

MULTI OBJECTIVE THERMAL AND ENERGY BASED DESIGN OPTIMIZATION OF
TELECOMMUNICATION CABINETS/SHELTERS

by

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ABSTRACT

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The miniaturization and convergence of the consumer electronic products such as cell phones and digital cameras has necessitated an increase in the number of transistors on a die, board and systems. This has resulted in a requirement for a more robust thermal management of such electronics to increase the reliability of the system.

Access networks provide the last mile of connectivity for the telecommunication network users. In the access network, the outside plant telecommunication cabinets houses electronic components and switching devices. These cabinets are standalone outdoor enclosures, and many a times they are located in hostile environments. With the current development in the telecommunication industry migrating from 2G to 3G and later to 4G, the heat loads in the electronic equipments has increased drastically and is expected to rise further in years to come. The cooling systems typically consume 30% of the energy required to operate a wireless cell site. There is, therefore, an impetus to embark on initiatives to reduce this percentage as part of an effort to both save money, and to reduce the carbon footprint. This study purely focuses on

the air cooling system deployed for cooling outdoor shelters/cabinets. A thermal optimization of the cooling system is performed and then analyzed for its energy consumption. Hence, the study is divided into parts: design guidelines for double walled telecom cabinets and thermal management of outdoor shelters using hybrid cooling system.

The first part of this deals with the design and thermal analysis of an outdoor double walled telecommunication cabinet with natural and forced convection in the air gap. Commercial CFD code has been used to design and compare various double walled cabinet configurations. Design guidelines for a double walled telecommunication cabinet have been proposed taking into consideration the thermal performance and the energy consumption of the cooling system.

The second part includes various thermal design options to cut down on the cooling energy loads for telecom shelters. The shelter houses a number of cabinets which have to be maintained within permissible temperature limits. The thermal impact of substituting an active cooling system with a hybrid one is analyzed. The hybrid cooling system consists of both the air conditioner and a blower. Various design options (different blower configuration) are considered for selection of the hybrid cooling system. CFD analysis is performed to compare these designs and come up with a robust design solution. The best cooling methodology showed an energy saving of 40% with negligible impact on the temperature.

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NOMENCLATURE

ρ	Density(Kg/m ³)
u	Velocity (m/s)
μ	Viscosity (N/m ² S)
p	Pressure (Pa)
B_x	Body force in x-direction per unit volume (N/m ³)
V_x	Viscous force in x-direction per unit volume (N/m ³)
h	Specific enthalpy (J/Kg)
k	Thermal conductivity (W/m-K)
T	Temperature (K)
S_h	Volumetric rate of heat generation (W/m ³)
T_{supply}	Supply temperature (°C)
T_{extract}	Extract temperature (°C)
M	Mass flow rate (cfm)
c_p	Specific heat capacity ()
P	Power (W)
Q	Flow rate (cfm)
SP	Static pressure (Pa)
TP	Total pressure (Pa)
\vec{v}	Cross-sectional velocity (m/s)
VP	Velocity pressure (Pa)
η_m	Mechanical efficiency (75%)

CHAPTER 1
INTRODUCTION TO TELECOMMUNICATION SYSTEMS COOLING AND LITERATURE
REVIEW

1.1 Introduction to Outdoor Telecommunication Cabinets/Shelters

1.1.1 Telecommunication Cabinets: An Introduction and Need for Cooling

Telecommunication cabinets are used to house electronic components like phone switches, optical fiber cables, transmitters and receivers. They are usually located close to the customer, remote from the central telecommunication office, and located in outdoor environments. The housed electronic equipments generate heat and there is an impetus to keep the air temperature inside the cabinets within prescribed limits. Thermal stress contributes to equipment malfunctions, reduced long-term reliability, and component failure. Thermal conditions are dependent on the conditions both outside and inside the cabinet. Thus, the ambient temperature, solar loading, and equipment power dissipation, including that associated with a possible engine generator, are critical factors. These factors pose a new challenge for packaging the electronics housed by these cabinets.

The main purpose of these enclosures is to protect the equipments from humidity, dust, solar heating and electromagnetic interference. Hence, prescribed temperatures are maintained within the enclosures for optimum performance of the electronics equipment.

The shelters are bigger in size when compared with the cabinets, the shelter usually house more than one cabinet inside them. With the current growth in performance of the CMOS chip and the corresponding reduction in size, it has led to a drastic increase in the heat density of the chips. Thus there is need for effective thermal management at device, board and system level for the electronics

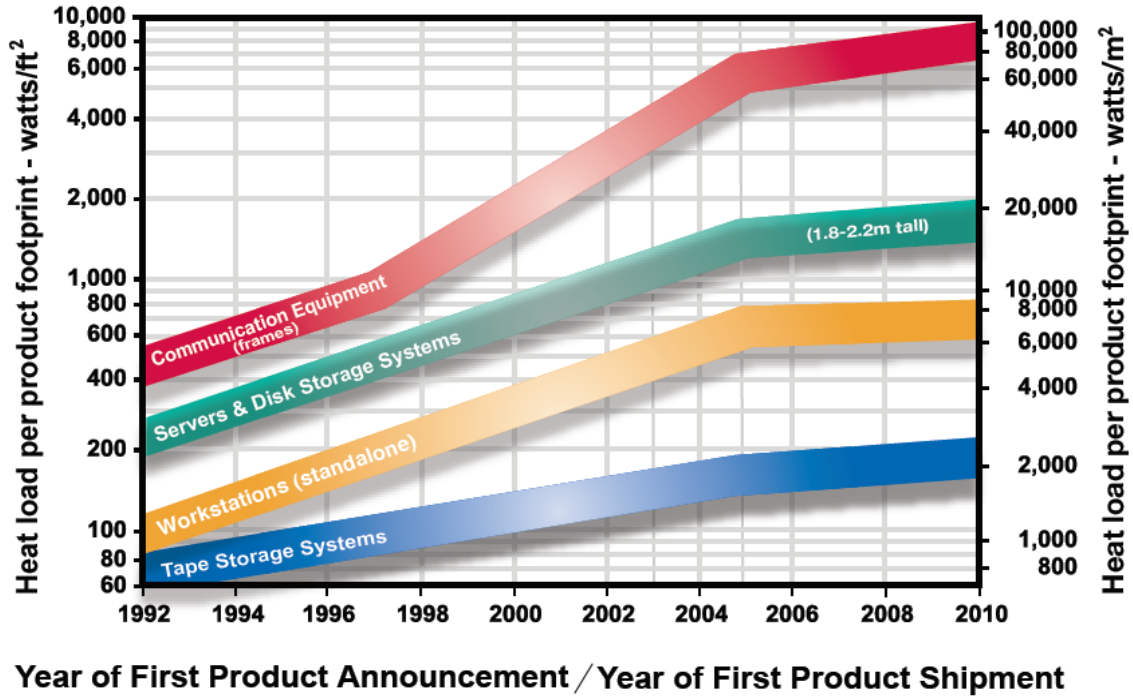


Figure 1.1: Heat density in electronic equipments [1]

Figure 1.1, shows the rise of heat density in various electronic equipments from the year 1992 to 2010 (interpolated). The rate of heat density increase for telecommunication equipments was 13% annually from 1992 to 1998, but after that it increased to 28%. From the year 2000 to 2001, there is an increase of 500 watts/ft² –footprint [1]. It is predicted to grow still higher in the coming years, as there is convergence of cell phones and laptops.

1.1.2 Need for CFD Analysis

The objective of a cfd code is to provide the engineer with a computer based predictive tool to analyze air flow process. It helps the system designers to drastically reduce the time-to-market for products. There has been a dramatic increase of the cfd codes in the design process of electronics from device to system level. The cfd codes are also extensively used in designing of data center facilities, as it can provide vital details like the cabinets temperature for the given data center.

The accuracy of the cfd code depends on a number of factors namely the algorithm used, method of discretization, mesh size, time steps involved and the mode of heat transfer.

Thus various thermal design options and its impact on the system can be simulated and studied, avoiding the need for experimental work thereby saving time and money.

1.1.3 Industry Standards for Telecommunication Cabinets

There are certain specific performance and safety requirements that the cabinet manufacturers must meet. The standards specify the testing requirements of the enclosures. National Electrical Manufacturers Association (NEMA) ratings, Telcordia GR-CORE standards, Underwriters Laboratory (UL) standards and Canadian standards association (CSA) are some of the most commonly followed standards.

1.1.3.1 National Electrical Manufacturers Association (NEMA):

The NEMA standard [2] specifies the enclosures types, their applications and their environmental conditions they are designed to protect against. For non-hazardous locations there are 16 classifications of enclosures out of these 10 of them are commonly followed by telecommunication standards for outside plant cabinets. They are listed below [3]:

Type 3 - Enclosures constructed for outdoor use to provide a degree of protection to personnel against access to hazardous parts. It also provides a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects like falling dirt, windblown dust, rain, sleet and snow. The enclosure will also be undamaged by the external formation of ice on its surface.

Type 3R - Enclosures constructed for outdoor use to provide a degree of protection to personnel against access to hazardous parts. It also provides a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects like falling dirt, rain, sleet and snow. The enclosure will also be undamaged by the external formation of ice on its surface.

Type 3S - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts It also provides a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like

falling dirt, windblown dust rain, sleet and snow and for which the external mechanism(s) remain operable even with formation of ice on the enclosure.

Type 3X - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts It also provides a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt, rain, sleet and snow. It also provides an additional level of protection against corrosion and that will be undamaged by the external formation of ice on the enclosure.

Type 3RX - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts It also provides a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt, rain, sleet and snow. The enclosure will be undamaged by the external formation of ice on the enclosure that provides an additional level of protection against corrosion; and that will be undamaged by the external formation of ice on the enclosure.

Type 3SX - - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts It also provides a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt, rain, sleet and snow. The enclosures also provides an additional level of protection against corrosion; and the external mechanism(s) remain operable when ice laden.

Type 4 - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects namely falling dirt and windblown dust. It also protects the electronic equipments inside from rain, sleet, snow, splashing water, and hose directed water. The enclosure is also undamaged by the external formation of ice on the enclosure.

Type 4X - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of

protection of the equipment inside the enclosure against ingress of solid foreign objects namely falling dirt and windblown dust. It also protects the electronic equipments inside from rain, sleet, snow, splashing water, and hose directed water. The enclosure is also undamaged by the external formation of ice on the enclosure. In addition the enclosure is also corrosion resistant.

Type 5 - Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt and settling airborne dust, lint, fibers, and filings. The enclosure also provides the equipments from ingress of water from dripping and light splashing.

Type 6 - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt. The enclosure also provides a degree of protection with respect to harmful effects on the equipment due to the ingress of water (hose directed water and the entry of water during occasional temporary submersion at a limited depth); and that will be undamaged by the external formation of ice on the enclosure.

Type 6P - Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects like falling dirt. The enclosure also provides a degree of protection with respect to harmful effects on the equipment due to the ingress of water (hose directed water and the entry of water during prolonged submersion at a limited depth). It also provides an additional level of protection against corrosion and that will be undamaged by the external formation of ice on the enclosure.

Type 12, Type 12K and Type 13 enclosures are designed for indoor use. They provide a degree of protection against dust, falling dirt and dripping non-corrosive liquids.

Table 1.1 shows the specific application of different type of enclosures for outdoor non-hazardous locations.

Table 1.1: Comparison of applications of enclosures for outdoor nonhazardous locations [4]

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	3	3X	3R*	3RX*	3S	3SX	4	4X	6	6P
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of water (Rain, snow, and sleet **)	X	X	X	X	X	X	X	X	X	X
Sleet ***	...	...	...	...	X	X	...	...	...	...
Ingress of solid foreign objects (Windblown dust, lint, fibers, and flyings)	X	X	...	...	X	X	X	X	X	X
Ingress of water (Hosedown)	...	...	...	...	...	...	X	X	X	X
Corrosive agents	...	X	...	X	...	X	...	X	...	X
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	...	...	...	X	X
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	...	...	...	X

* These enclosures may be ventilated.

** External operating mechanisms are not required to be operable when the enclosure is ice covered.

*** External operating mechanisms are operable when the enclosure is ice covered.

1.1.3.2 Underwriters Laboratory (UL) Standard:

The Underwriters Laboratory (UL) 50 standard is commonly used in the outdoor telecommunication cabinet industry, which covers the non-environmental construction and performance requirements for enclosures to provide a degree of protection to personnel against incidental contact with the enclosed equipment [5]. For UL ratings the enclosures need to be tested by qualified evaluators, they also check whether the manufacturers adhere to the prescribed manufacturing methods and material specifications. The UL have several enclosure ratings from Type 1 to Type 13, some of the commonly used ratings are [6]:

Type 3R: The enclosures protect the electronics against rain and dust. The cooling system used in these enclosures is an open loop system, wherein the outside air enters the

enclosures. The enclosures are undamaged by formation of ice on its surface. Outside AC breaker box is a fine example of an enclosure following this rating.

Type 4: These indoor/outdoor enclosures can protect against icing, rain, splashing water etc. The enclosure is fully sealed from outside air penetration.

Type 4X: It is similar to Type 4 enclosures, but also it is corrosion resistant. Stainless steel, aluminum or composites are some of the commonly used materials.

Type 6P: It is for cabinets that are submerged in water. These enclosures are also rarely used in tunnels and vaults.

Type 12: There are indoor and outdoor enclosures used in moderate temperature below than 40 F and no icing. The enclosures are sealed from outside air penetration. They protect against dust, dirt, fiber flyings and dripping water.

1.1.3.3 Telcordia GR Standard:

The Telcordia Generic requirement (GR) is used by telecommunication cabinet manufactures to design or test their equipment. There are generally three standards that are commonly followed for outdoor telecommunication cabinets. They are Telcordia GR-63, GR-487 and GR-1089 [7].

Telcordia GR-63 - The Generic Requirements document (GR) presents minimum spatial and environmental criteria for all new telecommunications equipment used in Central Offices (COs) and other environmentally controlled telephone equipment spaces. These NEBS (Network Equipment-Building System) criteria are developed jointly by Telcordia and industry representatives. They are applicable to switching and transport systems, associated cable distribution systems, distributing and interconnecting frames, power equipment, operations support systems, and cable entrance facilities

Telecommunications equipment, by nature of its physical installation in a building, may be exposed to environmental stresses. The NEBS generic criteria

are intended to help avoid equipment damage and malfunctioning caused by temperature, humidity, vibrations, airborne contaminants, minimize fire ignitions and fire spread, as well as provide for improved space planning and simplified equipment installation.

Telcordia GR-487 - This requirement provides criteria for analyzing Electronic Equipment Cabinets used in a variety of outside plant environments and applications, including wireless. It includes finish, metallic materials, lifting details, bonding & grounding, thermal shock, fire resistance, acoustical noise, corrosion resistance, seismic resistance and other design criteria [6]. It also covers cabinet requirements on thermal test procedure, acoustic noise issues, environmental vibration criteria and Restriction of Hazardous Substance (RoHS) criteria.

The standard GR-487-CORE R3-151, discusses the solar loading on the cabinet. A solar loading of 70 W/ft² is the recommended value. This heat is applied to any three sides of the cabinet. For test purposes, light banks are used to illuminate three sides of the cabinet. It covers the standard testing procedures for an enclosure with electronics. The objective of this test procedure is to provide a practical, repeatable means of determining and applying the solar load, which can account for cabinet design variables like material, shape, cooling methods etc. There are two categories of testing standards, depending upon the equipment inside the enclosure, if there is a fan or any means of air stirring within the cabinet then category 1 test procedure is followed or else the category 2 is followed.

Telcordia GR-1089 – The Electromagnetic Compatibility (EMC) and electrical safety criteria necessary for the telecommunication equipment to perform safely and reliably has been addressed. The NEBS (Network Equipment-Building System) criteria covers equipment in central offices and outside plant locations such as controlled environmental vaults, electronic equipment enclosures, and huts; equipment in uncontrolled structures such as cabinets; and network equipment at the customer premises. It also specifies criteria to avoid equipment

damage due to lightning, 60-Hz commercial power fault conditions, Electrostatic Discharge (ESD), Electrical Fast Transient (EFT) and Electromagnetic Interference (EMI).

1.2 Literature Review

1.2.1 Cabinet Cooling Technologies

A numerous research is done for the thermal management of outside plant telecommunication cabinets which deals with different cooling technologies for the cabinets. Also, research is done in the development of numerical and analytical modeling methodologies for these cabinets. Different cooling technologies used for cooling telecommunication cabinets are discussed below.

Wankhande et.al [8] analyzed and compared the cooling techniques used for outdoor electronics for determining their effectiveness. The paper described the different cooling techniques like special coatings, radiation shield, double walled enclosure, fans and air-to-air heat exchangers with and without solar loading. It was concluded that solar loading can significantly increase the internal air temperature by 20%. It was also seen that double walled enclosures had lower internal air temperatures. However, in this study one single value of air gap was considered for double wall.

Korte et al [9] studied the effect of solar loading on an outdoor cabinet. The paper discussed about the mechanical and thermal properties of an outdoor cabinet. The double wall cabinet was proposed as a measure to reduce the solar loading on the cabinet. Two different double wall configurations were studied. The configuration had different air flow paths around the single wall cabinet.

Marongiu [10] in his study classified techniques used for cooling as active cooling semi active and passive cooling techniques. The active cooling includes air conditioners and thermoelectric coolers. Semi active cooling techniques include air to air heat exchangers, while passive techniques include natural convection of air and Phase Change Materials (PCM). The cabinet is designed to house fairly low power electronics and a study is done to compare the

temperature inside the cabinets, with and without solar loading. It was found that without solar heating the temperature just crossed the design mark by 2-3°C. So the cooling system had to account for the temperature rise due to the electronics as well as the solar heating. A double-finned air-to-air heat sink was developed. This heat sink took the shape of long plate fins on either side of the solid wall of the cabinet. The design was developed using the cfd code ICEPAK and validated with experimental results.

Marongiu et.al [11] dealt with thermal management of outdoor enclosure by using Phase change materials (PCM) and natural convection. They used a heat exchanger based on PCM and its characteristics were mentioned. The PCM material used was Glauber's salt . It was found that the channeled wall took care of the solar loading and the thermal management of the cabinet was attained with the PCM heat exchanger. The PCM based heat exchanger was effective in maintaining the target temperature. It was also concluded that circular wall channel is better than parallel, square and triangular plates.

Teertstra et.al [12] developed an analytical model to predict the total heat transfer rate. The system consists of an isothermal plate in a enclosure which is a cuboid. A model that is valid over a wide range of plate geometries and flow conditions were developed. The authors combined three asymptotic solutions: pure conduction through the enclosed region, laminar boundary layer flow and transition flow convection into a composite expression.

Hegab et al [13] designed an innovative heat exchanger which dumps the heat removed from the electronic cabinet to soil. The cooling system consists of a heat exchanger with heat pipes located below the cabinet in the soil. The heat pipes dissipate the heat from the heat exchanger into the soil. Numerical simulations indicate that this type of heat exchanger is effective under certain circumstances. Though this system is effective, the initial cost of installation is also high.

Hamid et al [14] developed an innovative forced convection cooling solution for cooling of outdoor electronic enclosures. The cooling system consists of a sealed hollow pole (geopole)

and the electronics are mounted on top of this pole. A circulation fan is located within the geopole to circulate the closed loop of air. An analytical network based model was developed by the authors and compared with test results. Various parametric studies were carried out to improve the efficiency of the cooling system. The parameters considered were heat dissipation from the electronics, air flow rate, solar load, pole diameter and the various heat sink design for heat dissipation into the ground.

Feroz Ahamed et al [15] discussed the use of Thermo Electric Coolers (TEC) for cooling the battery compartment in an outdoor telecom cabinet. An analytical model was developed using the CFD code Flotherm and the model results were compared with experimental one. The study clearly showed that the battery cabinet temperature was maintained at the ambient level. Though sub ambient cooling is possible by TEC, it is not required for cooling the battery cabinet.

Cosley et al [16] modeled a compact heat exchanger for cooling of battery compartment of the telecom enclosure. An air to air heat exchanger was designed to cool the battery compartment and maintain the temperature within 10°C of the ambient. The sol-air method was used to calculate the solar loading and applied on the enclosure. 12 hour transient analysis was carried out using the cfd code Flotherm. The compact modeling of heat exchanger was considered in design.

Yuping et al [17] discussed energy savings options for an outdoor telecommunication cabinet. The free cooling and manhole cooling system were two options that were discussed in this paper. Free cooling system is a time tested method which directly uses the ambient air to cool the cabinet. In manhole cooling system, the manhole (part of underground maintenance infrastructure) is used as a huge heat sink. CFD simulations were performed to test the cooling efficiency of manhole cooling system and it was found that 60% of heat load can be dissipated into ground.

1.2.2 Cooling of Telecommunication Shelters

With introduction of high capacity GSM and 3G equipment into cabinets will increase heat loads and increase the attention on the cooling of telecom shelters. The smaller footprint of electronics makes it possible to put much more capacity into a shelter. In combination with the increased heat dissipation in the next generation of telecom equipment the heat loads in the shelters could double or triple. There are numerous papers which details different cooling technologies for the shelters.

Hedberg K [18] dealt with reduction of energy in a telecom shelter using an active cooling system. Three different types of active cooling system were discussed. The window units, which are mounted on the shelter, these units are used in places where the ambient temperature is high. The second one is the direct expansion split system (DX system) which on contrast with window unit can work at lower ambient temperature. In this system the condenser and evaporator are split and can be regulated separately. The third active cooling system discussed was precision compact units, these are cooling systems built for telecom shelters. They work in a wide range of temperature. This type of cooling is expensive as regular maintenance is required.

Hedberg K [18] also discussed the alternatives to active cooling. Filtered ventilation is one, which is most simple and least expensive. Since it can be used only at ambient temperature, it might lead to some reliability issues in the shelter. Another upcoming technique is use of heat exchangers, which prevents mixing of air in the shelter. The drawback of using heat exchanger is that, there needs to be a temperature difference between the ambient and the shelter temperature. A combination of active and passive cooling system is proposed by the author.

Hendrix et al [19] implemented an air side economizer in a shelter and studied its impact on temperature and energy consumption of the cooling system. A cfd model was used to optimize the location of economizer, inlet filter sizing, intake and exhaust locations and other

design parameters. By utilizing an air side economizer, the authors showed a savings of nearly 78% in energy per year.

Darwiche et al [20] discussed the various cooling technologies that are currently used in telecommunication shelters. The author discussed the following cooling techniques:

Exhaust fans: The simple technique to ventilate air from the shelter. The fans usually run on direct current. The airflow is usually designed to offset the power generated by the electronic equipments, with temperatures about 5 - 10° C above ambient.

Vortex coolers: It is used for cooling of equipments in the shelter. It works on the principle of that when pressurized gas is injected into a swirl chamber; the gas is split into two, cold and hot stream. The cold air is injected into the shelter.

Phase Change Materials (PCM): This technique is used in tropical regions. They cool the electronics as well as reduce the effect of solar loading on the shelter. It uses the difference in day and night time temperature to cool the shelter. It has no moving parts and occupies less space when compared with other cooling systems.

Air Conditioning System: The air conditioning system is used to maintain the temperature inside the shelter around human comfort level. It is very efficient in cooling of the shelter. But the power consumption is also very high.

Romagnoni et al [21] discussed about HITHERM 100 cooling device, an indirect free cooling device. The indoor air is cooled and re-circulated and two fans are used for internal air and for the external air flow, respectively. For numerical simulations TRNSYS code was used. The internal heat loads, fan performance and average day time temperature data were given as input for the code. Thus different fan configurations were compared from an energy point of view.

Kolousek et al [22] implemented a photo voltaic power plant to power a remote telecommunication site. Reliability, capital costs, operating costs, equipment operating

environment and maintainability were all key system constraints. This study was carried out by implementing the system at a place at Qubec for a year.

Mynampati et al [23] studied the effect of location of various cabinets in the shelter. It discussed the various locations of the cabinets with respect to the blower. The effect of containment in shelter was also discussed. It was recommended to use a partition in the shelter reduce the inlet temperatures of the cabinets.

1.3 Scope of the Work

First part of this work deals with impact of solar loading on single and double walled cabinet, it includes natural and forced convection in the air gap. This study led to identification of the best case design configuration. Then parametric analysis of the air gap thickness was carried out to find out the optimum air gap configuration. Next the fan locations were optimized based on inside cabinet temperature and energy consumed by the fans for various flow rates and location.

The second half of the study deals with study of a shelter with hybrid cooling system. The hybrid cooling system consists of air conditioner and blower. Various blower design configuration were considered and the blower was selected based on its thermal performance and its energy consumption.

CHAPTER 2

COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING

2.1 Introduction

Computational Fluid Dynamics (CFD) deals with the numerical simulation of fluid flow, heat transfer and chemical reactions. CFD is a simulation of fluids engineering systems using numerical methods (discretization methods, solvers, numerical parameters, and grid generations). A numerical prediction is a consequence of the mathematical model representing the physical domain of interest. This study involves the system level electronics like the telecommunication cabinets and shelters, the equipments housed in them and the surrounding conditions like the ambient temperature and solar heat load.

The objective of CFD is to provide the engineer with a computer-based predictive tool that enables the analysis of the air-flow processes occurring within and around electronics equipment [24]. It has a wide variety of applications namely aerospace, design involving thermal loads, automotive, biomedical chemical processing and a host of other industries.

2.2 Governing Equations

The numerical solution for heat transfer and fluid flow based problems is obtained from solving a series of three differential equations, the Governing Differential equations which are the conservation of mass, conservation of momentum and conservation of energy [25].

For a generalized case the conservation of mass is given by:

$$\frac{\partial \rho}{\partial t} + \text{div}(\rho u) = 0$$

The conservation of momentum for a generalized case is given by:

$$\frac{\partial}{\partial t}(\rho u) + \text{div}(\rho u u) = \text{div}(\mu \text{grad } u) - \frac{\partial p}{\partial x} + B_x + V_x$$

The conservation of Energy for a steady low velocity flow is given by:

$$\text{div}(\rho u h) = \text{div}(k \text{ grad } T) + S_h$$

2.3 Solution Methodology

The solution domain is the region of space where the governing equations are solved. The solutions of these equations are obtained by setting the boundary condition for the solution domain. The boundary conditions for the study of outdoor cabinets include ambient temperature and solar radiation. The conditions at the domain wall of the system also needs to be specified whether they are open, closed (wall) or symmetric. The fluid properties namely conductivity, density, viscosity, specific heat, expansivity and diffusivity need to be specified [24].

The governing equations and their associated boundary conditions do not have a general analytical solution. There are particular solutions for simple problems like a laminar flow in a rectangular channel. But for complex and more real world problems, the equations can only be solved numerically.

The different techniques that can be used to solve the governing equations are:

- Finite Difference Method: The differential terms are discretised for each element.
- Finite Volume Method (FVM): The governing equations are integrated around the mesh elements whose volumes are considered for the solution.
- Finite Element Method (FEM): The variation of variables within elements is approximated by a function, and a residual is minimized.

The CFD code used for this study is Flotherm, is based on the Finite Volume Method (FVM). In FVM the solution domain is discretised into a number of control volumes or grid cells, where the variables to be calculated is located at the centroid of the finite volume. The graphical representation of grids or elements is shown in Figure 2.1.

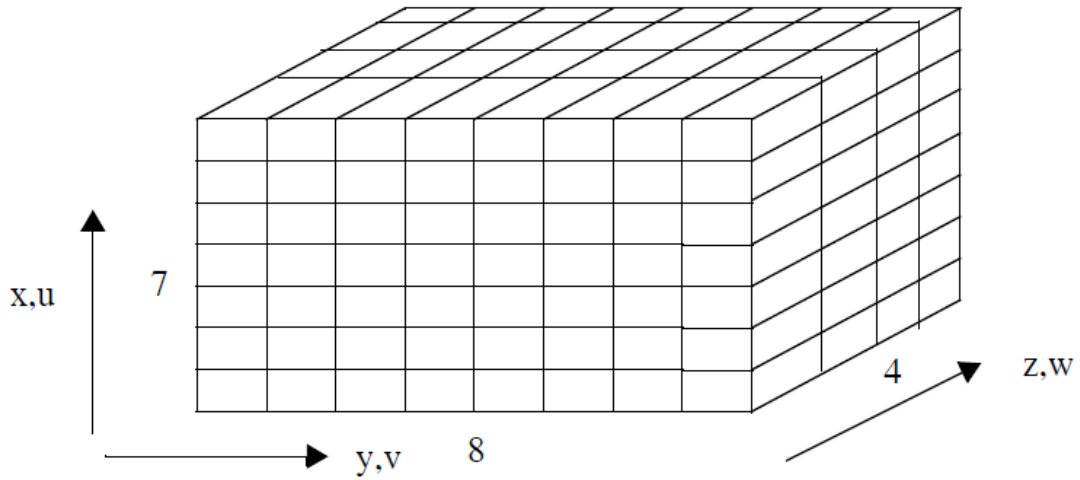


Figure 2.1: Graphical representation of a 3D grid

FVM works by integrating the differential form of the governing equations over each control volume. The Finite Volume Method has an inherent advantage that satisfies the conservation of mass, momentum and energy.

The discretization results in a set of algebraic equations, each of which relates the value of a variable in a cell to its value in the nearest neighbor cell. Taking the example of T , the temperature variable, it is computed by the algebraic equation:

$$T = \frac{C_0 T_0 + C_1 T_1 + C_2 T_2 + C_3 T_3 + C_4 T_4 + C_5 T_5 + C_6 T_6 + S}{C_0 + C_1 + C_2 + C_3 + C_4 + C_5 + C_6}$$

Where

T_0 Temperature value in the old time step

$T_1, T_2, T_3, T_4, T_5, T_6$ Temperature values in the six neighboring cells

C_s Coefficient that connects the in-cell value to each of its neighboring cell values

S Source term.

If there are n cells in the solution domain, then there are $5n$ algebraic equations to solve as the equation needs to be solved for each field variables T, u, v, w and p .

The above expression appears to be linear, but it is non linear as the coefficient C itself is a function of T, u, v, w and p.

Normally, fine grid is used in regions of the solution domain where the gradients of the variable are expected to be the high. Finer the grid better the algebraic equations approximates to the governing differential equations. It should be noted that having a grid independent solution alone does not guarantee a solution that simulates close to the real world problem. Other factors like the accuracy of the boundary conditions, the adequacy of the turbulence model affect the outcome of the solution and its accuracy.

2.4 Turbulence Modeling

The most prevalent method for cooling electronics is air-cooling. The air-flow regime in electronics usually ranges from laminar flow to the low Reynolds number turbulent flow. The two common ways by which Flotherm models this low Reynolds number turbulence flow region is by the LVEL turbulence model and the K-Epsilon turbulence model.

2.4.1 LVEL Turbulence model

This is a simple algebraic turbulence model which does not require the solution of any partial differential equations. The model depends on the calculation of the distance to the nearest wall (L), the local velocity (VEL) and the laminar viscosity to determine the effective viscosity [26].

In this turbulence model, poisson's equation is first solved which enables calculation of maximum local length scale and local distance to the nearest wall to be completed with relative ease.

$$D = \sqrt{|\nabla\varphi|^2 + 2\varphi}$$

$$L = D - |\nabla\varphi|$$

Where: $\nabla^2\varphi = -1$ with $\varphi = 0$ at the wall

The length and velocity scales are computed for each cell and are used in conjunction with classical boundary layer wall functions to determine the turbulent viscosities for each cell [27], where Φ is the dependent variable.

2.4.2 K-Epsilon Turbulence model

The K-Epsilon model is a two equation model that is extensively used for turbulent fluid dynamics. This is the most widely used and validated model for employed for turbulent fluid dynamics. This model computes viscosity on a grid cell to grid cell basis rather than computing viscosity as it is affected by the walls. It consists of two transport equations, one equation to describe the kinetic energy of turbulence and the second equation to represent the rate of turbulent dissipation [28].

The transport equations are:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \varepsilon$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}$$

The model has achieved notable success when dealing with thin shear layers and recirculating flows without the need for case-by-case modification of the model constants [27]. The predominant drawback of the standard $k-\varepsilon$ turbulence model, for this application area, is that the model was designed for high Reynolds number flows therefore resulting poorly in terms of model accuracy

2.5 Flotherm Smart Parts

This part deals with the commonly used smart parts which are used for modeling of telecommunication cabinets and shelters.

2.5.1 Cuboid

The cuboid smart part is the basic method of inserting block of solid material in the solution domain. The material property, surface, thermal and radiation attributes can be defined for a given cuboid. There is no mesh propagation inside a cuboid.

2.5.2 Enclosures

The enclosure smart part is used to define an outer box inside the system. The enclosure is a cuboid with 6 sides within which other components can be placed. Any of the 6 individual sides can be removed. There is mesh propagation inside the enclosure smart part.

2.5.3 Source

The source smart part is used for simulating velocity, pressure and temperature over a planar area or volumetric location within the solution domain. In this entire study the source is used to define a heat source in the model.

2.5.4 Regions

Region smart part is used for capturing summary of values for 2D or 3D space. It captures the flow rate, velocity and temperature on the specified space. The region smart part is extensively used in the study to capture the mean temperature in a given space and also flow rate across certain spaces.

In addition to the above functions, regions smart part can also be used to define a localized grid in space. One can attach a grid constraint to a region area for localized mesh.

2.5.5 Fans and Blowers – CFD Characterization

2.5.5.1 Introduction to fans and blowers

American Society for Mechanical Engineers (ASME) power test codes defines fans as machines which increase the density of the gas by no more than 7% when it travels from inlet to outlet [29]. They convert the torque supplied at the propeller shaft to impart kinetic energy to the air flowing across the fans, as well as increase the static pressure across the fan rotor.

In electronic cooling applications, the most commonly used fans for cooling are axial flow fans and centrifugal blowers. Axial flow fans deliver air in the direction parallel to the fan blade axis and can be designed to deliver high flow rates. While the air flow direction is perpendicular to the axis for a centrifugal blower and is usually designed to work against high pressure, but deliver relatively low flow rates. Fans and blowers are differentiated by the method used to move the air, and by the system pressure they must operate against [30]. The specific ratio, ratio of the discharge pressure over the suction pressure is the metric used to differentiate between fans and blowers. Table 2.1 compares the specific ratio for fans and blowers.

Table 2.1: Difference between fans and blowers

Equipment	Specific Ratio	Pressure Rise (mm Wg)
Fans	Up to 1.11	1136
Blowers	1.11 to 1.20	1136 – 2066

2.5.5.2 Fan Curve Characteristics:

The fan curve is a performance curve for a particular fan under a specific set of conditions. A fan curve is based on fan volume, systems static pressure, fan speed and power required to drive the fan. The static pressure versus the fan flow rate is the most important curve used for selection of a fan. The figure 2.2 shows a typical fan curve.

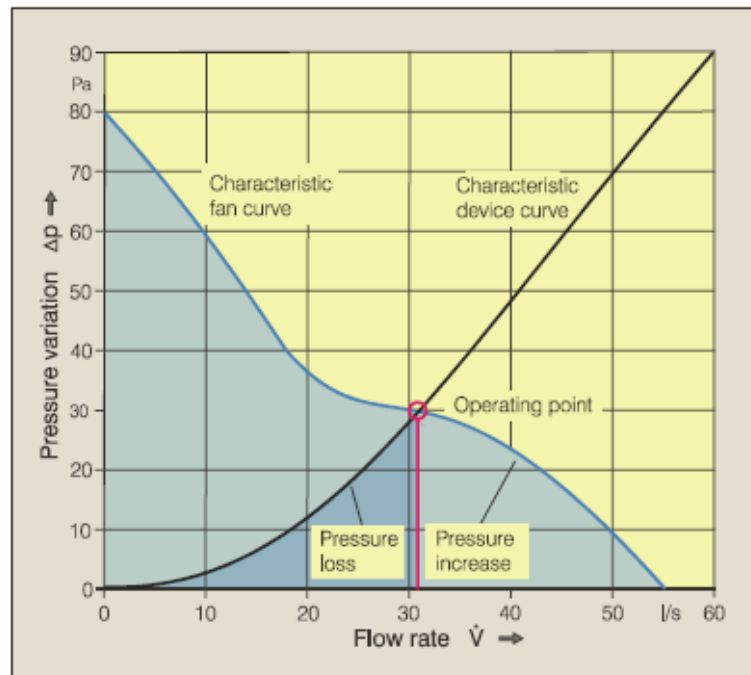


Figure 2.2: Fan curve and system curve

It is best to select a fan that will give an operating point located towards the high flow, low pressure side of the performance curve to maintain propeller efficiency and to avoid propeller stall. The fan curve is given by the fan manufacturer. The governing principle in fan selection is that any given fan can deliver only one flow at one pressure in a particular system. The fan selection depends upon the system where it is implemented. The intersection between the fan curve and the system curve gives the operating point of a fan for a particular rpm. This operating point is constant for a given system unless there is a change in the geometry of the system. For the fan to operate at its maximum efficiency, operating point should be in-between 60% to 80% of the maximum flow rate.

In the flotherm to model a fan there are two options namely:

- Fixed flow fans
- Axial flow fans

Fixed flow fans can deliver the specified flow rate into or away from a system. This fan does not model the pressure at the fan. This is a theoretical fan which is impractical in real time.

Axial flow fans can be used for specifying the actual fans with the fan curve. The axial fan smart part can model the fan to various level of accuracy as needed. It has an option of specifying the fan curve or fixed flow rate.

To model blowers in flotherm the recirculation device smart part is used. The flowing procedure is followed to model a blower [24]:

- A cuboid is created of similar dimension of the blower and 70% the width
- The recirculation device smart part is used, and the extract and supply are located on the surface of the cuboid
- Then the hub is created and it placed on the extract. To do a detailed model, prisms can be created on the outer diameter.
- The fan curve for the blower is specified and a flow dependent shear model is selected.

To specify the heat load of the blower when modeling it as a recirculation device, the rate of heat extraction option can be used to specify the heat load. This option is used to specify the amount of heat extracted or supplied as the air passes through the recirculation device. The heat added or removed from the air is governed by the flowing equation:

$$T_{supply} = T_{extract} + \frac{\text{Rate of heat extraction}}{m \times cp}$$

2.5.6 Filters

Filters are devices consisting of materials used for restricting the flow of air and capture the air borne materials and supply clean air into the system. The filters are usually placed at the inlet of outdoor system, to filter out the particulate matter in the air entering the system. Filters can increase the static pressure of air entering the system as it offers a resistance to the air

flow. The filters can be placed either in series or in parallel. When placed in series the resistance offered is more and the pressure drop across the filters is also high. During selection of a filter, the pollutants anticipated and capture efficiency of the media must be taken into consideration. As a dirty filter can increase the total static pressure of air distribution system, which translates into more fan power and reduced air flow.

Selection of filter mainly depends on the system where it will be used. Usually for telecomm shelters quadfoam filters are used. These filters offer high dust arrestance and low resistance.

In flotherm, filters are modeled using the resistance smart part. Depending upon the application either planar (2D) or volumetric (3D) resistance can be used. The free area ratio and loss coefficient can be specified for each filter.

CHAPTER 3

DESIGN GUIDELINES FOR A DOUBLE WALLED TELECOMMUNICATION CABINET AND OPTIMIZATION OF FAN LOCATION

3.1 Design Guidelines for a Double Walled Telecommunication Cabinet

3.1.1 Background

A typical telecommunication cabinet provides a secured enclosure for a wide range of electronic equipment including radio, multicarrier power amplifiers (MCPA) and back-up batteries. These cabinets optimize equipment density, heat transfer and dissipation, power reserves, environmental protection and ease of installation [31]. In addition to environmental protection, the cabinets must also incorporate a cooling system that supports the thermal requirement of electronics. And, with ever-increasing sensitivity to environmental impacts, the cabinets and the cooling system must have minimal aesthetic and acoustic impact on their surroundings.

These cabinets provide a wide range of cooling options namely:

- Positive pressure direct air cooling through a mesh filter or a hydrophobic filter
- Heat exchanger
- Thermoelectric cooler (TEC)
- Conventional air conditioning

The impact of double wall on solar loading and thermal management of the electronics in cabinets are studied. Flotherm [32], a CFD code is employed to propose guidelines for designing double walled cabinet and to perform optimization of fan location.

3.1.2 Model Description

3.1.2.1 Single Walled Cabinet – Baseline

RBA48 is a multi-purpose outdoor electronics cabinet. It is the mid-sized enclosure of CommScope's 'Integrated Cabinets Solutions' (ICS) product line. It supports wireline

applications in a telecommunication network. The enclosure approximately measures 30 inches wide, 48 inches tall and 35 inches deep. A typical RBA48 cabinet model is shown in Figure 3.1.



Figure 3.1: External view of RBA 48 telecommunication cabinet

The cabinet is divided into two parts, the battery compartment at the bottom and the electronics on the top. The RBA48 cabinet comprises of the customer telecommunications, rectifier shelf, Heat Exchanger (HX) and inner/outer loop fan trays, Thermo Electric Cooler (TEC) modules and a back up battery. The customer shelf consists of circuit cards, which dissipate heat into the system. The rectifier has three rectifier modules, each having complex electronic circuitry and two fans for cooling. The customer shelf and rectifier dissipates the 300 W and 250 W of heat in the cabinet respectively. The figure 3.2 shows the inside view of the cabinet with front door open, bottom part with the back-up battery and the top part consisting of the customer electronics and the rectifier shelf.

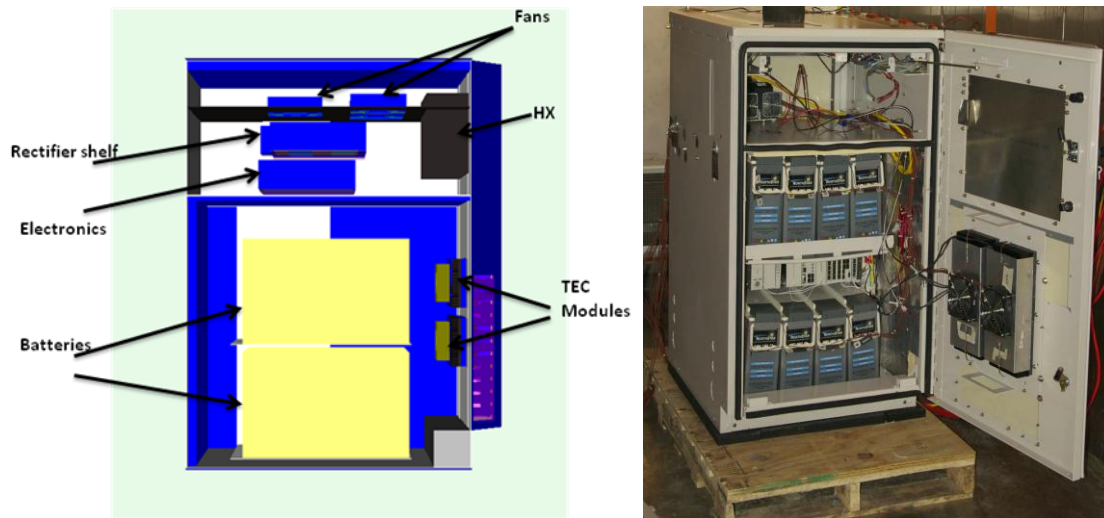


Figure 3.2: Internal components of the cabinet

The cabinet's top part consists of two fan assemblies for cooling the electronics

1. Bay fan tray
2. Heat exchanger fan tray

The bay fan tray creates the inner loop air flow, i.e. pulls in internal air from the bottom of the customer shelf and exhausts the hot air to the intake of the HX. It consists of three fans, each capable of delivering a maximum air flow of 240.4 CFM and a static pressure of 0.86 in. of water. The hot air from the customer shelf enters the inner loop of the HX from the top and the cool air leaves from the HX exhaust from the bottom. On the other hand, outer loop side, the HX fans pull ambient air from the bottom and exits from the top. While air is flowing through both the respective loops, heat transfer takes place following the counter-flow HX principle, cooling the inner loop air. The warmer outer loop air is exhausted to the atmosphere. This cycle continues and the cooling medium (air in this case) never mixes with the ambient. The heat exchanger fans are capable of delivering a maximum air flow of 307.5 CFM and a static pressure of 0.83 in. of water. The filters are installed in the door assembly to keep away all the undesired particles and moisture entering the enclosure. From fig 3.2, the batteries at the bottom part are cooled through TEC units.

Solar loading has been applied based on the Telcordia GR-487 CORE standards, which states that power of 70 W/ft^2 should be incident on any three walls of the cabinet. Heater strips are used for simulating the effect of solar loading similar to an experimental setup. The heater strips are located on the top, right and the rear sides of the cabinet. In order to reduce the effect of heat built-up due to solar loading, insulation is provided on the inner side of walls except on the front side of the cabinet. Insulation is also provided on the partition between the battery and electronic compartment.

3.1.2.2 Double Walled Cabinet – Solar Shields

In the double walled cabinet design, the two-layer wall is provided on the sides of the cabinet as shown in Figure 3.3, also termed as solar shields. The double wall is open at the front and rear side which allows air flow by means of natural convection.

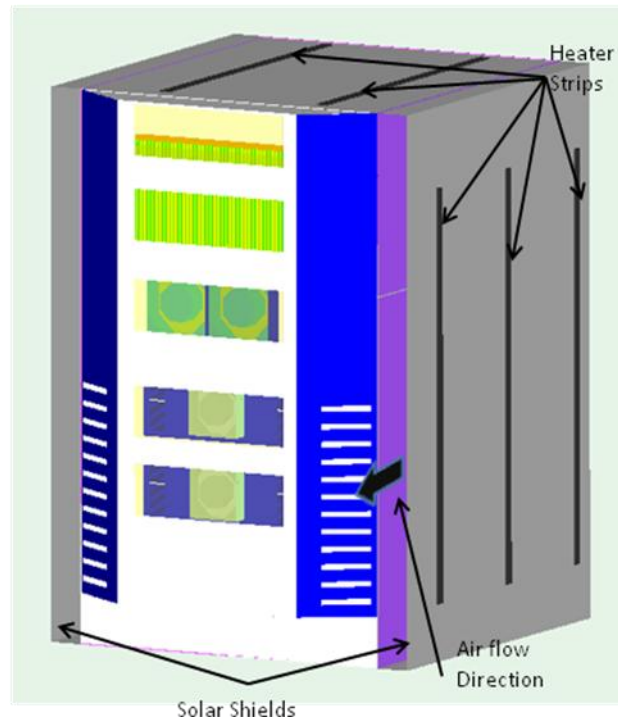


Figure 3.3: Telecommunication cabinet with double wall (solar shield)

The block arrow in the figure 3.3 indicates the air flow path. In order to study the thermal impact of double wall, a parametric study is carried out by varying the gap between the

double walls. Six different air gap values ranging from 0.5" to 3" with an increment of 0.5" are modeled.

3.1.2.3 Double Walled Cabinet – with Top Plenum

In this cabinet design, the double walls on the sides are open at the bottom and at the top plenum. The top plenum has a height of 7 inches from the top inner wall of the cabinet. On the right and left side of the plenum there is a set of louvers which allow the hot air from the cavity inside the double walls to vent out. The air in between the two walls is heated both by the power dissipated by the electronics in the cabinet as well as the external solar heating. The cabinet design is as shown in Figure 3.4.

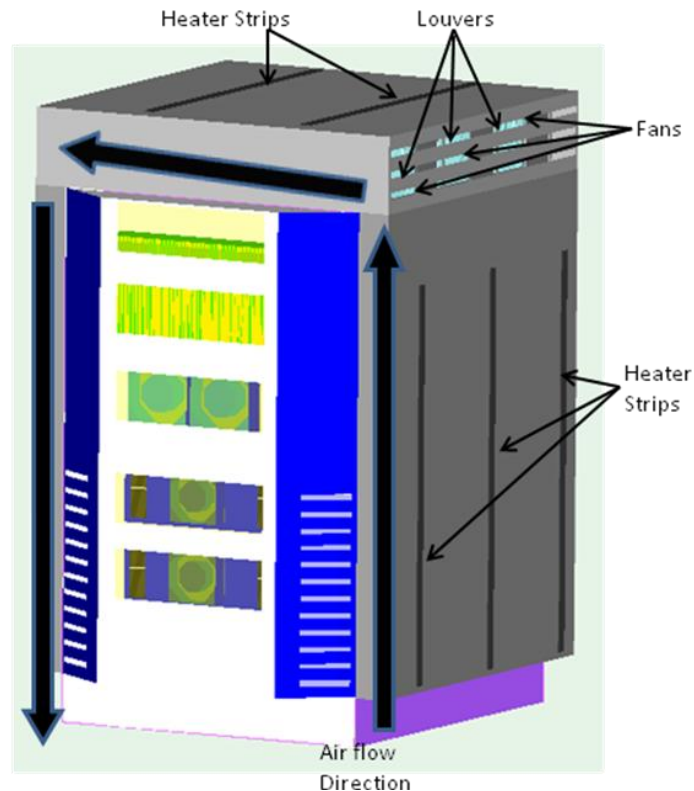


Figure 3.4: Double walled telecommunication cabinet with fans mounted on top plenum

The top plenum has set of three circulation fans. Each fan delivers a maximum air flow of 350 CFM and a static pressure of 0.96 in. of water. The fans pull the ambient air and due to the negative pressure, there is an increase in air flow at the double wall gap. The block arrows

in the figure .4 indicate the air flow path. In this configuration, the heater strips used to simulate the solar load, are placed on the outer double wall. The thermal impact is studied for different values of air gap ranging from 0.5” to 3” with an increment of 0.5”.

3.1.3 Numerical Modeling

There is an impetus to simplify the geometry as detailed modeling of telecommunication cabinet of this size and complexity would result in millions of elements and a prohibitively long CPU time to solve the CFD model. Hence one needs to develop the compact models of components to reduce grid count and solution time. Figure 3.5 shows the schematics of the modeling methodology.

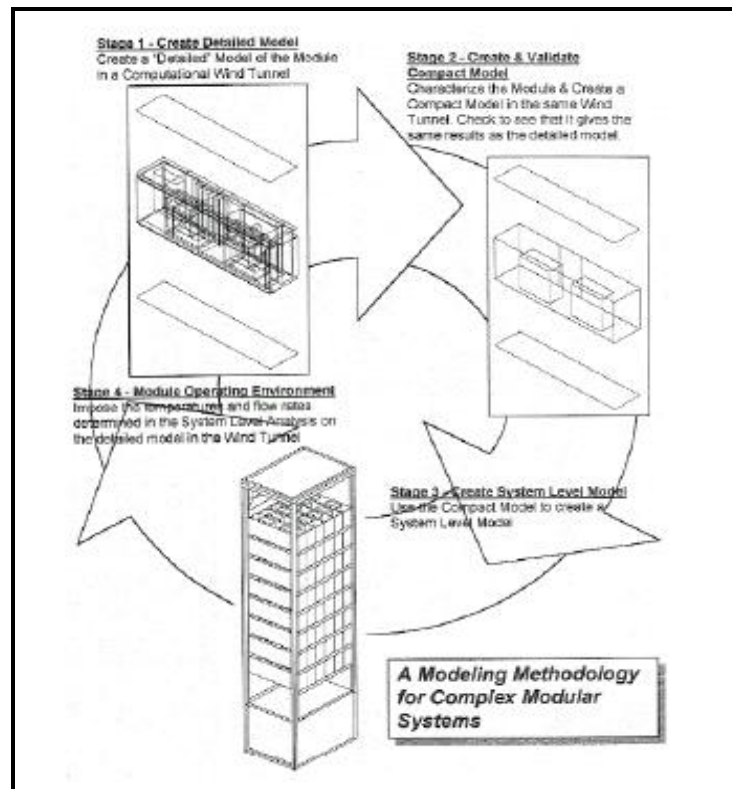


Figure 3.5: Schematic showing the compact modeling methodology [33]

The cabinet is modeled as a large enclosure with a partition to separate the electronic and the battery compartments. The solution domain is modeled with twice the height of the cabinet and an additional one-half the width and depth of the cabinet on all the four sides. All

the five sides of the domain are modeled with open walls except the bottom surface which is given a no slip condition (symmetry condition). The ambient temperature is set to 30°C. For the air-flow, automatic algebraic turbulence model is used. The effect of radiation is turned off as the primary mode of heat transfer is assumed to be convection and conduction.

All the electronic equipments have been modeled as compact models and so enclosures having openings at the bottom and top end are modeled. The system impedance of these components is modeled with advanced resistance macros in the software, which incorporates the pressure drop characteristics of the equipment.

To model the fans, inbuilt smart parts of Flotherm are used and the fan performance curve is specified, so that the correct operating point is attained during the analysis. The filter is modeled using the volumetric resistance smart part.

3.1.4 Results

The first part of result analysis deals with identification of the best design solution for the double walled cabinet. It also addresses the impact of having a double walled cabinet over a single walled cabinet. The second part includes determination of the optimal air gap between the walls of cabinet.

3.1.4.1 Mesh Sensitivity Analysis

The mesh sensitivity analysis is performed to verify that the solution obtained is independent on the mesh size and mesh count. The numbers of elements were varied from 2.9 million grid cells to 6.7 million cells. From the study it is concluded that the solution reaches grid independence at about 3.85 million cells. Figure 3.6 indicates the monitor point temperature vs grid elements.

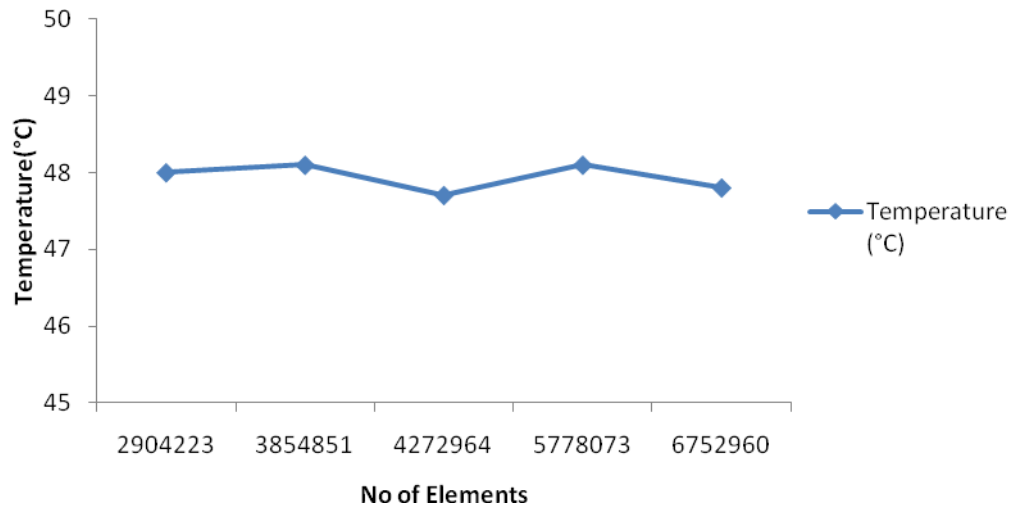


Figure 3.6: Mesh sensitivity analysis for double walled cabinet with solar shield (1" air gap)

3.1.4.2 Best Design Configuration

In order to compare the various cases and identify the best configuration, the monitor point temperatures of different configurations are compared. The figure 3.7 shows the location of monitor points inside the cabinet.

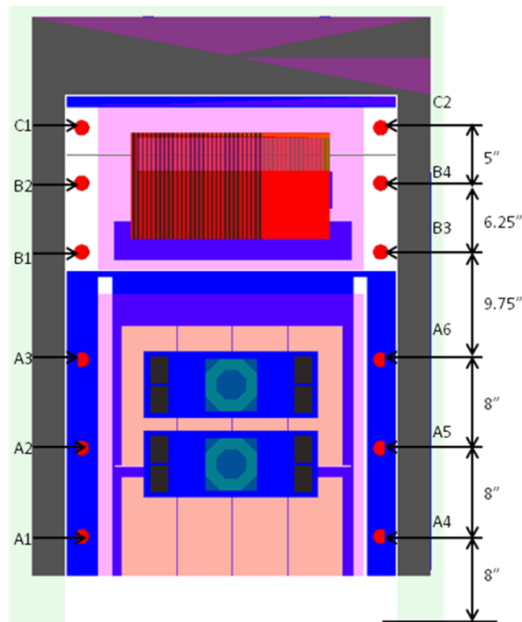


Figure 3.7: Location of monitor points inside the cabinet

There are a total of twelve monitor points inside the cabinet. These are located one inch away from inner walls of the cabinet. Nine monitor points are located in battery cabinet, four in customer shelf and two in bay fan tray.

All the twelve monitor point temperatures for a single walled cabinet are tabulated in table 3.1. Similarly table 3.2 and 3.3 tabulates the monitor point temperature for various air gaps for double walled with solar shields and double wall with top plenum and fan configuration respectively.

Figures 3.8 and 3.9 shows the all the three configurations and the monitor point temperature that are obtained at the different monitor points.

Table 3.1: Monitor point temperature for a single walled cabinet

Monitor point	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	C1	C2
Temp(°C)	54.7	55.5	55.9	55.5	55.7	56.4	68.6	69.4	70.1	71.2	74.9	77.5

Table 3.2: Monitor point temperature for a double walled cabinet (solar shields)

Air Gap (inch) Monitor point	Temperature (°C)					
	0.5"	1"	1.5"	2"	2.5"	3"
A1	48.3	47.8	48.0	47.8	48.4	48.6
A2	48.9	48.3	48.0	48.3	48.2	49.2
A3	48.9	48.7	49.2	48.7	49.0	49.3
A4	48.8	48.4	48.7	48.3	48.8	49.1
A5	48.6	48.3	49.0	48.4	48.7	48.9
A6	48.8	48.2	48.9	48.3	48.6	49.1
B1	66.3	65.9	66.3	65.9	66.2	66.3
B2	67.2	66.3	66.6	66.3	66.6	66.6
B3	66.9	66.6	66.5	66.3	66.5	66.8
B4	67.6	67.4	67.6	67.1	67.5	67.6
C1	72.5	71.7	72.0	71.7	72.0	72.1
C2	74.9	74.1	74.3	74.2	74.3	74.6

Table 3.3: Monitor point temperature for a double walled cabinet with top plenum and fans

Air Gap (inch) / Monitor point	Temperature (°C)					
	0.5"	1"	1.5"	2"	2.5"	3"
A1	39.2	38.4	38.4	38.2	38.6	38.6
A2	39.1	38.3	38.4	38.2	38.6	38.6
A3	39.2	38.4	39.0	38.4	38.7	38.8
A4	38.7	38.2	38.3	38.0	38.3	38.4
A5	38.7	38.3	38.3	38.0	38.5	38.4
A6	38.8	38.1	38.4	38.1	38.6	38.5
B1	56.2	54.6	55.6	55.4	51.9	57.4
B2	54.2	53.8	53.6	53.1	51.3	55.1
B3	52.1	50.7	50.6	50.3	52.1	52.3
B4	52.7	51.4	50.8	50.6	51.5	52.6
C1	55.2	53.5	54.1	53.7	55.2	56.2
C2	59.4	58.2	57.9	57.6	59.2	60.1

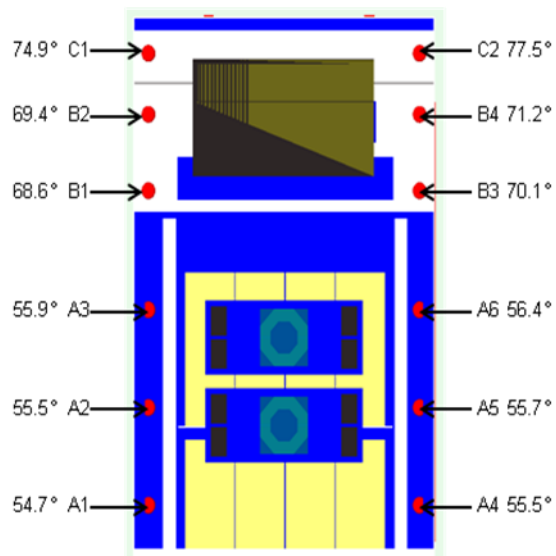


Figure 3.8: Monitor point temperature for a single walled cabinet

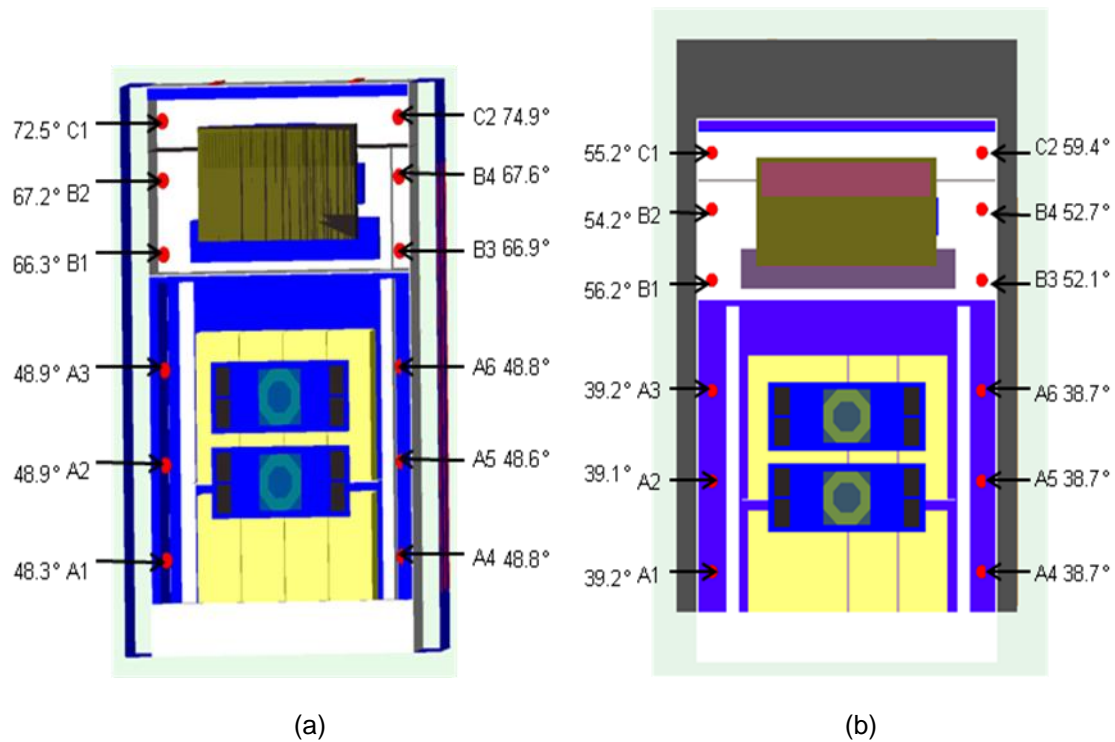


Figure 3.9: Monitor point temperature for double walled cabinet (0.5" air gap) a) Cabinet with solar shield b) Cabinet with top plenum and circulation fans

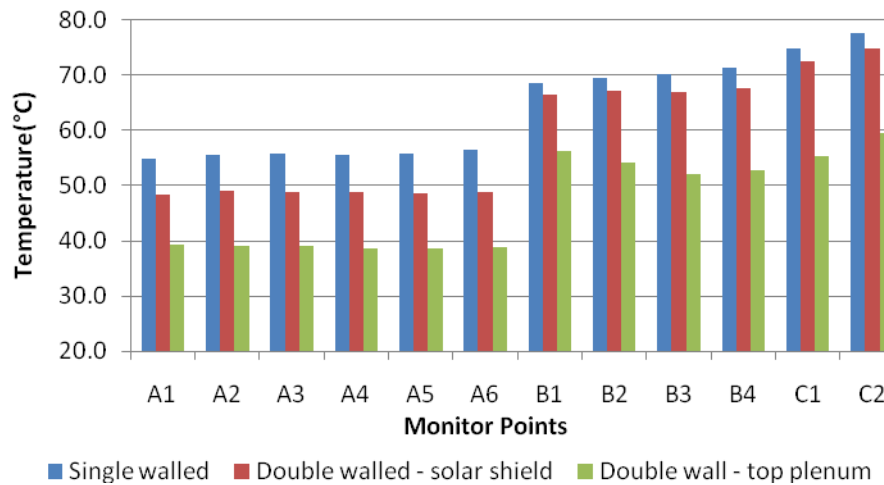


Figure 3.10: Comparison of monitor point temperature for 0.5" air gap

From the bar chart in figure 3.10, it can be concluded that, the double wall configuration is effective in reducing the solar load. It is observed that the double wall – solar shield

configuration has lower monitor point temperatures than the baseline case (single walled cabinet). Thus, it can be stated that double wall reduces the effect of solar load on the cabinet. The double wall with top plenum and circulation fans' configuration is better than the solar shield configuration. The circulation fans on top plenum increase the air flow through side walls compared to the earlier configuration, helps in reducing the solar load as wells as cooling of inner walls.

Figures 3.11, 3.12, 3.13, 3.14 and 3.15 show the temperature comparison of the monitor points for the other air gaps respectively.

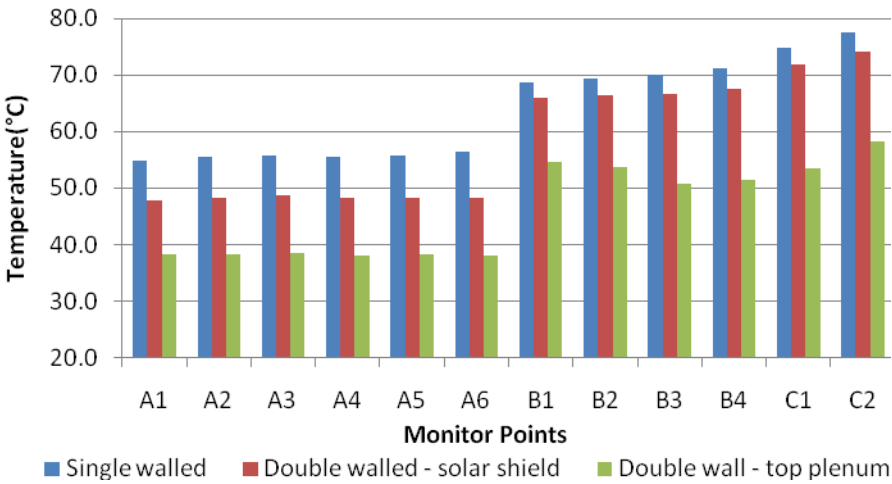


Figure 3.11: Comparison of monitor point temperature for 1" air gap

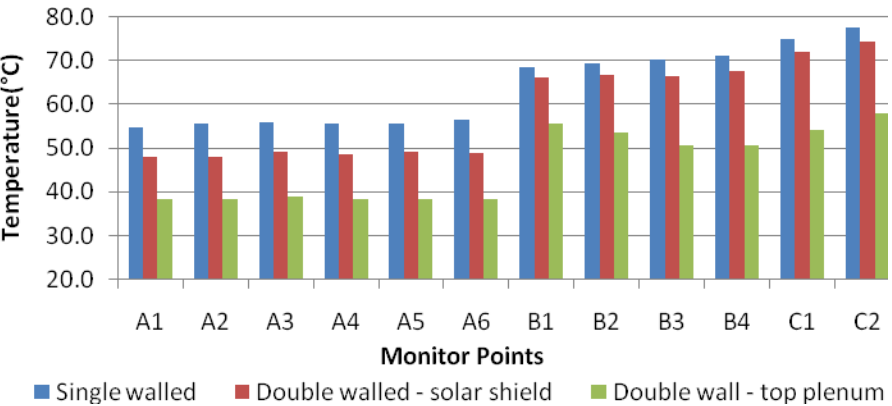


Figure 3.12: Comparison of monitor point temperature for 1.5" air gap

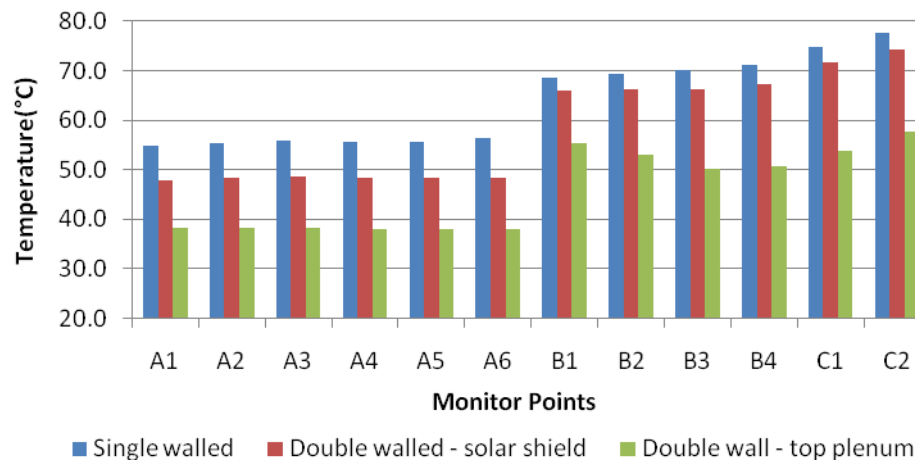


Figure 3.13: Comparison of monitor point temperature for 2" air gap

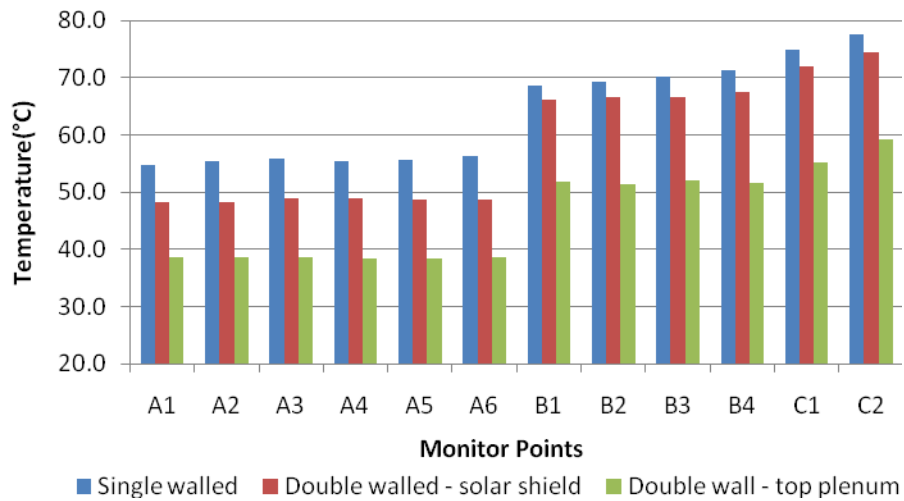


Figure 3.14: Comparison of monitor point temperature for 2.5" air gap

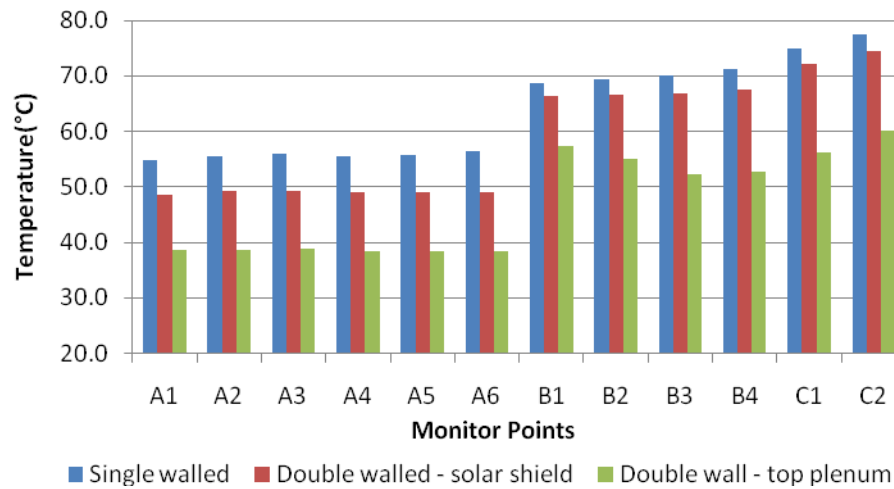


Figure 3.15: Comparison of monitor point temperature for 3" air gap

Thus, it can be concluded that for configurations with top plenum and circulation fans on the top records the lowest cabinet temperature. Therefore, the configuration with top plenum and recirculation fans on the top for the double wall is the best configuration.

3.1.4.3 Optimal Air Gap Thickness

3.1.4.3.1 Air Inlet Temperature of Electronics

The heat dissipated from the electronic equipment depends on the air inlet temperature, so it is necessary to monitor the temperature at which air enters the customer shelf and rectifier unit. Collapsed surface regions have been used for obtaining the air inlet temperature for the electronic compartment. Figure 3.16 shows the location of the collapsed surface regions.

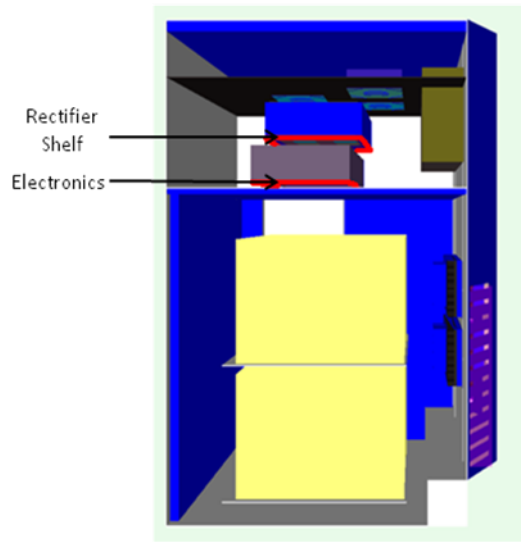


Figure 3.16: Location of collapsed region for monitoring the air inlet temperature

Table 3.4: Air inlet temperature for various configurations

Configuration	Air Gap (in)	Electronics ($^{\circ}\text{C}$)	Rectifier ($^{\circ}\text{C}$)
Single walled cabinet	-	70	74.1
Double walled cabinet solar shield	0.5	68.1	71.9
	1	67.5	70.8
	1.5	67.6	71.4
	2	67.4	71.0
	2.5	67.6	71.4
	3	67.5	71.4
Double walled cabinet top plenum and circulation fans	0.5	54.5	57.7
	1	53.5	57.1
	1.5	53.5	57.1
	2	54.7	56.2
	2.5	54.7	58.1
	3	56.7	58.3

From table 3.4, it is evident from a thermal perspective that the double walled cabinets are better than the single walled cabinets. A line plot of air gap versus the temperature is plotted in figure 3.17 for investigating the optimal air gap for a double walled cabinet.

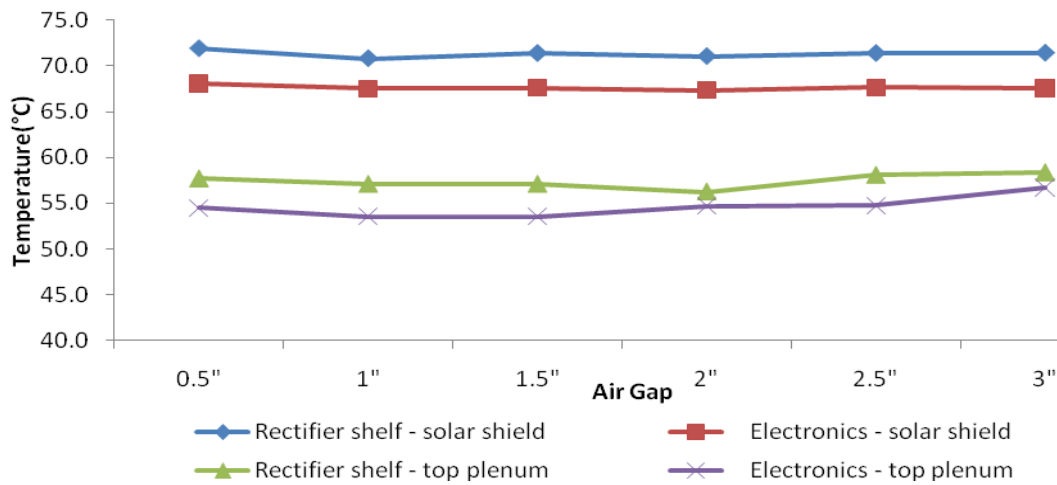


Figure 3.17: Airgap versus air inlet temperature of electronics and rectifier shelf

From the above figure, it is clear that the air gap variation has a negligible effect on inlet air temperature of the electronics and rectifier shelf, which gives flexibility to the design team for selecting an air gap based on the location of the cabinet and real estate available.

3.1.4.3.2 Mean Temperature Inside the Cabinet

The electronics compartment is divided into two: electronic and bay fans considered as a separate region. Hence, temperatures for three different compartments are recorded. Figure 3.18 shows the location of the volume region in the cabinet.

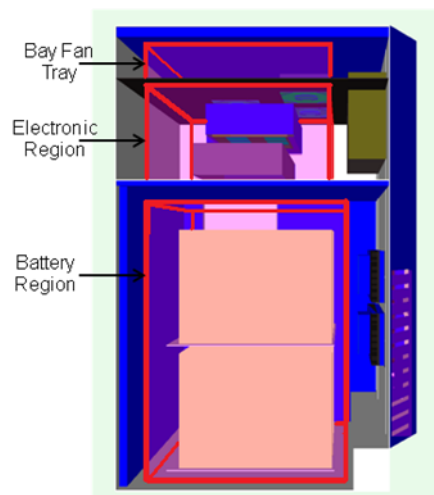


Figure 3.18: Location of volume regions in cabinet

Mean temperature is obtained from these volumetric regions and is tabulated in table 3.5

Table 3.5: Mean temperature inside the various volumetric regions

Configuration	Air Gap (in)	Electronic region (°C)	Bay fan tray (°C)	Battery (°C)
Single walled cabinet	-	73.2	74.1	55.4
Double walled cabinet solar shield	0.5	70.7	71.4	48.6
	1	69.9	70.7	48.1
	1.5	70.3	70.9	48.8
	2	69.9	70.6	48.2
	2.5	70.3	71.0	48.7
	3	70.3	71.1	48.9
Double walled cabinet top plenum and circulation fans	0.5	56.5	57.1	39.0
	1	55.5	55.6	38.3
	1.5	55.2	55.6	38.6
	2	54.9	55.2	38.2
	2.5	56.4	56.7	38.6
	3	56.9	57.7	38.5

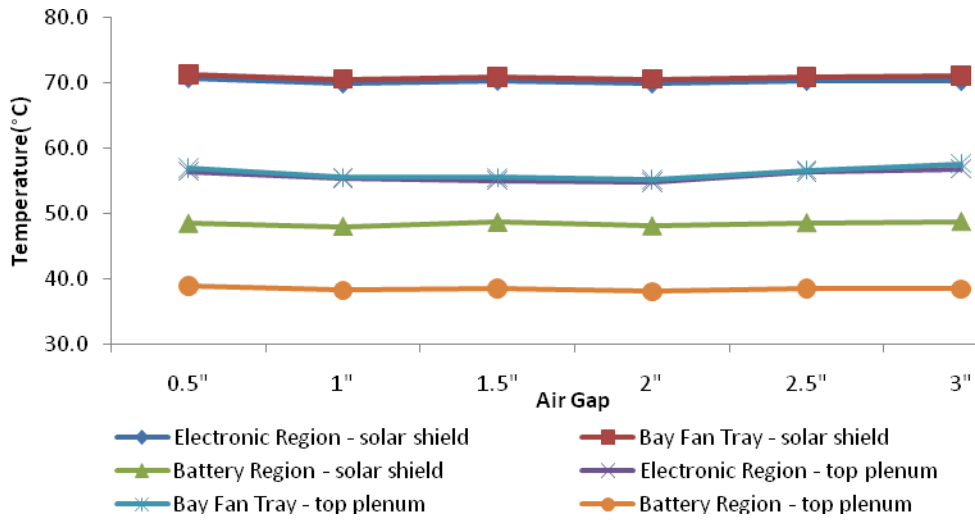


Figure 3.19: Air gap versus mean volumetric region temperature

From figure 3.19, it can be concluded that the air gap has negligible effect on the temperature within the cabinet. From the above study, the following are noted:

3.1.5 Guidelines

- ✓ The configuration of double wall with solar shield gives lower temperature than single walled cabinet. Hence, double walled cabinets reduce the impact of solar loading on the outdoor cabinets.
- ✓ The configuration of double wall with circulation fans is an ideal configuration as there is nearly 20% drop in the cabinet temperature when compared with single walled configuration (baseline case).
- ✓ It is noted that from a thermal point of view, the thickness of air gap plays a minor role in cabinet design. The variation of air gap thickness has a negligible effect on the cabinet temperature.

3.2 Optimization of Fan Location in a Double Walled Telecommunication Cabinet

3.2.1 Background

From the previous study, it can be concluded that cabinets with double wall and fans located on top is the best case scenario and the air gap is effective in reducing the solar load, however from a thermal perspective its thickness is insignificant. On this account, it is usual to implement double walls of minimal thickness in order to reduce the cabinet dimensions. However, this may have an impact on the energy consumption of the fan and may pose acoustic problems. Hence, a study is carried out for different fan configurations and its effect on cabinet temperature and energy consumption.

3.2.2 Model Description

3.2.2.1 Double Walled Cabinet – With Top Plenum – Baseline Case

The best case design of the previous study is used as baseline case in this part of study. The construction and boundary conditions of the cabinet remains same. The cabinet design is as shown in Figure 3.20.

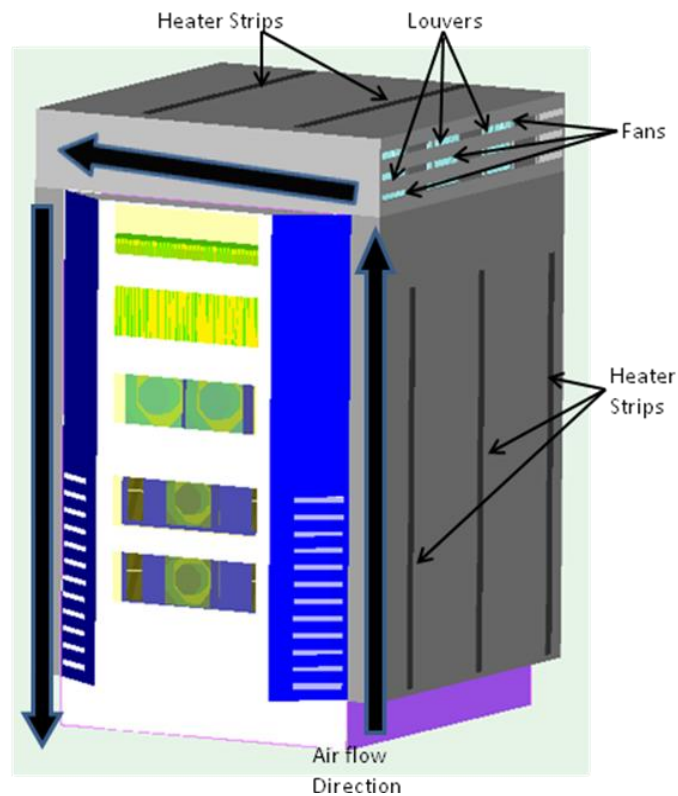


Figure 3.20: Double walled telecommunication cabinet with fans mounted on top plenum

3.2.2.2 Double Walled Cabinet – With Top Plenum – Fans on Side Wall

This configuration is similar in construction as discussed in 3.1.2.1 except that the position of fans is changed. The fans are located on the right side wall of the cabinet as shown in figure 3.21. Also there are no louvers present on the top plenum. In this configuration the axial fixed flow fans are used. The inlet is at the lower end of the right wall and the air flows around the cabinet. The exit vent is located on the low end of left wall. Thus, there is only one possible air flow path, i.e. flow around the cabinet. Two flow separators are placed in-between the fans on right wall in order to avoid merging of flow, due to high velocities. The arrows in figure 3.21 indicate the air flow path for this configuration.

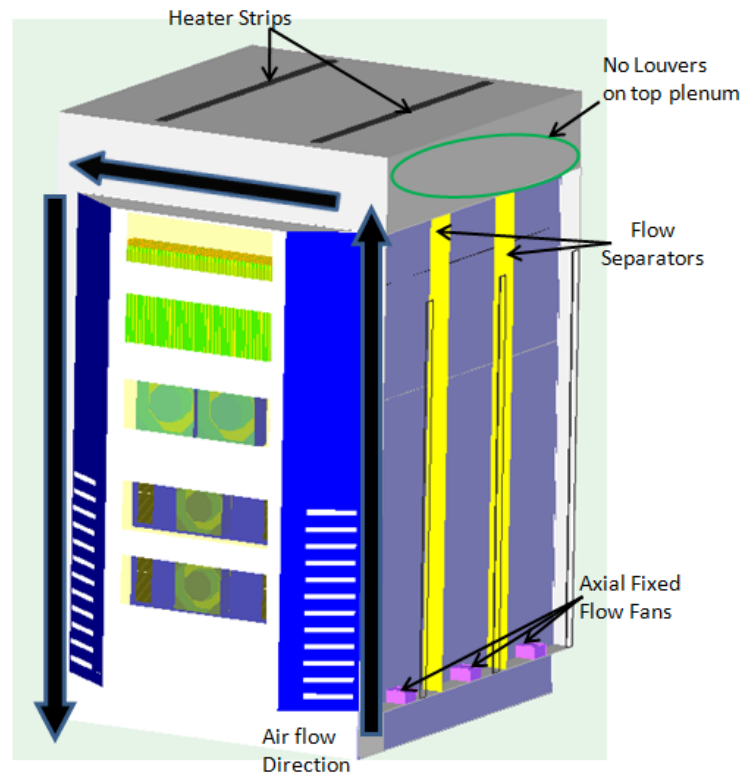


Figure 3.21: Double walled telecommunication cabinet with fans mounted on side wall

This configuration is modeled and studied for an air gap variation of 2" to 3" with increments in steps of 0.5". The axial fixed flow fans have a flow rate varying from 50 cfm to 125 cfm in steps of 25cfm for all the air gaps. The design of experiment for this study is defined in table 3.6

Table 3.6: Design of Experiment (DOE) of the study

Configuration	Case	Air gap (in)	Flow rate (cfm)
Fans on top Baseline case	1.1	2	269
	1.2	2.5	278
	1.3	3	281
Fans on bottom	2.1	2	50
	2.2	2	75
	2.3	2	100
	2.4	2	125
	3.1	2.5	50
	3.2	2.5	75
	3.3	2.5	100
	3.4	2.5	125
	4.1	3	50
	4.2	3	75
	4.3	3	100
	4.4	3	125

3.2.3 Results

First half of result analysis discusses the thermal impact on the cabinet due to the different fan configurations. In the second half, energy analysis is carried out. From a thermal-energy perspective, the best configuration of a double walled cabinet with fans is determined.

3.2.3.1 Thermal Analysis of Various Configurations

3.2.3.1.1 Air Inlet Temperature of Electronics

The heat removed from the electronic equipment depends on the air inlet temperature. Surface regions have been used for obtaining the average inlet temperature for both the electronics and the rectifier unit. Figure 3.15 shows the location of the collapsed surface regions.

Table 3.7 Inlet temperatures for electronics and rectifier unit

Configuration	Case	Air gap (in)	Flow rate (cfm)	Electronic component (°C)	Rectifier (°C)
Fans on top Baseline case	1.1	2	269	54.7	56.2
	1.2	2.5	278	54.7	58.1
	1.3	3	281	56.7	58.3
Fans on bottom	2.1	2	50	55.0	59.2
	2.2	2	75	54.1	58.2
	2.3	2	100	54.1	58.2
	2.4	2	125	53.2	57.4
	3.1	2.5	50	55.3	59.4
	3.2	2.5	75	54.6	58.7
	3.3	2.5	100	54.0	58.1
	3.4	2.5	125	53.4	57.6
	4.1	3	50	54.8	59.1
	4.2	3	75	54.2	58.3
	4.3	3	100	53.4	57.7
	4.4	3	125	53.2	57.5

From table 3.7, it can be mentioned that better thermal performance is achieved when fans are placed at the bottom. Thermal performance enhances with increase in flow rate. For lower flow rate (50 and 75cfm), relocation of fans has negligible effect on temperature when compared to the baseline case (1.1) but however, for higher flow rates, relocation shows improvement over the baseline case by nearly 2°C for electronics inlet. This trend is also noticed with air gaps of 2.5" and 3". Figure 3.22, 3.23 and 3.24 compares the inlet temperature between the baseline case and with different air gaps of varying flow rates.

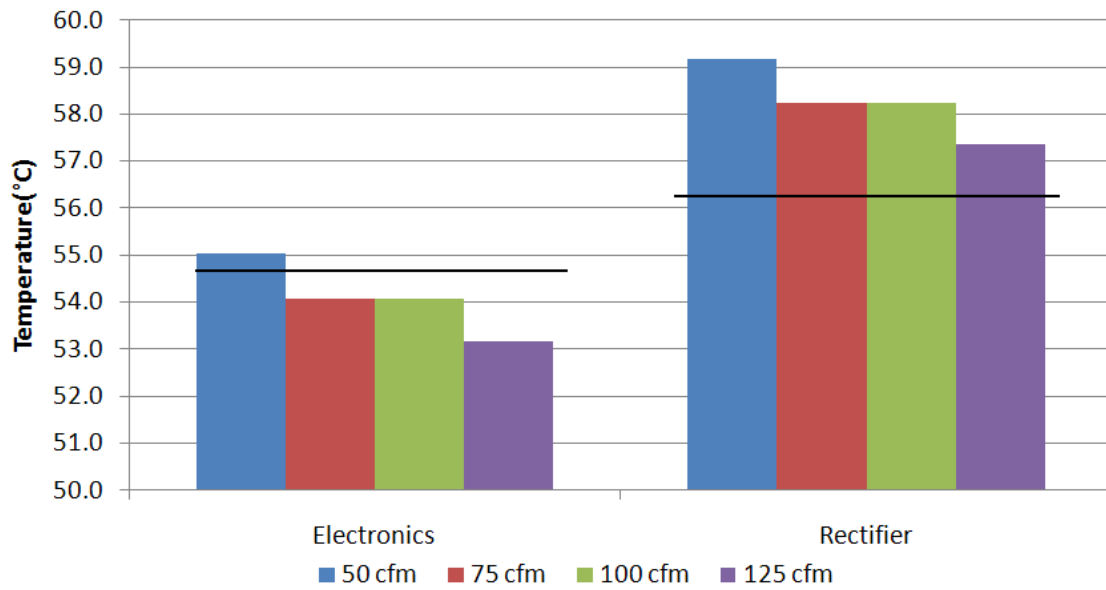


Figure 3.22: Inlet temperature of electronics and rectifier shelf for various flow rates for 2" air gap

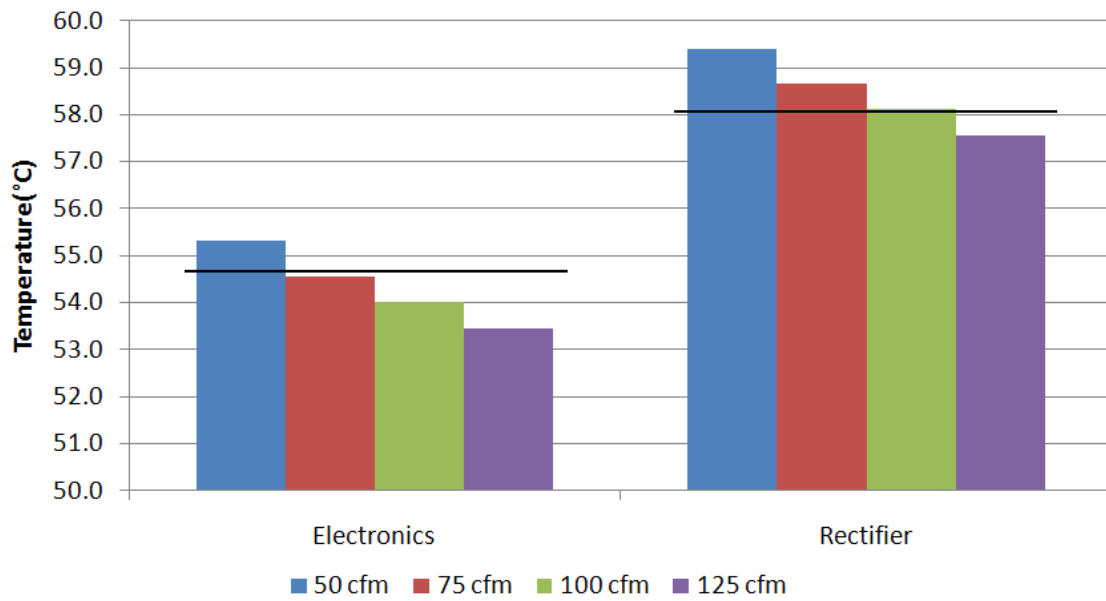


Figure 3.23: Inlet temperature of electronics and rectifier shelf for various flow rates for 2.5" air gap

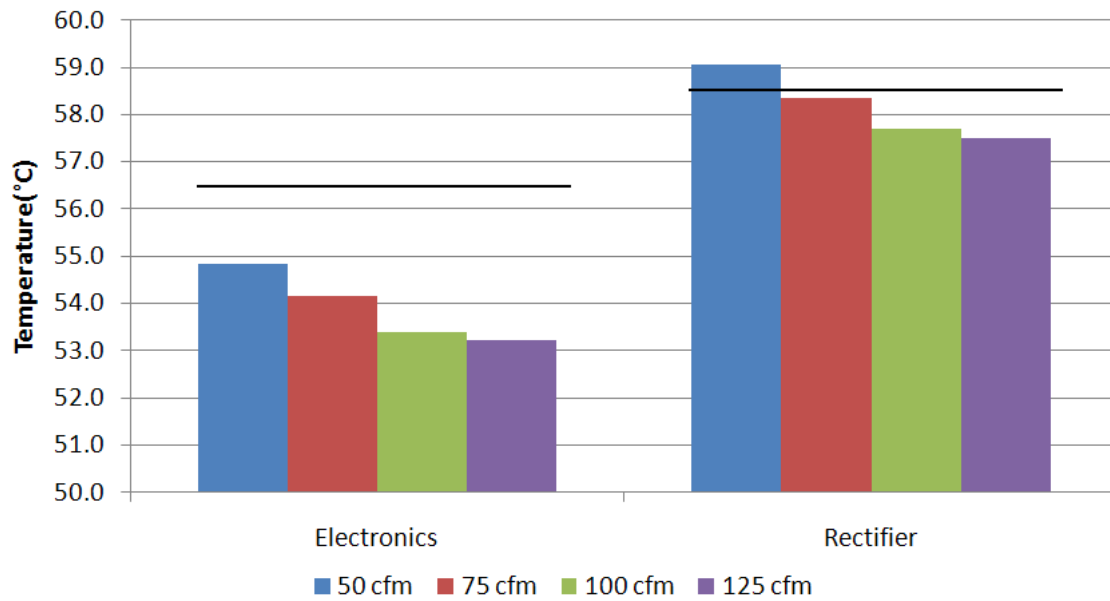


Figure 3.24: Inlet temperature of electronics and rectifier shelf for various flow rates for 3" air gap

3.2.3.1.2 Mean Temperature Inside the Cabinet

The temperatures for different compartments namely battery, electronics and bay fan tray are recorded. The location of the regions area is same as in the previous study (ref .4.2.2). Mean temperature is obtained from volumetric regions and is tabulated in table 3.8

Table 3.8: Mean temperature inside the various volumetric regions

Configuration	Case	Air Gap (in)	Flow Rate (cfm)	Electronic Region (°C)	Bay Fan Tray (°C)	Battery Region (°C)
Fans on Top Baseline case	1.1	2	269	54.9	55.2	38.2
	1.2	2.5	278	56.4	56.7	38.6
	1.3	3	281	56.9	57.7	38.5
Fans on Bottom	2.1	2	50	58.0	57.4	38.3
	2.2	2	75	57.0	56.4	37.8
	2.3	2	100	57.0	56.4	37.8
	2.4	2	125	56.1	55.4	37.3
	3.1	2.5	50	58.2	57.6	38.6
	3.2	2.5	75	57.4	56.7	38.1
	3.3	2.5	100	56.8	56.1	37.7
	3.4	2.5	125	56.2	55.5	37.5
	4.1	3	50	57.1	56.8	38.5
	4.2	3	75	56.3	56.0	38.3
	4.3	3	100	55.8	55.4	38.2
	4.4	3	125	55.4	54.9	37.8

As expected, a lower temperature is achieved in this scenario compared to the baseline case. This can be attributed to higher air flow on the side walls in this configuration by the virtue of fan location. Summary of table 3.8 is shown in the graphs 3.25, 3.26 and 3.27.

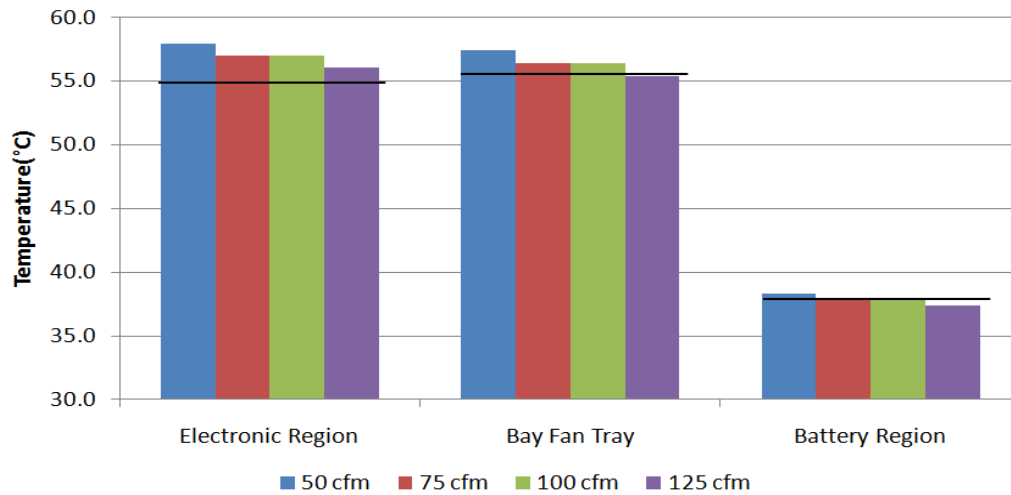


Figure 3.25: Temperature versus flow rate for 2" air gap for various regions

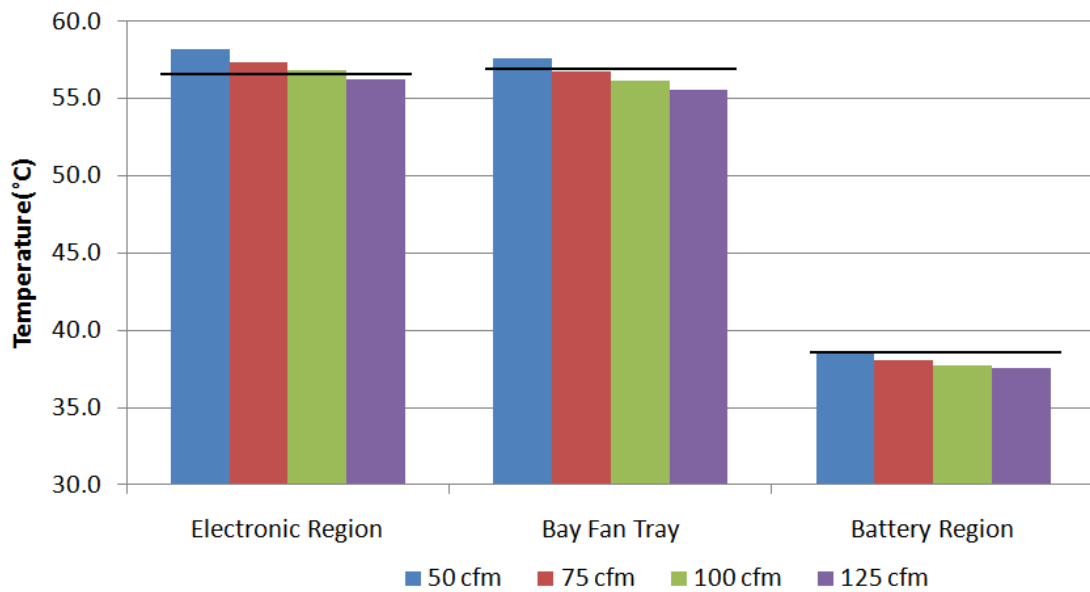


Figure 3.26: Temperature versus flow rate for 2.5" air gap for various regions

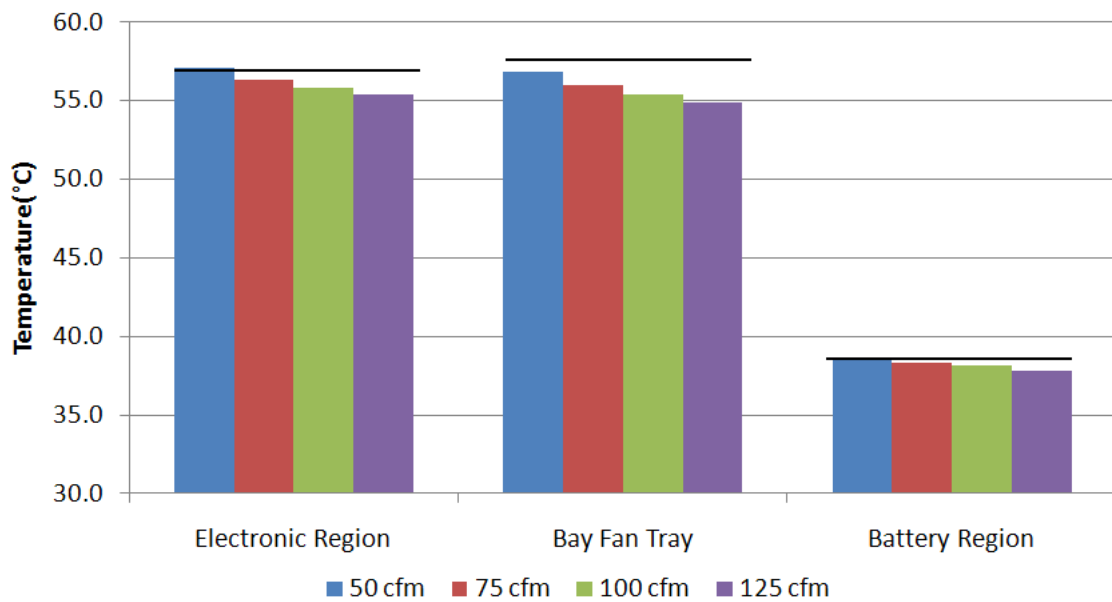


Figure 3.27: Temperature versus flow rate for 3" air gap for various regions

3.2.3.2 Energy Analysis of Various Configurations

From the above results, it is observed that temperature in the cabinet for both the configurations vary only by a negligible amount of 5%. However, energy consumed by the fans for various cases may vary having a significant impact on operation cost. Thus, it is vital to

perform energy assessment of all the cases. The energy consumed by these fans is estimated using the equations specified in Appendix A.

The power consumed by a fan is proportional to the static pressure and velocity pressure. The velocity pressure in turn is a function of flow rate and cross sectional area. The table 3.9 summarizes the mean electronics temperature and power consumed by additional fans on the double wall for all configurations.

Table 3.9: Mean electronics temperature and power consumption of various configuration

Configuration	Air Gap (in)	Flow Rate (cfm)	Temperature (°C)	Power (Watt)
Fan on Top	2	269	55.2	37.6
	2.5	278	56.4	33.8
	3	281	56.9	31.9
Fan on Bottom	2	50	58.0	7.9
	2	75	57.0	26.0
	2	100	57.0	62.5
	2	125	56.1	122.5
	2.5	50	58.2	7.2
	2.5	75	57.4	23.6
	2.5	100	56.8	54.9
	2.5	125	56.2	109.7
	3	50	57.1	7.2
	3	75	56.3	24.7
	3	100	55.8	56.6
	3	125	55.4	109.5

The figures 3.28, 3.29 and 3.30 compare the various configurations from both an energy and temperature perspective. The horizontal lines represent the baseline configuration.

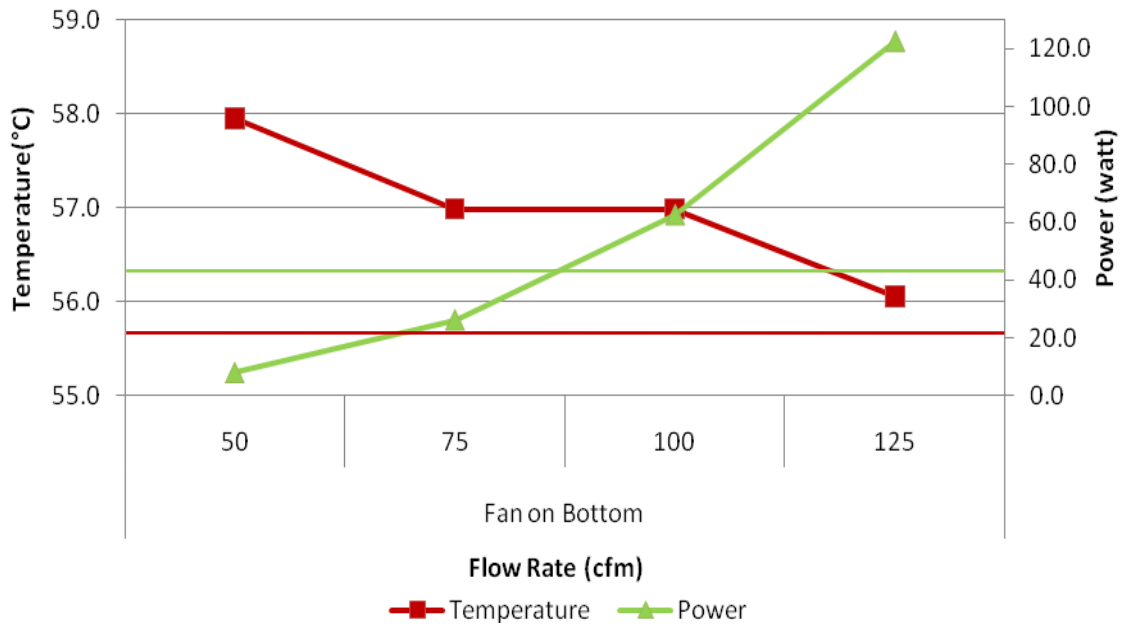


Figure 3.28: Temperature and power versus flow rate for 2" air gap

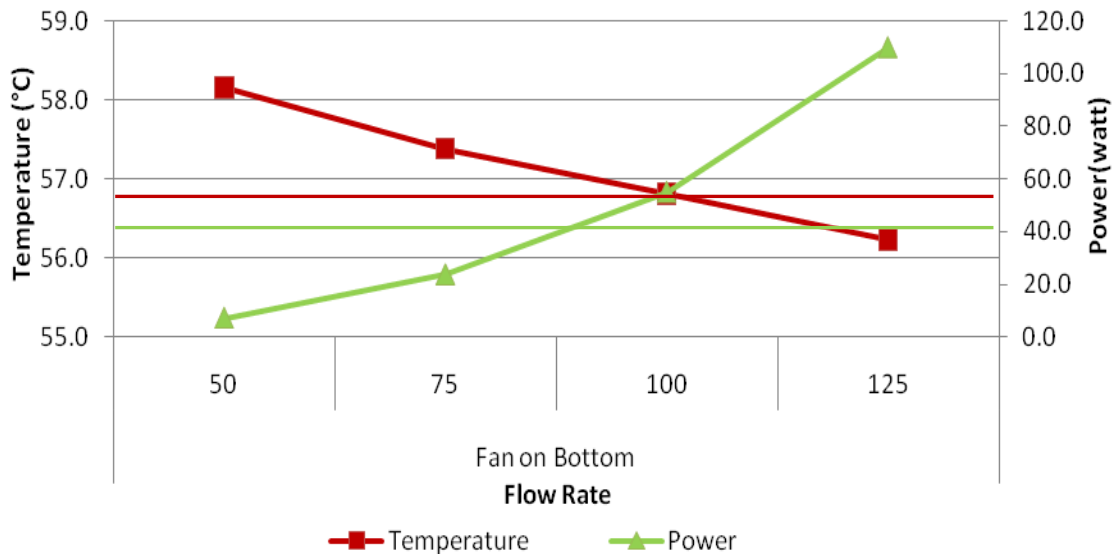


Figure 3.29: Temperature and power versus flow rate for 2.5" air gap

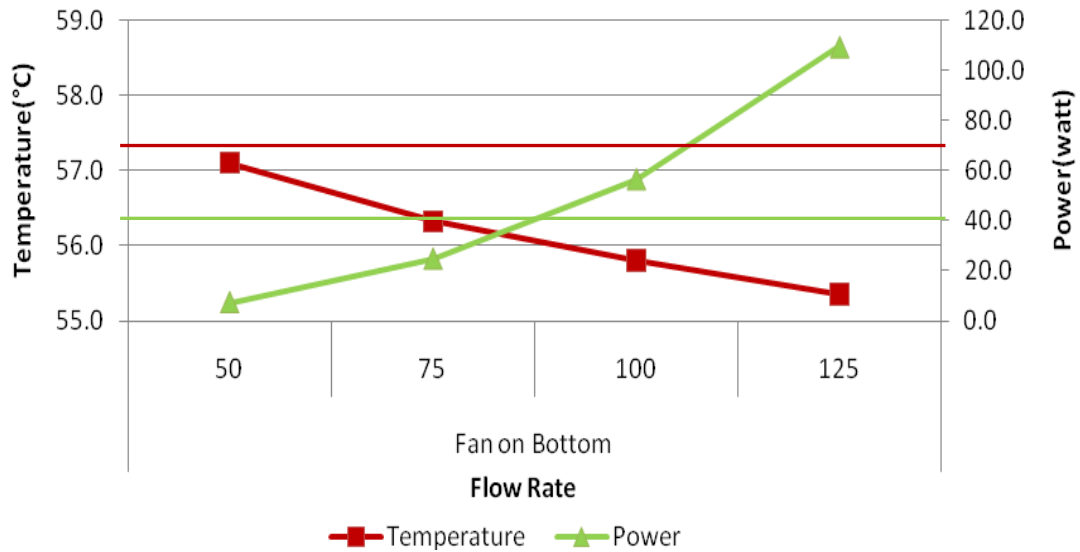


Figure 3.30: Temperature and power versus flow rate for 3" air gap

From the above analysis, it is noted that for nearly all air gaps, cases with higher flow rate (>100 cfm) records a lower temperature than the baseline case, but the power consumed by fans to blow the required flow rate is high. From the figure 3.27, 3.28 and 3.29, it is observed that the cases with lower flow rate (50 and 75 cfm) have low power consumption than baseline case with higher temperature. Hence, having an increase of up to 2°C inside the cabinet, savings of 25 watts of power on the circulation fans for the double wall configuration with fans (50 cfm) on bottom is achieved.

3.2.4 Guidelines

Listed below are the guidelines for designing the double walled cabinet with fans:

- ✓ From a thermal perspective, changing the location and flow rate of fans has a negligible effect on cabinet temperatures.
- ✓ From an energy point of view, the fan location and flow rate plays a major role in designing.

- ✓ When fans are mounted on the side of the double walls, it is recommended to use fans with flow rate lesser than 75 cfm, this will have low power consumption with a negligible thermal impact.
- ✓ Using fans with flow rate greater than 100 cfm is not recommended, though it reduces the cabinet temperature considerably, the power consumption is also very high.

CHAPTER 4

CFD MODELING OF ENVIRONMENTAL SYSTEM OPTIONS USED FOR COOLING OF TELECOMMUNICATION SHELTER

4.1 Background

Telecommunications shelters form an important component of wireless network. They are typically stand-alone structures with their own HVAC systems. They are used for housing dispersed telecom equipments [19]. The shelters must provide cooling for significant heat developed by typical cell site electronic equipment. This equipment includes wireless radios, backhaul transmission hardware, power distribution systems, and power backup systems. The advantages of using a telecommunication shelter are [17]:

- Flexibility of equipments
- House different equipments
- Expandable
- Comfortable space for maintenance during hot/cold climates

The shelters are normally climate controlled to maximize the life time of the housed equipments. Typical environmental requirements include -40°C to $+55^{\circ}\text{C}$ temperatures, high humidity, and corrosive environments. The shelters are designed to work over a wide range of conditions.

With the current development in technology especially in telecommunication where the generation is changing from 2G to 3G networks and also the introduction of high capacity GSM equipment has considerably increased the heat load of the shelter. Cabinets are used for housing the telecom equipments in a shelter. However, the cabinets inside the shelter must be maintained within permissible temperature limits in order to increase the life span of the equipments. The shelters also need to provide environmental protection for the housed

cabinets. These types of shelters, with their multiple equipment configurations, require tests and analysis to ensure the thermal performance.

The energy balance of a typical shelter results from the sum of a few components, mainly [34]:

- Thermal energy dissipated by telecom apparatus and auxiliary devices
- Auxiliary shelter systems thermal loads due to efficiency losses
- Thermal energy due to shelter transmission and conduction (heat losses or gain through shelter surface) and solar radiation

Cooling systems typically consume 30% of the energy consumed by a cell site. The reduction can be achieved by saving electricity consumption costs and the potential carbon footprint. The incentives to reduce this percentage are both financial, due to the electricity savings involved, and environmental because of the potential carbon footprint reduction. As per Dell'O Group, mobility report published in the first quarter of 2008 [35], there are nearly 1.13 million cell sites throughout the world. Cooling system performance can be optimized and validated prior to expensive and time-consuming field trials by using CFD analysis.

This study discusses the thermal impact of replacing an active cooling system with a hybrid system (air conditioner and blower) and the thermal impact on the shelter when additional blower/s is used. A parametric study is also carried out by varying the second blower's location. Also, the energy savings gained by replacing the active cooling system is discussed.

4.2 Model Description

The telecommunication shelter considered for analysis is 144 inches wide, 96 inches high and 108 inches deep.

The equipment inside the shelter is a function of application to be served. The shelter discussed in this study consists of various cabinets as follows:

- 2G cabinets-three
- 3G cabinet-one
- Power cabinet-one

The layout of the cabinets is shown in the figure 4.1. The shelter is cooled by active cooling technology (air conditioning unit).

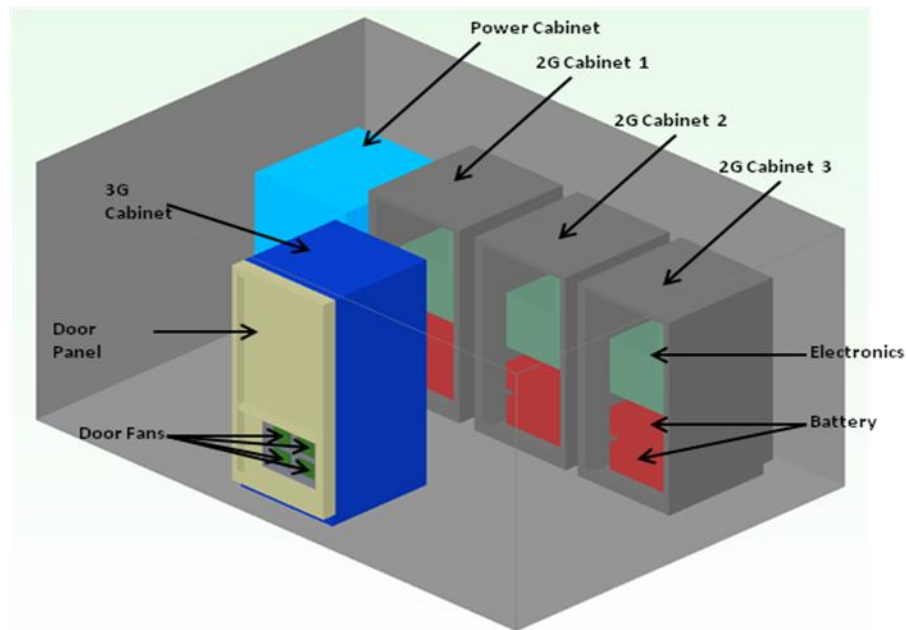


Figure 4.1: Layout of telecommunication shelter

4.2.1 Cabinet Description

The 2G and 3G cabinets have four door fans mounted on the front door to draw in the air. Axial fixed flow fans, capable of delivering 150 cfm of air are used. These cabinets have 60% vented back door configuration. For power cabinet, variable flow fans are mounted on the front door. The rear door is solid and it has an opening at the top end, which acts as a vent. Figure 4.2 shows the internal components of a cabinet.

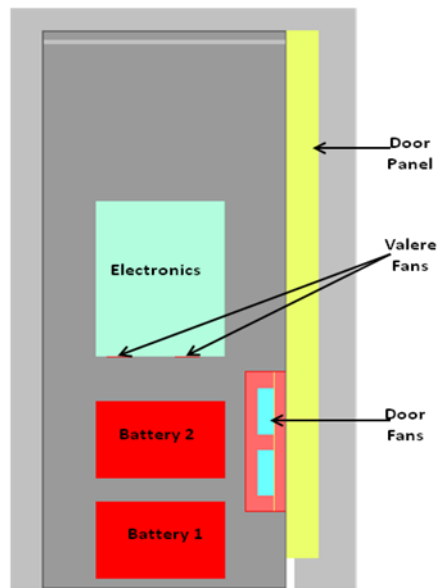


Figure 4.2: Internal components of the cabinet

Each cabinet comprises of two parts namely:

3. Battery compartment
4. Electronic compartment

The battery compartment consists of two trays of battery which are used as a backup. The electronic compartment consists of circuit cards, which dissipate heat into the system. Controlling the temperature inside the cabinet is of high priority as it can affect the performance of electronic equipment [20]. The door fans pulls in the air from the shelter directed towards the batteries. The electronics are cooled by the rectifier fan shelf. This rectifier fans, located on the bottom of the electronics, pushes the air in the upward direction. A total of eight axial flow fans are used in the rectifier shelf, each capable of delivering 48 cfm. The figure 4.3 indicates the location of cabinets and direction of air flow inside the cabinets.

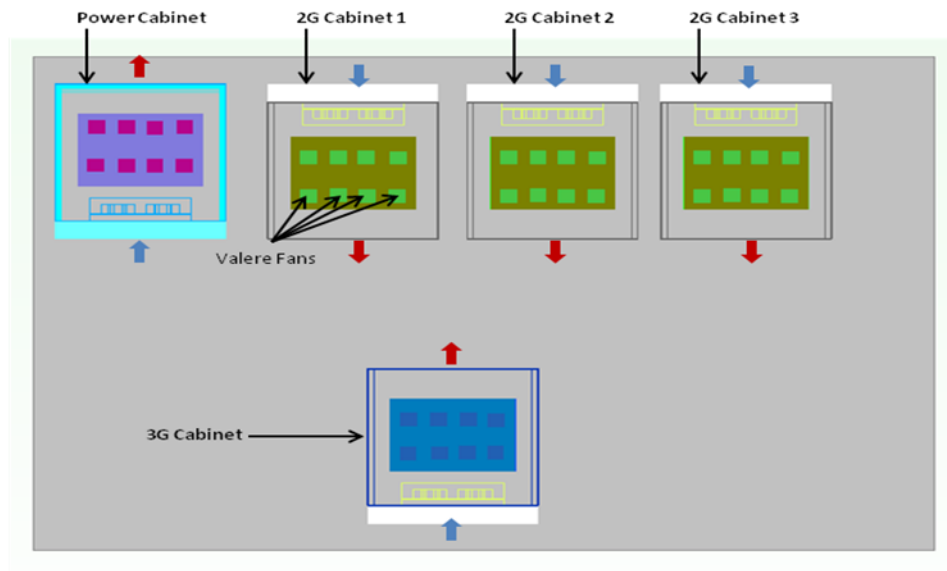


Figure 4.3: location and air flow direction of the cabinets

All the cabinets have 1 inch thick insulation of the sides and top of the cabinet. The overall heat load of the cabinet is 4.42kW. The table 4.1 indicates the heat load in different cabinets. The ambient temperature considered is 20°C.

Table 4.1: Heat load in the shelter

Unit Name	No of Units	Heat Load (Watt)
Power Cabinet - Electronics	1	450
2G Cabinet:1 - Electronics	1	1050
2G Cabinet:2 - Electronics	1	1050
2G Cabinet:3 - Electronics	1	1050
Nokia NodeB - RRU 1	1	150
Nokia NodeB - BBU	1	100
Nokia NodeB - RRU 2	1	150
Nokia NodeB - ALM	1	50
Nokia NodeB - RRU 3	1	150
Power Cabinet - Door Fans	4	55 W
Total Heat Load		4420

4.3 Modeling of Blower

To model the blower used in the shelter, recirculation device smart part of flotherm is used. The blower has the hub diameter of 175 mm and the exhaust being of dimension 286mm width and 360mm tall. The fan curve is obtained for the blower from the manufacturer. In this study, two different blowers with different fan curves are used. The figure 4.4 shows the two different fan curves used.

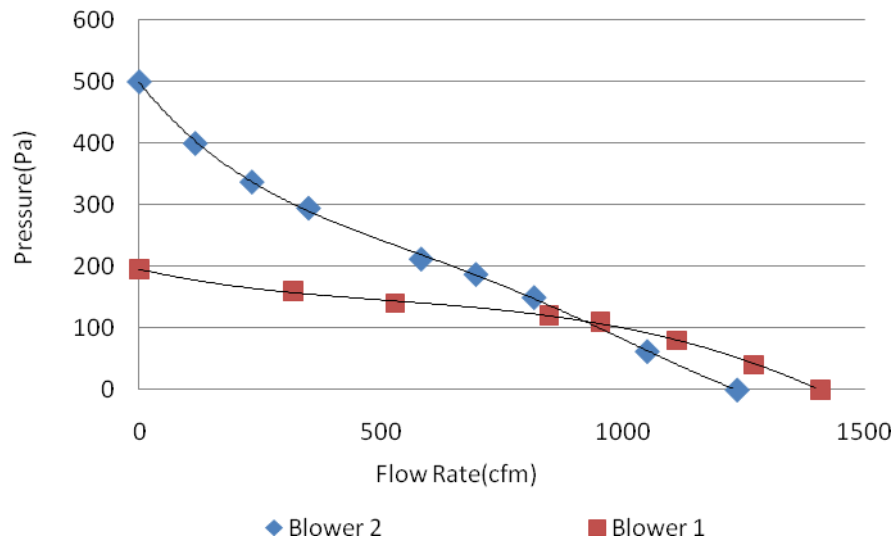


Figure 4.4: Blower fan curve

For comparing the two blowers, construction of the blowers must be same and only the blower curve is changed. The blowers of different dimensions have different system curve and hence cannot be compared. The system resistance must always be a function of only flow rate and independent of the blower construction.

4.4 Design of Experiments

4.4.1 Case 1 and Case 2 – Negative Pressure Blower with Blower Curve 1 & 2

In these configurations, a negative pressure blower is used. A negative pressure blower pulls in the air from the shelter and exhausts it towards the atmosphere. The blower curve 1 and 2 are respectively used for cases 1 and 2. The figure 4.5 indicates the location of the blower

and the inlet vent. A 0.25" quadfoam filter is used at the inlet vent to filter out the particulate matter.

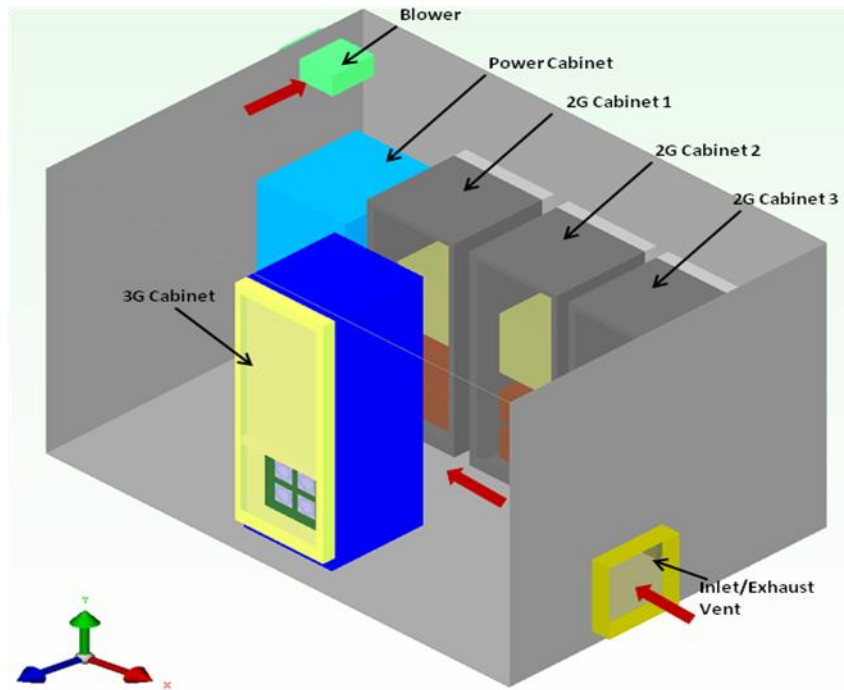


Figure 4.5: location of the blower and the inlet vent of the shelter

4.4.2 Case 3 and 4 – Positive Pressure Blower with Blower Curve 1 & 2

In these configurations, positive pressure blowers are used. They blow the air into the shelter from the atmosphere. The inlet vent will now act as an exhaust vent. The blower curves 1 and 2 are used also used for the cases 3 and 4 respectively.

The table 4.2 shows the design of experiment for this study.

Table 4.2: Design of Experiment

Scenario	Blower Fan Curve	Shelter Pressure
Case 1	Curve 1	Negative
Case 2	Curve 2	Negative
Case 3	Curve 1	Positive
Case 4	Curve 2	Positive

4.5 Results

4.5.1 Model Validation

4.5.1.1 Comparison of Experimental and Numerical Data

As per AIAA validation is defined as “*The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model*” [36]. Validation verifies the computational model (CFD) with the real world observations. The aim is to identify and quantify error and compare the results computationally and experimentally. The accuracy of the validation varies with the application.

For this study, the monitor point temperature obtained from the cfd model is compared with the temperature data of different thermocouples placed at the experimental test site [31]. Figure 4.6 shows the location of monitor points inside the telecommunication shelter.

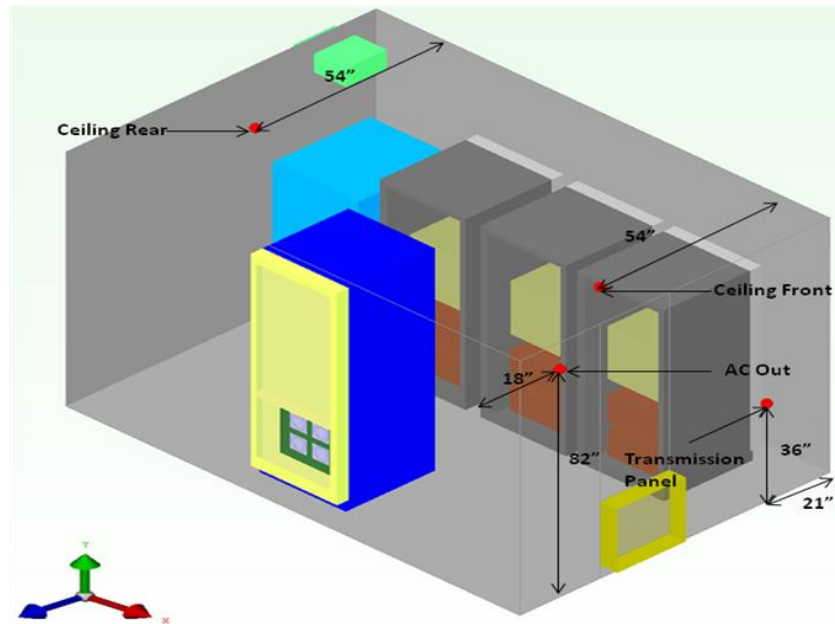


Figure 4.6: Location of monitor points inside the shelter

The table 4.3 compares the temperature data for the numerical and experimental model.

Table 4.3: Comparison of experimental and numerical data

Monitor Point	Experimental (°C)	Numerical (°C)	% Error
Ambient	19.9	19.9	0
Transmission Panel	26.6	25.9	2.6
AC Unit	29.4	29.5	0.34
Shelter Front	29.5	30.5	3.3
Shelter Ceiling rear	24.5	26.3	7.3

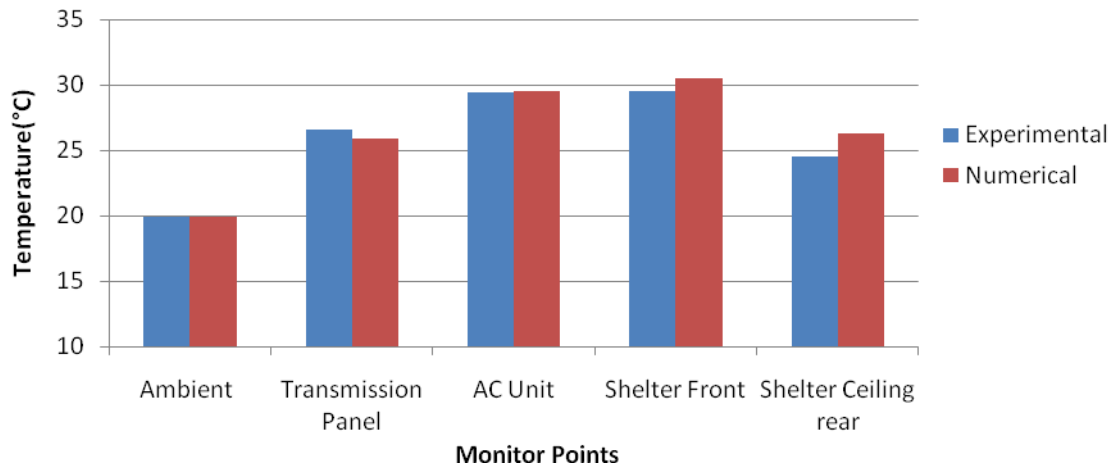


Figure 4.7: Comparison of experimental and numerical results

From the above table 4.2 and figure 4.7, the percentage of error in the temperature readings between the numerical and experimental data are not significant.

4.5.1.2 Mesh Sensitivity Analysis

Discretization errors also known as numerical error, in a cfd code occur from representing the governing flow equations and other physical models as algebraic expressions in a discrete domain of space (finite-difference, finite-volume, and finite-element) and time. The discrete spatial domain is known as the grid or mesh. The examination of the spatial convergence of a simulation is a straight-forward method for determining the ordered discretization error in a CFD simulation. The method involves performing the simulation on two or more successively finer grids. The term grid convergence study is equivalent to the commonly used term grid refinement study or mesh sensitivity analysis [37].

The solution obtained from a cfd simulation must be independent of the mesh size and mesh count. In this study the number of elements is varied from 1.4 million to 5.16 million. The figure 4.8 compares the temperature at various monitor points for when the mesh count is varied.

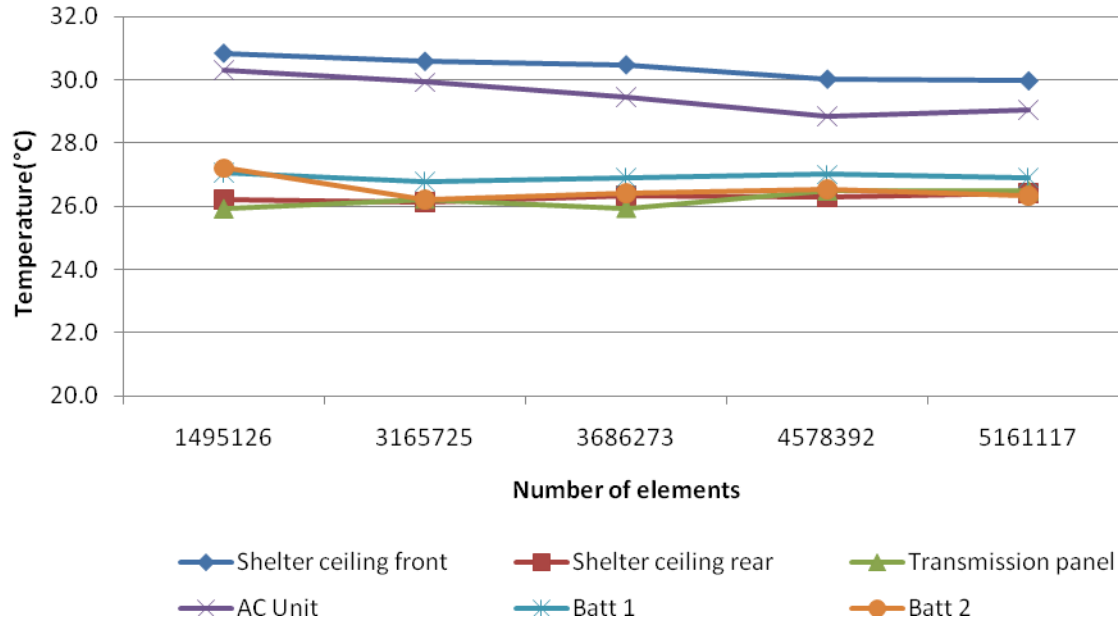


Figure 4.8: Mesh sensitivity analysis

From the study, it is concluded that the solution reaches grid independence at about 3.5 million cells.

4.5.1.3 Uncertainty Analysis

The uncertainty analysis deals with assessing the uncertainty in a measurement. Moffat R J [38] defines uncertainty analysis as a process of estimating the uncertainty in results calculated from measurements with known uncertainties. The uncertainty analysis is performed on the six different thermocouples which are used to monitor the temperature inside the shelter. The T type thermocouples are used to monitor the temperature inside the shelter. The maximum inherent error in T type thermocouples is $\pm 0.5^\circ\text{C}$. Thus, with each thermocouple reading, using Monte Carlo simulation, 100 different readings are generated within a variation of $\pm 0.5^\circ\text{C}$. The random number generator option available in excel is used for generating the different readings. The random number generator in excel is based on Monte Carlo method.

$$\% \text{ of Uncertainty} = \frac{\text{Standard deviation (Readings)}}{3}$$

The table 4.4 indicates the % uncertainty of various monitor point reading considered in the study.

Table 4.4: Percentage uncertainty for various monitor points

Monitor Point	% Uncertainty
Transmission Panel	3.42
AC Unit	2.92
Shelter Front	2.82
Shelter Ceiling rear	3.25
Battery 1	3.39
Battery 2	3.23

4.5.2 Battery Cabinet Temperature

The battery compartment should be thermally controlled for maximizing the life of the battery. The temperatures at the battery compartment are compared for different cases. The monitor points for the battery compartment are placed 1-inch above the batteries in the cabinet. There are two battery monitor points for each cabinet. Figure 4.9 shows the location of monitor points in the cabinet. The table 4.5 indicates the battery cabinet monitor point temperature and figure 4.10 plots the results of the temperature obtained when the different blowers are used .

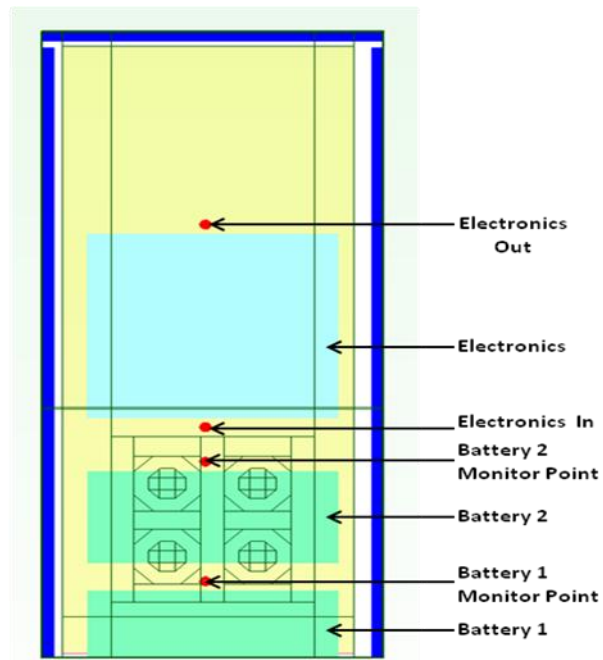


Figure 4.9: Location of monitor points inside the cabinet

Table 4.5: Comparison of monitor point temperature at battery compartments

Monitor Points	Temperature(°C)			
	Case 1 Fan Curve 1	Case 2 Fan Curve 2	Case 3 Fan Curve 1	Case 4 Fan Curve 2
Power Cabinet -1	25.9	26.1	27.1	27.8
Power Cabinet -2	26.1	26.3	27.7	28.5
2G Cabinet 1-1	26.2	26.7	27.2	28.0
2G Cabinet 1-2	26.9	27.4	27.6	28.4
2G Cabinet 2-1	24.7	25.0	27.1	28.0
2G Cabinet 1-2	28.2	28.5	27.7	28.5
2G Cabinet 3-1	23.8	23.8	26.6	27.4
2G Cabinet 3-2	28.5	28.6	26.8	27.7
Node Cabinet -1	25.0	25.5	26.8	27.6
Node Cabinet -2	22.2	23.1	27.3	28.2

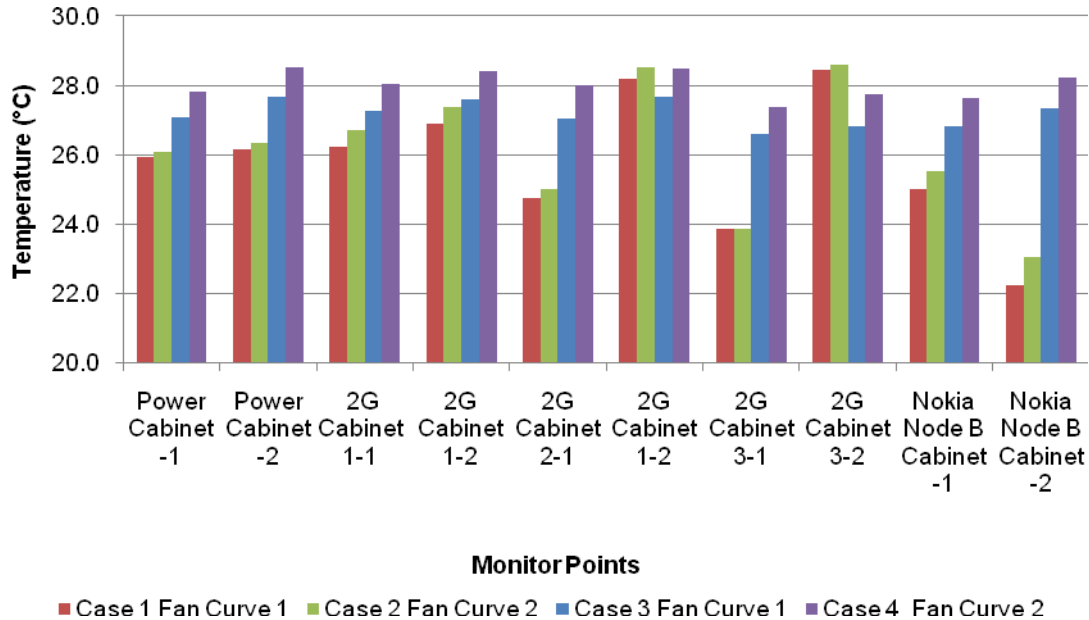


Figure 4.10: Comparison of battery cabinet monitor points between various cases

From the above bar chart it is clear that, when negative pressure blower is used, the change in the blower/fan curve has a negligible effect on the battery compartment temperature inside all the cabinets. In case of positive pressure blowers, it is found that fan curve 1 gives lower temperature than curve 2. But it is noted that, the difference is not appreciable, there is only a variation of lesser than 3⁰C. The 3G cabinet also known as Nokia node B cabinet, an appreciable difference in temperature due to difference in air flow pattern is observed. Thus, overall positive or negative operating blower with either one of the fan curve does not have any appreciable effect on the shelter.

4.5.3 Cabinet Inlet Temperature

The heat dissipated from the electronic equipment is dependent on air inlet temperatures. The inlet air temperatures for the cabinets are compared for various cases. A monitor point is placed in front of each cabinet door. Figure 4.11, shows the location of monitor points in the shelter which monitors inlet air temperature of the cabinets.

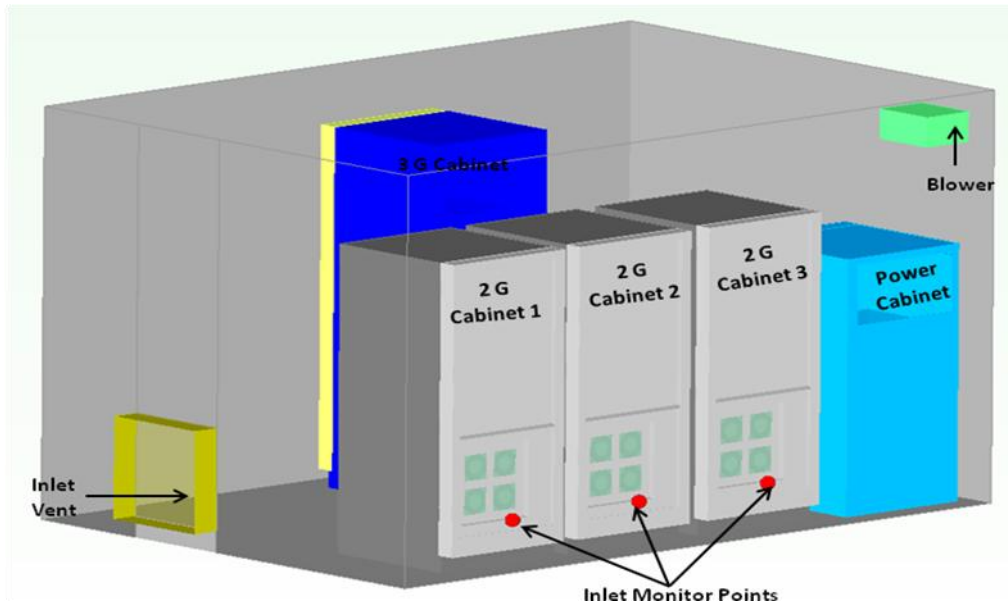


Figure 4.11: Location of cabinet's inlet monitor points

The different inlet temperatures are tabulated in table 4.6 and also plotted in figure 4.12.

Table 4.6: Inlet temperature of the cabinet for different blower configuration

Monitor Points	Temperature ($^{\circ}\text{C}$)			
	Case 1 Fan Curve 1	Case 2 Fan Curve 2	Case 3 Fan Curve 1	Case 4 Fan Curve 2
Power Cab - In	25.5	25.5	26.9	27.7
2G Cab 1 - In	26.0	26.4	27.3	28.1
2G Cab 2 - In	24.7	25.0	27.0	27.9
2G Cab 3 - In	23.0	22.9	26.5	27.2
Nokia Node B Cab - In	24.1	25.5	26.9	27.7

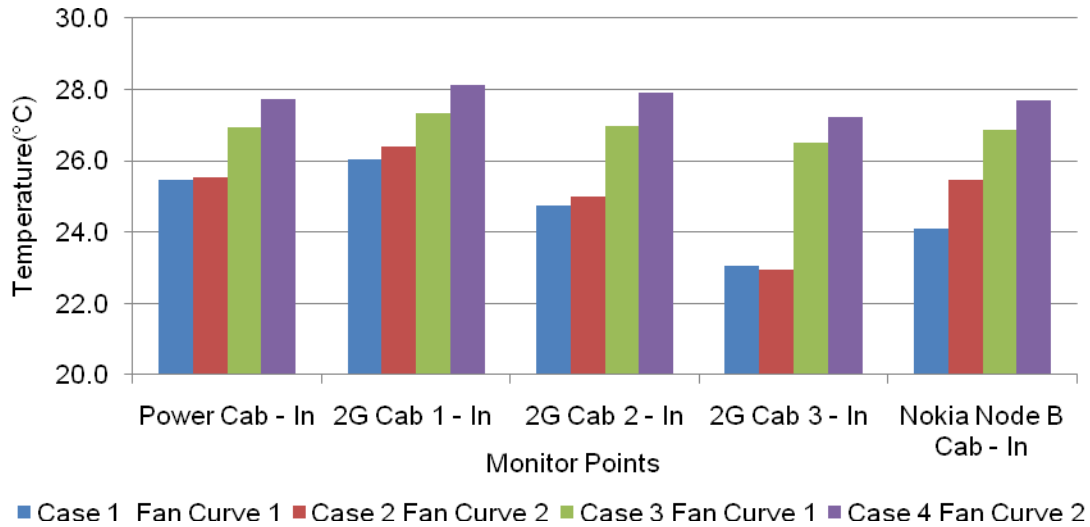


Figure 4.12: Cabinet's inlet temperature comparison for different blower configuration

From the above bar chart and table, a change in the fan curve for both positive and negative pressure operation of blower has shown a minimal effect on the inlet temperatures. A slight increase in temperature is observed with positive pressure blowers. The blower is blowing air into the shelter along side wall of the shelter; certain amount of air tends to bypass the 3G cabinet and flows directly towards the exhaust vent. Air bypassing can be clearly seen in the figure 4.13. The vector plot is taken at the mid height of the exhaust vent. In practice, there is also heat from the blower will increase the inlet temperature of the air.

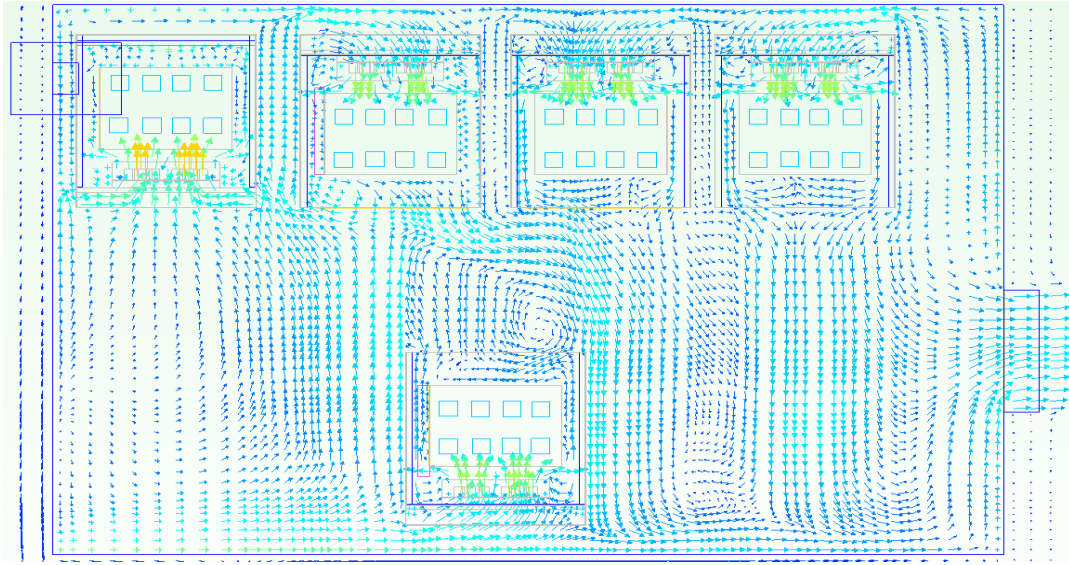


Figure 4.13: Vector plot of shelter indicating the air by pass

The figure 4.14 and 4.15 shows the thermal plots for the positive and negative pressure blower when implemented in the shelter with the blower curve 2. The thermal plots are taken at the exhaust level, indicating the inflow/outflow of air from the shelter.

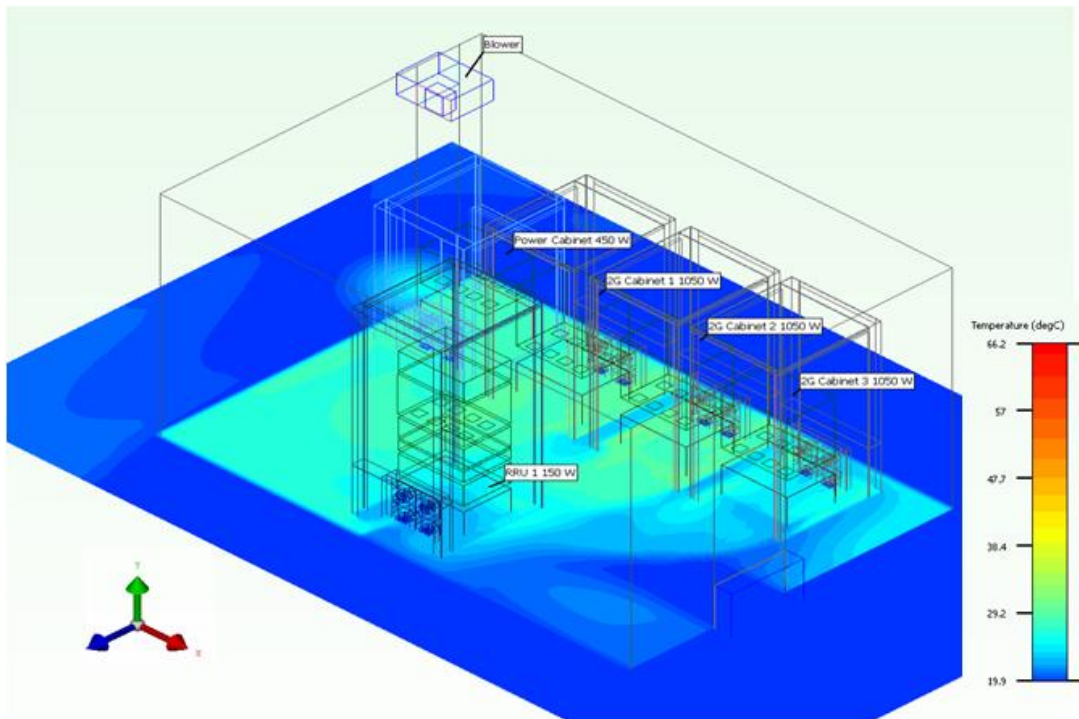


Figure 4.14: Thermal plot at mid height of intake/exhaust vent for Case 2

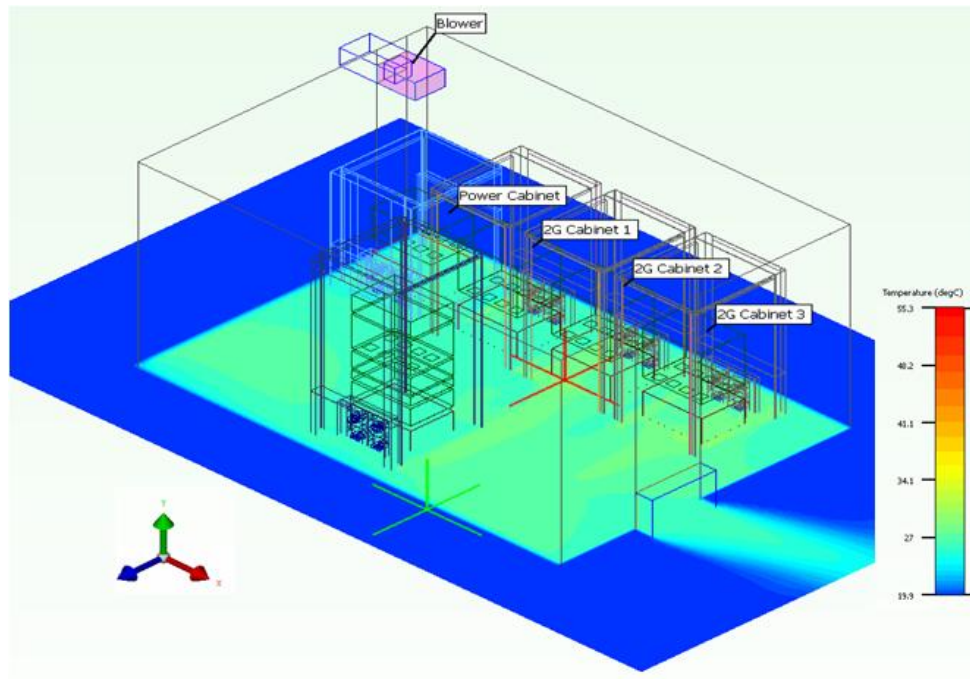


Figure 4.15: Thermal plot at mid height of intake/exhaust vent for Case 4

4.5.4 Impact of Additional Blower

From the above study it can be concluded that with usage of a blower, temperature can be maintained within permissible limits inside the shelter. Thus, for investigating further reduction in the temperature, an additional blower is added to the shelter. Also, a parametric study is carried out by varying the location of the second blower and analyzed its impact on temperature.

For the second blower, blower fan curve 2 is used. The second blower is located exactly below the first blower. The table 4.7 tabulates the monitor point temperature for the configuration with one and two blowers.

Table 4.7: Monitor point temperature comparison for different blower

Monitor Point	Temperature(°C)	
	1 Blower	2 Blowers
Transmission panel	25.9	25.3
AC Unit	29.5	28.6
Shelter ceiling front	30.5	33.8
Shelter ceiling rear	26.3	25.5
Batt 1- Power Cab	26.9	25.6
Batt 2- Power Cab	26.4	25.7

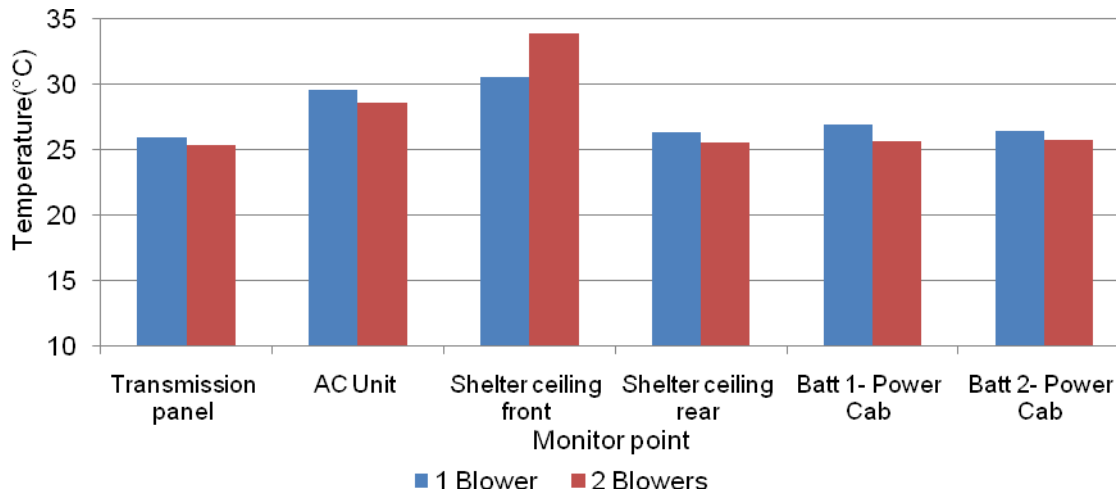


Figure 4.16: Temperature comparison between blower 1 and 2 configuration

From the figure 4.16, it can be observed that the addition of second blower has minimal impact on the monitor point temperatures. A parametric study is carried out by varying the distance between first and second blower. The second blower is moved 15" from the first blower in the negative Y direction in steps of 5". Then its location is varied along the positive Z axis. The figure 4.17 shows the location of the second blower and its various positions.

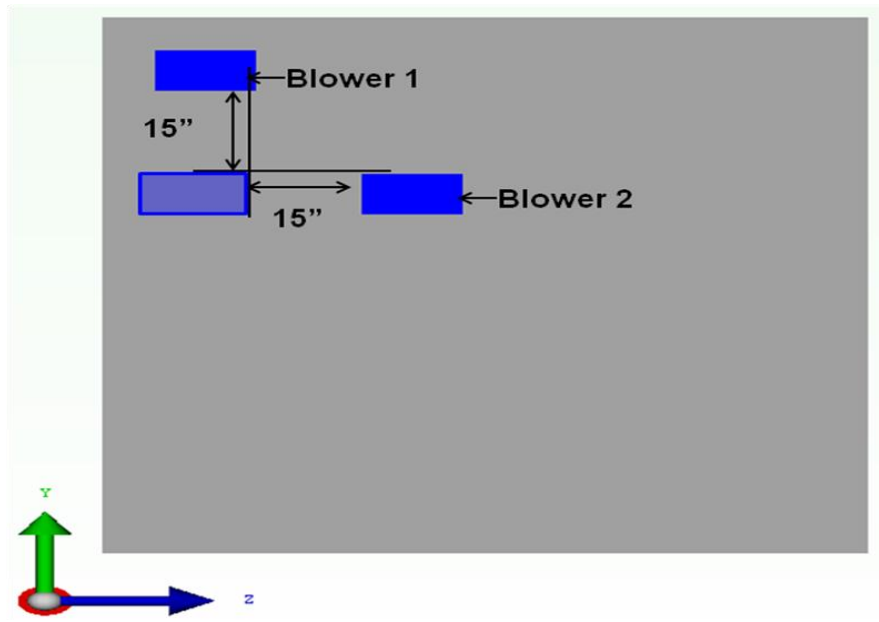


Figure 4.17: Location of the second blower in the shelter

Table 4.8 tabulates the various monitor point temperature when two blowers are used and the 2nd blower's location is varied. The line chart in figure 4.18 compares the temperature of different monitor points when the additional blower distance is varied along negative Y axis. The figure 4.19 compares the same when the distance is varied along the Z axis.

Table 4.8: Temperature inside the shelter for various blower locations

Monitor Point	Distance from Blower 1 along Y axis				Distance from Blower 1 along Z axis			
	0"	5"	10"	15"	0"	5"	10"	15"
Transmission panel	22.2	22.3	22.5	22.4	25.2	28.5	28.1	27.2
AC Unit	36.1	35.9	33.7	34.6	28.3	22.2	22.3	22.4
Shelter ceiling front	23.1	22.7	22.6	22.7	34.0	36.1	36.6	35.8
Shelter ceiling rear	28.5	27.0	25.3	25.8	26.4	23.1	22.6	22.3
Batt 1- Power Cab	23.4	23.2	23.0	23.1	26.0	23.4	23.2	23.2
Batt 2- Power Cab	24.4	24.2	23.8	24.0	26.1	24.4	24.1	24.2

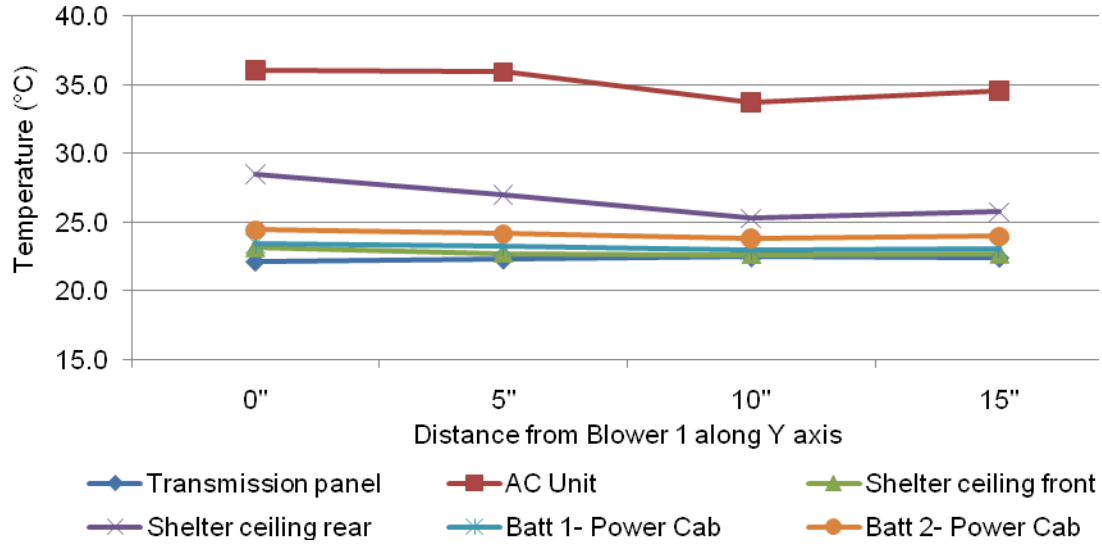


Figure 4.18: Distance of 2nd blower along Y axis versus temperature

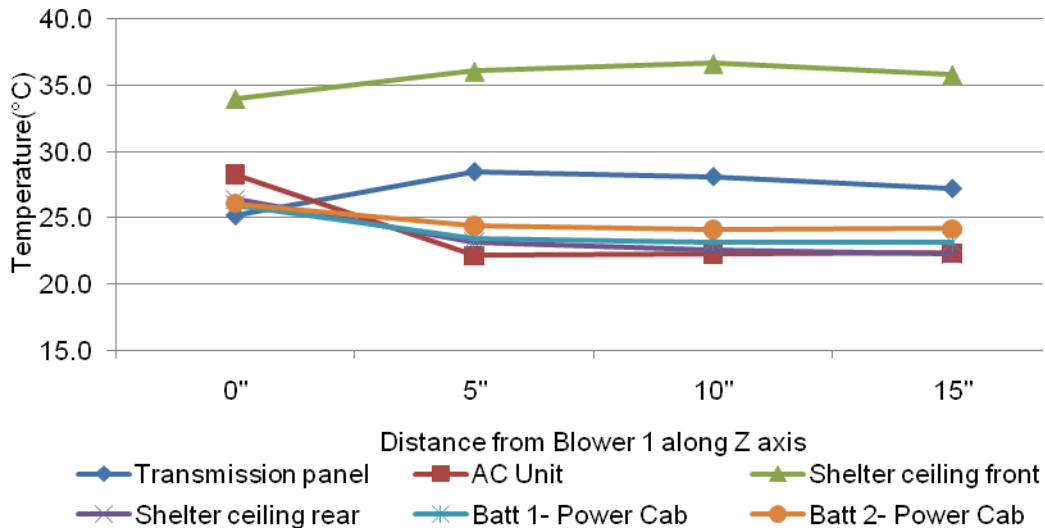


Figure 4.19: Distance of 2nd blower along Z axis versus temperature

From the figure 4.18 and figure 4.19, it is observed that the location of second blower has minimal impact on the temperature inside the shelter. Though, the global temperature of the shelter is reduced with the additional blower, it has no impact on the monitor points inside the telecom shelter. Hence, a second blower can be used for redundancy purpose.

4.5.5 Impact of Hybrid Cooling System on Energy

From the above study it is observed that by utilizing the blower with an ambient temperature of 20°C, the electronic equipments inside the shelter can be maintained within the design guidelines. Utilizing the blower in cold places will lead to considerable power savings. Most of the shelters are currently cooled with A/C system. Thus, it is proposed to have a hybrid cooling system for the shelter, which consists of both the air conditioner (A/C) and the blower. Depending on the ambient temperature, either the A/C or the blower can be used for cooling the shelter. The table 4.9 contains the various design configurations that can be implemented.

Table 4.9: Design of experiment for hybrid cooling system

Configuration	A/C	Blower
1	Yes	No
2	Yes	Curve 1 –ve pressure
3	Yes	Curve 1 –ve pressure
4	Yes	Curve 2 +ve pressure
5	Yes	Curve 2 +ve pressure

The following table 4.10 indicates the average temperature distribution at the test site location for the year 2009.

Table 4.10: Average temperature distribution for the year 2009 at test site

Month	Temperature		
	< 15°C	15°C - 20°C	> 20°C
January	31	0	0
February	27	1	0
March	14	17	0
April	9	20	1
May	3	16	12
June	2	7	21
July	0	1	30
August	0	0	31
September	0	9	21
October	10	20	1
November	25	5	0
December	31	0	0
Total	152	96	117

From the above table 4.10, it can be seen that for more than half the year, blower alone can effectively cool the shelter. It is assumed that the only blower functions when the temperature is below 15°C and only A/C functions when temperature is greater than 20°C. When the temperature varies from 15°C to 20°C, blower and A/C function 50% of time. Thus, the power consumed by the various DOE as listed in table 4.9, is calculated. The methodology used for power calculation is described below.

For calculating the power of A/C

The power rating of the air conditioner is 4.7A at 230V. It is considered that for configuration 1, A/C runs for 82% of time.

$$\text{Energy consumed (Kwhr)} = \frac{\text{Current} \times \text{Voltage} \times \text{time of operation}}{1000} \quad (1)$$

For calculating the power of blower, the procedure in Appendix A is followed.

The energy consumed by the active cooling system is found by using the equation 1. While the energy consumed by blower is calculated using the Appendix A. The table 4.11 tabulates the energy consumed by various configurations and the percentage savings in energy when the air conditioning system is replaced with a hybrid cooling system.

Table 4.11: Energy consumed by various configurations

Configuration	Energy consumed (Kw Hr)	% Savings of energy
1	7765.04	-
2	4852.65	37.5
3	4708.33	39.4
4	5048.9	35
5	4833.76	37.8

From the table 4.11, it can be clearly seen that by replacing the air conditioner with a hybrid cooling system, 40% savings in energy on the cooling system alone can be achieved.

When a hybrid cooling system is implemented and the compared with a shelter with air conditioning system, then a saving of 20% is possible.

4.6 Guidelines

The thermal impact of a blower, as a cooling unit for a telecommunication shelter is studied. Negative and positive pressure blower constructions are used for the study.

Listed below are the guidelines for designing the double walled cabinet with fans:

- ✓ From a thermal perspective, both the positive and negative blowers have similar performance.
- ✓ The addition of second blower in the shelter does not have any substantial effect on the temperature. But it is recommended to use an additional blower for redundancy.
- ✓ For places where the ambient air temperatures is low (around 20°C), the air conditioning system can be replaced by a hybrid cooling solution having a combination of both the air conditioner and a blower.
- ✓ An overall energy savings of about 40% is observed for the given shelter when the hybrid cooling system is implemented instead of an air conditioning system.

CHAPTER 5
BEST KNOWN METHOD (BKM) FOR DESIGN OF OUTDOOR TELECOM
CABINETS/SHELTERS

5.1 BKM for Design of Outdoor Telecom Cabinets

- ✓ The configurations of double wall with solar shield and with top plenum and fans have lower cabinet temperature than the single walled cabinet. Hence, double walled cabinets reduce the impact of solar loading on the outdoor cabinets.
- ✓ The configuration of double wall with circulation fans is an ideal configuration as there is nearly 20% drop in the cabinet temperature when compared with single walled configuration (baseline case).
- ✓ It is noted that from a thermal point of view, the thickness of air gap plays a minor role in cabinet design. The variation of air gap thickness has a negligible effect on the cabinet temperature.
- ✓ From an energy point of view, the fan location and flow rate plays a major role in designing.
- ✓ When fans are mounted on the bottom side of the double walls, it is recommended to use fans with flow rate lesser than 75 cfm, this will have low power consumption with a negligible thermal impact.
- ✓ Using fans with flow rate greater than 100 cfm is not recommended, though it reduces the cabinet temperature considerably, the power consumption is also very high.

5.2 BKM for Design of Outdoor Telecom Shelter

- ✓ The thermal impact of a blower, as a cooling unit for a telecommunication shelter is studied.
- ✓ From a thermal perspective, both the positive and negative pressure blowers have similar performance.
- ✓ The addition of second blower in the shelter does not have any substantial effect on the temperature. But it is recommended to use an additional blower for redundancy.
- ✓ An overall energy savings of about 40% is observed for the cooling system alone when the hybrid cooling system is implemented instead of an air conditioning system.
- ✓ Recommended to utilize the free air cooling at places with lower temperature as it will results in lower power consumption as well as lower carbon footprint for the shelter.

5.3 Recommendations for Future Work

1. In the study of double walled cabinets, fans were used to cool down the electronic equipments. The acoustic impact of fans on the environments needs to be studied.
2. For the telecom shelter, the blower and air conditioning system can be replaced by a single unit which can perform as a blower as well as air conditioner depending upon the ambient temperature.
3. ROI for the hybrid cooling system when implemented in a shelter can be determined.
4. Implement a renewable energy source (solar panels etc) at the test site to further reduce the carbon footprint of the telecom shelter.

APPENDIX A

METHOD TO COMPUTE THE POWER CONSUMED BY FANS AND BLOWERS

The power consumed by fans and blowers are calculated using the flow rate through them and the static pressure at the fans/blowers [39,40].

Power P, consumed by fan

$$P(W) = \frac{Q \times TP \times 0.3048^3}{60 \times \eta_m} \quad (1)$$

Total Pressure,

$$TP = SP + VP \quad (2)$$

Velocity Pressure,

$$VP = \rho v^2 \quad (3)$$

Energy consumed,

$$\text{Energy consumed} = \frac{P \times \text{time used}}{1000} \quad (4)$$

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Bharathkrishnan completed his Bachelors of Engineering in Mechanical Engineering from Anna University, Chennai, India. He completed his Master of Science degree in Mechanical Engineering in December 2010. He was part of the Electronics, MEMS, Nano-electronics Systems Packaging (EMNSPC) research team from October 2008. His research primarily deals with system level packaging for outdoor telecommunication cabinets/ shelters and data center cabinets. His research work has been done primarily in collaboration with Commscope Solutions Inc., Richardson, Texas. He has authored and coauthored six conference papers related to electronic packaging.