial unit (1 KWh)	Amount saved per day (PKR)	Amount saved per month (PKR)	Amount saved for 3 month (PKR)
SEECS	20	36,946	1,108,368	3,325,104
RCMS	20	4,937	148,118	444,355

Table 5-2 - Amount saved with free cooling

Free cooling is an extremely effective method of designing energy efficient buildings, especially data centers. In this study, the energy efficiency of SEECS data center has been enhanced by using the free cooling concept during the months of December, January and February. Temperature and humidity bin data for Islamabad has been used to define the recommended operational envelopes for free cooling, and an estimate of likely cost savings and increase in efficiency has been presented.

5.1 Future Recommendations

The present recommendations were based on the basis of the current setup/layouts in the two labs. In case, if we want to use the cooling potential in an even more holistic way, we can introduce an air-side economizer as well as water-side economizer. This free cooling concept can also be used in domestic cooling environment.

Evaporative cooling can also be introduced with the help of Environmental data for the data centre free cooling.

In winter when data centre is running on free cooling, instead of exhausting the return air, which is at higher temperature than the outside, can be supply to the comfort cooling zone.

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